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Section III – Sports and Physical Activity

Muscle Net Force, Flexibility, and Somatotype Determination of Fundamental Skating Abilities in Professional Ice-Hockey Players

by
Martin Blaha [1], Robert Roczniok [2,], Artur Terbalyan [2], Lukas Opath [3], Martin Musalek [1], Petr Stastny [1,*]*

Given the limited literature on the relationship between flexibility and hip muscle net force, this study aimed to examine how anthropometry, range of motion (ROM), and hip muscle strength influence fundamental skating performance in ice hockey players. Twenty-two professional ice hockey players (25 ± 2.9 years, 180.6 ± 5 cm, 81.4 ± 9.6 kg) completed a 6.1-m acceleration, a 30-m sprint, the Illinois agility test, a strength-speed endurance shuffle (6 × 54 m), and a 6 × 9-m acceleration test with brakes. The off-ice measures included body composition assessed by dual-energy X-ray absorptiometry, isokinetic hip flexor strength, isometric hip adduction/abduction, and the Y-Balance Test. Body height, isokinetic strength of the hip extensors at 120°, and functional ROM in the posterolateral and posteromedial directions were the strongest predictors, explaining 60.9% of the variability in all on-ice tests. Accelerations were best predicted by functional ROM (posteromedial direction) and the length of the lower limbs ($R^2 = 0.55$), while the strength of hip adductors emerged as the best predictor of backward skating ($R^2 = 0.37$). Strength-speed endurance (6 × 54 m) was significantly influenced by lower-limb fat-free mass ($R^2 = 0.53$). Coaches can improve skating by emphasizing the strengthening and power training of the hip extensors and adductors, combined with functional ROM. Body and lower-limb dimensions influence skating performance, with higher lower-limb fat-free mass support skating speed endurance. Our model suggests that different skating tasks relate to different prediction models, and that other factors, such as skating technique and neuromuscular coordination, should also be considered in practice and in future research.

***Keywords**: isokinetic; exercise; strength; power; change of directional speed*

Introduction

Ice hockey is a team sport that demands a multifaceted physical and technical fitness of players (Burr et al., 2008; Vigh-Larsen et al., 2020), requiring two consequent levels of specific skills involving skating and puck control (Slavicek et al., 2022). Skating is a fundamental skill for playing ice hockey, where a player must be able to accelerate, decelerate, and change direction (COD) during the offensive, transition, and defensive situations (Montgomery, 2000; Roczniok et al., 2024). Effective skating is a strategic tool for individual and team positional tactics on the ice and improves passing and shooting precision (Stanula et al., 2014). Since players cover long distances during a match, typically between 4,600 and 7,200 m, depending on their position and intensity of the game (Montgomery, 1988; Vigh-Larsen et al., 2024), skating efficiency plays a role in physiological fatigue (Allisse et al., 2020, 2021; Lamoureux et al., 2018). Moreover, the covered match distance is performed at different speed zones (Gamble et al., 2022), different acceleration and deceleration levels (Rago et al., 2022), and different shift duration, combined from forward skating, backward skating, and other COD (Brocherie et al., 2018; Dietze-Hermosa et al., 2025;

[1] *Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic.*
[2] *Sports Science Institute, The Jerzy Kukuczka Academy of Physical Education in Katowice, Katowice, Poland.*
[3] *Department of Physical Education and Sport, Faculty of Arts, Matej Bel University in Banska Bystrica, Banska Bystrica, Slovakia.*
* Correspondence: petr.stastny@ftvs.cuni.cz (P.S.); r.roczniok@awf.katowice.pl (R.R.)

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Vigh-Larsen and Mohr, 2024). Thus, testing players maximum acceleration, speed and COD performance is equally important as testing repeated efforts and speed endurance.

The skating tasks differ between defenders (4002 ± 787 m) and attackers (3681 ± 1058 m), with attackers achieving higher speeds while defenders cover longer distances at lower intensities and more backward-directed tasks (Jackson et al., 2016). Approximately 50% of this distance is covered at speeds exceeding 17 km/h, including periods of intense acceleration, deceleration, and physical collisions. These game requirements are typically assessed through 30-m sprint and 6.1-m acceleration tests, either forward or backward (Daigle et al., 2022; Stastny et al., 2023), repeated short stops or turns (Roczniok et al., 2016), and agility testing (Bieniec and Grabara, 2025; Novák et al., 2019; Slavicek et al., 2022). Since the average length of a shift is 85.7 s, with an effective playing time of 44 s, blood lactate concentrations range between 8.7 and 15.1 mmol/L, indicating high glycolytic stress that necessitates speed and strength endurance (Brocherie et al., 2018; Douglas and Kennedy, 2020; Vigh-Larsen et al., 2024). Thus, repeated speed endurance testing might include intermittent repeated sprints (Bond et al., 2018), or consecutive repeated sprints targeting to last slightly over the typical effective playing shift time, such as during 6 × 54-m sprint testing (Roczniok et al., 2024).

High-intensity skating requires the development of strength and power in the gluteus maximus, tibialis anterior, vastus lateralis, rectus femoris, adductor magnus, and gluteus medius muscles (Kaartinen et al., 2024). Thus, strong hip and thigh muscles enable players to generate a high level of force, which propels acceleration and progression in achieving maximum speed. During rapid changes of direction, positional tactics, and transitions between offensive and defensive plays, the hips provide stability while maneuvering (Chang et al., 2009; Kuhn et al., 2016; Prończuk et al., 2025). Strengthening the hips significantly contributes to faster starts, change of direction (COD) performance (Secomb et al., 2021; Prończuk et al., 2025), and stability during puck battles (Kuhn et al., 2016; Prończuk et al., 2025). Hips also play a key role in transferring force between the lower limbs and the trunk, affecting the precision and accuracy of shots and passes. Research emphasizes that hip strength at specific skating angles directly influences acceleration and the ability to change direction quickly, with off-ice tests serving as good predictors of skating performance, especially during fast sprints (Keiner et al., 2024; Secomb et al., 2021). However, the contribution of individual muscle groups and their functional range of motion (ROM) to skating performance is not well recognized.

Isokinetic strength of the knee joint during flexion and extension (at 60 °/s) has been utilized to evaluate improvements in the skating program, whereas the hip muscles have not been assessed for flexion and extension, despite hip flexion being a distinguishing factor across different levels of skating performance (Budarick et al., 2020; Prończuk et al., 2025; Shell et al., 2017; Skalski et al., 2025, 2025a). Other studies indicate that intensive ice hockey training directly decreases hip adductor and abductor isometric strength (by −4.6 to −8.6 kg) and hip rotation range of motion (ROM) (by 14 to 23 degrees). This reduction in strength and flexibility, which directly impacts speed and stability, may increase the risk of hip and groin injuries, highlighting the significance of optimal muscle function for the safety and performance of ice hockey players (Suits et al., 2024; Skalski et al., 2025, 2025a). Thus, evaluating hip muscle strength in both dynamic and static modes, along with ROM, should be conducted to assess the contribution of this muscle group to skating performance.

Due to the lack of established relationships in the literature between ROM and the net force of hip muscles, this study aimed to determine how anthropometry, range of motion, and hip muscle strength contribute to fundamental skating performance in ice hockey players. We hypothesized that strength of the hip abductors, adductors, flexors, and extensors, along with the range of motion in the hip, would strongly predict overall skating performance, including agility, acceleration, speed, and strength-speed endurance.

Methods

Participants

The research participants comprised 22 ice hockey players (aged 20 to 30 years, mean body height: 180.56 ± 5.15 cm, mean body mass: 81.35 ± 9.66 kg) who were active in the three top ice hockey

leagues in the Czech Republic. Eight players were defenders and the rest were offensive players, two of them right-handed according to the side which they hold the hockey stick closer to the blade. Participants were informed about the potential risks and benefits of the study, and informed consent was obtained from them. The selection criteria stipulated that the target group consisted of active players from these leagues who had not experienced any performance-limiting injuries in the two months prior to the study, not suffered any illnesses during or before the testing sessions, and were physically fit to perform testing at maximum intensity. Ice hockey players had been in regular training cycles for the preceding 6 years and played at a competitive level, with at least two matches and four ice hockey training sessions per week for the preceding three years.

The sample size (n = 22) was determined using G*Power version 3.1.9.7 (Düsseldorf, Germany) for bivariate normal correlation (p = 0.6, power: 0.8, significance level: 0.05), which resulted in a critical r = 0.48, and a maximum of nine predictors for multiple linear regression (p^2 = 0.6, power: 0.8, significance level: 0.05). The correlation of 0.6 was based on previous studies that investigated the relation and determination between on-ice and off-ice performance (Janot et al., 2015; Wagner et al., 2021).

This study was conducted following the principles of the Declaration of Helsinki 2013, and approved by the Ethics Committee of the Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic (approval code: EK190/2023; approval date: 03 October 2023).

Study Design

The experimental design evaluated the relationship between non-specific (off-ice) and specific (on-ice) performance. Players were divided into two groups to enhance testing efficiency. One group completed laboratory testing on the first day, while the other group performed on-ice testing on the same day. The next day, the groups switched roles; players from the first off-ice group moved onto the ice, while the second group completed on-ice testing. This arrangement helped ensure that all players successfully completed both types of testing in a short time (Figure 1). On-ice testing included assessments of acceleration (a 6.1-m sprint, forward and backward), maximum speed (a 30-m sprint, forward and backward), COD (the Illinois test), directional changes (6 × 9 m with brakes), and strength-speed endurance (6 × 54 m; Figure 2). Paired photocells (Algetiming PRO, ALGETIMING GmbH, Lustenau, Austria) were utilized to accurately measure times for all tests. Before testing began, players performed a warm-up on the ice to prepare optimally for skating. Each test was preceded by detailed instructions to ensure players executed the test correctly. Each player had two timed attempts per test, with a work-to-rest ratio of ~1:11, with the better of the two results used for statistical analysis.

The laboratory testing utilized three different measurements using advanced devices: body composition analysis through a Dual Energy X-ray Absorptiometry (DXA, Hologic, Marlborough, MA, USA) scanner, an isokinetic dynamometer for hip flexion and extension (CYBEX Humac Norm, Computer Sports Medicine, Inc., Stoughton, MA, USA), and an isometric dynamometer for hip adduction/abduction (Vald Performance, Brisbane, AU). Before the DXA measurements, basic anthropometric measures were taken, including total body height, mass, thigh circumference, hip range of motion, right and left lower limb lengths, tibia bone length, femur length, and epicondyle width. Prior to strength testing on the CYBEX Humac Norm and Force Frame VALD, an individual warm-up was performed to minimize the risk of injury and ensure maximum performance during the tests.

Measures

Off-Ice Testing

Anthropometric Measurements and Passive Range of Motion

The first measurements included body height (in cm) determined using a stadiometer (SECA 264, Seca GmBH & Co Kg, Hamburg, Germany), and body mass (in kg) determined using a scale (SECA 899, Seca GmBH & Co Kg, Hamburg, Germany) and performed according to the Lohman protocol (Lohman et al., 1988). ROM in hip adduction/abduction was measured in the supine position with the proband holding the contralateral hip at a 90° angle while the tested leg was on an elevated surface (approximately 30 cm high) to determine a neutral starting position for

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abduction (Charlton et al., 2014). Range in the hip was measured on both lower limbs using a goniometer according to standardized procedures (Charlton et al., 2014).

The total length of the lower limbs was measured using a tape from the anterior superior iliac crest (spina iliaca anterior superior: ASIS) to the point of the inner ankle (malleolus medialis; Sabharwal and Kumar, 2008). The length of the tibia (shin bone) was measured as the distance between the center of the knee joint and the center of the ankle joint (Myer et al., 2010). Femur length was measured using a tape to determine the distance between the greater trochanter, located by palpation, and the lateral femoral condyle (Wang, 2021). Another variable was the circumference of the thigh, measured in the supine position, with the knee flexed to an angle of 10° and the width measured at approximately 2/3 of the length of the femur (thigh bone; Agarwal et al., 2021), and the width of the epicondyle measured using a caliper when the knee was flexed to 90°. The extremity width was measured between the medial and lateral epicondyle of the femur (Knapik et al., 1996).

Body composition—Dual Energy X-ray Absorptiometry

The first measurement was the Dual Energy X-ray Absorptiometry (DXA) body composition measurement. The full body scan were performed two weeks apart, with a single experienced and trained laboratory worker taking the measurements. Coefficients of variation (CV) and the ICC were calculated for the data obtained with a significance level of $p < 0.05$. The results confirmed the high accuracy of DXA measurements, for total body mass (ICC = 0.999; CV = 2.3%), fat mass (ICC = 0.998; CV = 1.6%), muscle mass (ICC = 0.995; CV = 0.3%), and bone mineral content (ICC = 0.996; CV < 0.1%) (Moreira, 2018).

Isokinetic Measurement of Hip Flexion/Extension

The isokinetic dynamometer (Humac Norm, Computer Sports Medicine, inc, Stoughton, MA, USA) was set to the zero position with the horizontal position of the bench. The lever arm device's rotation was directed toward the greater trochanter of the femur of the participant lying on his back. The test was performed at an angular velocity of 60° and 120° per s in the hip flexion range from 0° to 120°. Before testing, each participant completed an individual warm-up and a stretching routine to minimize the risk of injury. The participant performed five test repetitions at both angular velocities, gradually increasing the intensity to 80% of their maximum strength. These sets were used to optimally warm up the muscles and prepare them to perform at full intensity. After a 30-s rest interval, a set of five valid repetitions was performed and the best result was used in the subsequnt analysis. The reliability coefficient of the Cybex instrument was ICC = 0.88 (Kilicer et al., 2017).

Isometric Measurement of Hip Adductors/Abductors

Strength of hip abduction and adduction was assessed using the Force Frame VALD device, which had been previously validated. It had shown excellent test-retest reliability (ICC = 0.94) for testing adductor strength at a 60° hip flexion angle. Additionally, it has good to excellent reliability for adduction (ICC = 0.92) and abduction (ICC = 0.90) at a 45° hip flexion angle (Desmyttere et al., 2019). The initial position of the player was lying on their back with the hip in 45° flexion and the knee in 90° flexion, with angles measured using a goniometer. The player's arms were crossed over their chest, and their feet were positioned at hip-width apart. The height of the Force Frame VALD was adjusted so that the center of the knee joint aligned with the center of the measuring surfaces of the device. Before the actual test, players performed individual stretching. Then they performed three repetitions of hip abduction and three repetitions of hip adduction to activate and warm up the muscles. Subsequently, participants moved on to testing, with each set consisting of one repetition of abduction and one repetition of adduction, with a 3-s hold in each position. There was a 30-s rest interval between each set.

Functional Range of Motion—Y-Balance Test

The Y-balance test was performed three times for each leg and direction, on a standard Y-balance device (FMS, Danville, VA, USA). The measured maximal reach distances were normalized using leg length for anterior, posterolateral, and posteromedial directions. Before testing, each participant received instructions and orientation to the balance

assessments. The order of the three directions was randomized to account for the impact of fatigue and the learning effect. Each test was demonstrated and scored by the same researcher who was certified to administer the Y-Balance Test (Plisky ets al., 2009).

On-Ice Testing

Illinois Agility on Ice

The test was selected because the Illinois test provides sufficient validity and reliability (SEM: 0.07, minimum detected change per 95% CI = 0.201) (Makhlouf et al., 2022) and sufficient separation of ice-hockey specific skills (Slavicek et al., 2022). In this research, players went through the track without the puck; they were instructed to skate with the stick on the ice when passing the cones and photocells. Cones marked out the track and the start line and the finish line by the position of the photocells (Figure 2A). Players started from a self-selected position in front of the photocells with the hockey stick behind the photocells. Additionally, they started the test at will to eliminate the influence of reaction time.

30-m Sprint Forward and Backward

The 30-m sprint was performed forwards and backwards. Players started the sprint from the left, the right or the straight position, always with the stick over the photocells, ensuring that the photocells were not activated before the actual start. The player started the sprint at 10–20 cm from the initial goalie line (Figure 2B). Three pairs of photocells were positioned along the length of the course (30 m; Figure 2B): the first photocell was placed at the start line, the second at the acceleration point (6.1 m) and the third at the finish line (30 m). The distance of 6.1 m was recommended as the distance to achieve maximum acceleration and 30 m for maximum speed, taking into account the requirements of the match (Stastny et al., 2023).

6 x 9-m Starts with Brakes

First, players received detailed instructions to reduce errors while passing through the photocells. Two pairs of photocells were used: the first pair at the start and the second pair positioned 9 m away (Ma et al., 2014; Figure 2C). To prevent potential mistakes, a colored spray was applied to the ice to clearly mark the deceleration area, ensuring the players passed through the photocells correctly. The data from the photocells were transmitted directly to the computer using the TIMY Backup Challenge software, which enabled real-time analysis of the results.

6 x 54-m Repeated Sprint Test

The test of strength-speed endurance, which also measures anaerobic capacity on ice, was performed as the last one, due to its fatiguing effect and glycolytic response. Three pairs of photocells were used along the track, the first at the start, the second at 47.9 m, and the third at 54 m (Figure 2D). Players skated six repeated rows diagonally over a length of 54 m with a brake and no rest between the rows. Data from the photocells were transferred directly to the computer via TIMY Backup Challenge software, which then allowed for immediate analysis of the results. This test was performed once due to its physical demands. Players were instructed to perform each 54-m section at maximum intensity without spreading the effort over the entire test. This test was previously reported to distinguish between the ice hockey performance levels (Roczniok et al., 2024), and its duration (~50–55 s) relates to the length of an ice hockey shift.

Statistical Analysis

The statistical analysis included basic descriptive statistics, where the measured values were expressed as the mean, standard deviation, and 95% confidence intervals indicating the lower and upper bounds (Tables 1 and 2), with data analysis conducted in Microsoft Excel and Jamovi version 1.6.23.0 (The Jamovi Project, United Kingdom). Statistical significance was set at $p < 0.05$. Normality of the distributions was verified using the Shapiro-Wilk test, and the absence of missing data was confirmed. Pearson correlation was used to determine the relationship among anthropometry, off-ice, and on-ice performance ($p < 0.05$), in accordance with the normal distribution of the variables. Based on the correlation analysis, the most significant variables were selected for a multiple-stepwise forward regression (entry $p < 0.05$, removal $p > 0.10$). The predictors were the strength variables of the abductors, adductors, flexors, and extensors of the hip, passive and functional ROM, and anthropometric values. The dependent variables

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included on ice performances, where multiple regression was run for all on-ice tests first and then for each on-ice test separately, reporting standardized β coefficients and R^2 values. Force and torque values were not normalized by body mass, since body mass itself might covariate or cross-variate the raw value and possibly cause false significance.

Results

The results were analyzed by calculating basic descriptive statistics, and no data disrupted the normality of distribution (Tables 1 and 2). The correlation resulted in various low to moderate correlations between net force, ROM, anthropometry, and skating values (Table 3), where the strongest correlations were subsequently used in regression analysis (Table 3).

Four key statistically significant predictors ($p < 0.05$) were identified for all basic skating skills on the ice (acceleration, maximum speed, strength-speed endurance, agility COD): total body height (β = −0.830), strength of the hip extensors in the left lower limb at an angular velocity of 120° (β = −0.670), functional range in the posterolateral direction on the left lower limb (β = −0.761), and posteromedial on the right lower limb (β = −0.690). These predictors together explained 60.9% of the variability in all on-ice test results (Table 4).

Functional range in the posteromedial direction on the left lower limb (β = −0.860; $p < 0.05$) and total length of the left lower limb (β = 1.460; $p < 0.05$) were the strongest predictors, which explained 54.8% of the variability in acceleration test results (Table 4). Hip adductors on the left lower limb were the best predictor of backward skating (β = 0.463; $p < 0.05$). Fat free mass on the right lower limb (β = 2.280; $p < 0.05$) was the strongest predictor for strength, speed, and endurance (6 × 54 m) (Table 4). The length of the femur on the left lower limb was the strongest predictor for the agility test performance (β = 0.455; $p < 0.05$) (it explained 34.9% of the variability in the agility test, Table 4). Furthermore, variables such as total body height, hip extensor strength, hip flexor strength, the percentage of body fat, the both thigh circumferences, and functional ranges of motion (posterolateral, posteromedial, anterior) can be identified as suitable predictors for explaining skating performance in ice hockey (Table 4).

Table 1. Descriptive statistics of on-ice performance.

Variables	Mean ± *SD*	95% CI
6.1-m forward sprint (s)	1.25 ± 0.11	1.2–1.3
30-m forward sprint (s)	4.23 ± 0.18	4.15–4.30
6.1-m backward sprint (s)	1.40 ± 0.08	1.36–1.43
30-m backward sprint (s)	5.0 ± 0.18	4.93–5.08
Illinois agility test (s)	14.84 ± 0.37	14.68–14.99
6 x 9 m – brakes (s)	13.98 ± 0.64	13.71–14.25
1. straight (6 x 54 m) (s)	6.59 ± 0.26	6.48–6.7
2. straight (6 x 54 m) (s)	6.44 ± 0.34	6.29–6.58
3. straight (6 x 54 m) (s)	7.72 ± 0.38	7.56–7.88
4. straight (6 x 54 m) (s)	7.25 ± 0.57	7.02–7.49
5. straight (6 x 54 m) (s)	8.33 ± 0.55	8.1–8.56
6. straight (6 x 54 m) (s)	7.79 ± 0.61	7.53–8.04
Total time (6 x 54 m) (s)	52.82 ± 1.84	52.06–53.59

SD: standard deviation; CI: confidence interval

Table 2. Descriptive statistics of body composition, range of motion, and net force measurements of ice hockey players.

Variables	Mean ± SD	95 % CI
Body height (cm)	180.56 ± 5.15	178.41–182.71
Body mass (kg)	81.35 ± 9.66	77.31–85.38
Thigh circumference (left limb) (cm)	56.37 ± 3.79	54.78–57.95
Thigh circumference (right limb) (cm)	58.85 ± 9.80	54.76–62.95
Lower limb length (left) (cm)	98.20 ± 3.26	96.84–99.56
Lower limb length (right) (cm)	98.17 ± 3.50	96.70–99.63
Range of motion (left adductors) (°)	51.36 ± 5.79	48.95–53.78
Range of motion (right adductors) (°)	51.60 ± 8.61	48.0–55.20
Epicondyle width (left) (cm)	10.16 ± 0.53	9.96–10.40
Epicondyle width (right) (cm)	10.78 ± 0.53	9.96–10.4
Pelvis width (cm)	32.42 ± 3.46	30.94–33.90
Femur length (left) (cm)	44.46 ± 2.52	43.41–45.52
Femur length (right) (cm)	44.81 ± 2.3	43.85–45.77
Tibia length (left) (cm)	40.12 ± 1.96	39.30–40.94
Tibia length (right) (cm)	39.80 ± 2.18	38.89–40.72
Extensors strength (right) 60° (N·m)	320.68 ± 67.21	292.6–348.76
Extensors strength (left) 60° (N·m)	311.91 ± 57.3	287.97–335.85
Flexors strength (right) 60° (N·m)	174.18 ±26.04	163.3–185.06
Flexors strength (left) 60° (N·m)	166.45 ± 16.51	159.56–173.35
Extensors strength (right) 120° (N·m)	265.64 ± 58.86	241.04–290.23
Extensors strength (left) 120° (N·m)	251.45 ± 50.47	230.37–272.54
Flexors strength (right) 120° (N·m)	148.55 ± 23.9	138.56–158.53
Flexors strength (left) 120° (N·m)	144.45 ± 20.3	135.97–152.94
Adductors strength (left) (N)	435.7 ± 113.6	388.24–483.17
Adductors strength (right) (N)	450.39 ± 70.8	420.81–479.98
Abductors strength (left) (N)	415.86 ± 58.91	391.25–440.48
Abductors strength (right) (N)	425.74 ± 64.86	398.64–452.84
Fat mass (g)	16369.45 ± 3425.72	14937.96–17.800.95
Fat-free mass (g)	63946.0 ± 14193.54	58015.0–69877.0
Body fat (%)	19.54 ± 2.6	18.45–20.63
Left lower limb fat-free mass (g)	11598.72 ± 1298.07	11056.3–12141.14
Right lower limb fat-free mass (g)	11605.51 ± 1329.64	11049.9–12161.13
Left lower limb fat mass (g)	2909.61 ± 760.39	2591.87–3227.35
Right lower limb fat mass (g)	3050.01 ± 722.93	2747.92–3352.
Trunk fat-free mass (g)	31890.95 ± 3279.83	30520.42–33261.47
Trunk fat mass (g)	7189.12 ± 1612.84	6515.17–7863.07
ROM Anterior Left (cm)	67.14 ± 6.58	64.39–69.88
ROM Posterolateral left (cm)	115.77 ± 6.57	113.03–118.52
ROM Posteromedial left (cm)	111.14 ± 6.09	108.59–118.52
ROM Anterior right (cm)	70.05 ± 7.49	66.92–73.17
ROM Posterolateral right (cm)	114.73 ± 6.35	112.07–117.38
ROM Posteromedial right (cm)	112.41 ± 6.67	109.62–115.19
Flexion left (hamstrings) (°)	88.36 ± 5.51	86.06–90.67
Flexion right (hamstrings) (°)	89.77 ± 6.75	86.95–92.59

60: angular velocity of the CYBEX Humac Norm; 120: angular velocity of the CYBEX Humac Norm; N·m: Newton·metr; N: Newton; SD: standard deviation; CI: confidence interval; ROM: range of motion

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Table 3. Relationships between on-ice test anthropometry and off-ice testing of basic conditioning variables. Values are in Pearson´s correlation coefficient *r*.

Variable	6.1-m forward sprint	30-m forward sprint	6.1-m backward sprint	30-m backward sprint	Illinois test	6 × 9 m (brakes)	6 × 54 m
Trunk fat-free mass	−0.259	−0.271	−0.161	−0.332	−0.341	−0.030	−0.560**
Fat (%)	0.401	0.493*	−0.009	−0.030	0.223	0.341	0.387
Thigh circumference (left)	−0.011	0.020	−0.130	−0.318	−0.225	−0.072	−0.204
Thigh circumference (right)	−0.041	−0.067	−0.131	−0.391	−0.281	−0.127	−0.141
Body height	−0.280	−0.180	−0.294	−0.408	−0.294	−0.101	−0.508*
Body mass	0.180	0.154	0.192	0.305	0.394	0.101	0.426*
Lower limb length (left)	−0.239	−0.164	−0.251	−0.364	−0.233	−0.272	−0.544**
Lower limb length (right)	−0.203	−0.093	−0.211	−0.316	−0.144	−0.265	−0.521*
Femur length (right)	0.148	0.103	−0.022	0.059	0.070	0.504*	0.084
Left lower limb fat-free mass	−0.190	−0.194	−0.053	−0.283	−0.313	−0.109	−0.505*
Right lower limb fat-free mass	−0.147	−0.160	−0.025	−0.278	−0.281	−0.155	−0.453*
ROM Anterior (left)	−0.601**	−0.547**	−0.009	−0.008	−0.306	−0.295	−0.512*
ROM Posterolateral (left)	−0.369	−0.358	0.005	−0.177	−0.192	−0.363	−0.615**
ROM Posteromedial (left)	−0.397	−0.369	0.125	−0.083	−0.180	−0.317	−0.462*
ROM Anterior (right)	−0.174	−0.147	0.103	−0.113	−0.337	−0.367	−0.434*
ROM Posterolateral (right)	−0.248	−0.224	−0.071	−0.208	−0.228	−0.516*	−0.414
ROM Posteromedial (right)	−0.543**	−0.526*	−0.063	−0.161	−0.222	−0.201	−0.679***
Hip adductor strength (left)	0.073	0.005	0.460*	0.152	−0.058	0.066	−0.044
Hip adductor strength (right)	−0.135	−0.208	0.140	−0.160	−0.441*	−0.302	−0.406
Hip extensors strength (right) 60°	−0.239	−0.182	−0.098	−0.227	−0.241	0.007	−0.375
Hip extensors strength (left) 60°	−0.248	−0.156	−0.102	−0.072	−0.170	0.065	−0.392
Hip extensors strength (right) 120°	−0.362	−0.302	−0.220	−0.366	−0.386	−0.080	−0.500*
Hip extensors strength (left) 120°	−0.306	−0.272	−0.137	−0.378	−0.573**	−0.267	−0.422
Hip flexors strength (right) 60°	−0.219	−0.096	−0.249	−0.353	−0.242	−0.002	−0.471*
Hip flexors strength (left) 60°	−0.399	−0.351	−0.183	−0.322	−0.405	−0.131	−0.662***

ROM: range of motion; 60 and 120: angular velocity of the CYBEX Humac Norm.
** p < 0.05; ** p < 0.01; *** p < 0 .001*

Table 4. The overall model and partial linear regression models for predicting speed in skating tests.

Test	Predictors	Model I β	R^2
Overall model for the summary of all skating test results	Hip Flexor strength (left leg) at 60° (N·m)	0.520	
	Body fat (%)	0.540	
	Body height (cm)	−0.830*	
	Thigh circumference (left leg) (cm)	−0.210	
	Thigh circumference (right leg) (cm)	0.625	0.609
	Extensor strength (right leg) 120° (N·m)	−0.670*	
	ROM Posterolateral (left) (cm)	−0.761*	
	ROM Posteromedial (right) (cm)	−0.690*	
	ROM Anterior (left) (cm)	−0.479	
6 × 54 m – Total time	Left lower limb fat-free mass (g)	−2.100	
	Right lower limb fat-free mass (g)	2.282*	
	Trunk FFM (g)	−0.179	
	Lower limb length (left) (cm)	−0.231	0.528
	ROM Posteromedial (left) (cm)	−0.522	
	ROM Posterolateral (right) (cm)	−0.121	
	Hip flexors strength (left leg) 60 °/kg	−0.033	
Backward sprint 6.1 m + 30 m	Hip adductors strength (left leg) (N)	−0.463*	
	Flexors strength (right leg) 120° (N·m)	−0.549	
	Frame Index (right)	−1.100	0.369
	Frame Index (left)	1.281	
	Trunk fat-free mass (g)	−0.010	
Forward sprint 6.1 m + 30 m	Body fat (%)	−0.087	
	ROM Posteromedial (left) (cm)	−0.723	
	ROM Anterior (left) (cm)	−0.324	
	Hip extensors strength (right leg) 60° (N·m)	−0.541	
	Hip extensors strength (left leg) 60° (N·m)	0.778	0.359
	Frame Index (right)	0.599	
	Body height (cm)	0.093	
	Hip adductors strength (right) (N)	−0.244	
Agility – Illinois test	Femur length (left) (cm)	0.455*	
	Hip extensors strength (left leg) 120° (N·m)	−0.230	
	Hip adductros strength (right leg) (N)	−0.301	0.349
	Hip Flexion right (°)	−0.062	
Short sprints 6.1 m + 6 × 9 m	ROM anterior left (cm)	−0.421	
	Hip extensors strength (right leg) 60° (N·m)	−0.613	
	Hip extensors strength (left leg) 60° (N·m)	0.578	
	ROM posteromedial left (cm)	−0.862*	
	Frame index (left)	0.336	0.548
	Frame index (right)	0.293	
	Body fat (%)	−0.132	
	Lower limb length (left) (cm)	1.462*	
	Lower limb length (right) (cm)	−1.010	

FFM: Fat free mass; 120 and 60: angular velocity of the CYBEX Humac Norm; ROM: range of motion.
** $p < 0.05$*

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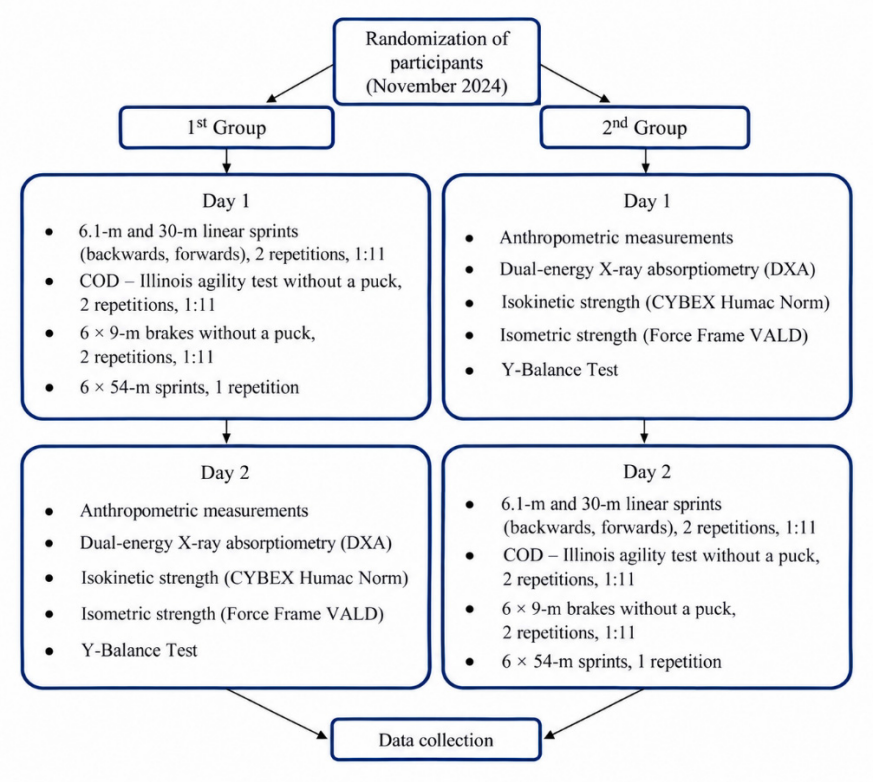


Figure 1. Flow chart of on-ice and off-ice measurements design.
DXA: Dual-energy X-ray absorptiometry; 1:11 denotes the work to rest ratio

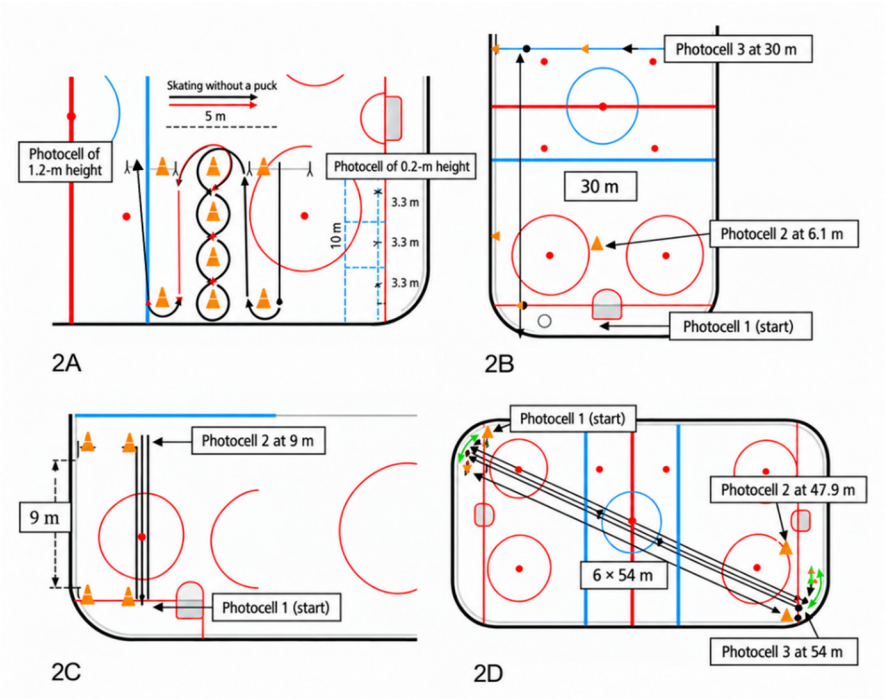


Figure 2. Testing battery for on-ice performance; all tests performed without a puck. (A) Illinois agility test performed without a puck (Roczniok et al., 2024); (B) 30-m linear sprint; (C) COD test performed without a puck (6 × 9 m); (D) 6 × 54-m repeated sprints

Discussion

We hypothesized that strength of the hip abductors, adductors, flexors, extensors, and the range of motion in the hip would strongly predict the overall skating performance (agility, acceleration, speed, and strength-speed endurance). Regression analysis confirmed that strength of the hip extensors ($\beta = -0.670$; $p < 0.05$), hip flexors ($\beta = 0.520$), and all measured ranges of motion in the hip (posteromedial ($\beta = -0.690$; $p < 0.05$), posterolateral ($\beta = -0.761$; $p < 0.05$), anterior ($\beta = -0.479$) and body height ($\beta = -0.830$; $p < 0.05$) were significant predictors along with anthropometry. While higher hip flexor strength and body fat tended to slow down the skating speed, the ROM motion, higher hip extensor strength, and personal height speeded up the skating (Table 3). On the other hand, the strength of the hip abductors and adductors was not a significant predictor for all selected tests (Tables 3 and 4). These results confirm previous predictions that functional ROM (Grabara and Bienec, 2024; Suits et al., 2024), lower limb power and body height (Boland et al., 2019; Silvestri et al., 2025; Wagner et al., 2021) contribute to skating performance. At the same time, the results demonstrated that different skating tasks had different prediction models, e.g., a forward sprint, a backward sprint, and COD. This different predictability was previously suggested in youth ice hockey players (Rice et al., 2024), and may also be present in other sports (Korkmaz et al., 2026; Sal-de-Rellán et al., 2026).

A previous study focusing on the importance of hip strength (abductors and adductors) for skating performance in semi-professional ice hockey players showed that hip strength at the angles of 25° and 50° in the skating position, along with vertical jump performance (CMJ), contributed to acceleration and change of direction performance (Secomb et al., 2021). Our research indicates that adductor strength predicts backward sprinting ($\beta = -0.463$; $p < 0.05$), agility ($\beta = -0.30$) and straight start and sprint performance (Table 3), which depend on the acceleration ability. Preseason screening of NHL players revealed that the adductor-to-abductor strength ratio was a good predictor of adductor overloading. A ratio below 80% had a relative risk of 17:1 for adductor strain (Rodriguez et al., 2020; Tyler et al., 2001). In a follow-up study, strengthening the adductors led to a reduction in injuries (Tyler et al., 2002). Our results confirm that hip abductor and adductor strength are important skating contributors, especially in combination with the hip joint range of motion (Table 3). Therefore, balancing the strength of hip abductors and adductors with their ROM is crucial for long-term skating development.

Potteiger et al. (2010) did not find a significant relationship between isokinetic strength and on-ice skating performance; however, other studies have shown that maximal strength, especially in the squat (1RM), is associated with skating performance, particularly in linear sprints (Boland et al., 2019; Keiner et al., 2024; Secomb et al., 2021). A previous study on hockey players reported that the isokinetic net force of knee flexion and extension muscles at 60 °/s was approximately 118 ± 10.3 and 240 ± 15.6 N·m, respectively (Cornish et al., 2006). The current study adds data on hip flexor and extensor muscle strength, providing values of 174.18 ± 26.04 and 320.68 ± 67.21 N·m, respectively (Table 1). The role of the hip extensors has been described previously (Buckeridge et al., 2015; Kaartinen et al., 2024), and this study confirms their importance for short sprints, forward sprinting, and agility. Less known, however, is the role of the hip flexor, which appears to be an indicator of strength-speed endurance (6 × 54 m) and backward sprint performance (30 m; Table 3). Another important role of hip flexors might be in antagonist prime mover mechanisms, where activity inhibition of the gluteus maximus in transition between skating phases supports peak speed development (Kaartinen et al., 2024), and where hip flexors have to reposition the lower limb after the push-off.

Hip strength and the range of motion are significantly influenced by ice hockey training and matches (Suits et al., 2024), which may lead to long-term changes in the hip joint conditions, such as a reduction in intra-articular space (Mala et al., 2025) and the progression of femoroacetabular impingement (Silvestri et al., 2023). Biomechanical studies show that as skating speed increases, the activation of the hip flexors also increases. Consequently, more experienced players tend to have a wider range of motion in their hips, indicating higher demands on the hip flexors at higher speeds (Buckeridge et al., 2015; Kuhn et al., 2016). Our study confirms that higher passive and

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dynamic ROM are factors that support skating performance.

The correlation results (Table 3) unveil that the speed-endurance 6 × 54-m test provided the most amount of relationships to the measured variables (ROM, strength, body composition, anthropometry), which might be explained by its high relevance to match requirements and the presence of specific fatigue. This fatigue effect has more variables (time and the number of strides) to distinguish among the effects of critical factors on performance. In many cases, the correlations are much different for the right and left lower limbs, which is understandable since ice hockey is a game with a high laterality effect (Dubeau et al., 2025; Grondin et al., 2024), which is evident even in the hip joint structural condition (Mala et al., 2025).

One of the limitations of the present study is that this is not an interventional study; however, the results indicate which combination of flexibility, body dimensions, composition and muscle strength should be the focus of further studies or practical training. This study does not evaluate vertical jumps and vertical force production, since this relationship has been repeatedly confirmed (Laakso and Secomb, 2024). On the other hand, this study uses precise measures of isokinetic strength, body composition, anthropometry, and ROM, which have good predictive value. Since the overall prediction model explained only 60% of the variance (R^2 = 0.601), future studies should consider other skating-related factors, such as full-stride technique, push-off duration, ice contact time per stride, stride frequency, and neuromuscular coordination. Thus, full kinematics and dynamics data might further improve this prediction model.

Conclusions

The study findings confirm that the muscles in the hip area have a key impact on skating skills and performance in ice hockey. The specific muscle groups that determine skating acceleration, speed, and agility are the strength (net force production) of the hip extensors, hip flexors, and adductors. Players with taller body heights perform better in tests of power-speed endurance due to longer stride length, and other factors like body composition, leg length, hip range of motion, or body composition influence skating performance. Functional hip range of motion is particularly important for agility and COD. The results prove that the strength and ROM of different muscle groups are important for different skating tasks; however, specific muscle groups influence overall skating abilities. Body dimensions might decrease or support skating performance, where overall height or partial lower limb dimensions might play a different role for different skating tasks.

Since the prediction model in this study did not explain all data variability and the study had a limited sample size, future studies should consider other skating-related factors such as technique of skating push-off, stride duration, ice contact time at each stride, stride frequency, and neuromuscular coordination.

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ORCID iD:

Martin Blaha: https://orcid.org/0009-0008-0442-9177

Robert Roczniok: https://orcid.org/0000-0001-6551-9151

Artur Terbalyan: https://orcid.org/0000-0002-3628-8849

Lukas Opat: https://orcid.org/0000-0003-1125-683X

Martin Musalek: https://orcid.org/0000-0003-1070-8304

Petr Stastny: https://orcid.org/0000-0003-2841-374X

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