

RELATIONSHIP BETWEEN HOCKEY SKATING SPEED AND SELECTED PERFORMANCE MEASURES

DAVID G. BEHM, MICHAEL J. WAHL, DUANE C. BUTTON, KEVIN E. POWER,
AND KENNETH G. ANDERSON

School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's, Newfoundland, Canada.

ABSTRACT. Behm, D.G., M.J. Wahl, D.C. Button, K.E. Power, and K.G. Anderson. Relationship between hockey skating speed and selected performance measures. *J. Strength Cond. Res.* 19(2):326–331. 2005.—The objective of this study was to determine the relationship between specific performance measures and hockey skating speed. Thirty competitive secondary school and junior hockey players were timed for skating speed. Off-ice measures included a 40-yd (36.9-m) sprint, concentric squat jump, drop jump, 1 repetition maximum leg press, flexibility, and balance ratio (wobble board test). Pearson product moment correlations were used to quantify the relationships between the variables. Electromyographic (EMG) activity of the dominant vastus lateralis and biceps femoris was monitored in 12 of the players while skating, stopping, turning, and performing a change-of-direction drill. Significant correlations ($p < 0.005$) were found between skating performance and the sprint and balance tests. Further analysis demonstrated significant correlations between balance and players under the age of 19 years ($r = -0.65$) but not those over 19 years old ($r = -0.28$). The significant correlations with balance suggested that stability may be associated with skating speed in younger players. The low correlations with drop jumps suggested that short contact time stretch-shortening activities (i.e., low amplitude plyometrics) may not be an important factor. Electromyographic activities illustrated the very high activation levels associated with maximum skating speed.

KEY WORDS. electromyography, balance, speed, flexibility, strength

INTRODUCTION

Training specificity is a well documented aspect of conditioning (2, 20, 21). An inadequate matching of the actions that predominate in hockey and those used in training would result in wasted effort and time and inadequate results. The goal when skating at maximum speed is the same as when sprinting: to move from the initial point to the final destination in the shortest amount of time. Thus, it would seem logical that training for maximum hockey skating speed would parallel training for sprinting.

Plyometrics has been documented as an effective training mode for sprint-type activities that involve a significant eccentric or stretch-shortening component (22). Similarly, Young et al. (25) reported a significant correlation between a drop-jump contact time/jump-height ratio and sprinting speed. Blatherwick and Knoblauch (5) reported that a training protocol of sprints, hill running, and plyometrics significantly improved on-ice acceleration and endurance. However, hockey skating skills place a greater emphasis on impulse (force exerted for a given period) (12) rather than stretch-shortening cycle actions. A number of studies have demonstrated strong correla-

tions between vertical-jump performance and skating acceleration or speed (6, 7, 10). Hence, maximum rather than reactive leg strength may be a more vital aspect of skating speed.

It is common for training texts and articles to promote flexibility training for all sports and specifically hockey (18, 24). However, Jones (15) has shown a negative correlation between range of motion (flexibility) and middle distance running speed. Consequently, the question is raised whether plyometrics, resistance training, jump training, and stretching activities are suitable training modalities for hockey-specific skating skills.

Hockey involves significant balance or stability challenges because of the small surface area (skate blades) in contact with a low-friction surface (ice). Thus, balance may also be an important component of skating skills. It is pertinent to discover whether there is a strong relationship between maximum skating speed and stability.

In order to formulate scientifically sound resistance training programs, the degree of muscle activation should be investigated to provide hockey-specific training intensities. Since the electromyographic (EMG) activity of the muscle is strongly correlated to force output (4, 19), a comparison between the EMG activity during hockey skating and the EMG associated with maximal dynamic and static contractions would permit an evaluation of the work intensities involved with hockey skating demands. There is no research, to our knowledge, that identifies the intensity of lower limb muscle contractions while skating.

The objectives of the present study were to (a) investigate the correlations between on-ice hockey skating speed and selected physiological measures, and (b) determine the relative action of the lower limb muscles with a variety of hockey skating activities. Since skating emphasizes impulses exerted on an unstable surface, it was hypothesized that the highest correlations would occur with strength and balance measures.

METHODS

Experimental Approach to the Problem

In order to evaluate the intensity of muscular effort involved with ice hockey skating activities, EMG electrodes were placed on the quadriceps (vastus lateralis) and hamstrings (biceps femoris). EMG activity was monitored during maximum speed skating, short-radius turns, and abrupt unanticipated stops. To develop correlations with the on-ice measures, measurements of lower body strength (isometric and dynamic), 40-yd (36.9-m) sprint, concentric squat jump, drop jump, flexibility, and static

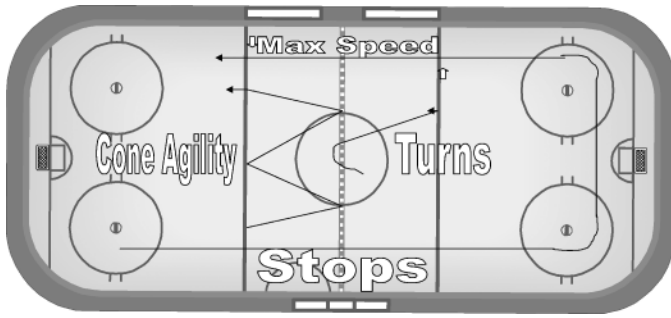


FIGURE 1. A hockey rink with the paths of the on-ice tests. On-ice tests included maximum skating speed between blue lines, unanticipated stops (reacting to a whistle), abrupt turns around a pylon, and the strides associated with a cone agility (multiple changes of direction) test.

balance on a wobble board were performed and compared to the on-ice performances.

Subjects

Thirty secondary school as well as current and former junior level hockey players participated in the correlation study (19.8 ± 3.5 years, 178.6 ± 6.5 cm, 78.9 ± 10.1 kg). Players ranged in age from 16–25 years with 5–13 years of hockey playing experience. Twelve of the hockey players participated in the limb EMG portion of the study. Subjects were verbally informed of the procedures and provided written consent prior to participation. The study was approved by the Memorial University of Newfoundland Human Investigation Committee.

On-Ice Measures

The athletes were tested in a nonfatigued condition. The following on-ice skating activities were randomly ordered with a minimum 3-minute rest period between repetitions.

The unanticipated stop test had subjects starting at the goal line. The skaters would begin skating on their own accord with the intention of reaching near maximal speed by the center zone (between blue lines). The researcher, who was out of sight of the skater, would blow a whistle when the skater was within the center zone, indicating that the skater should stop as abruptly as possible with the dominant leg outside (Figure 1).

The forward maximum speed skating test had skaters starting at the opposite goal line at their own discretion. They used the far side of the rink, the turn around the goal, and the area prior to the near blue line to attain maximum speed. Skaters were timed between the blue lines (Figure 1).

The short-radius turns test had skaters start at the blue line on their own discretion and turn abruptly around a cone on the center line. Skaters also started at the blue line for the cone agility test. On a whistle, subjects skated as quickly as possible around 3 pylons situated on the center red line (2 cones) and blue line (2 cones) (Figure 1). All activities were performed at the highest speed that would still allow successful completion of the task.

Electromyographic activity of the dominant leg (determined by the preferential leg used for a soccer ball kick) was measured during the on-ice skating activities and normalized to both an isometric maximum voluntary con-

traction (MVC) and a 1 repetition maximum (1RM) leg press. Surface recording EMG electrodes (MediTrace Pellet Ag/AgCl electrodes, Graphic Controls Ltd., Buffalo, NY) were attached 2 cm apart (dimensions 3×2 cm) to the midbelly of the vastus lateralis (VL) and long head of the biceps femoris (BF). The electrodes were attached to leads inserted into a portable EMG preamplifier (1,000x) at the athlete's waist. The portable preamplifier was attached to the main amplifier and acquisition unit (Biopac Systems MP100WSW; Holliston, MA) by a 60-m low-weight insulated cord. The EMG signal was collected at 2,000 Hz, amplified (1,000x), filtered (10–1,000 Hz), and smoothed (averaged over 10 samples). The maximum amplitude of the root mean square (RMS) of the EMG signal was evaluated over the duration of each skating stride on ice as well as with the separate MVCs and 1RM leg press.

In order to evaluate stride duration and recovery, elevated VL EMG activity was used as an indication of skating stride duration (push-off phase), while the return to baseline EMG activity was considered indicative of the recovery phase of the stride (returning leg to the front of the body). Skaters were digitally videotaped, with the timing of the videotape and EMG acquisition data coordinated to identify the temporal sequence of stride duration and recovery.

Off-Ice Measures

Data were analyzed using the average of 2 measures for all physiological testing other than the leg press 1RM. If the 2 measures were not similar (within 5%), a third trial was administered. EMG activities associated with MVC force (knee extension and flexion) and a 1RM leg press were used for EMG normalization. Specific muscles could be tested separately with isometric MVC to ensure maximal voluntary activation. Because skating actions are dynamic in nature, the dynamic 1RM leg press was also utilized. The 2 sets of figures allow a comparison of EMG activity to maximal voluntary isometric activation as well as the activation associated with a typical resistance training exercise for overall leg strength.

Each subject was seated on a padded bench with the hips and knees flexed at 90° for isometric knee extensions. Knee flexion was performed from a standing position with the lower limb fully extended and the hips braced against a padded table. The subject's lower limb was inserted into a padded strap at the ankle and attached by a high-tension wire to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc., LCCA 250, Don Mills, Ontario). All forces or torques were detected by the strain gauges, amplified (Biopac Systems Inc., DA 100: analog-digital converter MP100WSW; Holliston, MA), and monitored on computer (Sona Phoenix, St. John's, Newfoundland). Data were stored on a computer at a sampling rate of 2,000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc., Holliston, MA).

Other tests included a hand-timed 40-yd (36.9-m) sprint on an indoor track. Subjects began from a stationary sprint start (3 or 4 point) and reacted to a whistle.

Concentric squat jumps with an arm swing were performed with an initial knee angle of 100° with no countermovement permitted. Jump height and relative power were derived from the contact mat kinematics (Kinematic Measurement System, Muncie, IN) and body mass and

calculated by the associated software (Innervations, Muncie, IN) (Absolute power [W] = body mass \times gravity \times jump height/[contact time/2]; relative power = power [W]/body mass). Drop jumps from a height of 30 cm were performed with the subjects emphasizing the shortest possible contact time and the greatest jump height. Contact time, jump height, and the contact time/jump height ratio were calculated by the software (Innervations).

Dominant leg strength was evaluated with a single (dominant) leg 1RM leg press. The leg press device (Cybex, Medway, MA) had the subject seated with hips and knees at 90°. The seat of the Cybex device was configured so that the weight plates were pushed on a track at a 45° angle. Single repetitions of submaximal loads were attempted until the greatest possible leg press load was achieved with full knee extension. Following a warm-up of 5 repetitions of a submaximal load, estimated by the perceived effort of the subject to be less than 50% of their maximal load, subjects typically performed 3–5 more repetitions in order to achieve their 1RM. Two-minute rest periods were allotted between initial lower load resistance attempts, with 3-minute (or longer) rest periods for the maximum or near maximum attempts.

The sit-and-reach flexibility test was administered according to the Canadian Physical Activity, Fitness and Lifestyle Assessment (CPAFLA) standards (8).

A 30-second wobble board test (Kinematic) was performed, and a software program (Innervations) was used to calculate a balance ratio (contact with floor to no contact time). A metal plate connected to the computer hardware was placed under the wobble board. When the perimeter of the wobble board made contact with the metal plate, the duration and frequency (during the 30-second test) of contact was recorded by the software. Subjects received an orientation session for the balance board on a separate day, as well as 1–2 practice attempts on the day of testing. The day-to-day reliability of the test using a Pearson product moment correlation was determined to be 0.8 with a between-test (single session) reliability of 0.89.

Statistical Analyses

Descriptive statistics included mean \pm *SD*. Stepwise multiple linear regression analyses were used to examine the relationship between all on-ice and off-ice variables (SPSS Version 11.5 for Microsoft Windows). Pearson product moment correlations were used to calculate data between individual on-ice and off-ice variables. For statistical purposes, subjects were divided into 2 age groups: under 19 years and 19 years of age or over. All correlations were calculated for the 2 age groups separately, as well as for the entire group. Electromyographic activity during skating activities was compared to the EMG activity produced during MVCs and 1RM in the laboratory to determine the degree of maximal activation.

RESULTS

Mean scores for the off-ice testing are presented in Table 1. Maximum skating speed correlated significantly ($p < 0.005$) with both sprint speed and balance ratio (Table 2). The correlations indicate that approximately 25% of the variability associated with maximum skating speed could be explained by changes in the 40-yd (36.9-m) sprint time. A similar relationship was found to exist between maximum skating speed and the balance ratio ($p < 0.005$). The

TABLE 1. Descriptive testing data.*

Off-ice tests	Group mean \pm <i>SD</i>
40-yd sprint (s)	5.8 \pm 0.3
Squat-jump height (cm)	32.8 \pm 6.8
Squat-jump power (W)	118.1 \pm 36.9
Drop-jump contact time (milliseconds)	173.1 \pm 26.3
Drop-jump height (cm)	18.7 \pm 5.9
Drop-jump ratio	2.3 \pm 0.42
1RM leg press (kg)	133.9 \pm 48.5
Relative 1RM leg press (kg/body mass)	3.7 \pm 0.8 kg
Sit-and-reach flexibility (cm)	28.1 \pm 7.3
Balance ratio	2.7 \pm 1.8

* 1RM = 1 repetition maximum.

TABLE 2. Pearson product moment correlations.†

	Maximum skating speed correlations (<i>r</i>)	Cone agility correlations (<i>r</i>)
40-yd sprint‡	0.51*	0.32
Squat-jump height	-0.3	-0.18
Squat-jump power	-0.25	-0.29
Drop-jump contact time	-0.1	-0.13
Drop-jump height	-0.16	-0.1
Drop-jump ratio	-0.14	-0.13
1RM leg press	-0.3	-0.27
Relative 1RM leg press	-0.31	-0.29
Sit-and-reach flexibility	0.32	0.15
Balance ratio§	-0.51*	-0.22

* $p < 0.005$.

† 1RM = 1 repetition maximum.

‡ Maximum skating speed (y) = 1.1647 + 0.1451x.

§ Maximum skating speed (y) = 2.0765 - 0.236x.

combination of both variables (sprint speed and balance) increased the correlation to $r = 0.615$ ($p = 0.037$), suggesting the 2 variables together could account for approximately 38% of the variance in maximum skating speed. Adding all other variables (squat jump, drop jump, leg press measures, and flexibility) increased the correlation coefficient to $r = 0.719$ ($r^2 = 0.516$).

A further correlation was performed to determine whether the significant correlations with balance were related to skating experience. Players under the age of 19 years had a significant ($p < 0.01$) correlation of $r = -0.65$, while those players 19 years or over showed a nonsignificant correlation of $r = -0.28$. There were no other significant correlations with maximum skating speed (Table 2).

Furthermore, there were no significant correlations between the individual testing measures and cone agility scores. With all variables included, a correlation coefficient of 0.596 was obtained, indicating that the multiple tests of sprint speed, leg press strength, squat and drop jump measures, balance, and flexibility provided approximately 35% of the variables associated with decreased times in the cone agility drill test.

The normalization of skating EMG activity to an MVC and a 1RM leg press resulted in differing results for the VL and the BF. The BF differed substantially, possibly because the BF were not maximally activated during the 1RM leg press. Since maximal or near maximal activation

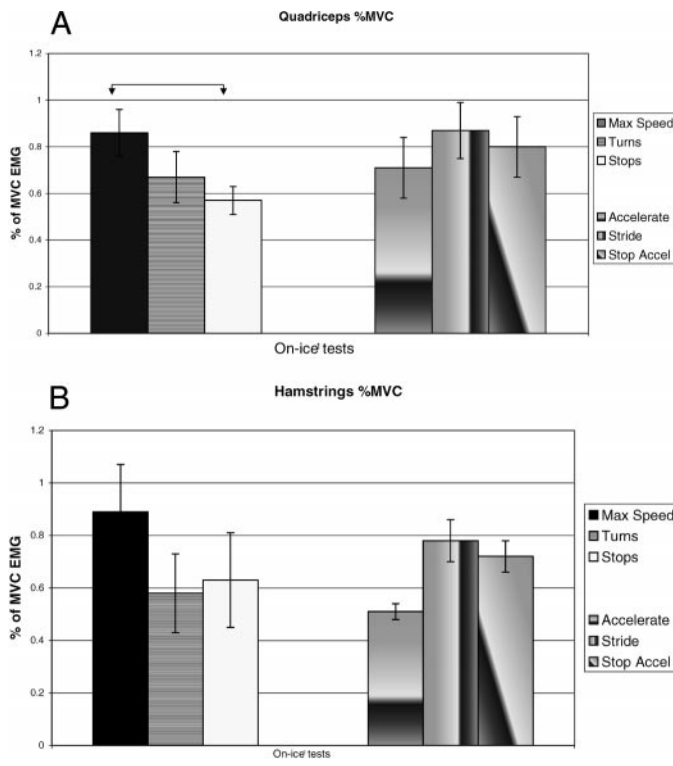


FIGURE 2. Bars represent the mean normalized (on-ice/maximum voluntary contraction [MVC]) electromyographic (EMG) activity of the vastus lateralis (VL) (Figure 2a) and the long head of the biceps femoris (BF) (Figure 2b) during on-ice tests of maximum skating speed, high speed turns, unanticipated stops, and the strides associated with a cone agility (multiple changes of direction; accelerate, stride, and stop acceleration) test. Vertical lines represent standard deviation. Arrows indicate significant differences at the $p < 0.05$ level.

should have been achieved with the MVC, the following text will emphasize the MVC normalization values.

Electromyographic activity for all tested muscles was either significantly reduced or exhibited nonsignificant reductions during both turns and stops as compared to maximum skating speed. The VL EMG activity during maximum skating speed exceeded that during turns and stops by 22.1% and 33.7%, respectively ($p < 0.05$) (Figure 2a). The BF EMG activity during maximum skating speed exceeded that during turns and stops by 34.8% and 29.2%, respectively ($p < 0.05$) (Figure 2b). During maximum skating speed, the VL and BF had similar relative activation levels (85% and 89% of MVC, respectively). Normalized 1RM EMG values are presented in Figure 3.

The mean duration of EMG activity for all muscles tested during maximum skating speed ranged from 324–387 milliseconds. There were no significant correlations with maximum skating speed and the contraction durations of the VL ($p = 0.1$; $r = 0.51$) and BF ($r = 0.26$). The mean recovery intervals of EMG activity for all muscles tested during maximum skating speed ranged from 238–326 milliseconds. There were no significant correlations between skating speed and the recovery of the VL ($r = 0.23$) and BF ($r = 0.16$) contractions between strides.

DISCUSSION

Maximum skating speed significantly correlated only with the 40-yd (36.9-m) sprint time and balance ratio. The

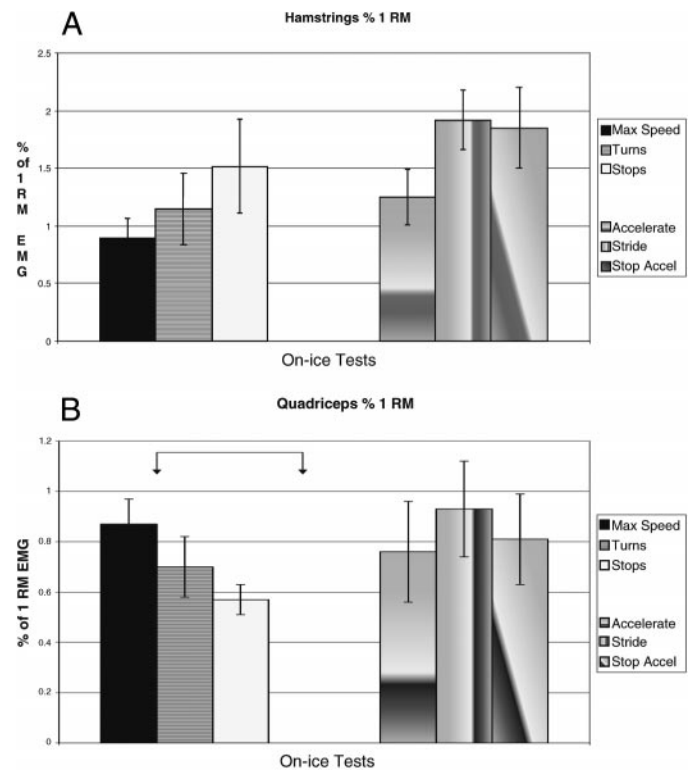


FIGURE 3. Bars represent the mean normalized (on-ice/1 repetition maximum [1RM] leg press) electromyographic (EMG) activity of the vastus lateralis (VL) (Figure 3a) and the long head of the biceps femoris (BF) (Figure 3b) during on-ice tests of maximum skating speed, high speed turns, unanticipated stops, and the strides associated with a cone agility (multiple changes of direction; accelerate, stride, and stop acceleration) test. Vertical lines represent standard deviation.

correlation with running sprint time concurs with other hockey-related studies (7, 10). Two factors affecting speed during running and skating are stride rate and stride length. Stride length with skating may be affected by the power generated during the push-off phase (24), the angle of push and take-off, and lower body flexibility or range of motion (18). The nonsignificant skating speed correlations with squat-jump power ($r = -0.25$), height ($r = -0.3$), absolute ($r = -0.3$) and relative ($r = -0.31$) leg press 1RM suggest that the leg press strength or jump-related power factors explained less than 10% of the variance involved with skating speed in the present study.

The lower correlations contradict the stronger correlations found between skating speed and vertical jump in a number of other studies (6, 10, 14, 17). Whereas in the present study, a concentric-only vertical jump was used, it is not clear whether a countermovement jump (6, 10, 14, 17) was used in some of the other studies. In addition, sample populations of younger boys (10–14 years) (6) and women (7) differ from the present study. Perhaps the most important difference between the studies was that skaters in the present study were given approximately two-thirds of the rink (see Figure 1: opposite goal line to blue line) to build up maximum speed. Hence, acceleration should not have been a major consideration and maximum speed should have been achieved near the first blue line. With the lack of inertia to overcome and the mo-

mentum generated prior to the measurement of sprinting speed, power and strength factors may not have played as pivotal a role as technique. Thus, the power associated with a vertical jump did not show a significant relationship in the present study.

Skating is a skill that emphasizes impulse during the push-off phase (12). Impulse is the product of force and the duration of the applied force (13). Hence, full knee extension should increase the stride length and, with high forces, enhance skating speed. Correlations between the maximum skating speed and the duration of quadriceps EMG activity approached significance ($p = 0.1$) with a correlation of $r = 0.51$. This correlation suggests that the duration of the quadriceps contraction may be associated with approximately 25% of the variability related with skating speed.

Balance was also significantly associated with higher skating speeds. However, more in-depth analysis illustrated that the significant correlations were only present in the younger hockey players (less than 19 years). This relationship may be related to the motor development of the younger skaters. The complex skills associated with skating would necessitate a more refined balance that would improve with maturity and perhaps training. Since skating is performed on a very small surface area (blade) in contact with a low friction surface, younger individuals with greater stability may have an advantage in executing the specific skating skills.

Some studies have reported that force output is impaired with decreasing stability (1, 3). Anderson and Behm (1) reported a 60% decrease in chest press isometric maximal force with unstable conditions, yet EMG activity remained unchanged between stable and unstable conditions. This response indicates that the limb muscles' activity was altered from primarily a motive function to a combination of motive and stabilizing functions. It could be hypothesized that individuals who have greater balance or stability are able to use a greater proportion of their muscular activation towards force production rather than stabilization and balance. It appears from the present study that this hypothesis may be correct for the younger players.

Although strength measures in the present study did not demonstrate significant correlations with skating speed, leg power is often reported to be a necessary component of high-speed skating (12, 23). Another explanation for the low correlations with leg press strength and jump-related power may be explained by the fact that these off-ice measures were performed under very stable conditions. As cited in the previous paragraph, force output while unstable impairs force production (1, 3). Thus, an individual who can exert great forces or power under stable conditions may not be able to exert similar forces under the less stable conditions of skating. Furthermore, the leg press is performed primarily on the sagittal plane, whereas skating also involves a certain degree of frontal plane movement with leg abduction. Thus, future studies should investigate whether training to improve balance or stability would contribute to improvements of hockey skating speed in younger players.

A common training method for sprinting, jumping, and many complex sports including hockey is the implementation of plyometrics. Plyometrics involve depth jumping, bounding, skipping, and a variety of other activities that emphasize the stretch-shortening cycle.

Blatherwick and Knoblauch (5) reported that a training protocol that included plyometrics in addition to sprints and hill running significantly improved on-ice acceleration and endurance. However, hockey skating does not involve a significant stretch-shortening component but rather emphasizes impulse. Thus, the nonsignificant correlations with drop-jump height, contact time or contact time/jump height ratio might be expected. These findings suggest that plyometric training emphasizing short contact times would not be the most skating-specific training method, because it is only associated with approximately 1% of the variability related to high skating speed. Whereas an emphasis on plyometrics involving short duration contact times may not be the most task-specific training method for hockey skating, higher amplitude plyometrics involving longer contact times (greater emphasis on impulse) should still be advantageous. Since the duration of quadriceps EMG activity during the push-off phase ranged from 324–387 milliseconds, hockey-specific training modalities such as high amplitude plyometrics should mimic the contraction duration. Therefore, improvements in hockey skating speed could be achieved with a training program that emphasizes improvements in impulse (concentric only or in conjunction with stretch-shortening activities), balance, and the ability to exert forces under unstable conditions.

Similarly, the nonsignificant correlation with flexibility ($r = 0.32$) indicates that less than 10% of the variance associated with range of motion are shared with skating speed. Jones (15) reported a negative correlation between range of motion (flexibility) and middle distance running speed. While this lack of a significant relationship between range of motion and running speed might be expected in an activity that emphasizes the efficient transfer of force through a stretch-shortening cycle, skating, in the present study, seemed to be less reliant on increased musculotendinous stiffness.

There were no significant correlations between the off-ice measures and the on-ice cone agility (multiple change of direction) test. This finding indicates that there was not any single variable in the present study that provided a significantly greater relationship to success with multiple changes of direction in hockey.

Electromyographic activity for all tested muscles was either significantly reduced or exhibited nonsignificant reductions during both turns and stops as compared to maximum skating speed. This decreased EMG may be attributed to the eccentric nature of the turning and stopping actions. Eccentric contractions have been reported to elicit lower EMG activity than similar loads involving concentric or isometric contractions (8, 11, 16).

On-ice tests of BF EMG activity relative to an isometric knee flexion MVC were always less than a ratio of 1. Conversely, with the exception of maximum skating speed, all on-ice tests of BF EMG activity relative a 1RM leg press exceeded a ratio of 1. This higher ratio with the 1RM normalization would indicate that a dynamic leg press does not provide the extent of activation specific to the needs of hockey skating. Either skating-specific resistance exercises or exercises that can specifically isolate the hamstrings are required to provide the necessary level of activation.

The high levels of activation found with skating seem to indicate that high-intensity contractions should be utilized during hockey-specific resistance training programs.

Although linear relationships have been reported between EMG activity and isometric muscle force output (19), the high percentage of EMG activity with skating does not necessarily translate into equivalent relative force. In a study from our laboratory (1), comparable EMG activity was recorded with stable and unstable isometric chest presses, even though the unstable press exerted 59.6% less force. The similar EMG with the unstable press was attributed to increased stabilization functions. The previously discussed low correlations between stable force (1RM leg press) and skating speed emphasize the need to train the athletes to perform higher intensity contractions under relatively unstable conditions.

PRACTICAL APPLICATIONS

In conclusion, hockey skating is a complex skill involving the contributions of many diverse components. The ability to generate power during a stride will provide a more meaningful contribution to skating speed if the player exerts the force while well balanced or stable. Instability resistance training using Swiss balls, inflated discs, and unilateral resisted movements could enhance the overall balance of the player while teaching the neuromuscular system to provide greater motive (propulsive) in contrast to stabilizing forces. The benefits of off-ice sprint speed training could have some crossover effect to skating, as evidenced by the significant correlation with maximum speed skating time. The high and similar EMG (activation) levels of the VL and BF during maximum speed skating highlight the importance of ensuring intermuscular balance when training. Since contraction durations during the skating strides averaged approximately one-third of a second (324–387 milliseconds), plyometric training should involve higher amplitude activities resulting in longer ground contact times, ensuring hockey-specific contraction profiles. Therefore, based on the correlation and EMG findings, resistance training for maximum speed skating should involve high levels of muscle activation involving resistance under relatively unstable conditions.

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Address correspondence to Dr. David Behm, dbehm@mun.ca.