Forward skating in ice hockey: comparison of EMG activation patterns of at three velocities using a skate treadmill.

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Abstract

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This study investigated the EMG muscle activation patterns of forward ice hockey skating at three velocities. Seven varsity hockey players from McGill University (age = 22.1 ± 1.2 years, height = 1.8 ± 0.1m, weight = 82.1 ± 8.5 kg) participated. Testing was done using a skating treadmill. Skin was shaved, abraded and cleansed in the area of the electrode placement over the vastus medialis (VM), adductor magnus (AM), biceps femoris (BF), gluteus maximus, tibialis anterior (TA), peroneus longus (PL), and lateral gastrocnemius (GL) of the right lower limb. Subjects skated at 12 km/hr, 18 km/hr, and 24 km/hr. Repeated measures ANOVAs were performed, followed by Tukey post hoc tests. In general, the amplitude at speed 24km/hr was significantly higher than the speed of 12km/hr. There were few significant differences in temporal values. In conclusion, this study has shown that an increase in velocity results in an increase in the amount of muscle activation, but the muscle coordination patterns remain the same.

DEDICATION

I dedicate this thesis to my husband, Chris, whose love, support, and encouragement enabled me to complete this undertaking. To the Lorentz family (Mom L and Ian), in thanks for their support and financial assistance. To my mom, who has always encouraged higher education, and supported my choices. To my friend, Elizabeth, who gave me the inspiration and courage to attempt graduate studies.

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Cette étude a étudié les configurations d'activation musculaire par électromyographie (EMG) d'un joueur de hockey sur tapis roulant patinant vers l'avant à trois vitesses. Sept joueurs d' hockey de l'équipe universitaire de McGill (âge = 22,1 ± 1,2 ans, taille = 1,8 ± 0.1 m, poids = 82,1 ± 8,5 kilogrammes) ont participé. L'étude a été faite à l'aide d'un tapis roulant pour patin. La peau était rasée, scarifiée, et nettoyée au site de placement des électrodes au dessus du vaste interne (VM), grand adducteur (AM), biceps fémoral (BF), grand fessier (GM), tibial antérieur (TA), long péronier latéral (PL), et le gastrocnémien latéral (GL) sur la jambe droite. Les sujets ont patiné à 12 km/h, à 18 km/h, et à 24 km/h. Des ANOVAs à mesures répétées ont été exécutées, suivi des tests post hoc de Tukey. En général, l'amplitude de l'EMG à la vitesse 24km/h était sensiblement plus haute que la vitesse de 12km/h. Il y avait peu de différences significatives de l'ordre d'activation des muscles. En conclusion, cette étude a démontrer qu'une augmentation de la vitesse résulte en une augmentation de la quantité d'activation musculaire, mais le patron d'activation musculaire reste le même.

Chapter I

Introduction

The skating treadmill is a relatively new piece of equipment that ice hockey players may use for technical and power skating training as well as part of a rehabilitation regime. In addition, it provides a great opportunity for detailed, scientific study of forward skating movements in a controlled environment. The manner in which it functions is similar to that of a running treadmill; that is, it has a moving surface of polyethylene sections that allows an athlete to both glide and push-off wearing regular skates. For most athletes, it is typically wide enough to permit full and regular skating strides.

There are various situations where a skating treadmill allows for better accessibility and convenience than ice. It is a more specific medium for the fitness evaluation of skaters than other equipment currently being used, such as a bicycle ergometer or running treadmill. Being in a laboratory setting, the skating treadmill facilitates both biomechanical and physiological evaluation of ice hockey forward skating. Specifically, it allows the researcher to better control speed, which in turn ensures “steady state” data collection. It can also be used by physical therapists when rehabilitating and evaluating lower limb injuries. Coaches are able to make good use of it to teach and correct technique to allow players to maximize performance.

Another area where the skating treadmill is considered an asset is in industrial research. Given that the skate is the interface between the athlete and the ice (or gliding surface), it is fundamental to evaluate the mechanics of skating when making changes in a skate materials, construction or design. Changes in skate design affect comfort and efficiency, which in turn ultimately affects skating performance. To date, the biomechanical evaluation of skating has proven technically difficult due to the nature of the task and the environment needed for performance. Hence, the skating treadmill represents an excellent opportunity to bring both the athletes and skates into the laboratory for a more rigorous, scientific examination between the user and the product.

One common method of evaluating gross movement patterns is to record the muscle recruitment patterns needed to execute the task. Surface electromyography (EMG) is a non-invasive method used to evaluate gross muscle activity during a movement (Kleissen, 1998; Deluca, 1997; Basmajian, 1985; Winter, 1990). This technology allows us to quantify the amount of muscle activity and the pattern/order of muscle activation. There are several applications of EMG in biomechanics. For example, it can be used to study motor unit activity, or the relationship of EMG to muscle force and tension, as well as muscular fatigue. It can be used to look at the design and tools in the workplace. In rehabilitation, EMG is used to diagnose abnormalities, as well as to control artificial limb movement. In a sports science setting, EMG can be used to evaluate the muscle coordination patterns of a specific skill, which would then allow for comparison between different conditions (for example: comparing skilled and unskilled athletes). Though a common method in biomechanics, in skating, particularly in the ice hockey context, this technique has not been employed extensively. Only one study to date has been reported. In this study, Hinrichs (1994) was able to compare EMG activity of the lower limb in ice hockey forward skating on the skate treadmill to on-ice skating. In general, it was found that the "on – off" muscle activity was similar in both conditions.

1.1 Nature and Scope of the Problem

Since it is a relatively new technology (i.e. since 1993), there have been very few studies using skating treadmill. The research completed has mostly focused on physiological parameters involved in ice hockey skating.

Dreger and Quinney (1999) established a protocol for maximal oxygen uptake determination on the skate treadmill. Using six elite male hockey players, they compared the protocol to a cycle ergometer protocol. Each subject performed an incremental test to fatigue on both the skate treadmill and the bicycle ergometer. It was established that the physiological responses on both ergometers were similar. They felt, however that the skating treadmill provided more applicable information because it permits the use of a skating stride, which is more closely related to the task demands of the sport.

Nobes et al. (2001) compared the skating economy of fifteen male university hockey players on-ice and on the skating treadmill. Using similar protocols on-ice and on the skating treadmill, the subjects skated for four minutes at 18, 20, and 22 km/hr (5.0, 5.6, and 6.1 m/s respectively) with a 5 minute recovery between each test. In general, the VO_2 max was similar in both conditions, but the on-ice sub-maximal VO_2 was lower than on the skating treadmill. Nobes also presented some kinematic data showing that at the average given velocity, the stride rates were lower on ice than on the treadmill.

Hinrichs (1994) compared lower limb muscle EMG “on-off” patterns of the ice hockey forward stride on ice versus a skate treadmill, to quantify the similarity in recruitment patterns. Fourteen experienced hockey players skated at three selected speeds, 10.5, 14, and 16.5 km/hr (2.9, 3.9, and 4.6 m/s), on the treadmill. The stride rate for each speed was determined, then matched on the ice (42, 49.5, and 54 strides/min). The same stride rate in both conditions produced higher speeds on the ice. Of the seven muscles studied (tibialis anterior, gastrocnemius, vastus medialis, rectus femoris, adductor longus, biceps femoris, gluteus maximus), the adductor longus muscle was the only muscle to show a significant difference between the two conditions. The conclusion of this study was that, overall, the recruitment patterns during treadmill skating were similar to on-ice skating.

1.2 Significance of the problem

There has been very limited research on the muscle activity patterns in the lower limbs while skating. The study discussed in the above section, (Hinrichs, 1994), is the only EMG research in ice hockey skating. In this study only the “on and off” activation patterns were studied. No attempt was made to determine the magnitude of activation or changes in temporal relation of agonist and antagonist. However, two speed skating studies have shown that more specific EMG results can be acquired (de Koning et al., 1991; Houdijk et al., 2000). The EMG results in these studies were reported either graphically as a fraction of maximal voluntary contraction, or as a percent of the maximum EMG obtained during the stride. These studies focused on the push-off phase of the skating stride. These studies also demonstrated the application of EMG to quantitatively evaluate skating techniques as well as assess implications of skate design changes.

1.3 Objectives of the study

The purpose of this study is to compare the EMG activity of the lower limb muscles in forward skating at three different speeds, 12, 18, 24 km/hr (3.3, 5.0, 6.7 m/s), using the skating treadmill.

1.3.1 Hypotheses

1) The peak values of muscle activation will be lowest at 12 km/hr (3.3 m/s) and highest at 24 km/hr (6.7 m/s).
2) There will be minor differences in the activation times between the three speeds, such as earlier peaks at 12km/hr (3.3 m/s) compared to 24 km/hr (6.7 m/s).

1.4 Operational Definitions

Skating stride:	Movement pattern from blade contact to blade contact of the right foot.
Stride rate:	The number of strides per minute

Stride Phases and/or Events:

1) Initial Contact (IC): blade-to-surface contact begins
2) Glide (G) Phase: following initial contact; blade orientation guides body movement forward
3) Push-off (PO): at the end of glide phase, blade turns outward (external) to allow of hip extension, abduction and external rotation, knee extension and ankle plantar flexion to propel body forward on contralateral limb
4) Swing phase (SW): lower limb non-weight bearing; hip, knee flex and ankle dorsiflex to allow lower limb to swing forward to begin the next stride

1.5 Limitations

1) Direct accessibility of muscles is limited with surface EMG, therefore deeper muscles can not be examined
2) Only skating treadmill conditions were evaluated

1.6 Delimitations

1) The muscles examined included the vastus medialis (VM), biceps femoris (BF), gluteus maximus (GM), adductor magnus (AM), tibilas anterior (TA), peroneus longus (PL), and lateral gastrocnemius (GL)
2) Interuniversity ice hockey players: McGill Redmen
3) Subjects were acclimatized to treadmill

4) Subject ages 19 – 25

5) Subjects included both forwards and defensemen

6) Only three skating velocities were studied.

Chapter II

Review of the Literature

Ice Hockey is a sport that requires a combination of numerous skills including skating, puck handling, shooting, and checking skills. Though a popular sport, to date research on the biomechanical evaluation of the ice hockey skills have been limited to a few studies regarding the stick (e.g. Doré and Roy, 1973; Roy and Belisle, 1984; Hoerner, 1989; Rosthsching, 1997) and forward mechanics of skating (Marino 1977, 1979, 1983). Given the limited research specific to ice hockey, our best understanding of forward skating mechanics may be drawn from research focused on speed skating (de Boer et al, 1985, 1987; de Koning et al, 1991; van Ingen Schenau et al, 1989). Interpretation of speed skating mechanics can be useful for identifying the general movement patterns similar to ice hockey; however, one should note that fundamental differences in equipment, skill, repertoire, and play context preclude suggesting a direct transfer of speed skating to ice hockey skating (Marino, 1979).

Athletes, coaches, and athletic trainers would benefit to have more information on the specific ice hockey stride biomechanics so as to improve skating technique development and maintenance, as well as, aid in establishing rehabilitative regimes during recovery from lower limb injuries. The text that follows reviews the skating research completed in both sports.

2.1 Basic Patterns of the Skating Stride

The skating stride is a complex series of simultaneous joint movements. The locomotion in skating is fundamentally different from other forms of human locomotion. Minkoff et al. (1994) describes that the primary differences are seen in skating during push-off when a lateral motion is generated by synchronous hip extension, hip abduction, and knee extension but with limited plantar flexion. The coordination pattern in skating is therefore a unique adaptation of the more natural movements of walking or running (van Ingen Schenau et al., 1989).

Marino (1977) stated that the forward stride is bi-phasic with alternating periods of single and double support. In speed skating, the periods of single support and double support were described as glide and propulsion phases, respectively. During the propulsion phase the body is accelerating forward, and with deceleration occurring during the glide phase.

According to Marino and Weese (1979), using 2D kinematic film analysis of four players, a relationship exists between the skating acceleration patterns and the various phases of a maximum velocity skating stride in ice hockey players. Although time spent in double and single support is dependent upon velocity, they suggested that the skaters typically spent 18% of the stride time in double support and 82% of the stride time in single support. Their data also showed that the skaters were able to generate propulsive forces during both single and double support periods. They concluded that the acceleration begins halfway through the single support phase and continues until early double support. The onset of acceleration is associated with the external rotation of the thigh, and initial extension of the hip and knee. Shortly after the contralateral (non-support) foot is placed on the ice, the ipsilateral (driving) limb finished the propulsion with full extension of knee, hyperextension (i.e. 5°), and abduction of hip, and plantar flexion of the ankle, thereby shifting body weight to the contralateral limb. This sequence suggests that the torques of hip and knee muscle contraction were summated during the propulsive phases of ice skating. The skating cycle was completed by the lifting of the ipsilateral skate from the ice (ending the double support) thus, leading into a swing phase and the next consecutive foot placement.

Differences have also been observed between forward skating at a constant velocity versus accelerating. In particular, there appears to be a substantial decrease in the double support phase when accelerating in the forward direction. Marino (1979) recorded the acceleration patterns of four moderately to highly skilled hockey players. It was noted that the skaters were able to maintain positive acceleration throughout both the single and double support phases of the stride. During the beginning of the acceleration phase the skaters had a tendency to use very short, choppy strides. The recovery leg came down in a position of lateral rotation combined with hip flexion, knee flexion, and ankle plantar flexion. This position contributed to the propulsion that began during the double support phase and lasted throughout the stride. Subjective evaluation suggested that the striding pattern while skating at a constant, fast speed consisted of a smooth stroking motion in which the skate did not complete its outward turn until the non-support foot approached touchdown. No period of glide was detected in the initial strides of the acceleration phase. The percentage of stride time in the single support was about 85.3%, which is longer than the 82% observed during steady state skating.

There are various ways to segment the phases of the ice hockey skate stride for analysis. In the studies discussed above, the stride was separated into a double support and single support phase. Double support is when both skates are touching the surface, while single support is when only one skate in on the skating surface. Minkoff et al. (1994) used terminology (explained by Stamm, 1989) that subdivides the stride into four phases: 1- wind-up, the coiling action; 2- release, the application of force from the coiled position; 3- follow through, completion of momentum until the leg is fully extended away from the body with hip flexion, knee flexion, and plantar flexion; and, 4- recovery, the return of the thrusting leg to a point under the body in preparation for the next stride. The speed skating stride also has been described in three phases: 1- the gliding phase, when the skate is placed on the ice and the skater is gliding forward; 2- the push-off phase, when the gliding sideward push-off occurs; 3- a repositioning phase, when the leg is brought into the starting position to begin the next stride (de Koning et al 1991). Pearsall, Turcotte, and Murphy (2000) presented an illustration (figure 1) that shows different variations of stride phases.

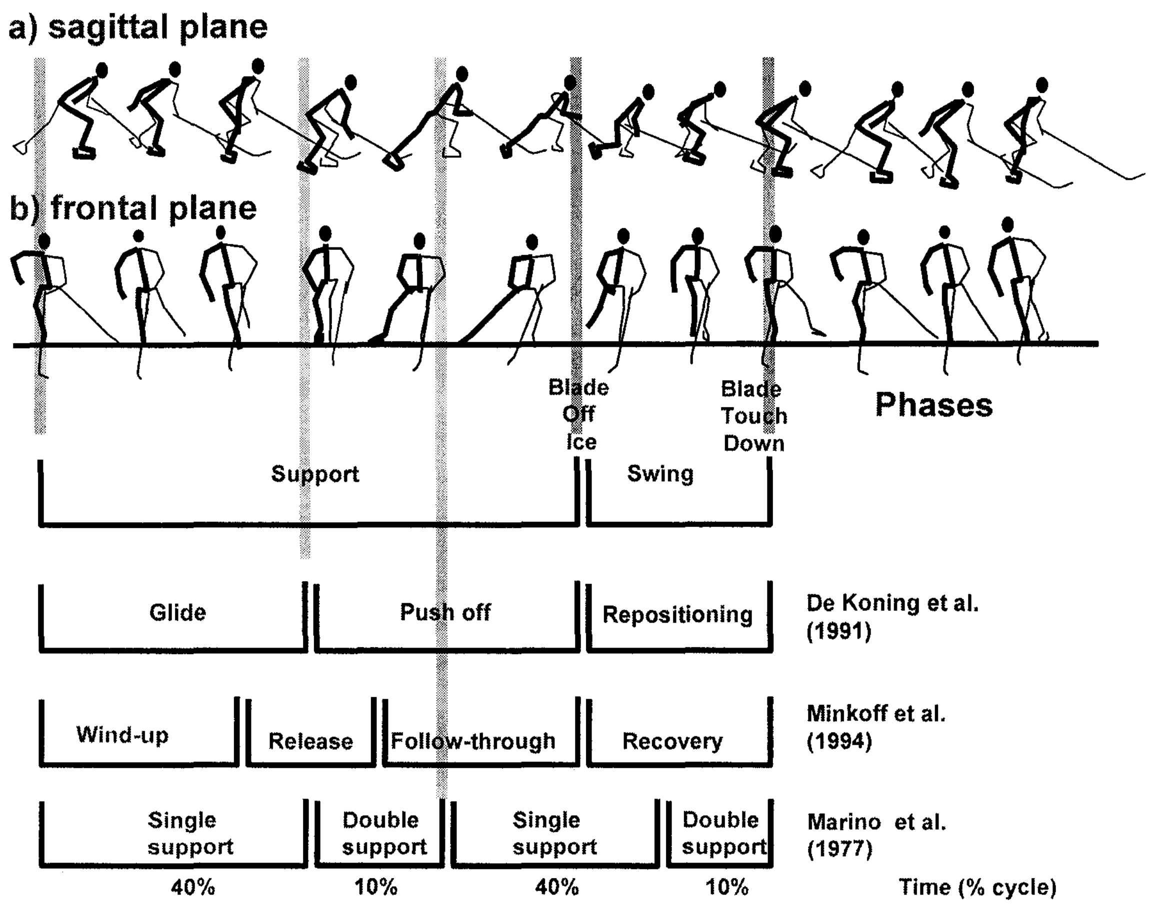


FIGURE 1: PHASES OF FORWARD STRIDE (ADAPTED FROM PEARSALL, TURCOTTE AND MURPHY, 2000)

2.2 Stride Rate versus Velocity

The primary factors that contribute to horizontal skating velocity have been identified as stride rate and stride length. Marino (1977) investigated three velocities in skating to identify the specific interactions of stride length and stride rate, as well as to determine if changes in the single and double support relationship occurred with different speeds. In general he found that as skating velocity increased, the stride rate increased (Table 1). Although there was a positive correlation between velocity and stride rate, there was no discernable trend in mean stride length that accompanied the change in skating velocity. This lack of discernable trend may be due to a lack of consistent increments in speed; 3.8 m/s represented a slow speed, then 6.1 m/s and 6.9 m/s represented medium and fast speeds.

Both the single and double absolute support times decreased as the skating velocity increased. During fast skating speeds it appeared (from subjective analysis by the researchers) that the propulsion phase was decreased (Marino, 1977). In addition, it was observed that the skaters' postures changed with the different velocities. For example, skaters tended to be more upright at slow and medium speeds than at maximum speeds. The researchers also noted that there was a disproportionate (i.e. non-linear) decrease in the double support time at the highest velocity.

***Table 1**: Kinematic variables measured at three speeds (adapted from Marino 1977)*

Speed	Horizontal Velocity (m/sec)	Stride Length (m)	Stride Rate (st/sec)	Single Support Time (sec)	Double Support Time (sec)
Fast	6.92 ± 0.59	2.58 ± 0.44	2.68 ± 0.41	0.262 ± 0.031	0.111 ± 0.040
Medium	6.13 ± 0.51	2.93 ± 0.61	2.09 ± 0.40	0.317 ± 0.063	0.161 ± 0.051
Slow	3.75 ± 0.70	2.90 ± 0.53	1.29 ± 0.21	0.436 ± 0.056	0.339 ± 0.069

With respect to the skating treadmill there is a discrepancy in the reported stride rates for specific speeds when comparing the various treadmill studies to on-ice study conditions (Tables 2 and 3). Furthermore, three separate studies have reported different stride rates for similar speeds on-ice (Table 2). At speeds from 22.0 to 22.9 km/hr (6.1 to 6.4 m/s) we can see reported stride rates ranging from 39.3 to 62.7 strides/min (0.7 to 1.0 strides/s). Although independently each study show an increase in stride rate with speed, the stride rates greatly vary for given speeds. These differences could be due to a variety of factors. This may include subtle variations in skating styles exhibited by hockey players. There is also the potential for variation of time during the glide phase between different styles of skating. Also, it is difficult to regulate stride cycles on the ice when skating on straights and turns.

***Table 2**: Comparison of stride rates on-ice for Marino (1977), Hinrich (1994), Nobes (2001)*

study	Velocity km/hr (m/s)	Stride rate Strides/min
Marino	13.5	38.7
Nobes	18.0	32.0
Nobes	20.0	34.6
Hinrich	21.0	42.0
Marino	22.1	62.7
Nobes	22.0	39.3
Hinrich	22.9	49.5
Marino	24.9	80.4
Hinrich	25.0	54.0

The same phenomenon is seen the two studies using the treadmill (Nobes et al., 2001; Hinrich, 1994).

***Table 3**: Comparison of stride rates on the skate treadmill for Hinrich (1994) and Nobes (2001)*

study	Velocity km/hr	Stride rate strides/min
Hinrich	10.5	42.0
Hinrich	14.0	49.5
Hinrich	16.5	54.0
Nobes	18.0	42.6
Nobes	20.0	46.7
Nobes	22.0	47.6

Each study independently shows an increased stride rate with an increase in velocity; however, when compared, similar stride rates can be seen at different speeds. For example, a stride rate of 42.0 strides/min is seen at a velocity of 10.5

km/hr in Hinrich's study; whereas in Nobes (2001), a stride rate of 42.6 is seen at 18 km/hr. No clear explanation for these discrepancies, between studies, is apparent. It may possibly be due to fairly small sample sizes (Marino = 10 subjects, Nobes = 15 subjects, and Hinrichs =14 subjects), and/or the method of measuring the stride rate. Marino determined stride rate using film analysis, while Nobes visually counted the number of skating strides for 60 seconds. Hinrichs did not report the method used to determine the stride rates for his study. In addition, individual skating styles, as noted above, for on-ice studies, and the question of subject familiarity with the skating treadmill may in part be responsible the variation in stride rate-to-skating speed relationship on the treadmill.

2.5 Fundamentals of Surface Electromyography (EMG)

EMG is a common measurement tool used to estimate the activity of individual muscles in terms of their contribution to complex coordination patterns (Basmajian, 1985; Clary, 1987; DeLuca, 1997; Stegeman et al., 2000). Surface EMG is a non-invasive method used to investigate muscle involvement of gross motor patterns. It is important to understand the factors that generate the signal, as well as precautions to eliminate as much signal interference as possible. De Luca's (1997) comprehensive review paper discusses the usefulness and limitations of the EMG in biomechanics. For instance, EMG can be used to indicate periods of muscle activation, and provide the timing sequence of one or more muscles performing a task. It can also be used to estimate the relationship to the force produced by a muscle or a group of muscles. A third application of EMG is a general indicator of fatigue occurring within a muscle by displaying time-dependent changes prior to any force modification, thus predicting the onset of contractile fatigue. When EMG signals are rectified and smoothed, the amplitude may be qualitatively related to the amount of force measured (Deluca 1997), although the accuracy can be questionable due to the many factors that can influence an EMG signal.

Several external factors that can affect the signal are the electrode location and configuration, cross talk (electrical activity of other muscles), and the orientation of the electrodes with respect to the muscle fibers (DeLuca, 1997; Herzog and Nigg, 1999). Internal factors that also have an effect on the signal are the number of active motor units, fiber type, blood flow, fiber diameter, depth and location of the active fibers, as well as the amount of tissue between the surface of the muscle and the electrode. Other factors affecting the signal can include band-pass filtering aspects of the electrode, detection volume of the electrode, superposition of action potentials in the detected EMG signal, conduction velocity of the action potential, and spatial filtering due to the position of the electrode compared to the active muscle fibers.

If care is given during research to account the variables that can influence the EMG signal, EMG analysis can be a useful tool to describe the state of the muscle in certain applications, such as, when the muscle is active ('on' or 'off') and during specific phases of the movement or task, as well as, the relative scale of intensity of the contraction.

To ensure the EMG signal is detected and recorded with maximum fidelity, a differential electrode configuration (i.e. bipolar) should be used, and the electrodes located on the muscle belly between the myotendinous junction and the nearest innervation zone (DeLuca, 1997; Delagi et al., 1980). The resulting signal magnitude should be expressed as the Root Means Square (RMS) from the raw signal (DeLuca, 1997).

Further, it has been common practice in the literature to normalize EMG signal amplitudes with the respect to the maximal EMG signal detected during a maximal voluntary contraction (MVC). However, the validity of using MVC has been questioned, since it is difficult to determine if the subject is truly generating maximal contraction. Further, attention to the joint position and body posture of the subject is important to isolate the muscles of interest. If the joint is constrained in a satisfactory fashion, and the muscle contraction is brief, the largest value obtained is acceptable to use as the maximum value or MVC.

For optimal EMG acquisition, it is recommended to use surface electrodes with a bipolar configuration (Basmajian, 1985; DeLuca, 1997). This differential amplification arrangement will remove the majority of unwanted false electrical signal or noise. A standard one centimetre spacing is appropriate with the anatomical arrangement (ie. size and shape) of most muscles, and has other advantages, such as a lower impedance and elimination of the noise component, especially the noise generated at the electrode/tissue interface. To further improve electrical contact with the electrodes, superficial cutaneous cells should be removed by use of an abrasive paper and alcohol swabs.

In addition, all efforts must be made to eliminate cross talk (i.e. inter-muscle signal transmissions) so as to obtain a signal that represents the specific muscle being observed. Therefore, it is necessary to devise a procedure to determine electrode placement for each muscle. The Anatomic Guide for the Electromyographer by Delagi et al. (1980) maps out a suggested electrode placement for each specific muscle. Attention to accurate and consistent electrode placement, as well as consistent electrode size, can in part reduce the potential for cross talk from adjacent muscles.

To permit comparisons between muscle stride patterns measured at different stride velocities, it is common to "normalize" the stride cycle duration. Winter (1990) explains a procedure of averaging the EMG signals of several strides (i.e. from contact to contact), by transforming the time values onto a normative time scale from 0 to 100. This allows for comparisons within and between subjects. This has become an accepted way to present data in literature.

Basically, for the purpose of our research, surface EMG is an acceptable method to determine the muscle activation pattern in ice hockey skating, provided the above described precautions are taken into account during the data collection and limitations of measures understood.

2.6 EMG and the Similarity of the Forward Skating Stride

Given that general movement patterns of the strides in ice hockey and speed skating are similar, it may be assumed that the gross pattern of muscle activity in the ice hockey stride can be inferred, at least in part, from speed skating research. The following text summarizes observations collected by de Boer et al. (1987a) on EMG speed skating patterns.

De Boer et al. (1987) estimated the patterns of moments of force and power output of the lower limb during skating based on the analysis of push-off forces, body kinematics and muscle coordination of two elite speed skaters. The subjects skated five trials at a submaximal speed (10 m/s). The following muscles were studied: gluteus maximus, biceps femoris (long head), semitendinosus, vastus medialis, rectus femoris, gastrocnemius (lateral head) using a portable 7-channel TEAC HR 30 data cassette recorder (analog). Their results suggest that the power during skating forward is mainly supplied by the gluteus maximus. The hamstrings are active during the gliding phase, but due to eccentric contraction they do not contribute to power generation. Power at the knee joint is generated by the quadriceps. It has been shown in other studies (van Ingen Schenau et al., 1987) that the push-off in speed skating occurs before maximal knee extension, therefore it does not contribute maximally to power output at that point. It is believed that this constraint is due to the lack of plantar flexion.

Subsequently, de Koning et al. (1991) studied the coordination patterns of muscles during speed skating. Eleven elite male speed skaters completed five 400m laps at a submaximal velocity (10 m/s). The kinematic, kinetic and EMG data were obtained for the right side of the body. The speed skating stride was broken down into three phases: the gliding phase, the push-off phase, and a repositioning phase. They did not observe complete extension in the joints during the push-off. EMG data were collected from the semitendinosus, biceps femoris (long head), rectus femoris, vastus lateralis, vastus medalis, gastrocnemius (medial and lateral), soleus and tibialis anterieur muscles. The data were presented as percent of maximum values obtained (during the stroke) during part of the gliding and push-off phases (Figure 2).

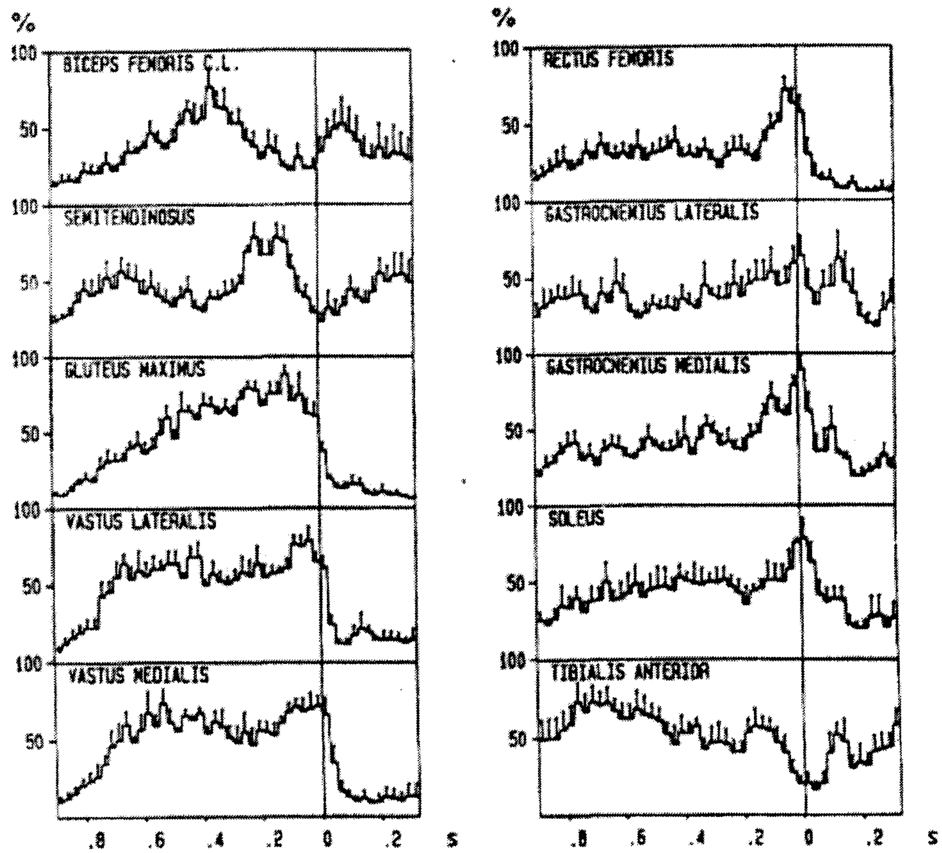


Figure 2: *Typical electromyography patterns of lower limb muscles during forward speed skating Percent of maximal value obtained during a stroke versus time, t = 0 is when the push-off forces are zero. (from De Koning et al 1991)*

During the initial part of the stroke the hip and knee are flexed. The EMG activity levels of the vastus medialis and lateralis are fairly constant, and the gluteus maximus contribution increases. The biceps femoris and semitendinosus both peak during this phase, but not at the same time point. In the last 200 ms of the stroke there is a rapid extension in the hip and knee, with plantar flexion of the ankle joint. During this period, there is a simultaneous decrease in the activity of the semitendinosus and increase in the activity of biceps femoris. The researchers felt this activity is present due to an external rotation in the hip joint prior to push-off. The push-off phase shows a decrease in hamstring activity and increase in the rectus femoris activity, resulting in a strong decrease in the net hip moment.

Some similarities between the demands of the tasks of vertical jumping and speed skating have been suggested (de Koning et al., 1991). The general proximal-distal sequences are similar in both jumping and skating propulsion. However, the task of speed skating involves more constraints than vertical jumping. While skating, the extension velocities of joints are lower than in jumping; more specifically, the peak hip extension, and the plantar flexion velocities are lower when comparing them to the knee extension velocity. These differences may arise due to a more horizontal position of trunk while skating. The researchers stated that the observed patterns of muscle coordination can be interpreted as a compromise between the constraints of the specific skating movement and the advantageous effect of a proximo-distal sequence in unconstrained jumping.

Minkoff's et al. (1994) review paper describes the typical kinematics and muscle activity involved in ice hockey skating. Table 4 represents the muscle activity that Minkoff qualitatively describes, during various phases of an ice hockey stride. During the release phase, there is a contraction of the gluteus maxmius, gluteus minimus, semitendinosis, biceps femoris, triceps surae. This results in a progression of the hip and knee towards full extension, abduction, and external rotation. The ankle is in neutral position. During the follow through phase, there is a push-off with full extension of the knee and hip. The hip and knee flex to 40° and 90° respectively during the recovery phase, then the hip rotates internally and the ankle is maximally dorsiflexed. The end of the recovery phase should correspond to the release phase of the contralateral leg.

Upon closer inspection of the table, descriptive errors are evident; for example, it states that the BF and ST (semitendinosis) are working eccentrically to extend the hip and knee, but these muscles work concentrically during support to extend the hip. These errors will be discussed further when comparing result of various studies.

***Table 4:** Muscle Activity of the lower limb skating (adapted from Minkoff et al., 1994).*

	Wind-Up	Release	Follow Through	Recovery
Gluteus Maximus	Active concentric (hip extension)	Active concentric (hip extension)	Inactive	Inactive
Biceps femoris & Semitendinosis	Active Eccentric (hip and knee extension)	Active Eccentric (hip and knee extension)	Inactive	Active concentric (knee flexion)
Quadriceps	Active Eccentric (knee extension)	Active Eccentric (knee extension)	Active Eccentric (knee extension)	Active concentric (hip flexion)
Triceps Surae	Active Eccentric (knee extension)	Active Eccentric (knee extension)	Active concentric (ankle plantar flexion)	Inactive
Anterior Tibialis	Inactive	Inactive	Inactive	Active Concentric (dorsiflexion)

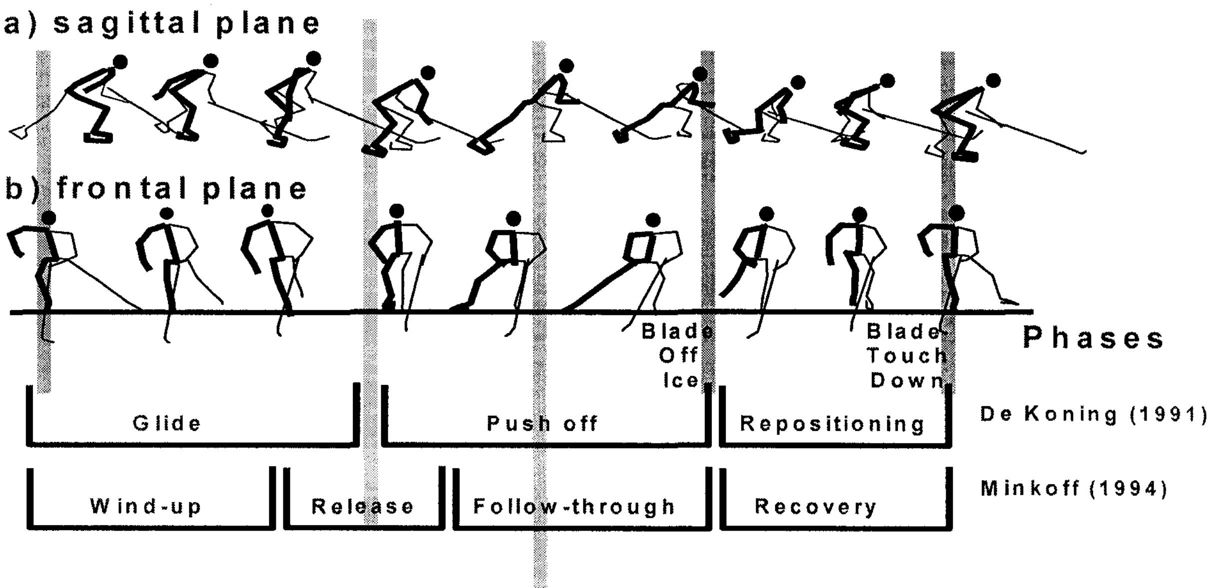
One study has recorded the lower limb muscle EMG patterns of the ice hockey stride. Hinrich (1994) compared lower limb muscle EMG patterns of the ice hockey forward stride on ice versus a skate treadmill (Standard Industries, North Dakota) to quantify the similarity in recruitment patterns, specifically muscle activation times during the stride (normalized to percent stride time). In this study the tibialis anterior, gastrocnemius, vastus medialis, rectus femoris, adductor longus (AL), biceps femoris, and gluteus maximus muscles of the right leg were compared. Data collection was done with a telemetric EMG transmitter. Three different skating velocities were compared, with the stride frequencies being the same on both surfaces (i.e. a stride frequency of 42 strides/minute produced a speed of 10.5 km/h on the treadmill and 20.97 km/h on ice). The skate treadmill had an elevation grade of 2.5%. On ice and treadmill tests were conducted on the same day. Fourteen experienced ice hockey players between the ages of 18 and 32 completed four trials in each condition. The average of two strides was analyzed and the activation times for each muscle were calculated at a percent of overall stride time. The adductor longus muscle was the only muscle to show a significant difference between the two conditions. During the stride, the AL muscle is active twice; it turns on at the beginning of the stride (initial), then it is inactive, and finally turns on a second time. The initial AL muscle activity was similar in the two conditions; however, on-ice skating elicited the second AL activity sooner than the skate treadmill condition (i.e. on ice the 2nd activation was at 46.3% of stride time, on the treadmill it was at 57.8%, $p < .0001$). The adductors are thought to act as a hip stabilizer during this part of the stride (during the second activation). The researcher commented that this difference could be due to the grade on the skate treadmill and the fact that the skating surface is moving under the skate. This may have resulted in a difference of foot placement during the support phase of the skating stride, causing a lag time from when the skate blade contacted the treadmill until the foot was outside the midline of the skaters' hips to allow the initiation of hip extension. The author suggested that this lag time may have produced the delay in the onset of the second muscle activation. The conclusion of this study, based on the "on-off" patterns of the muscles studied, was that, overall, the recruitment patterns during treadmill skating were similar to on-ice skating.

2.7 Comparison of Muscle Activity

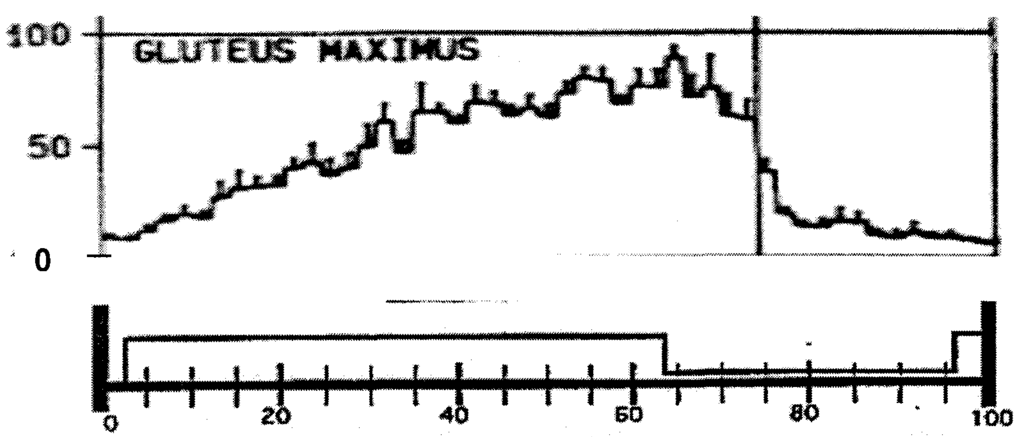
Differences in data presentation between studies make it difficult to compare muscle activity and electromyography results. The following section attempts to compare the specific findings between three studies. There are five muscles displayed: Biceps Femoris, Gluteus Maximus, Vastus Medialis, Gastrocmemius, and Tibilas Anterior (Figures 3a – 3e). The three studies are represented by the following numbers (1) Minkoff et al. (1994), is represented by a table which gives a qualitative description (2) de Koning et al. (1991) results, where the push-off is marked by the line and the time is scaled in seconds; and (3) the 'on and off' activity found in Hinrichs' study (1994); the activity during the stride from blade contact to blade contact. There are some errors evident in the work presented by Minkoff, which will be discussed in the appropriate section.

2.7.1 Comparison of Muscle Activity for the Gluteus Maximus

There appears to be a general consensus on the activity of this muscle (Figure 3a). All three studies show that the muscle is active during the early part of the stride until push-off. After push off the muscle is then inactive.



Active concentric (hip extension)	Active concentric (hip extension)	Inactive	Inactive	1 (Minkoff et al., 1994)



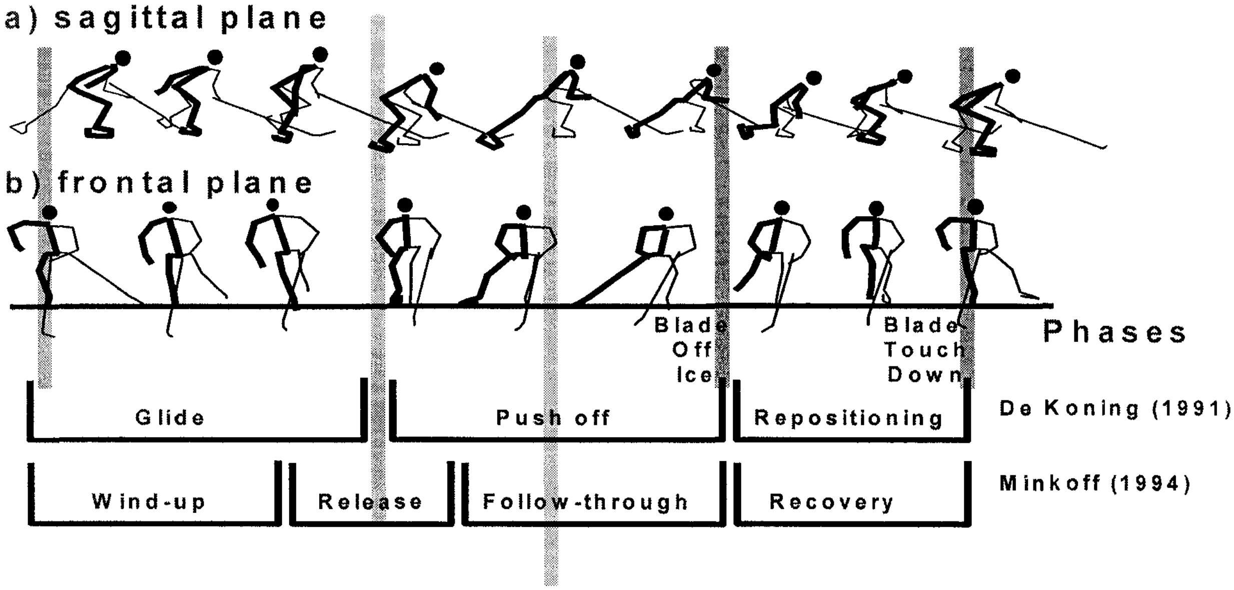
2 (de Koning et al., 1991)

3 (Hinrichs, 1994)

FIGURE 3A: COMPARISON OF MUSCLE ACTIVITY FOR THE GLUTEUS MAXIMUS

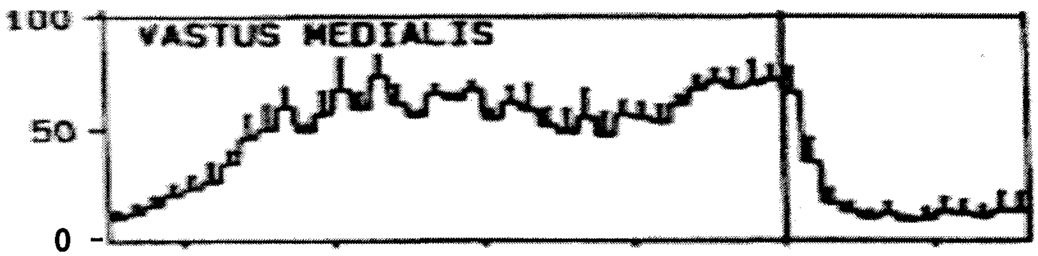
2.7.2 Comparison of Muscle Activity of the Vastus Medialis

For this muscle the three studies have similar results (Figure 3b). De Koning et al. shows that the muscle activity peaks at 0.6 s before the end of push-off, then remains constant during the glide phase of the stroke. There is very little activity in the muscle after push-off. During the wind-up and release phases, Minkoff et al. describes the VM muscle activity as being eccentric due to knee extension, but it is concentric VM activity that would result in knee extension. Minkoff et al. also reports active concentric hip flexion during the recovery phase, this refers to the entire quadriceps muscle group; which would include the rectus femoris activity. Since he does not report is knee flexion or extension, it may be assumed that the vastus medialis is inactive (off). Hinrichs also shows that late in the stride the muscle is “off”.

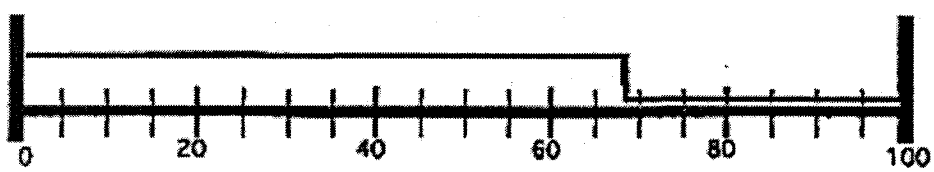


Active Eccentric (knee extension)	Active Eccentric (knee extension)	Active Eccentric (knee extension)	Active Concentric (hip flexion)

1 (Minkoff et al., 1994)



2 (de Koning el al., 1991)

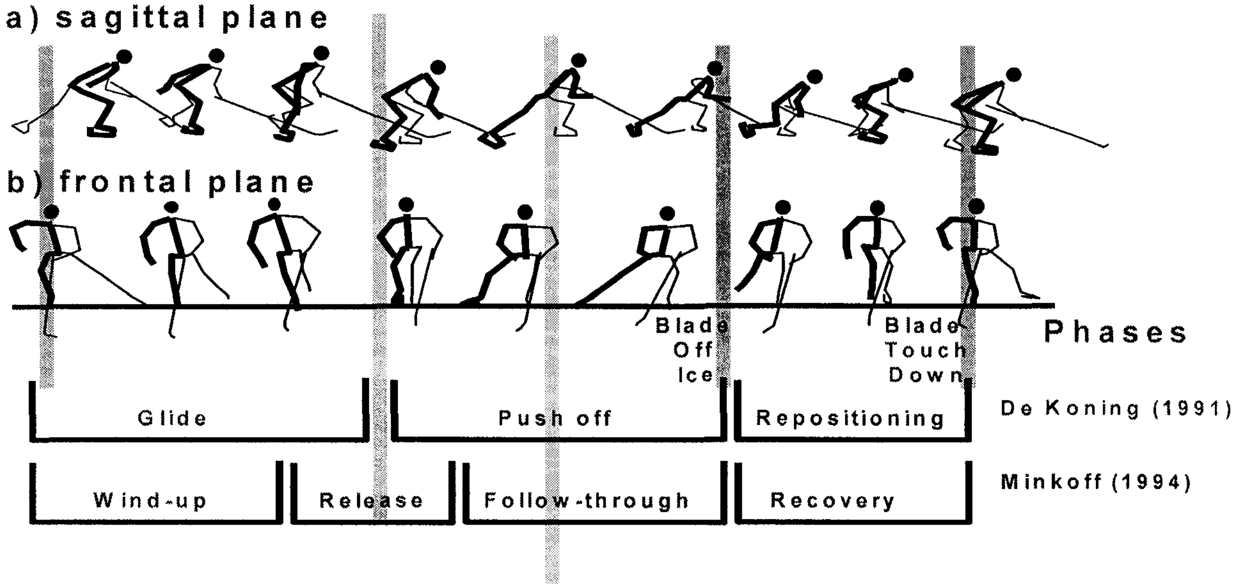


3 (Hinrichs, 1994)

FIGURE 3B: COMPARISON OF MUSCLE ACTIVITY OF THE VASTUS MEDIALIS

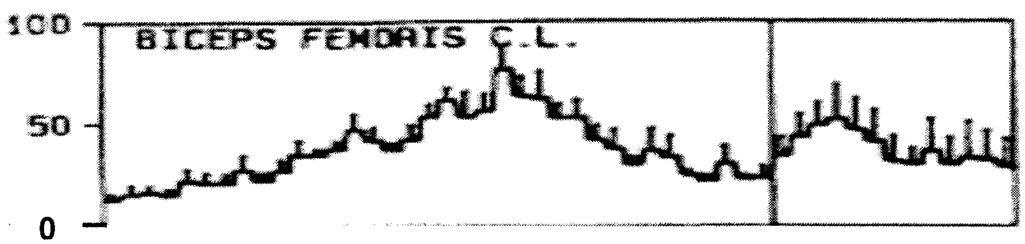
2.7.3 Comparison of the Muscle Activity of the Biceps Femoris

From de Koning and colleagues' work, it appears that the biceps femoris muscle is always "on", although there is less than 25% of maximal activity at the beginning of the stride and just before the push off (Figure 3c). At the end of a stroke in speed skating, there is a quick extension at the hip and knee, resulting in an increase in activity. Minkoff's et al. description seems to agree with these results; i.e. the muscle may be inactive during push off phase, but active again during the recovery phase. However, it is more likely that the BF activity is concentric hip flexion (rather than eccentric hip and knee flexion) during the wind-up and release phases of the stride. Hinrichs' results suggest something slightly different; i.e. the muscle is "off" during the recovery phase of the stride, but turns "on" again just before contact.

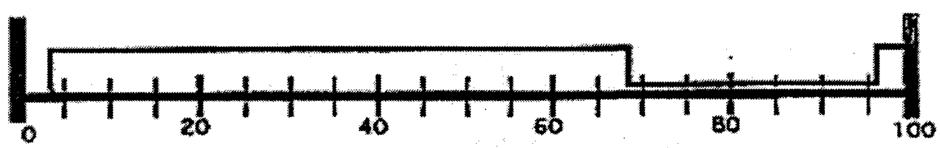


Active Eccentric (hip and knee extension)	Active Eccentric (hip and knee extension)	Inactive	Active Concentric (knee flexion)

1 (Minkoff et al., 1994)



2 (de Koning et a 1991)

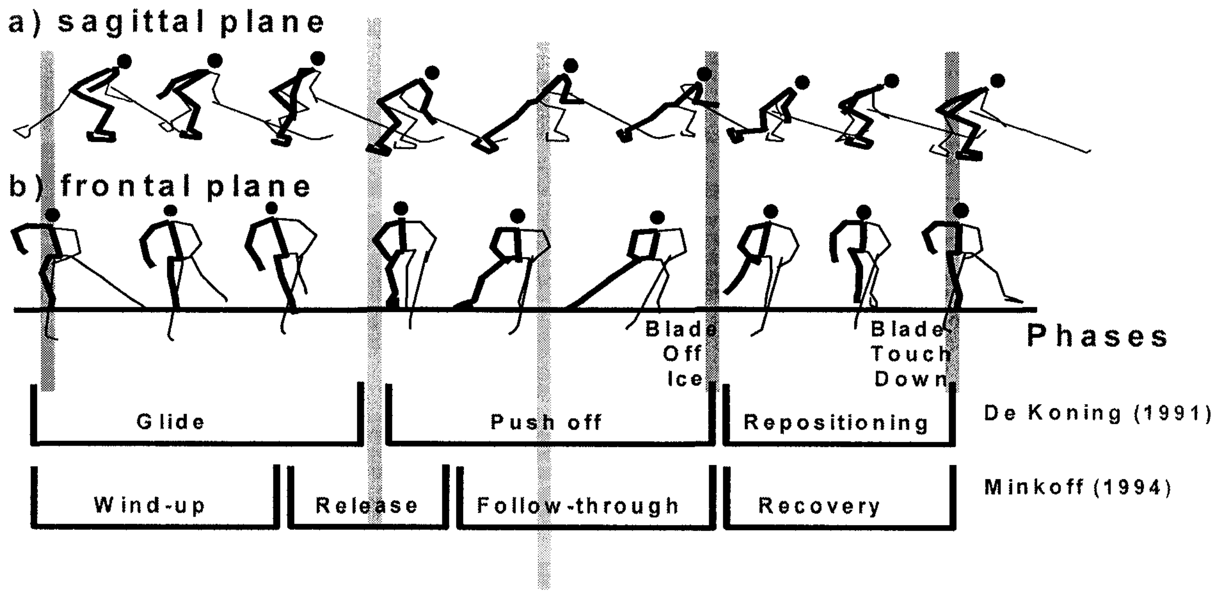


3 (Hinrichs, 1994

FIGURE 3C: *COMPARISON OF THE MUSCLE ACTIVITY OF THE BICEPS FEMORIS*

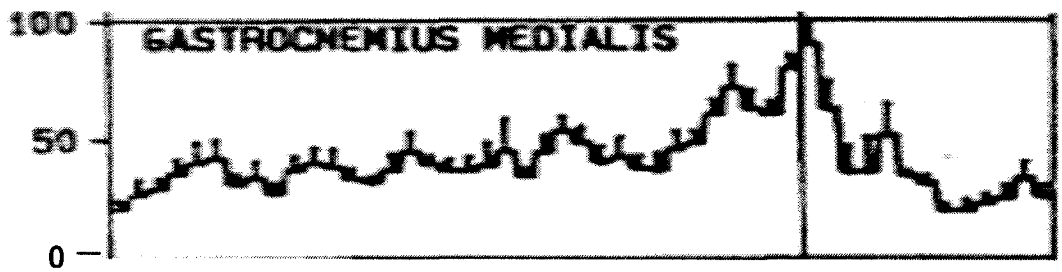
2.7.4 Comparison of Muscle Activity of the Gastrocnemius

From all three studies (Figure 3d), it can be determined that the gastrocnemius is primarily active throughout most the stride, until after push-off. De Koning et al. shows activity present from the beginning until peaking at push off. After "push-off" the activity declines. Minkoff et al. suggests that early in the stride the gastrocnemius is working eccentically during knee flexion; however, it is possible that the activity seen in the muscle is generating concentric plantar flexion.

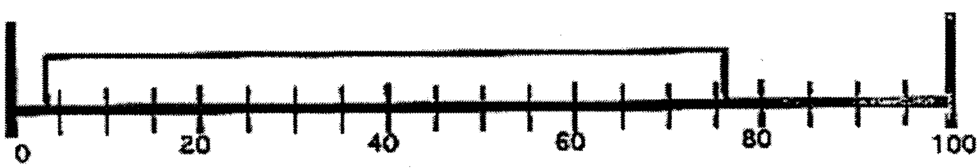


Active Eccentric (knee extension)	Active Eccentric (knee extension)	Active Concentric (ankle plantar flexion)	Inactive

1 (Minkoff et al., 1994)



2 (de Koning et al., 1991)

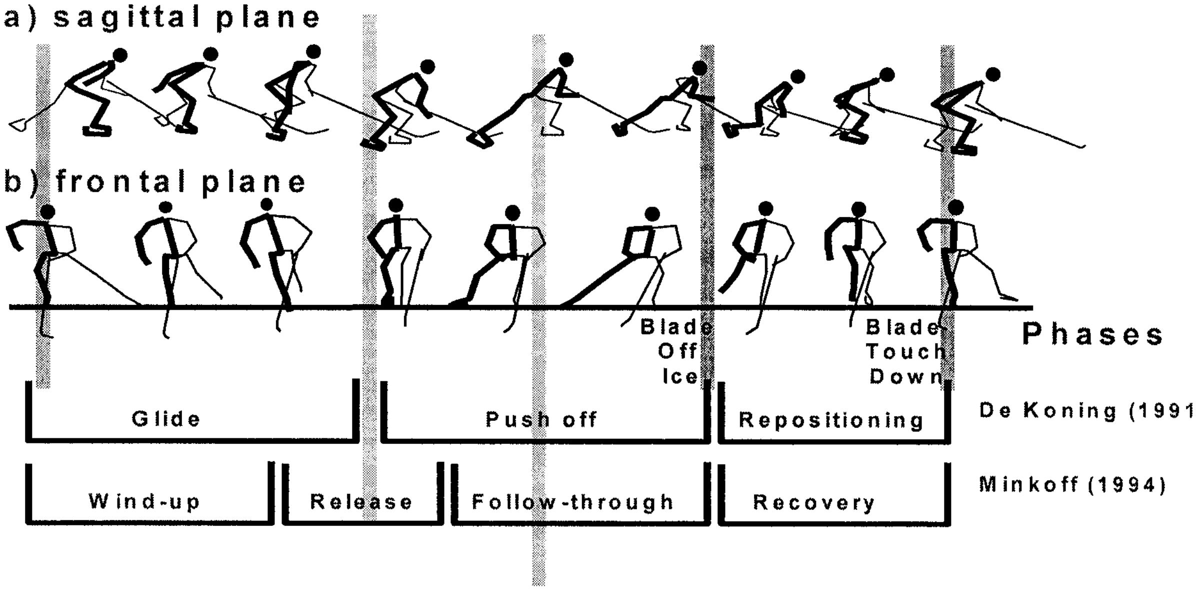


3 (Hinrichs, 1994)

FIGURE 3D: COMPARISON OF MUSCLE ACTIVITY OF THE GASTROCNEMIUS

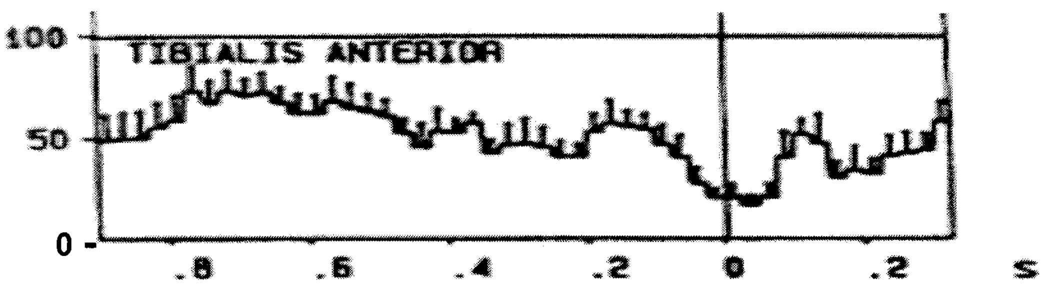
2.7.4 Comparison of the Muscle Activity of the Tibialis Anterior

There is a large discrepancy between Minkoff's et al. suggestion, and both de Koning's et al. and Hinrichs' results (Figure 3e). Minkoff reports the tibialis anterior is inactive until the recovery phase. The other studies show that the muscle is active except for a small duration of time in the middle of the stride. This period of muscle inactivity appears to correspond to the push-off in de Koning's study.

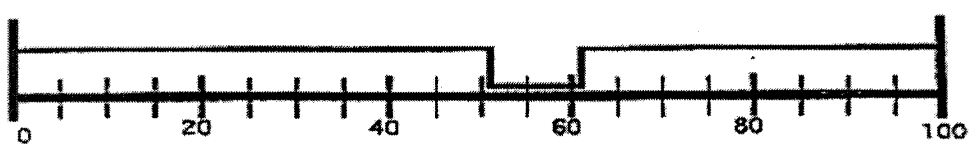


Inactive	Inactive	Inactive	Active Concentric (dorsiflexion

1 (Minkoff et al., 1994)



2 (de Koning et al., 1991)



3 (Hinrichs, 1994)

FIGURE 3E: COMPARISON OF THE MUSCLE ACTIVITY OF THE TIBIALIS ANTERIOR

2.8 Specificity of Training

There has been much research related to training specificity (Cox et al, 1995; Daub et al, 1983; de Boer et al, 1987). There is a general consensus that the closer a training activity can mimic the actual sport activity, the greater the motor conditioning benefit. This is because the nature of the adaptations is dependent on the specific modality of training used. Unfortunately, since ice surfaces are limited in the summer, it has been difficult to find activities that mimic the physiological and biomechanical demands specific to skating. The challenge has been to find training methods specific for hockey player during the summer months. De Boer (1985) reviewed the specificity of training in speed skating with regard to the physiological and biomechanical characteristics. Cycling, although adequate for the oxygen transport system, required completely different muscle coordination patterns. Board skating and roller-skating were more suited for establishing local muscle adaptations. A study by Daub et al (1983) investigated the specificity of physiological adaptations of ice hockey training and found that the adaptation from ice hockey did not extend to submaximal cycling.

In-line skating has become a popular method of dry land training, because it allows the athletes to work only on the gross skating fundamentals. However, another study by de Boer et al (1987b) has shown that dry land skating shows substantial differences in the biomechanics when compared to speed skating on ice. For example: in dry skating, a significant decrease in knee angle and angular velocity were found; and the maximal knee angular velocity occurred before the end of the push-off.

Dreger (1997) published an article “Using the skating treadmill to train hockey players for speed”. He explained that the skating treadmill is similar in function to a running treadmill and allows for sport-specific training. Since players can wear their own skates and carry a stick, he or she feels that it provides an increased sport-specific training effect. To improve speed strength he suggests that the athletes can train in one of two ways on the skating treadmill: one is for athletes to train at speeds 5 to 10% higher than their top speed; and, the second is to train at an incline. This raises issues about how incline is a factor in lower limb movement, such as possible increasing the amount of flexion need during the swing phase to reposition the foot for initial contact. Although another positive is the ability to set appropriate speeds consistently on the treadmill allows for greater control of training volume and intensity of the players.

This evidence suggests that the skating treadmill is a useful modality for specific training in ice hockey. It can also be a valuable research tool for the collection of physiological and biomechanical data during the performance of forward skating. It provides an environment that facilitates the use of analytical equipment. Previously, it had been determined that the cycle ergometer was the most task specific device related to skating available in a laboratory setting (Cox et al 1995) in the “absence” of a skating treadmill. The development of the skating treadmill has allowed for the possibility of training and research in a laboratory setting.

Chapter III

3.1 Equipment

The skating treadmill (figure 4) has a skating surface 1.8 m wide x 1.8 m long (3.2 square meters), covered by a series of polyethylene slats that are 1.80 m long x 0.28 m wide x 0.64m thick. The slats are attached to a rubber conveyer belt that rolls over two drums. An electronic motor for speed and slope is connected to a control box. The skating treadmill has a range of speeds up to 32 km/hr (8.9 m/s), and a range of grades between 0 and 16%. There is a safety grab bar about waist level, in front of the skate surface. A safety harness is worn by subjects around their thighs, waist, and upper body and is attached by a safety rope to an overhead suspension bar. On the wall in front of the treadmill is a mirror (1.5m x 1.8m) to allow skaters visual feedback on their body position and movements, thus allowing them to make position adjustments.

The EMG signal was measured using the Multi Signal System ME3000P8 muscle tester unit (Mega Electronics, Finland). It is a portable data logger used as a collection and recording device. A 32 MB memory card allows for independent storage of data, which can subsequently be downloaded into a computer. The signal from the muscle is transmitted to the unit using EMG pre-amplified cables (The gain of the preamplifiers is 375. The resolution is 2.95 uV per bit). To avoid aliasing, raw signals were recorded at 1000Hz.

3.2 Methods

Motor Point Identification was done to determine the best procedure for electrode placement (Appendix B).

Pilot studies were done to verify procedure and protocols for the study, as well as to determine the method of processing EMG signals and analysing data. A test-retest trial was also completed (Appendix C) indicating high repeatability in parameters.

A total of seven subjects voluntarily participated in the study. All of the subjects were varsity hockey players from McGill University (age = 22.1 ± 1.2 years, height = 1.8 ± 0.1m, weight = 82.1 ± 8.5 kg).). Subjects had varying playing experience at the intercollegiate level (i.e. 1 to 4 years).

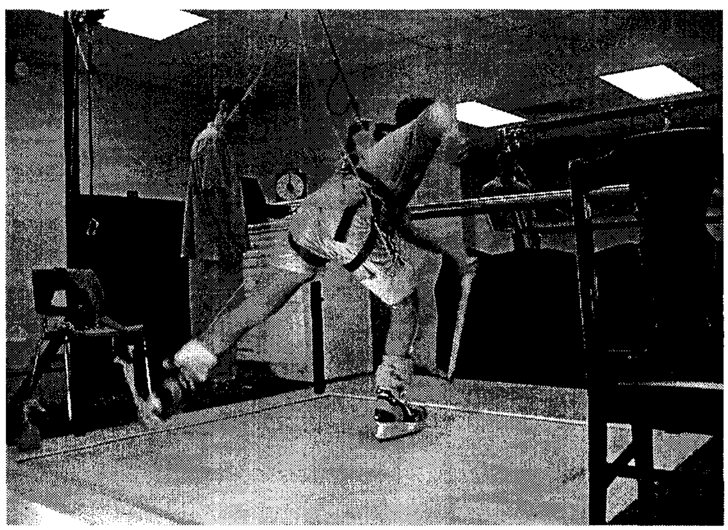


***FIGURE. 4** SKATING TREADMILL*

Prior to testing all subjects were familiarized with the skating treadmill. Subjects participated in one testing sessions on the skating treadmill at the McGill University Seagram Sports Science Centre.

Upon arrival, a verbal explanation of the procedures was given to subjects, as well as informing them of any potential risks or benefits inherent to the research. The consent form (Appendix D) was signed to demonstrate that they were aware of the physical demands of the testing protocol, and their willingness to participate. Subject information was entered into the database. Electrode site locations on the right leg were prepared by removing local hair, abrading the skin with abrasive scrub pads, then cleaning the area with rubbing alcohol. One-inch disc (2.5 cm) shaped disposable bipolar differential electrodes (Meditrace Inc., conductive adhesive electrodes) were placed with the centres 2.5 cm apart. The equipment set up was limited to collecting only four muscles simultaneously, reserving the additional four channels for goniometer measures, therefore the data were collected in two sets: 1) the thigh and 2) the lower leg, with the vastus medialis being the common muscle in both sets. The electrodes were placed on the muscles of interest using the guidelines from Anatomical Guide for the Electromyographer (Delagi et al., 1980; Appendix A) oriented with respect to the direction of the muscle fibre (figure 5).

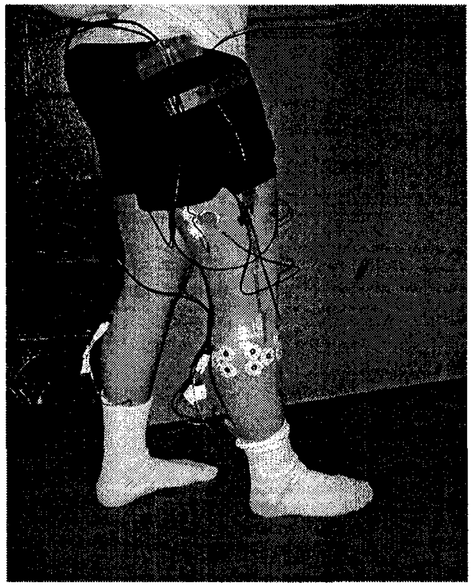


FIGURE 5: *ELECTRODE PLACEMENT OF THIGH AND LOWER LEG MUSCLES*

The EMG signal was measured using the Multi Signal System ME3000P8 muscle tester unit (Mega Electronics, Finland). Data was sampled at 1000Hz. An online measurement and maximal voluntary contractions (MVCs) were taken to ensure that all channels were receiving signals from the appropriate muscle sources. The ME3000P8 was inserted into a padded casing and then into a backpack (figure 6) attached around the waist of the subject. Subjects themselves were attached then to the safety harness via two suspension cables. Prior to skating, the harnesses were tested to ensure carriage of the subject's body weight. While skating, subjects held a hockey stick to replicate typical skating conditions (figure 4).

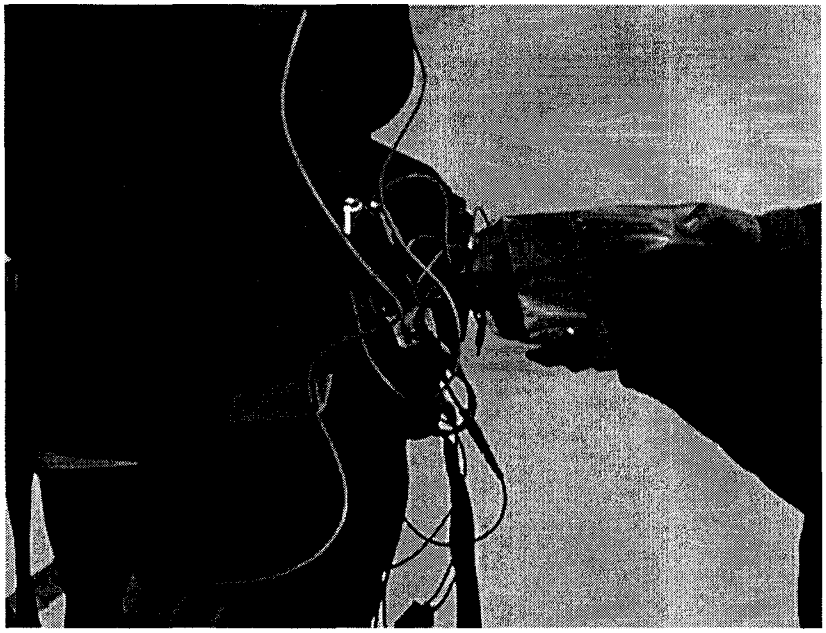


FIGURE 6: BACKPACK USED TO HOLD THE PORTABLE ME3000P8 EMG COLLECTION SYSTEM

The treadmill was set at a 1.2% grade. Subjects warmed up for a minimum of one minute at each collection speed. Subjects performed one trial of 30 strides at each of the following speeds: 12 km/hr (3.3 m/s), 18 km/hr (5.0 m/s), and 24 km/hr (6.7 m/s), with a two- minute rest between trials. After the trials were completed for the 1st set (thigh); the data were downloaded by interfacing the ME3000P8 with a Hewlett Packard e-Vectra (Pentium III) computer, via an integrated optic cable. The electrode cables were switched to the 2nd set (lower leg) of muscles and the procedure the skate trials repeated. In addition to the above, goniometers (Penny and Giles XM110; Blackwood, UK) were used to collect kinematic data simultaneously, and film record logs were kept. These data will be reported in a separate report.

Megawin® 1.21 software displayed and processed the signals. In each trial condition, 20 strides measures of muscle activity were parsed and imported into an in lab program using Matlab® 6.0. Within this program, the raw EMG signals were rectified, and processed using a 4th order Butterworth filter (zero lag). The individual strides were segmented and normalized to 100% stride, equivalent to stride time duration (blade contact to blade contact). The EMG magnitudes were normalized to 100% of the maximum value obtained during dynamic contraction for each subject when skating at 24 km/hr (MDC_{24}). An ensemble average was calculated following intrasubject calculations of 20 strides per subject. The data were exported into spreadsheet format for Microsoft Excel® 2000 and Statistic® 5.0 for analysis and graphing.

Specific points (amplitude and time) were determined for each muscle. The mean value and standard deviation, of each parameter, for each subject was calculated. A one-way repeated measure ANOVA was performed, and then followed by Tukey post hoc tests.

3.3 Results

The data were normalized to the maximum value obtained during the stride at 24 km/hr. Maximal voluntary contractions (MVCs) were recorded, however, the EMG values obtained during the dynamic activity of skating were considerably higher than the MVCs. Two exceptions were the m. biceps femoris (BF) and m. tibialis anterior (TA). The MVC values of the BF and TA were higher than the values obtained while skating, which may indicate that the muscles are not working very hard.

The stride rate increased with an increase in speed (Table 5). It can be seen that stride rate increased with speed. There was a significant difference between all speeds.

***Table 5**: Stride rate*

speed km/hr (m/s)	strides/min (stride/s)
12 (3.3)	45.1 ± 5.0 (0.75 ± 0.08)
18 (5.0)	52.5 ± 6.0 (0.88 ± 0.10)*
24 (6.7)	68.0 ± 11.5 (1.13 ± 0.19)* **

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

There are three stride phases and/or events in skating: glide phase, when the skate is on the surface and the skater is moving forward, the contralateral leg is providing propulsion; push-off: the leg is gliding laterally providing the propulsion; swing phase, the leg is moving back to the starting position to begin the next stride. The beginning of the stride, the initial contact (blade contact), is when there is weight acceptance. The graphs below illustrate the EMG activity for the entire stride from blade contact to blade contact at three velocities (figures 7-14).

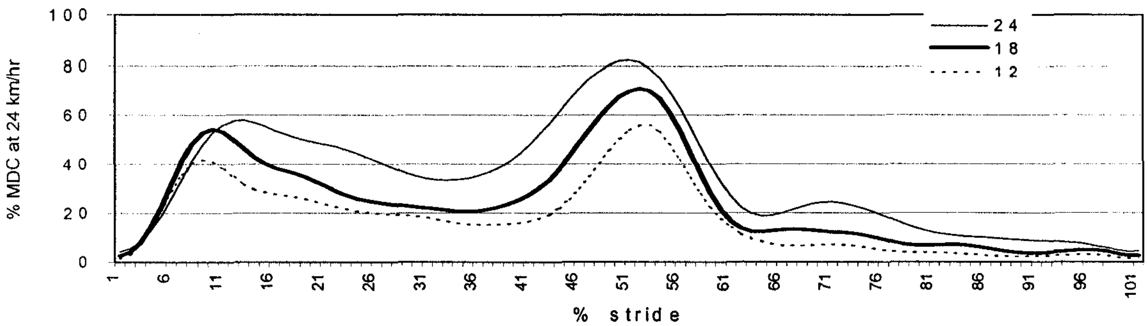


FIGURE 7: *M. VASTUS MEDIALIS: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, and 24km/hr*

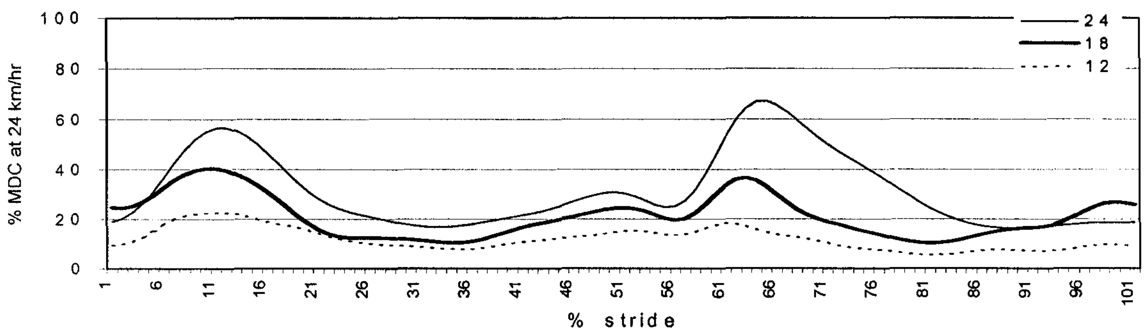


FIGURE 8: *M. ADDUCTOR MAGNUS: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, and 24km/hr*

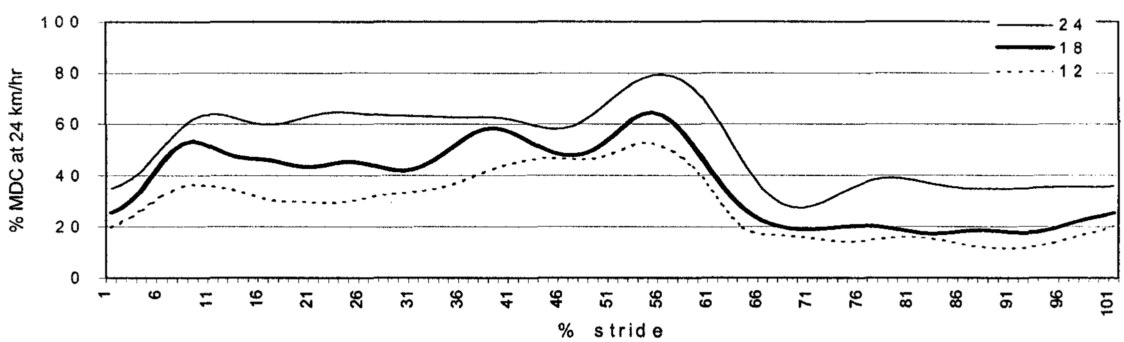


FIGURE 9: *M. BICEPS FEMORIS: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, and 24km/hr*

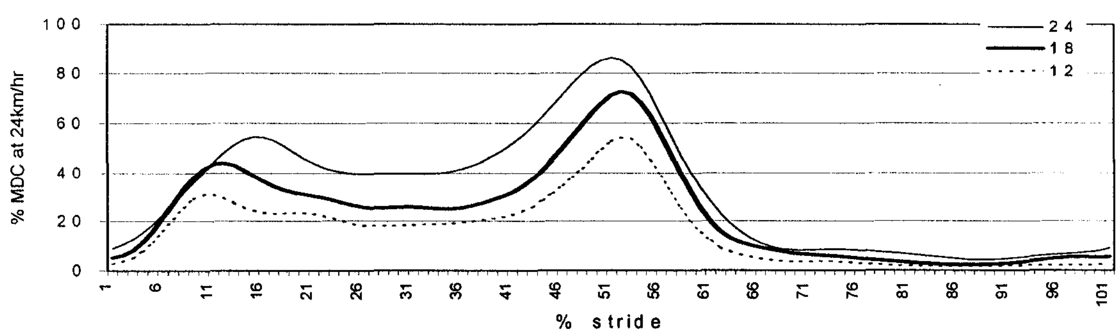


FIGURE 10: *M. GLUTEUS MAXIMUS: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, and 24 km/hr*

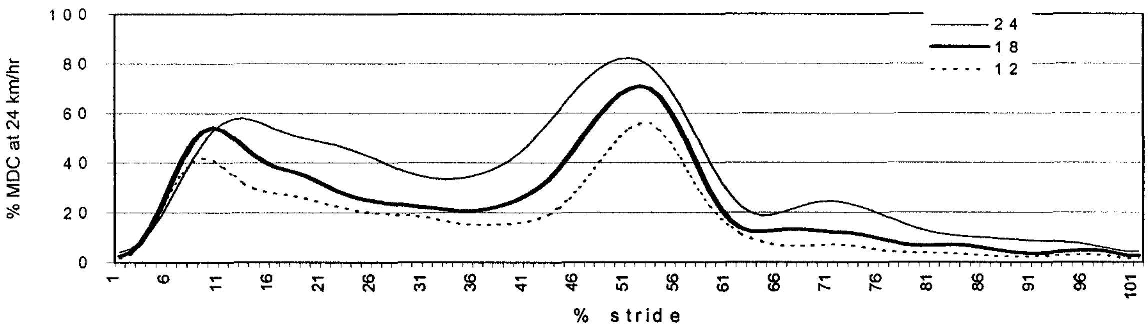


FIGURE 11: M. VASTUS MEDIALIS: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, and 24 km/hr

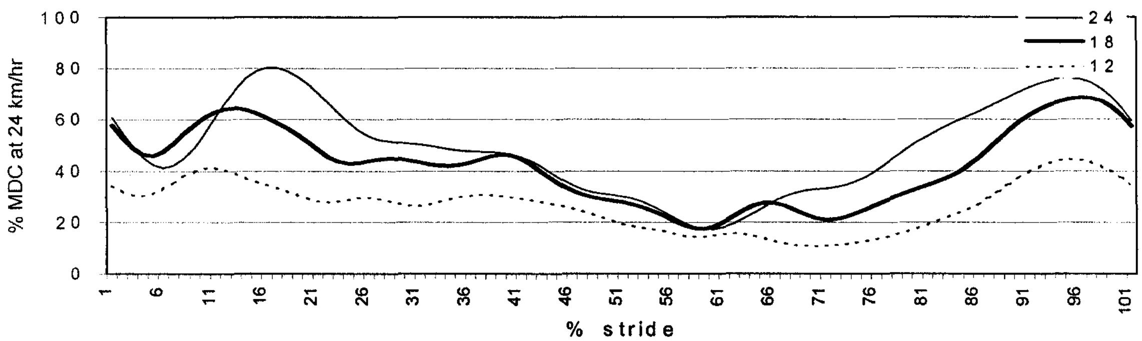


FIGURE 12: M. TIBIALIS ANTERIOR: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12,18, and 24 km/hr

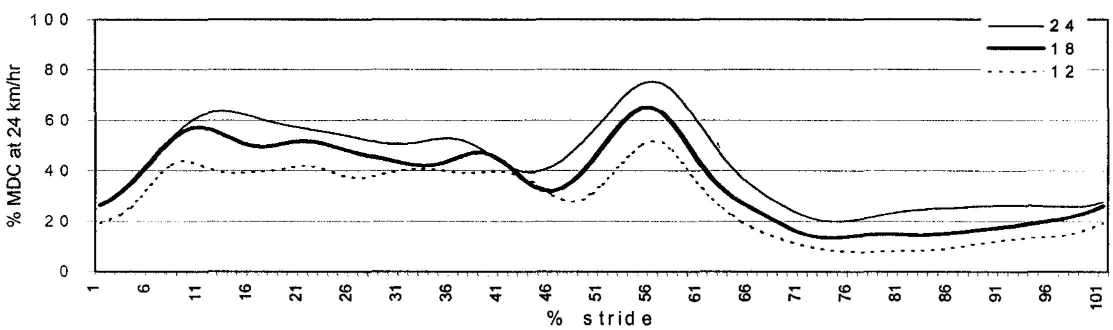


FIGURE 13: PERONEUS LONGUS: GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, AND 24 KM/HR

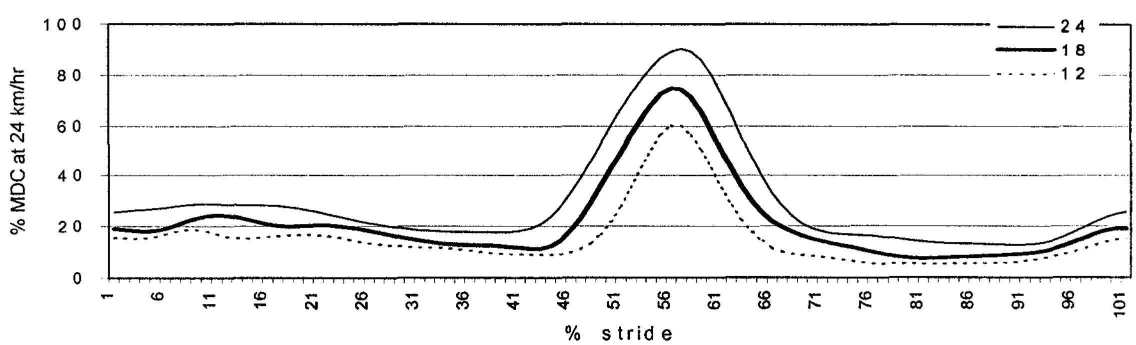


FIGURE 14: M. GASTROCNEMIUS (LATERAL) : GROUP AVERAGE EMG PATTERNS OF FORWARD SKATING AT THREE VELOCITIES; 12, 18, and 24 km/hr

On initial support there was activity beginning in the m. vastus medialis (VM), m. adductor magnus (AM), m. biceps femoris (BF), m. gluteus maximus (GM), and m. peoneus longus (PL). For all these muscles, during the glide phase, the activity increased from the initial contact until a 1st peak of 60 to 80% of the MDC_{24} is obtained at 10-15% of the stride. After the 1st peak, there was a decrease in activity for the VM, AM, and GM to approximately 20 to 40% MDC_{24}. Greater muscle activation persisted during this phase for the BF and PL (approximately 40 –60% of MDC_{24}). The m. tibialis anterior activity began with a 1st peak, which coincided with the above muscles in the first 10-15% of the stride, then had a decrease in activity. The m. gastrocnemius lateral (GL) showed no activity during the glide phase.

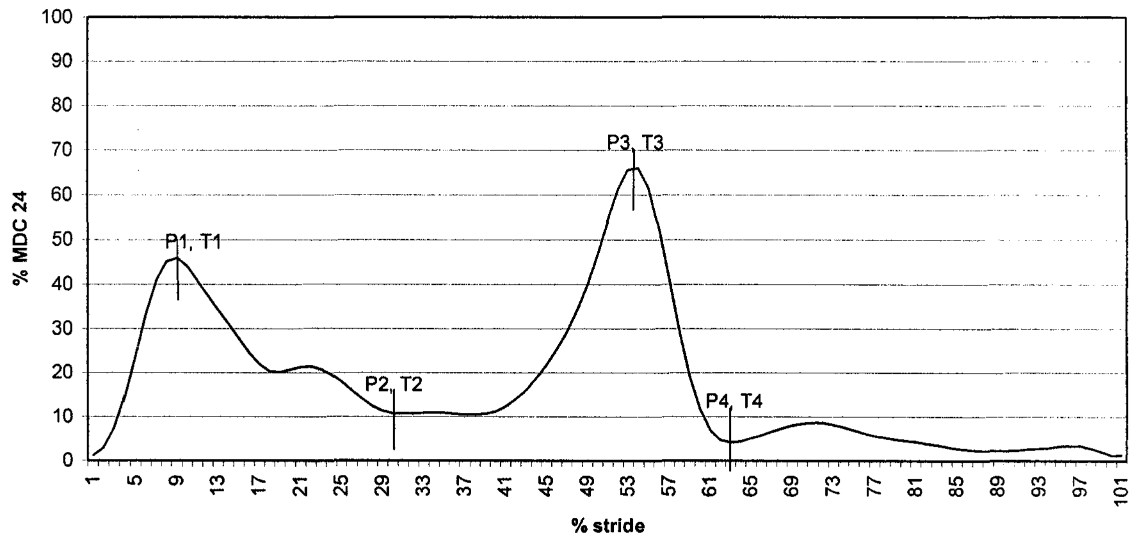
As the push-off phase began there was an increase in VM, and GM activity. A 2nd peak occurred at 50 to 60% of the stride, with a higher amplitude (70 to 100% of MDC_{24}) than the 1st peak was seen at the push-off point. The VM and GM peaked first at 52% in the stride, followed by the BF, GL, and PL which peaked at 58% of the stride. The AM and TA peaked during the swing phase at 68% and 91% respectively. The activity was minimal or off in the VM, BF, GM, PL, and GL during the swing phase. There was a clear increase in muscle activity with an increase in speed, but temporal differences were minimal, although some significant differences were found.

A description of the muscle activity at 24 km/hr, determined from the results of the current study, is presented in Table 6. The eccentic and concentric activity is a qualitative determination based on visual examination.

***Table 6**: Chart of muscle activity; determined from EMG results of forward skating in ice- hockey*

At 24 km/hr	**Glide** 0 - 33% stride	**Push-off** 33 – 63% stride	**Swing** 63 – 100 % stride
Vastus Medalis	Knee flexed Smaller peak at activity onset, then decreases. Eccentric to act as stabilizer	Peaks at mid push-off phase Knee extension Concentric work	Off
Adductor Magnus	Smaller peak at activity onset, decreasing Eccentric stabilizing hip	Off, with slight increase Eccentric, hip is abducting	Peaks after push-off, decelerating hip abduction Concentric, hip adduction
Biceps Femoris	Hip flexed, knee flexed Peak then constant activity Eccentric knee extension	Peaks just after VM Concentric hip extension	Low activity, eccentric Knee flexion due to gravity, weight of foot pulling tibia down during hip flexion
Gluteus Maximus	Similar pattern to VM Hip flexion, internal rotation Eccentric, stabilizing hip	Peaks at same time as VM Concentric Hip extension and external rotation	Off
Tibialis Anterior	Ankle dorsiflexed Peaks, then decreases Isometric activity	Off Ankle extension	On, peaks Dorsiflex to reposition
Peroneus Longus	Ankle dorsiflexed Peaks then decreases Eccentric ankle flexion	Peaks as ankle pushes into plantar flexion Concentric ankle extension	Off Ankle flexion
Gastrocnemius (lateral)	off	Peaks Ankle extension Concentric activity	Activity decreases, then off

The averages of amplitude of the signal (P) and time (T) of the stride were calculated at specific parameters (figure 15): P1 and T1, 1st peak; P2 and T2, valley between peaks (minimum value); P3 and T3, 2nd peak; P4 and T4, end of deactivation (when activity ceased to change) after 2nd peak. For the TA: P1 and T1 represents the 1st peak seen in the glide phase; P3 and T3 represents valley between the peaks during the push-off; P5 and T5 represent the 2nd peak during the swing phase. The GL had only one peak during the push-off phase P3 and



T3.

FIGURE 15: *EXAMPLE OF PARAMETER POINTS ON THE M. VASTUS MEDIALIS*

Significant differences were seen in the amplitude of muscle activation for most muscles, as well as a few temporal differences. There was usually a significant increase in the peak amplitude at 24 km/hr when compared to 12km/hr. The results for each muscle are displayed in Tables 7-13.

Table 7: *m. vastus medialis: measurement parameter values of amplitude (P) and time (T)*

Parameter	12 km/hr (3.3 m/s)	18 km/hr (5.0 m/s)	24 km/hr (6.7 m/s)
P1	55.6 ± 11.4	63.1 ± 9.1	76.0 ± 13.6*
P2	21.6 ± 10.1	27.6 ± 14.0	34.9 ± 21.6*
P3	78.4 ± 15.3	91.0 ± 18.2	95.1 ± 12.9*
P4	12.3 ± 8.8	12.3 ± 9.3	14.4 ± 9.5
T1	9.1 ± 0.9	10.4 ± 0.8	17.3 ± 7.3* **
T2	34.1 ± 6.0	31.9 ± 7.0	30.1 ± 4.3
T3	52.6 ± 1.5	52.4 ± 2.4	50.5 ± 3.3
T4	62.9 ± 3.3	62.4 ± 2.0	63.4 ± 2.1

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

Table 8: *m. adductor magnus: measurement parameter values of amplitude (P) and time (T)*

Parameter	12 km/hr (3.3 m/s)	18 km/hr (5.0 m/s)	24 km/hr (6.7 m/s)
P1	35.0 ± 11.6	51.9 ± 22.9	67.6 ± 30.8*
P2	11.1 ± 6.6	10.7 ± 3.7	17.3 ± 9.7
P3	32.7 ± 10.5	57.7 ± 13.3*	91.0 ± 16.3* **
P4	8.7 ± 3.1	14.4 ± 6.8	21.7 ± 14.6*
T1	10.1 ± 3.2	11.7 ± 3.4	13.3 ± 3.7
T2	36.9 ± 3.1	36.1 ± 3.1	35.4 ± 2.4
T3	60.6 ± 8.5	63.0 ± 4.1	65.3 ± 3.4
T4	72.3 ± 5.2	75.3 ± 8.7	81.6 ± 8.2* **

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

Table 9: *m. biceps femoris: measurement parameter values of amplitude (P) and time (T)*

Parameter	12 km/hr (3.3 m/s)	18 km/hr (5.0 m/s)	24 km/hr (6.7 m/s)
P1	56.0 ± 18.7	64.9 ± 8.7	78.0 ± 18.2*
P2	37.3 ± 16.8	41.6 ± 16.6*	59.1 ± 27.1* **
P3	80.4 ± 22.3	87.3 ± 19.2	93.0 ± 12.7
P4	15.1 ± 5.6	15.1 ± 7.4	28.9 ± 12.1* **
T1	9.6 ± 3.2	9.4 ± 2.6	11.7 ± 5.0
T2	25.9 ± 5.8	28.3 ± 6.1	26.3 ± 7.4
T3	56.3 ± 3.8	55.9 ± 3.5	55.6 ± 3.9
T4	67.3 ± 4.8	66.7 ± 5.5	67.3 ± 3.9

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

***Table10**: m. gluteus maximus: measurement parameter values of amplitude (P) and time (T)*

Parameter	12 km/hr (3.3 m/s)	18 km/hr (5.0 m/s)	24 km/hr (6.7 m/s)
P1	37.4 ± 11.9	49.4 ± 16.7	59.4 ± 24.1*
P2	20.1 ± 5.6	26.6 ± 6.8	38.6 ± 22.2*
P3	71.4 ± 19.8	85.3 ± 14.5	100.0 ± 1.5* **
P4	7.7 ± 3.3	10.1 ± 5.3	10.8 ± 2.2
T1	10.1 ± 2.4	12.0 ± 2.7	14.1 ± 6.3
T2	29.4 ± 5.3	28.7 ± 5.4	28.1 ± 5.3
T3	53.0 ± 1.0	53.1 ± 1.8	52.4 ± 2.1
T4	64.0 ± 1.5	63.4 ± 2.1	66.1 ± 3.4

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

***Table 11**: m. tibialis anterior: measurement parameter values of amplitude (P) and time (T)*

Parameter	12 km/hr (3.3 m/s)	18 km/hr (5.0 m/s)	24 km/hr (6.7 m/s)
P1	58.7 ± 15.5	75.1 ± 24.4	95.0 ± 9.4* **
P3	12.1 ± 6.3	15.1 ± 7.0	16.6 ± 7.3*
P5	61.1 ± 11.7	80.0 ± 21.7*	92.1 ± 8.5*
T1	11.0 ± 1.4	15.6 ± 5.2	16.4 ± 4.0*
T3	63.1 ± 7.1	62.6 ± 8.4	61.9 ± 7.6
T5	95.9 ± 2.7	94.1 ± 2.9	94.9 ± 3.4

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

***Table 12**: m. peroneus longus: measurement parameter values of amplitude (P) and time (T)*

Parameter	12 km/hr (3.3 m/s)	18 km/hr (5.0 m/s)	24 km/hr (6.7 m/s)
P1	59.0 ± 4.8	75.0 ± 13.3	74.7 ± 74.7
P2	32.9 ± 8.8	31.9 ± 8.6	40.3 ± 14.7
P3	68.3 ± 12.3	76.9 ± 17.9	90.9 ± 15.0* **
P4	14.7 ± 9.0	22.9 ± 25.0	24.4 ± 11.0
T1	11.7 ± 4.7	11.7 ± 4.5	13.7 ± 3.6
T2	44.1 ± 8.9	45.9 ± 6.6	43.6 ± 6.5
T3	56.9 ± 2.5	56.9 ± 4.8	54.3 ± 7.4
T4	69.4 ± 3.6	70.3 ± 3.5	67.6 ± 7.4

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

***Table 13:** m. gastrocnemius: measurement parameter values of amplitude (P) and time (T)*

Parameter	**12 km/hr** (3.3 m/s)	**18 km/hr** (5.0 m/s)	**24 km/hr** (6.7 m/s)
P3	80.1 ± 23.4	92.6 ± 16.3	100.0 ± 1.9*
P4	13.0 ± 9.6	16.3 ± 9.5	19.1 ± 10.3
T3	56.6 ± 2.1	57.6 ± 3.0	57.1 ± 2.6
T4	66.0 ± 2.6	67.3 ± 3.3	69.3 ± 3.7*

values represent mean ± SD
* indicates a significant difference from speed 12 km/hr ($p < 0.05$)
** indicates a significant difference from speed 18 km/hr ($p < 0.05$)

The VM had significantly higher values at 24km/hr for both peaks (P1, P3) and deactivation (P2) between the peaks when compared to 12 km/hr. The timing of first peak (T1) was significantly later at 24 km/hr. It happened at 17.3% of the stride compared to 9% and 10.4% of the stride at 12 km/hr and 18 km/hr.

The 1st peak (P1) of the AM was significantly higher at 24 km/hr compared to 12 km/hr. The 2nd peak (P3) showed that 18km/hr was significantly higher than 12km/hr; and 24km/hr was significantly higher than 18km/hr. The timing of deactivation after the 2nd peak is significantly at 24km/hr (81% of the stride, in comparison to 72 and 75% of the stride).

The BF showed a significantly higher activation level at 24 km/hr at the 1st peak when compared to 12 km/hr. The deactivation amplitudes between the peaks were significantly different in all conditions, with the lowest value at 12km/hr and highest at 24 km/hr. The push-off peak (P3) was not significantly different between conditions. The level of deactivation after the push-off peak was significantly higher for 24km/hr when compared to 12 and 18 km/hr.

The GM showed a significantly higher 1st peak and then deactivation level at 24km/hr compared to 12 km/hr. The push-off peak (P3) was significantly higher for the 24km/hr condition compared to both 12 and 18 km/hr conditions.

The 1st peak of the TA during the glide phase was significantly higher at 24 km/hr compared to both 12 km/hr and 18 km/hr. The timing of the 1st peak (T1) was also significantly later at 24km/hr compared to 12 km/hr. The amplitude of deactivation during the push-off and the peak during the swing phase were significantly higher at 24km/hr compared to 12km/hr.

There were few significant differences for the PL. The amplitude of the 2nd peak (P3), seen during push-off, had significantly higher values at 24km/hr when compared to 12 and 18 km/hr.

The GL had a significantly higher amplitude at the push-off for 24 km/hr, in relation to 12km/hr. The end of deactivation time occurred later at 24 km/hr compared to at 12 km/hr.

3.4 Discussion

In general, increased velocities in forward skating produced identical muscle coordination patterns with augmented activation (amplitude). EMG was shown to discriminate the activity of individual muscles in terms of their contribution to complex coordination patterns (Basmajian, 1985; Clary, 1987; DeLuca, 1997; Stegeman et al., 2000).

Isometric maximal voluntary contractions (MVCs) were recorded for all subjects for each muscle studied. Several issues were raised during testing (i.e.

how to normalize EMG amplitudes). Most of the muscles studied produced higher peak EMG values while skating at 24km/hr with the exception of the biceps femoris (BF) and tibialis anterior (TA). Comparing MVCs to dynamic activity has been debated throughout literature (Deluca 1997). For instance, the perception of maximal efforts is subjective and varies between subjects. Secondly, it is difficult to constrain a joint to isolate a target muscle without precluding synergistic muscle activity. Also, it is undetermined whether it is completely acceptable to compare isometric contractions to dynamically contracting muscles. For instance, EMG signals will not necessarily correspond to equivalent force production as muscle length changes alter the tensions produced (Winter, 1990). Not withstanding the above limitations, the comparison of EMG skating records to MVC values can provide an approximate inference of the level of muscle exertion. In general, the majority of muscles' skating EMG measures exceeded their respective peak MVCs, with the noted exceptions of the BF and TA that had peak values of approximately 75% of MVC.

This study, heretofore not published, describes the muscle involvement in ice hockey forward skating with improved fidelity. The results from this study agree in general with previous research, though some specific discrepancies exist.

Marino (1977) identified stride rate as being the primary factor that changes with different velocities; that is, with the stride rate increasing with an increase in velocity. The results from this study agree with that interaction. The range of stride rates in this study is narrower than Marino's: 45.1 stride/min at

12km/hr to 68.0 stride/min at 24km/hr compared to 38.7 stride/min at 13.5 km/hr to 80.4 stride/min at 24.9 km/hr, respectively. However, this was somewhat constrained by the treadmill. As well, the results of this study are similar to Hinrich's (1994) treadmill stride rates, but differed from Nobe's et al (2000) treadmill results where no noticeable increases in stride rate with increased speed were observed.

In comparison to de Koning (1991) speed skating patterns and Hinrich's (1994) "on-off" muscle function, similar patterns are seen though with some specific differences. There are some obstacles in direct comparison of results. For example, Hinrich's study does not state the threshold value for "on-off" activity, so low levels of activity in the current study may correspond to "off" in Hinrich's results. Further, Hinrich's data were collected at speeds of 10.5, 14.0, and 16.5 km/h. The skating treadmill patterns collected at 12.0 km/hr were similar to the on-ice and treadmill measures by Hinrich with a few exceptions; the AM activity in this study drops at the end of the swing phase (i.e. would turn "off" at approximately 85% of the stride rather than remain "on"), and the BF as well as GM did not increase until the glide phase (i.e. Hinrich's "on" at 99% of stride). Further, the TA activity looks similar with the muscle activity decreasing in the push-off phase.

Similar EMG patterns were observed in comparison to de Koning's study, where the data were collected at 36 km/hr (10 m/s), with a few notable exceptions. For instance, there was a minor difference in VM activity: De Koning identified more constant activation during the glide phase, whereas our data shows a slight decrease during the glide phase after the initial peak. Subsequently both studies show similar increases in muscle activation during the push-off phase and decline at the beginning of the swing phase. A noticeable difference in EMG patterns between the two studies was for the BF. De Koning's speed skaters demonstrated an increase in muscle activity peaking in the glide phase, decreasing during push-off, and once again increasing during the swing phase. Our skaters exhibited constant muscle activity that peaked during push-off and subsequently declined during the swing phase. Another discrepancy with de Koning's results was found for the GM: their study showed a gradual increase in muscle activity to the peak, whereas this study showed a 1st peak in the glide phase followed by an intervening decline leading to a 2nd (higher) peak at the push-off. Several muscles demonstrated similar activation patterns. The TA EMG pattern was similar in both studies with a peak in both the glide and swing phases, followed by a decline in activity at the push-off. The GL in this study showed a more distinct peak at the push-off, but the pattern was similar with on large peak at the push-off and low activity during the glide and swing phases. The differences between studies may be explained in part by differences in skating techniques and speed. The speed skating technique is precise and cyclical, executed in a control environment with a constant skating course. This is not seen in ice hockey, where each player skates in constant transition between other movements such as starts, stops, and turns, in response to changes in the game environment. Differences in technique may thus be expected.

The glide phase, beginning with weight acceptance, occurred during approximately 0-33% of the stride, followed by the push-off (33-63%), then completed with the recovery (swing) phase (63-100%). During the glide phase an increase was seen in the activity of all muscles except the GL. In general, a first peak in muscle activity appeared in the glide phase: VM and BF peaked earliest, followed by the AM and GM, and then finally the TA and PL. These first peaks all took place in the first 9-15% of the stride. This would suggest that at weight acceptance (i.e. initial glide), when the skater has a flexed hip, knee and ankle, the BF, VM, AM, GM, and PL (Table 6) were working eccentrically to stabilize the joints. The TA was working isometrically to stabilize the ankle. After weight acceptance, there was then a general decrease in activity for all the muscles except the BF (i.e. BF remained at 40% to 65% throughout). As the skater approached the push-off there was an increase in activity for the VM, BF, GM, PL, and GL (i.e. second peak most, 1st peak for GL). The VM and GM peaked earliest, followed by the BF, GL and PL about 4% later in the stride. This suggests that muscle contributing to hip and the hip and knee extension are active first, followed by the muscles contributing to ankle extension. De Koning et al. (1991) indicated that proximal-distal sequences are similar for both jumping and skating propulsion. These researchers stated that the observed patterns of muscle coordination can be seen as a compromise between the constraints of the specific skating movement and the advantageous effect of a proximo-distal sequence in unconstrained jumping. Our results show that the musculature producing movement around the hip and knee during extension were effectively simultaneous, then followed by the muscle activity producing ankle extension.

During the swing phase the activity decreased in VM, BF, GM, PL, and GL, in general; however, two exceptions included the AM and TA that demonstrated substantial muscle activation peaking at 68% and 94% of the stride cycle. The activity in the AM during the push-off phase was eccentric while the hip is abducting, while during the swing phase it would be acting concentrically to promote hip abduction.

The primary hip flexor is the illiopsoas, which is not readily accessible via surface electrodes. No hip flexor was studied, although the adductor muscles do contribute to hip flexion. During support, the BF and GM worked at the same time and had similar EMG patterns. Since the MVCs may indicate that the BF was not working to its capacity during support, it suggests the GM was the main hip extensor, these findings agree with De Boer's (1987) results. The co-contraction that can be observed at the knee between the BF and VM during support contributes to knee extension. These muscles were active at the same time, during both the glide and push-off phases, then inactive during the swing phase. Initially during the glide phase, upon weight acceptance when the knee and hip are flexed, it appears that the VM worked eccentrically and the BF concentrically. Then as the skaters entered the push-off phase, the knee and hip were extending. The VM works concentrically.

At the ankle we can observe the influence of the GL, TA, and PL activity. Activation can be seen between agonist and antagonist activity. High TA activity was seen upon weight acceptance while the ankle was dorsi flexed while its antagonist, the PL, was activated at the same time but its activity was eccentric. The activity in both muscles decreased, but as the push-off phase was reached, the TA continued to decrease and the PL increased to its peaks. The GL acted synergistically with the PL during the push-off. Both muscles peaked at the same time as the ankle extends. The GL was only active during the push-off phase. Then, as the activity decreased in both the GL and PL, an increase in TA activity was observed. During the swing phase the ankle dorsi-flexed (concentric activity) to bring the foot back into position for touchdown.

Some significant differences can be seen between the three speeds of forward ice skating. Generally, as expected, it can be seen that as speed increased so does the level of activation. In most cases speed 24km/hr was significantly higher than the speed of 12km/hr. The medium speed of 18 km/hr showed few significant differences from the slow and fast speeds. This may be accounted by the inter-subject variability found in EMG.

Unexpectedly, there were fewer significant differences in temporal values than expected (this was with stride time normalized data; in absolute seconds some differences would exist). Marino (1977) showed from on-ice measures that the amount of time in single and double supports changes with speed. At the highest velocity there was a decrease in double support time from (i.e. from 18% of stride to 15% of stride). This would lead to the idea that, perhaps, the push-off phase time would decrease causing the peak at push-off to be earlier and more condensed; however, this was not the case. There were no significant differences in T3 (time to push-off) for any muscle at any speed. At T1 (peak during the glide phase) the VM and TA were significantly later at speed 24 km/hr. Since the level of activation was higher at this speed, it may have taken longer for VM to stabilize the knee. The TA may be pulling the ankle further into dorsi flexion to generate more power during the push-off. At T4 (the end of deactivation after the push-off) the AM and GL were significantly later at speed 24km/hr. The peak of the AM and GL at the push-off was significantly higher than both speeds of 12 and 18 km/hr. It may be that the muscles need more time to deactivate. Given that the muscle impulse (amplitude and duration) increase with speed, temporal changes can be attributed to this, in part.

The lack of differences in temporal effects could be accounted by the fact that as speed increased, the stride rate increased, not necessarily the stride length. The skater was taking more steps, and essentially the muscle coordination pattern remained constant.

It maybe more insightful to compare the skating pattern to walking rather than running since both skills have similar single and double support phases. For instance of typical walking gait literature, Winter (1983) presented EMG patterns of five muscles at three speeds of walking on a treadmill. The results show that the patterns remain essentially the same with the exception of the amplitude, which increases with speed. This interaction is identical to the effect found in the current forward ice skating study. Specific muscle comparisons between walking and skating show a similar TA pattern, except that in skating the peak in the swing phase is higher. The higher TA activity in skating may be due to the extra weight of the skate causing the muscle to work harder while dorsi flexing the foot in preparation for touch down. The BF activity was completely different between the tasks of walking and skating. In walking after the BF peak at contact the activity decreases and stays low, acting primarily as a hip extensor, until the swing phase when it peaks again, as the leg comes forward and the knee is flexed. In skating the BF becomes active at contact and stays active only until the swing phase. It would suggest that BF may be implicated in hip extension during the glide and push-off phases (during support), but was not acting as a knee flexor during the swing phase. Thus knee flexion during the swing phase must be produced by inertial swing of the thigh due to active hip flexion.

The data for this study were collected on the skating treadmill. The one study (Hinrich, 1994) that compared forward ice hockey skating on-ice to the skating treadmill showed a significant difference for m. adductor longus activity. The initial AL muscle activity was similar in the two conditions; however, on-ice skating elicited a second AL activity sooner than the skating treadmill condition (i.e. on ice the 2nd activation was at 46.3% of stride time, on the treadmill it was at 57.8%, $p < .0001$). The adductors are thought to act as a hip stabilizer during this part of the stride. The researcher commented that this difference could be due to the grade on the skate treadmill (the data were collected with a 2.5% grade on the treadmill) and the fact that the skating surface is moving under the skate. This may have resulted in a difference of foot placement during the support phase of the skating stride, causing a lag time from when the skate blade contacted the treadmill until the foot was outside the midline of the skaters' hips to allow the initiation of hip extension. He felt that this lag time could have produced the delay in the onset of the second muscle activation. The conclusion of this study was that, overall, the recruitment patterns during treadmill skating were similar to on-ice skating.

Though the skating patterns on the treadmill appear to be similar, subtle differences may exist. Caution is warranted; for example, differences in both kinematics and muscle activation patterns have been seen when looking at overground and treadmill running (Wank et al., 1998). These differences included step frequency, step length and contact time. More specifically, it was found that running on the treadmill was characterized by a higher stride rate and a shorter step length. It was suggested that this may be due to a lower swing amplitude of the leg in the treadmill. EMG differences were seen in the vastus lateralis (i.e. lower activity), and the biceps femoris (i.e. more activity) when running on the treadmill compared to overground running. It is thought that these differences in muscle activity may because there was a more forward lean of the body when on the treadmill. These studies suggest that further research comparing on-ice and skate treadmill patterns is warranted. It would be beneficial to see if muscle patterns would change on-ice when compared to the skate treadmill.

Ice hockey skating is more difficult to analyse than speed skating because each skater has their own style, unlike speed skating where all the skaters are taught the same precise technique. From observing the individual data and film records, subject style differences were apparent. Some players tend to have a more smooth, even stride throughout the trial, while others had a tendency to have shorter, choppy strides. These differences were more pronounced at the high velocities. At 24 km/hr the standard deviation for the stride rate was 11.5 stride/min compared to 5 and 6 stride/min at 12 and 18km/hr. However, the variances are proportionally similar when calculating the coefficient of variation the three velocities (values of 12 to 16% were obtained). For specific subjects, certain muscles had activation patterns that deviated from the group ensemble. For example, one subject did not have a peak in the AM during the glide phase. Another subject had a phase shift in activity of all the muscles at 24 km/hr when compared to speeds 12 and 18 km/hr. These differences would indicate that caution is warranted for researchers and therapists when making assumptions based on "normal" EMG activity for forward ice hockey skating (i.e. interpersonal variations in skate technique exist and thus so will EMG profiles).

A reason that ice hockey players are not as standardized in their forward skating style, as speed skaters, is because forward skating is only one of the many skills needed for ice hockey. Hockey skills include skating movements such as forward and backward skating, stops, starts, and turns. There are also stick handling, and checking skills (Pearsall & Turcotte, 2000). Forward skating mechanics only account for one small portion of a player's skills. In contrast, speed skating techniques have been developed to technical perfection (Miller, 1981; de Koning 1991).

The EMG profiles may provide some further insight into injury mechanisms. Forces generated by power skating (Minkoff 1994) can predispose players to musculotendinous injuries of the groin. Some aspects contributing to type and severity of an injury are the position of the body part during the trauma, the amount of muscle recruitment during the trauma, and the momentum and direction of the athlete during the trauma (Montepare et al 1996). Adductor strains are a common and frequently occurring injury in NHL hockey (Emery et al. 1999). Two mechanisms of injury to the adductors can be powerful abduction stress during simultaneous adduction of the leg when performing a cutting motion, and overuse from repetitive adduction (such as the swing phase in forward skating) (Lacroix et al 2001). The sudden change in direction from sharp cutting movements results in a forceful eccentric contraction (rather than concentric contraction), which can cause a muscle/tendon strain. When looking at the AM profile in the study, it can be seen that the peak in the swing phase was significantly higher at 24km/hr when compared to 12 and 18 km/hr. At 18 km/hr the muscle was only working at approximately 50% of the maximum obtained at 24 km/hr. Hockey players skate at relatively high velocities during a game. Marino and Weese (1979) found the mean horizontal velocity of hockey players to be 8.78 m/sec (31.6 km/hr). At this speed the AM muscle is working at a high capacity both eccentrically and concentrically; and this larger activation at 24 km/hr could indicate why groin injuries are common. Further investigation of adductor muscle activity during skating acceleration and deceleration could provide insight to the mechanism of injury in groin strains of hockey players.

Other research ideas in forward skating in hockey could include studying both right and left limbs simultaneously, to investigate skating asymmetries. It is likely that skaters have a dominant side, and it would be interesting to see if the lower limb muscle patterns vary from right to left.

Another area where EMG profiles may prove to be an asset is in industrial research. Given that the skate is the interface between the athlete and the ice (or gliding surface), it is fundamental to evaluate the biomechanics of skating when making changes in a skate materials, construction or design. Changes in skate design affect comfort and efficiency, which in turn ultimately affects skating performance. For example, De Koning et al. (2000) compared the new innovative “Klapskates” to the standard speed skate. It was determined that there were significant kinematic differences, but not muscle activation differences. This observation helps to highlight the complexity relating skate design on performance theory. The lack of changes in EMG patterns is not necessarily a poor result. Combined with other measurement parameters such as joint kinematics and in boot pressure, EMG provides the necessary information to understand the body’s adaptations to skate changes. It has been shown that an orthotic can alter the muscle activity of the tibialis anterior (Tomaor and Burdett 1993) when walking. Should major differences be made to hockey skate design, it would still be beneficial to see if the changes would produce any significant changes in the resulting muscle activation patterns.

In conclusion, this study has provided insight to the coordination patterns found in forward ice hockey skating. It has also been shown that an increase in velocity results in an increase in the amount of muscle activation, but the muscle coordination patterns remain the same.

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Appendices

Appendix A: Electrode Placement

The electrodes were placed on the muscles of interest using the guidelines from Anatomical Guide for the Electromyographer (Delagi et al., 1980).

1. Vastus Medalis (distal fibers) four fingerbreaths proximal to superiomedial angle of the patella
2. Gluteus Maximus: mid-way between the greater trochanter and the sacrum
3. Biceps Femoris (long head): mid-point between fibular heaad and ischial tuberosity
4. Adductor Magnus: mid-way between medial femoral epicondyle and pubic tubercule
5. Gastrocnemius (lateral head): one handbreath below the popliteal crease on the lateral mass of the calf
6. Peronius Longus: three fingerbreaths below the fibular head, directed towards the lateral aspect of the fibula
7. Tibialis Anterior: four fingerbreaths below the tibial tuberosity and 1 fingerbreath lateral to the tibila crest

Appendix B: Motor Points

Five subjects, 3 females and two males volunteered to have the motor points of ten lower limb muscles identified by the means of electrical stimulation. The identification of these motor points was to serve as information for future electrode placement during EMG data collection while skating. The ten muscles that were examined were: gluteus maximus (GM), biceps fermoris(BF), adductor magnus (AM), vastus lateralis (VL) and medialis (VM), tibialis anterior(TA), peronius longus (PL), lateral head of the gastrocnemius(Gas), the lateral aspect of the soleus (Sol), and the abductor hallucis (AH). The subjects were positioned specifically to optimally isolate the target muscle during stimulation. The muscle length was then measured according from the origin to the insertion. If either of these landmarks were unclear, the muscle length was measured using bony landmarks as reference points.

For the GM, BF, Gas, and Sol the subject lay prone with legs extended and arms out to the side. A small cushion was placed under the ankles to allow for ankle and neutral foot position. The measurment for the GM was taken from the edge of the mid-sacrum to the greater trochanter. The motor point was then measured along the same line from greater trochanter. The BF length was measured from the ischial tuberosity to head of fibula, then the motor point measure with respect to the ischial tuberosity. The Gas length was measured from lateral epicondyle to calcaneous, and the motor point measure with respect to the lateral epicondyle. The Sol length was measured from the head of the fibula to the calcaneous, and motor point with respect to the head of the fibula.

For the Add the subject lay in supine, with the leg in slight abduction (~20°) and neutural rotation. The muscle length was measured from pubis to adductor tubercle, then the motor point measure with respect to the adductor tubercule of the femur.

For the remaining muscles, the subject was seated in a chair. The VM and VL stimulation were conducted with the hip at 90° and leg extended, while the TA, PL, and AH were measured with the knee and ankle at 90°. The VL length was measured from the greater trochanter to the patella, and the motor point measurement from the patella. The VM length was measured from pubis to patella and then the motor point was measured from the patella. The TA length was measured from the head of fibula to the insertion at the 1st cuneiform. The motor point was measured 90° from a line between the fibula head and exteral tuberosity of the tibia. The PL length was measured from lateral malleoli to head of fibula, with motor point measured from the head of the fibula. The AH length was measured from medial tuberosity of the calcaneous to proximal phalange of the big toe, and the motor point measured from medial tuberosity of the calcaneous.

To locate the motor point the subject was electrically stimulated, using a Myotron 6050. The muscle in question was stimulated using a higher currency (20 mA) until the subject could identify the largest contraction experienced at that current. Once the position of the highest contraction was located the voltage was lowered and the subject was stimulated in the areas immediately surrounding the point. The voltage was continuously lowered until the subject no longer experienced a contraction. The point at which the lowest voltage produced a contraction was determined to be the motor point. The placement of the point according to the length of the muscle was determined by measuring the distance of the point from the specified landmark. This distance (of the motor point) was divided by the total muscle length to determine the proportion of the muscle at which the motor point is placed. The results of the motor point identification are presented in Table 14. Generally the motor points are found to be in the same general area on all the subjects.

***Table 14**: Motor Point Location(percent of muscle length from origin)*

	subject 1	subject 2	subject 3	subject 4	subject 5	average	SD
GM	0.6	0.4	0.4	0.4	0.4	0.4	0.11
BF	0.4	0.6	0.6	0.4	0.4	0.5	0.09
AM	0.3	0.4	0.4	0.4	0.4	0.4	0.04
VL	0.3	0.3	0.3	0.3	0.3	0.3	0.02
VM	0.3	0.3	0.3	0.3	0.3	0.3	0.01
TA	0.1	0.2	0.2	0.2	0.2	0.2	0.04
PL	0.3	0.2	0.2	0.2	0.2	0.2	0.03
Gas	0.3	0.3	0.3	0.3	0.3	0.3	0.03
Sol	0.5	0.6	0.6	0.5	0.5	0.5	0.07
AH	0.3	0.6	0.5	0.3	0.3	0.4	0.15

The researchers then compared their finding to the standard given by Delagi et al (1980) in the Anatomic Guide for the Electromyographer. Their suggestions compare favourably with the results found in this experiment. The compared results can be seen in Table 15.

From the results of this experiment, it was decided use the placements suggested by Delagi for the study.

***Table 15**: Comparison of motor point identification (in italics) with standard electrode placement suggested by Delagi (1980)*

Gluteus Maximus Mid-way between the greater trochanter and sacrum *0.4 of length (16.5cm) from greater trochanter to sacrum*
Biceps Femoris Mid-point between fibula head and ischial tuberosity *0.5 of length (25.9cm) from ischial tuberosity towarda ischial tuberosity*
Adductor Magnus mid-way between medial femoral epicondyle and pubic tubercule *0.4 of length (25.4cm) from adductor tubercule towards pubic tubercule*
Vastus Lateralis Lateral aspect of thigh, one handbreath above the patella *0.3 of length (24.7cm) from patella towards greater trochanter*
Vastus Medialis Four fingerbreaths away from proximal to suuperiomedial angle of the patella *0.3 of length (22.1cm) from knee towards pubic tubercule*
Tibialis Anterier Four fingerbreaths below the tibial tuberosity and 1 fingerbreath lateral to the tibial crest *0.2 of length (18.3cm) from external tibial tuerosity towards 1st cuneiform)*
Peronius Longus Three fingerbreaths below the fibular head, directed towards the lateral aspect of the fibula *0.2 of length (16.4cm) from head of fibula towards lateral malleolus*
Gastrocnemius (medial) One handbreath below the popliteal crease on the medial mass *0.3 of length (23.1cm) from from lateral to calcaneous*
Soleus Distal to the belly of the gastrocnemius, medial and anterior to the calcaneous *0.5 of length (27.4cm) from calcaneous towards head of fibula*
Abductor hallicis One fingerbreath below the navicular bone, on the midportion of the medial aspect of the foot *0.4 of length (7.1 cm) From medial tuberosity of calcaneous to proximal phalange of big toe*

***Table 15**: Comparison of motor point identification (in italics) with standard electrode placement suggested by Delagi (1980)*

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Gastrocnemius (medial) One handbreath below the popliteal crease on the medial mass *0.3 of length (23.1cm) from from lateral to calcaneous*
Soleus Distal to the belly of the gastrocnemius, medial and anterior to the calcaneous *0.5 of length (27.4cm) from calcaneous towards head of fibula*
Abductor hallicis One fingerbreath below the navicular bone, on the midportion of the medial aspect of the foot *0.4 of length (7.1 cm) From medial tuberosity of calcaneous to proximal phalange of big toe*

Appendix C : Reliability Test/Retest

Pilot testing was completed to check for repeatability of results in EMG. One subject was tested for repeated samples in a test session, then a follow-up session two hours later; involving the reapplication of electrodes. The subject completed 20 strides at three velocities; 8 km/hr, 10 km/hr and 12 km/hr. The signal was averaged and ensembled for 15 strides. The Pearson Product correlation values can be seen in the table below.

For the vastus medalis (VM), gluteus maximus (GM), tibilas anterior (TA), peroneus longus (PL), and the gastrocnemius (Gas) the correlation values range between 0.81 and 0.97. The adductor magnus (Add) and biceps femoris (BF) has lower correlation values with a range of 0.14 to 0.60 and 0.52 to 0.84 respectively.

Table16: *Pearson Product Correlation Values for reliability test/retest*

		8km/hr	10km/hr	12/km/hr
VM	test 1,2	0.97	0.89	0.96
	test 1,3	0.95	0.95	0.88
Add	test 1,2	0.46	0.45	0.60
	test 1,3	0.40	0.46	0.14
GM	test 1,2	0.92	0.83	0.95
	test 1,3	0.94	0.91	0.94
BF	test 1,2	0.69	0.66	0.85
	test 1,3	0.69	0.84	0.52
TA	test 1,2	0.84	0.82	0.81
	test 1,3	0.81	0.64	0.82
PL	test 1,2	0.93	0.82	0.92
	test 1,3	0.94	0.92	0.92
Gas	test 1,2	0.95	0.81	0.95
	test 1,3	0.93	0.93	0.93

Appendix D : Consent Form and Ethics Certificate