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Improvement of Ice Hockey Players' On-Ice Sprint With Combined Plyometric and Strength Training

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Background: Combined plyometric and strength training has previously been suggested as a strategy to improve skating performance in ice hockey players. However, the effects of combined plyometric and strength training have not previously been compared with the effects of strength training only. ***Purpose:*** To compare the effects of combined plyometric and strength training on ice hockey players' skating sprint performance with those of strength training only. ***Methods:*** Eighteen participants were randomly assigned to 2 groups that completed 5 strength-training sessions/wk for 8 wk. One group included plyometric exercises at the start of 3 sessions/wk (PLY+ST), and the other group included core exercises in the same sessions (ST). Tests of 10- and 35-m skating sprints, horizontal jumping, 1-repetition-maximum (1 RM) squat, skating multistage aerobic test (SMAT), maximal oxygen consumption, repeated cycle sprints, and body composition were performed before and after the intervention. ***Results:*** The participants increased their 1RM squat, lean mass, and body mass ($P < .05$), with no difference between the groups. Furthermore, they improved their 3×broad jump, repeated cycle sprint, and SMAT performance ($P < .05$), with no difference between the groups. PLY+ST gained a larger improvement in 10-m on-ice sprint performance than ST ($P < .025$). ***Conclusion:*** Combining plyometric and strength training for 8 wk was superior to strength training alone at improving 10-m on-ice sprint performance in high-level ice hockey players.

Keywords: skating sprint, stretch-shortening cycle, off-ice training, strength and conditioning

Skating acceleration and maximal skating velocity are among the most important physical determinants of ice hockey performance.[1,2] However, due to a long and intensive ice hockey season,[3] training to improve these capacities typically occurs outside of the competition season. A strong relation has been identified between these skating capacities and running sprint, and horizontal and vertical jump performance.[4–7] It is therefore believed that ice hockey players should seek to improve these off-ice capacities to enhance their skating performance.[5] Although conflicting results exists,[4] muscle strength and power has been related to skating, sprinting, and jumping performance.[8,9] Therefore, muscular strength and power are likely important physical determinants of ice hockey performance.

Among others, plyometric training and strength training with maximal mobilization could potentially improve muscular power.[10] Furthermore, plyometric training has been found to effectively improve skating, sprinting, and vertical jump performance.[1,7,11,12] However, plyometric training has been found to be less effective than heavy strength training for increasing sprint and vertical-jump performance.[11] Therefore, the effect of combining plyometric and strength training has been compared with strength training only, however, with conflicting results.[13–15] Specifically, combined plyometric and strength training was found to be superior in moderately strength-trained individuals,[14] whereas no differences were found in elite soccer and handball players.[13,15] However, it is likely that a considerable amount of the muscle actions occurring during regular soccer and handball training is plyometric in nature. Thus, adding specific plyometric training to these players' strength training may not cause an additional positive training effect.[15] Due to a longer ground-contact time during high-velocity skating than running,[4,16] it can, however, be hypothesized that fewer plyometric muscle actions occur during ice hockey versus soccer and handball. Although combined plyometric and strength training has been found to be effective for the purpose of improving skating performance, the effect of strength training alone has not, to our knowledge, been controlled in previous studies.[1,7]

During maximal velocity skating, ice contact time lasts approximately one-third of a second.[4] However, the kinematics of the initial acceleration phase during speed and ice hockey skating is similar to a running sprint, with a push-off against a fixed point.[17,18] Because the ground contact time during the acceleration phase of sprint running is approximately one-fifth of a second,[16] it can be hypothesized that ice-contact time during the acceleration phase of skating is shorter than during maximal-velocity skating. This implies that accelerating on skates may rely on somewhat different neuromuscular capacities than maximal-velocity skating. Therefore, a short (10 m) and a longer (35 m) distance of sprint skating were investigated in the current study.

The primary purpose of the current study was to compare the effects of combined plyometric and strength training to strength training supplemented by core training on enhancing 10- and 35-m skating sprint performance. As a part of this, factors related to sprint performance, like maximal strength and lean mass in the

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lower body, as well as different horizontal-jump performances, were measured. In addition, endurance capacity was measured both on ice and off ice.

Methods

Participants

Eighteen male under-18-years-old (U18) and under-20-years-old (U20) ice hockey players competing in the highest national division for their age in Norway volunteered to participate in the study. The study was approved by the local ethics committee at Lillehammer University College, and informed written consent was obtained from all participants before participation. Written consents were also collected from the legal guardians of participants that were under the age of 18. Participants were stratified by age (U18 and U20) and randomly assigned to a plyometric training group (PLY+ST; n = 9) or a strength-training group (ST; n = 9). Two participants, both in the ST group, were excluded from the study due to an injury (unrelated to the intervention) and illness, respectively.

Design

A 2-arm randomized prepost design was used to investigate our hypotheses. All participants completed 5 sessions of heavy strength training per week. In addition, the PLY+ST group included plyometric exercises in the first part of 3 strength-training sessions, whereas the ST group included core exercises in the end of the same 3 sessions.

Test Protocols

Five test sessions were completed over 7 days both before (pre) and after (post) the intervention. The order of the test sessions and rest days were the same at both occasions. Tests of cycle sprints, maximal oxygen consumption (VO_2max), and on-ice endurance were completed separately in session 1, 2, and 5, respectively. In session 3, standing broad jump (SBJ) and 3×broad jump (3BJ) was tested, while 10- and 35-m skating sprints and 1 repetition maximum (1 RM) squat was tested in session 4. Measurements of body composition were completed outside of the test week (± 1 wk). The tests were conducted by the same researchers and at the same time of day at pretest and posttest. Strong verbal encouragement was provided on all tests.

Repeated Cycle Sprints

Before this test, a standardized warm-up was performed on a stationary bike. The warm-up consisted of 10 minutes of cycling at an intensity corresponding to 12-to-14 ratings of perceived exertion (RPE) on a Borg 6–20 RPE scale,[19] followed by two 30-second submaximal cycling sprints corresponding to 14 to 15 and 15 to 16 RPE, respectively. The test was composed of 10 cycling sprints with a duration of 35 seconds. Between sprints there was a 90-second passive break followed by a 10-second active break where participants were allowed to cycle at ≤70 RPM at a power output of 100 W. This test had a total duration of 20.8 minutes and was developed to measure maximal performance during a 20-minute period of a game, which is characterized by short intensive work for 30 to 40 seconds on the ice interspersed with passive recovery in the players' bench area for 90 to 180 seconds.[3] The test was conducted on a cycle ergometer from Lode (Lode Excalibur Sport, Lode BV, Groningen, Netherland) with a constant pedal torque (torque factor 0.8 Nm/kg). The goal of the test was to achieve the highest average power output possible over the course of the 10 sprints.

Maximal Oxygen Consumption

The same warm-up protocol and ergometer cycle as reported for the cycle sprints test was used for the VO_2max test. A graded all-out protocol described by Rønnestad and Hansen[20] was used. Briefly, the start resistance for pre- and posttest was determined as 3-W/kg pretest body weight (rounded down to the nearest 50 W). Power output was increased with 25 W every minute until exhaustion. Maximal aerobic power output (MAP) was calculated as the mean power output during the last minute of the incremental test. Pulmonary gas exchange measurements were obtained using an analyzer from VIASYS (Jaeger Oxycon Pro, VIASYS healthcare GmbH, Hoechberg, Germany).

Horizontal Jumps

Before the tests, a brief warm-up consisting of 5 minutes of cycling, 5 minutes of jogging, and 3 submaximal trials for each of the 2 tests was completed. SBJ was tested before 3BJ. Starting standing with both feet behind a baseline, the participants performed a forward counter movement jump incorporating an arm swing.[6] The feet had to remain parallel and length was measured at the heel of the most rearward foot at the point of landing, as determined by one of the investigators. In the 3BJ test, participants were instructed to not stop completely between each jump. Five trials were allowed on both tests, with an interrepetition rest between 2 and 4 minutes. The best trial at each test was used for statistical analysis. The reliability of the tests was near perfect, with intraclass correlations (ICC) of .99 and .98 for the SBJ and 3BJ, respectively.

Skating Sprints

The tests were performed in an indoor ice hockey arena, and the participants wore the same gear as in competition and carried a stick during the test. A brief warm-up consisting of 5 minutes of skating with self-determined intensity followed by 3 submaximal sprints was completed before the test. Timing gates (TC-timer, Brower timing system [Draper, UT, USA]) were used to record temporal data for the 10- and 35-m skating sprints. Before starting, the participants had to stand still with their skates between 2 cones placed 15 cm behind the timing gates. This assured that the timing was initiated as the participants took their first stride. The starts were self-determined and participants were allowed 5 trials with an interrepetition rest between 2 and 4 minutes. The best 10- and 35-m time was used in statistical analysis.

Squat

Before the test, participants completed a brief warm-up consisting of 5 minutes of cycling and submaximal squats at 50%, 70%, 80%, and 90% of self-estimated 1 RM (10, 6, 3, and 1 repetitions, respectively) with 2 minutes rest between sets. Squat depth was standardized to parallel (thigh parallel to the ground) for each participant individually, using an adjustable cross bar. The participants were allowed

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5 trials with an interrepetition rest of 3 minutes. The largest mass successfully lifted to the standardized depth was recorded as the participant's 1 RM. All participants reached their 1 RM within the maximum 5 trials allotted.

Skating Multistage Aerobic Test

Participants performed a warm-up consisting of 10 minutes of low intensity skating and a trial of the first 5 stages of level 1 of the skating multistage aerobic test (SMAT). During the test, participants skated back and fourth on a 45-m track with marks at the midline (22.5 m) as described by Leone et al.[21] An application (Bleep Test Solo for iPhone, Top End Sports) provided audible signals in accordance to the protocol for the SMAT.[21] If a participant was out of synchronization with the audible signals 3 times in a row, his test was regarded as finished.

Body Composition

Measurements of body composition were conducted using dual-energy X-ray absorbtiometry (DEXA; Prodigy Advance PA+302047, Lunar, San Francisco, CA, USA). The measures were completed within ±1 week of the first testing session, according to the guidelines for DEXA scans. Participants were asked not to engage in strenuous physical activity in the previous 12 hours and not to eat in the previous 3 hours before the measurement.

Nutritional Intake

All participants performed a 4-day weighted food record in the middle of the intervention period as described by Rønnestad et al.[22] In an attempt to standardize the protein and energy consumption in the time around exercise, all participants ate the same protein chocolate bar (Ironcore Chunk of Protein, Proteinfabrikken, Norway) that contained 30 g of protein and 411 calories immediately after each bout of strength training.

Training Protocol

Throughout the 8-week intervention, both groups completed 1 high- and 1 low-repetition-maximum session for upper body and lower extremities separately each week. Furthermore, 2 4×5 minute aerobic interval sessions at intensities between 90% to 100% of maximal heart rate with an interinterval rest of 2.5 minutes were completed on stationary exercise bikes for the first 2 weeks of the intervention. From the third intervention week, one of these sessions was replaced with a whole body strength-training session. For the last 3 weeks of the intervention, the participants also completed on-ice training sessions with their ice hockey team. One member of the research team supervised all training sessions.

The exercises, sets, repetitions, and intensities (n RM) used in the strength-training program were similar in the 2 groups (Table 1). All strength-training exercises used in the current study had previously been a part of the participants' regular strength-training program for at least 3 months. The PLY+ST group included the plyometric exercises—skating jumps, broad jumps, and side jumps—in the start of the strength-training sessions that targeted the lower extremity and the whole body (Table 1). In the skating jumps, the participants jumped diagonally forward from one leg to the other, resembling a skating stride. The broad jumps were performed as described for the 3BJ test above, and the side jumps were performed jumping laterally from one leg to the other. Participants were instructed to exert maximal effort and not to stop fully between the jumps within a set. The ST group included the core exercises—plank, side plank, and sling crunch—at the end of the same sessions to assure similar total training time in both groups (Table 1). The plank exercise was performed supporting the body on the toes and both elbows, while maintaining a straight and rigid posture. In the side plank exercise, the participants supported their body on 1 elbow and the lateral aspect of the foot with the lateral side of the body facing the ground. For the prescribed time, the participants lowered and raised the pelvis with respect to the ground. Finally, the sling crunch was performed with the feet placed in suspension cords and the body supported with both elbows on the ground. From a straight body position, the participants flexed their knees and hips, while contracting their abdominal muscles before returning to the starting position.

Statistical Analysis

All statistical analysis was conducted in SPSS v23.0 (SPSS Inc, Chicago, IL). Mixed ANOVAs were used to analyze time × group interaction effects, and both time and group main effects. The assumption of normality, homogeneity of variance, homogeneity of covariance, and sphericity was confirmed using Shapiro Wilk test of normality, Levene test of equality of error variance, Box test of equality of covariance matrices, and Mauchly test of sphericity, respectively. Independent-sample *t* tests were used to compare the group's characteristics, adherence to the training protocol, and nutrition intake. Means ± SD are reported for all variables, and effect sizes (ES) are reported as partial η^2. The level of significance (α) was set to .05.

Results

Participant characteristics, adherence, and nutritional intake were similar in the 2 groups ($P > .05$; Table 2).

Performance Tests

After the 8-week intervention, the PLY+ST group had a greater reduction than ST in time spent on 10-m skating (–2.8% ± 3.1% vs 0.4% ± 1.4%, respectively; $P = .022$, Figure 1). No significant main or interaction effects were found at the 35-m skating sprint (Figure 1). PLY+ST had a tendency toward larger improvements than ST in SBJ (1.0% ± 2.0% vs –1.1% ± 2.1%, $P = .064$; Table 3).

Both groups improved their performance in 3BJ, 1 RM squat, SMAT, and repeated cycle sprint test from pretest to posttest ($P < .05$; Table 3). However, no interaction or group main effects were found at any of these tests ($P > .05$; Table 3). Further, no significant interaction or main effects were found for VO_2max or MAP ($P > .05$; Table 3).

Body Composition

Both groups increased total-body mass, whole-body lean mass, and lower-extremity lean mass increased from pretest to posttest ($P < .05$; Table 3). However, no significant interactions were present in any of the body-composition parameters ($P > .05$; Table 3). Furthermore, no main or interaction effects were found for body-fat percentage ($P > .05$; Table 3).

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Table 1 The Strength, Plyometric, and Core-Training Program Used in the Training Intervention

	Wk 1–2				Wk 3–5					Wk 6–8				
	Day 1	Day 2	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
Strength exercises, sets × repetitions														
power clean		3 × 6		4 × 4	3 × 6			4 × 3		4 × 4			5 × 2	
lunges		3 × 10		4 × 6	3 × 8		2 × 10	4 × 5		3 × 6		2 × 8	4 × 4	
squat (to parallel)		3 × 10		3 × 6	3 × 8			3 × 5		3 × 6			3 × 4	
lateral lunges		3 × 10		4 × 6	3 × 8		2 × 10	3 × 5		3 × 6		2 × 8	4 × 4	
stiffleg deadlifts		3 × 10		4 × 6	3 × 8		2 × 10	4 × 5		3 × 6		2 × 8	4 × 4	
Nordic hamstring				3 × 6				3 × 5		3 × 6			3 × 4	
calf raises		3 × 10		3 × 6	3 × 8			3 × 5		3 × 6			3 × 4	
bench press	3 × 10		3 × 6			3 × 8			3 × 5		3 × 6			4 × 4
decline bench press	3 × 10		3 × 6			3 × 8	2 × 10		3 × 5		3 × 6	2 × 8		3 × 4
military press	3 × 10		3 × 6			3 × 8	2 × 10		3 × 5		3 × 6	2 × 8		4 × 4
lateral deltoid raise						2 × 10			2 × 8		3 × 6			3 × 4
dips	3 × 10		3 × 6			3 × 8			3 × 5		3 × 6			3 × 4
pull-ups	3 × 10		3 × 6			3 × 8	2 × 10		3 × 5		3 × 6	2 × 8		4 × 4
Pendley rows	3 × 10		3 × 6			3 × 8	2 × 10		3 × 5		3 × 6	2 × 8		4 × 4
biceps curl	3 × 10		3 × 6			3 × 8			3 × 5		3 × 6			3 × 4
Plyometric exercises, sets × repetitions														
skating jumps		2 × 5		2 × 5	3 × 5		2 × 5	3 × 5		3 × 7		2 × 7	3 × 7	
broad jumps		2 × 5		2 × 5	3 × 5		2 × 5	3 × 4		3 × 5		2 × 5	3 × 5	
side jumps		2 × 5		2 × 5	3 × 5			3 × 5		3 × 5			3 × 5	
Core exercises, sets × time (s)														
plank		3 × 60		3 × 60	3 × 90		2 × 90	3 × 90		3 × 90		2 × 90	3 × 90	
side plank		3 × 30		3 × 30	3 × 45		2 × 60	3 × 45		3 × 45		2 × 60	3 × 45	
sling crunch		3 × 45		3 × 45	2 × 90			4 × 90		4 × 90			4 × 90	

Table 2 Subject Characteristics at Pretest, Adherence to the Training Protocol, and Energy Intake in the Middle of the Intervention Period, Mean ± SD

	PLY+ST (n = 9)	ST (n = 7)	PLY+ST vs ST *P*
Age (y)	17.2 ± 1.0	17.1 ± 0.7	.86
Height (m)	1.82 ± 0.03	1.84 ± 0.05	.18
Adherence (%)	84.8 ± 10.8	82.3 ± 8.4	.65
Energy intake[a] (kJ · kg^{-1} · d^{-1})	170.7 ± 37.9	133.9 ± 59.4	.28
carbohydrate intake[a] (g · kg^{-1} · d^{-1})	5.1 ± 1.4	3.8 ± 1.5	.21
Fat intake[a] (g · kg^{-1} · d^{-1})	1.4 ± 0.3	1.1 ± 0.7	.43
Protein intake[a] (g · kg^{-1} · d^{-1})	2.0 ± 0.4	1.5 ± 0.6	.27

Abbreviations: PLY+ST, combined plyometric and strength-training group; ST, strength-training group.

[a] Including protein chocolate bars.

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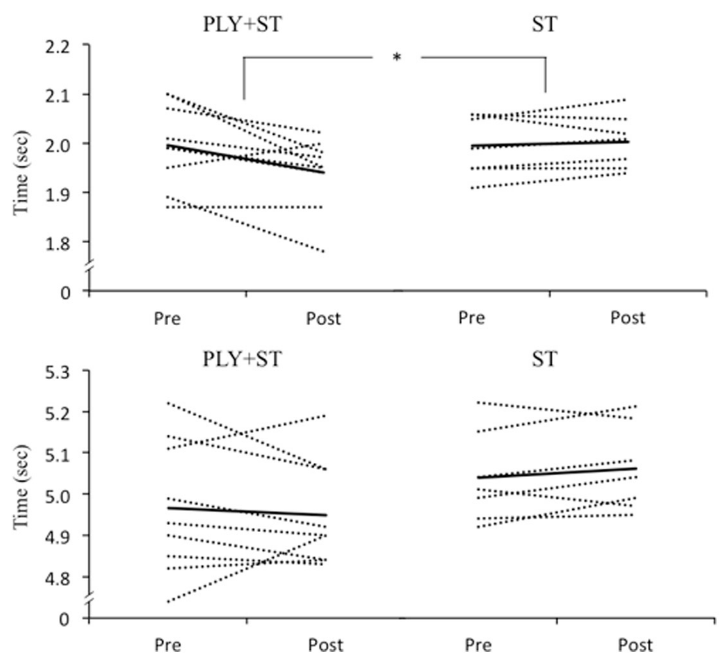

Figure 1 — The individual (dotted lines) and mean (solid lines) results of the 10-m (top panels) and 35-m (bottom panels) skating sprint test for PLY+ST (left panels) and ST (right panels) group. The asterisk indicates a significant time by group interaction ($P < .05$). Abbreviations: PLY+ST, combined plyometric and strength-training group; ST, strength-training group.

Discussion

The results of the current study indicated that combined plyometric and strength training is superior to strength training supplemented by core training on improving 10-m skating sprint performance. However, no significant effect was observed on the 35-m skating sprint.

Lower-extremity strength and power output could potentially affect skating sprint performance. These capacities have previously been associated with better running and skating sprint performance.[6,8,9] The strength-training program used in the current study successfully increased both groups' lower-extremity and whole-body lean mass. Moreover, both groups increased their 1 RM squat. Due to the relationship between lean mass and strength,[23] the increase in lower-extremity strength is largely attributable to the simultaneous increase in lower-extremity lean mass. However, the increase in lower-extremity strength and lean mass was not accompanied by an increase in performance at the 35-m skating sprint in any of the groups. Furthermore, only the PLY+ST group improved their performance at the 10-m skating sprint test. Therefore, changes in lean mass or lower-extremity strength cannot explain the PLY+ST group improvement on the 10-m skating sprint. As 1 RM back squat is primarily limited by knee- and hip-extensor strength,[24] it may be hypothesized that increasing strength in these muscle groups alone is not sufficient to improve skating sprint performance in high-level ice hockey players. A previous study supported this notion.[4]

Skating sprint performance has previously been shown to be strongly associated to jumping performance.[5–7] Furthermore, combined plyometric and strength training has previously been shown to effectively improve skating performance.[1,7] In the current study, both groups improved their performance on the 3BJ test. Surprisingly, this improvement did not seem to affect skating performance as only the PLY+ST group improved their 10-m

Table 3 Results From the Horizontal-Jump, Strength, Endurance, and Body-Composition Tests for the PLY+ST and ST Groups at Pretest and Posttest, Mean ± SD

	Pretest	Posttest	Relative Δ	*P*	η^2_p
3×broad jump (m)[a]					
PLY+ST	7.96 ± 0.37	8.04 ± 0.39	1.0% ± 0.9%	T: .050	.007
ST	7.81 ± 0.33	7.91 ± 0.41	1.3% ± 2.5%	G: .504	
Standing long jump (m)					
PLY+ST	2.59 ± 0.10	2.62 ± 0.08	1.0% ± 2.0%	T: .952	.225
ST	2.60 ± 0.07	2.57 ± 0.09	–1.1% ± 2.1%	G: .600	
1-repetition-maximum squat (kg)[a]					
PLY+ST	126.7 ± 23.2	140.0 ± 24.1	10.8% ± 4.6%	T: .000	.043
ST	124.3 ± 10.2	140.0 ± 11.9	12.7% ± 5.7%	G: .906	
Skating multistage aerobic test (m)[a]					
PLY+ST	3187 ± 229	3330 ± 321	4.5% ± 7.1%	T: .005	.095
ST	3169 ± 345	3468 ± 150	10.3% ± 10.2%	G: .636	
VO_2max (mL/min)					
PLY+ST	4768 ± 549	4623 ± 389	–2.7% ± 5.2%	T: .092	.014
ST	4876 ± 543	4765 ± 365	–1.9% ± 5.4%	G: .601	
Maximal aerobic power output (W)					
PLY+ST	384.4 ± 30.4	373.4 ± 33.7	–2.9% ± 4.1%	T: .496	.128
ST	387.5 ± 23.9	391.1 ± 30.4	1.0% ± 6.5%	G: .490	
10 × 35-s cycle sprint (W)[a]					
PLY+ST	524.4 ± 58.3	568.1 ± 75.9	8.2% ± 5.2%	T: .007	.172
ST	604.2 ± 67.6	623.4 ± 53.3	3.5% ± 5.4%	G: .107	
Total body weight (kg)[a]					
PLY+ST	78.3 ± 7.3	81.3 ± 7.1	3.9% ± 2.0%	T: .000	.084
ST	83.7 ± 7.8	85.8 ± 8.2	2.5% ± 2.2%	G: .210	
Whole-body lean mass (kg)[a,b]					
PLY+ST	62.4 ± 4.3	64.2 ± 4.1	2.8% ± 1.6%	T: .000	.042
ST	67.0 ± 2.0	68.3 ± 1.8	1.9% ± 2.1%	G: .022	
Lower-extremity lean mass (kg)[a,b]					
PLY+ST	21.5 ± 1.4	22.2 ± 1.2	3.2% ± 2.0%	T: .000	.004
ST	23.7 ± 1.8	24.3 ± 1.6	2.7% ± 2.3%	G: .010	
Fat mass (%)					
PLY+ST	16.2 ± 4.6	17.2 ± 5.3	—	T: .123	.012
ST	15.7 ± 6.3	16.3 ± 7.0	—	G: .809	

Note: *P* values are reported for time (T) and group (G) main effects. Effect sizes (η^2_p) for interaction effect sizes are reported in the table.

Abbreviations: PLY+ST, combined plyometric and strength-training group; ST, strength-training group; VO_2max, maximal oxygen consumption.

[a] Significant main effect: T, $P \leq .05$. [b] Significant main effect: G, $P \leq .05$.

skating sprint; thus, this finding conflicts with previous findings.[1,7] However, the level of the participants were not specified in these studies. Therefore, a difference in physical conditioning or skating technique between the participants in the current study and those who participated in previous studies may be responsible for these conflicting findings. One could also hypothesize that the improvement found on the 3BJ test was due to a learning effect, but this seems highly unlikely given the high ICC found at this test. Thus, the mechanism behind the discrepancy between current and previous findings remains unclear.

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In contrast to the ST group, the PLY+ST group improved their performance on the 10-m skating sprint. However, none of the groups improved their performance at the 35-m skating sprint. The acceleration phase of skating is similar to a running sprint, with short ground contact times and push-off against a fixed point on the ice.[17,18] Since the skate is not required to glide in this phase, foot plantar flexion may allow the ankle plantar flexors to contribute considerably to the work performed during the strides of the acceleration phase.[25] In contrast, foot plantar flexion is unfavorable during the gliding strides when a fixed-blade skate is used, as the blade would dig into the ice and create a breaking impulse at the end of each stride.[26] Moreover, a recent study found that forefoot forces were greater during acceleration than during gliding strides.[2] Taken together, these findings indicate that ankle plantar-flexor strength may be of greater importance to skating acceleration performance compared with maximal-velocity skating. Increased muscle cross-sectional area, tendon stiffness, and muscle fascicle lengths, as well as decreased muscle-fascicle pennation angles, are known adaptions to plyometric training.[11,12,27,28] In theory, all these adaptions may increase the force applied to the ground, particularly when ice-contact times are short, such as during the acceleration phase of skating. Specifically, a larger muscle cross-sectional area, longer fascicle lengths, and smaller pennation angles would allow greater force to be produced by the ankle plantar flexors at high muscle-fascicle-shortening velocities, whereas an optimal tendon stiffness would assure an effective transfer of these forces to the ice.[11,12,27,29] Therefore, it seems likely that such adaptions manifested in the ankle plantar flexors can explain the PLY+ST improvement on the 10-m skating sprint. The ground contact times during the gliding stride phase is longer than during acceleration, and favorable adaptions in ankle plantar flexor muscles and tendons may therefore not affect performance on longer skating sprints. Thus, alterations in ankle plantar-flexor cross-sectional area, fascicle lengths, pennation angles, and tendon stiffness may be a plausible explanation of the findings on the 10-m and 35-m skating sprints in the current study.

The SMAT is a measure of on-ice endurance, and therefore an important predictor of ice hockey–specific endurance. The participants' VO_2max and MAP did not change from pretest to posttest. However, both groups increased their performance at the SMAT and repeated cycle sprint test. It might be suggested that this improvement is due to improved anaerobic capacity because an important determinant of the anaerobic capacity, lean mass, increased.[30] Furthermore, the current study shows that the volume and intensity of the applied endurance training was sufficient to maintain the players' endurance capacity.

Practical Applications

Practitioners seeking to increase players' skating acceleration performance may implement plyometric training as a supplement to heavy strength training. However, the specific mechanism through which the plyometric training improves this capacity remains unclear. Due to the plausibly greater involvement of the ankle plantar flexors during acceleration compared with gliding strides, and their large involvement during a running sprint, future research should seek to understand the different roles of these muscles during different stride types. Finally, to prevent deterioration of endurance capacity during periods focusing on heavy strength training, 1 or 2 sessions of high-intensity aerobic intervals per week may be included in these periods.

Conclusions

Combined plyometric and strength training was superior to strength training supplemented with core training in improving 10-m on-ice sprint performance. However, a similar effect was not present at 35-m on-ice sprints.

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