Original Research

The Effects of a Plyometric Training Program on Jump Performance in Collegiate Figure Skaters: A Pilot Study

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ABSTRACT

International Journal of Exercise Science 9(2): 175-186, 2016. Plyometric training has been implemented to increase jump height in a variety of sports, but its effects have not been researched in figure skating. The purpose of this study was to determine the effects of a plyometric training program on on-ice and off-ice jump performance. Six collegiate figure skaters (19.8±1.2 years; 164.7±4.9 cm; 60.3±11.6 kg) completed a six-week sport-specific plyometric training program, consisting of low to moderate intensity plyometric exercises, while eight collegiate figure skaters (21.1±3.9 years; 162.6±6.0 cm; 60.4±6.1 kg) served as the control group. Significant increases were found for vertical jump height, standing long jump distance, (F = 31.0, p < 0.001), and flight time (F = 11.6, p = 0.007). No significant differences were found for self-reported jump evaluation (p = 0.101). Six weeks of plyometric training improved both on-ice and off-ice jump performance in collegiate figure skaters, while short-term skating training alone resulted in decreases. These results indicate that figure skaters could participate in off-ice plyometric training.

KEY WORDS: Jumping, vertical jump, long jump, flight time

INTRODUCTION

Over the past two decades, the sport of figure skating has become increasingly more technical. In 2002, the International Judging System replaced the 6.0 System around the world with the aim to make the judging of figure skating more objective (11). With this new judging system, development of the free skate became mathematical, allowing skaters to stack their programs with more difficult elements to be awarded the highest points possible. As a result of the increasing demands, skaters are training to achieve greater revolutions in jumps, more difficult spins, and more intricate step sequences, while also having to maintain the elegance and artistry of the sport.

According to a survey study (7), high-level figure skaters reported practicing, on average, two to six hours each day for six days per week, with a majority of that time spent practicing on-ice jumps. In this competitive sport, mastering jumps in a reasonable amount of time is a crucial tool that the skater can use to accumulate higher points. Judges award points for jumps performed in competition based on height, length, and proper technique (1), thus these elements have been previously investigated in biomechanical studies. One study (16) revealed that male skaters who were capable of landing a quadruple toe-loop, a high level figure skating skill, demonstrated increased jump heights and flight times when compared to male skaters who could not complete quadruples. King and associates (16) attributed this finding to greater vertical force production observed in the skaters who could perform quadruples. Aleshinsky (3) reported more experienced skaters to have increased jump heights and increased takeoff velocities in his study, while Albert and Miller (2) reported longer flight times in double versus single jumps. It is evident that flight time and jump height are critical components to successful jumping.

In order to maximize performance, off-ice training programs have been proposed by figure skating researchers and professionals in the field (4). Specifically, the recommendation for figure skaters to implement off-ice plyometric training, which is quick, powerful movement using prestretch, or countermovement, involving the stretch-shortening cycle, has been proposed (26, 27, 28, 29). Plyometric exercise may be a viable off-ice supplement to on-ice training, especially because on-ice jumps rely on horizontal and vertical power, explosive actions, significant balance, and postural control (27). In addition, plyometric training is time efficient and can be performed in the skating rink without equipment.

Plyometric training and its effects on jump performance have not yet been researched in figure skating, despite being recommended by figure skating professionals (16, 26, 28). The majority of plyometric research focuses on its implementation in sports such as volleyball (10, 24) and basketball (17, 22) where vertical jumping is a crucial component to success. In addition to the vertical component, skating jumps incorporate horizontal and rotational components, in addition to the vertical component, which may require creative training programs to improve performance.

Current research on other aesthetic sports, such as dance and gymnastics, which similarly incorporate vertical, horizontal and rotational components, resulted in increases in vertical jump height after six (5) and seven week (8) plyometric training interventions. Additionally, increases in vertical jump height in rhythmic gymnasts have been observed after four weeks of plyometric training in the pool (12). Because limited research has been conducted in aesthetic sports, the purpose of this study was to examine the effects of a six-week off-ice plyometric training program on on-ice and off-ice jump performance in collegiate figure skaters. We hypothesized that six weeks of sport-specific plyometric training would increase off-ice vertical jump height, off-ice standing long jump distance, on-ice flight time, and on-ice self-reported jump evaluation.

METHODS

In order to examine the effects of plyometric training on figure skaters, a pre-post test design was utilized. Figure skaters from an intercollegiate figure skating team participated in six weeks of plyometric training, while skaters of another intercollegiate skating team represented the control group. Perception of jump improvement and flight time of the figure skating jump, analyzed via Dartfish® software, were used to determine the effects of the intervention on on-ice jump performance, while tests of vertical jump height and standing long jump distance were used to evaluate off-ice jump performance. Both groups maintained their normal training schedules throughout the duration of this study.

Participants

The Institutional Review Board of the investigator's university granted approval of this study. All participants read and signed an informed consent prior to participating. A total of 14 collegiate figure skaters (20.6±3.1 years; 163.5±5.5 cm; 60.4±8.5 kg) participated in this study (Table 1). One male and five females represented the intervention group from the intercollegiate skating team of one college, while eight females from the intercollegiate team of another college represented the control group. Inclusion criteria included subjects greater than or equal to 18 years of age, active involvement in their collegiate team, no lower extremity injury in the past 30 days, and passing of a movement screen. The principal investigator conducted the movement screen consisting of hip and knee range of motion measures and squat jump assessment to ensure that subjects could safely execute the movements required by plyometric exercise. Subjects were included in this study if hip and knee range of motion measures were within normal limits and if they exhibited proper form for both a squat and squat jump, based on the National Strength and Conditioning protocol (9).

Table 1. Age, Height, Body Mass, and Body Fat Percentage of Collegiate Figure Skaters*

	Age (years)	Height (cm)	Body Mass (kg)		Body Fat (%)	
			Pre	Post	Pre	Post
PG (n=6)	19.8±1.2	164.7±4.9	60.3± 11.6	59.9 ± 10.4	21.8±1 2.9	20.8 ± 13.2
CG (n=8)	21.1±3.9	162.6±6.0	60.4± 6.1	60.0 ± 6.8	25.4 ± 3.0	25.0 ± 5.8

PG = plyometric training group; CG = control group; *No significant differences between groups.

All subjects were actively involved in their collegiate team with 10 of the participants having competed in a minimum of one competition per year. None of the skaters were involved in a plyometric training program prior to this study. Throughout the duration of this study, skaters in the plyometric training group spent a mean of 19.3 (0-36.0) hours training on-ice and attempted a mean of 316 (0-1800) on-ice jumps, while skaters in the control group spent a mean of 23.1 (0-70.5) hours training and attempted a mean of 341 (0-1131) on-ice jumps. As seen from the lower bound of the range, two figure skaters in the plyometric training group and two in the control group did not practice on-ice over the six weeks. It should be noted that this study was conducted during the off-season, which may explain why those skaters did not train on-ice.

Protocol

Figure skaters from one of the participating intercollegiate skating teams attended off-ice plyometric training sessions, each lasting 15-20 minutes, twice per week for six weeks with a minimum of 48 hours separating sessions (Table 2). Subjects were instructed to bring their own athletic shoes to wear during training. The flooring was rubber matting, which is considered a safe plyometric training surface (29). The plyometric training program consisted of double leg (except power skips), low to medium intensity plyometrics (29). This training program was adopted from the plyometric training plan created by Hewett et al. (10), in which a six-week low to moderate intensity program for athletes improved vertical jump height by 10%. The program consists of a three-phase progression with each phase lasting two weeks. This progression allows subjects, especially those who have never experienced plyometrics, to develop proper form while minimizing risk of injury. Phase I focuses on establishing proper technique to include correct posture, jumping straight up, soft landings, and instant "recoil" preparation for next jump (10). Low subject to investigator ratio allowed close monitoring of technique, and verbal instruction was constantly given to the subjects to ensure proper technique was being utilized. Phase II focuses on fundamentals in order to work on increasing power, while phase III stresses improvement in performance of the plyometric exercises. Throughout all phases, maximum effort for all plyometric exercises was encouraged. The plyometric program used in this study was made sport-specific to figure skating by incorporating a rotational component, consisting of quarter and half-turn rotations. The subjects experienced increased volume through an increased amount of foot contacts each week. Prior to each plyometric session, the subjects participated in five minutes of warm up. Within the warm up, subjects jogged for three minutes and performed lower extremity dynamic stretching for two minutes.

Anthropometric measures were obtained pre- and post-test in order to assess changes over the six weeks. Height was measured to the nearest tenth of a centimeter using the Health O Meter® Professional stadiometer (Jarden Corporation; Boca Raton, FL) or tape measure against the wall during pre-test. Body mass, measured to neared tenth of kilogram, and body fat percentage were assessed pre- and post-test with the Tanita TBF-521 Scale (Tanita Corporation; Japan).

Vertical jump height was measured using the Just Jump System (Probotics, Inc.; Huntsville, AL). This is a valid method (r=0.967) for measuring vertical jump height when compared to the criterion reference, a three-camera motion analysis system (18). Subjects stood on the mat barefoot with legs straight. They were provided verbal instruction and demonstration on how to perform the countermovement jump with arm swing, a movement most similar to on-ice figure skating jumps. Prior to recording, subjects were allowed three practice trials with auditory feedback from the investigator to ensure proper technique. When ready to record, subjects were instructed to execute

Table 2. Plyometric training program for collegiate figure skaters, adopted from Hewett et al. (10)

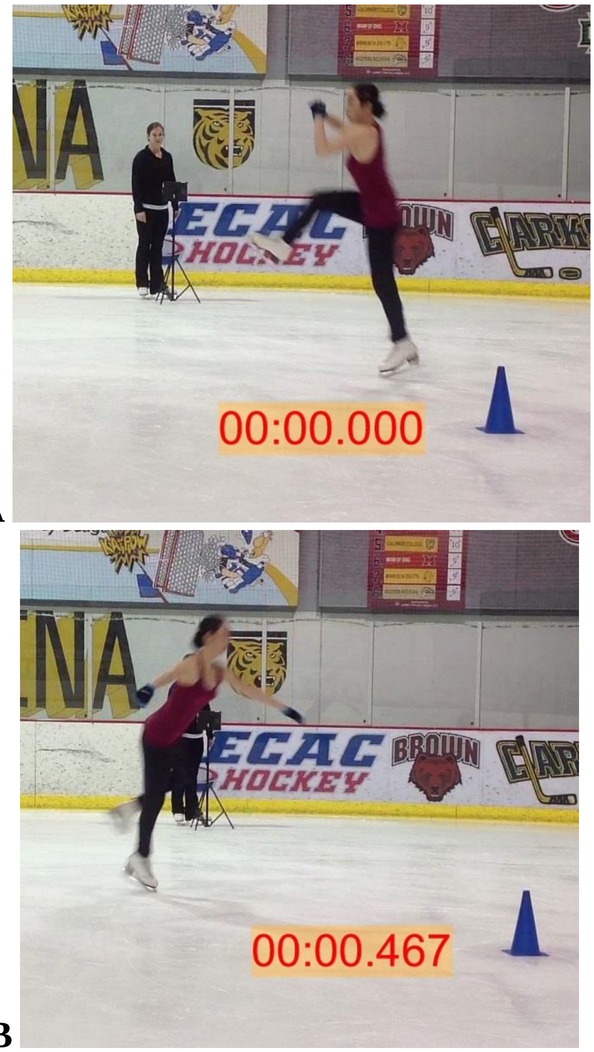
Exercise	Sets x Repetitions	
Phase I: Technique	Week 1 (50 FC)	Week 2 (60 FC)
Ankle Bounces	1x10	1x10
SJ	1x10	1x10
CMJ	1x10	2x10
SLJ	1x5	1x10
Power Skips, in place	1x15	1x10
Phase II: Fundamentals	Week 3 (70 FC)	Week 4 (80 FC)
Scissor jumps	1x10	1x10
Lateral Hops	1x10	1x10
Quarter Air Turns	2x10	2x10
CMJ, 90° rotations	2x10	2x10
Power Skips, for distance	1x10	2x10
Phase III: Performance/ Sport Specific	Week 5 (90 FC)	Week 6 (100 FC)
Half Air Turns	2x10	2x10
CMJ, 180° rotations	3x10	3x10
Lateral Hops, 180° rotations	2x10	3x10
Power Skips, backward	2x10	2x10

SJ = Squat jump; CMJ = Countermovement jump; SLJ = Standing long jump; FC = Foot contacts

maximum effort when performing the countermovement jumps. Utilizing the National Strength and Conditioning Association's protocol for vertical jump height (9), the best of three trials was used for data analysis with subjects resting for 30 seconds between each trial. If the third trial was the highest, the subject earned another attempt, until the succeeding jump was less than the previous effort.

The standing long jump required subjects to stand, wearing athletic shoes, with their toes behind a piece of tape that served as the starting line. Each subject performed a countermovement jump with arm swing to jump forward as far as possible. If subjects did not stay balanced on two feet, the trial was repeated. The long jump was measured from the starting line to the back of the rearmost heel using a tape measure. The best of three trials was recorded to the nearest centimeter. If the third trial was the highest, the subject earned another attempt. Likewise, if each succeeding attempt was higher, then another attempt was earned. Subjects were given 30 seconds rest in between trials (9).

After completing the off-ice trials, subjects put on their own figure skates and completed five minutes of on-ice warm-up, to include stroking. Stroking involves forward and backward gliding from one blade to the other around the skating rink. All subjects were required to perform the same jump, the waltz jump, which was the common denominator among the collegiate skaters who participated in the on-ice portion of this study (Figure 1). The waltz jump is a one-half revolution (180 degrees in the air) jump, where the skater takes off from a forward outside edge and lands on the backward outside edge of the opposite foot (1). Following one of the straight lines painted on the ice, the subjects were allowed one half circle on the forward outside edge on the opposite foot of waltz jump takeoff. For example, if a skater was a right-handed jumper, meaning she rotated to the right, she completed a half circle on the forward outside edge on the right foot. Once she returned to the line, she stepped onto a forward outside edge on the left foot to complete the waltz jump as previously described. This is typically how beginner skaters practice their waltz jumps before they are ready to increase their speed. If the subject did not land the waltz jump, then another attempt was earned. Failure to land the jump included falling, landing on two feet, stepping out, and putting one or both hands down on the ice. Three trials of the jump, with 30 seconds rest between jumps, were recorded with two digital cameras on either side of the subject. Using the Dartfish® (Dartfish®, Version 7.0; Alpharetta, GA) Analyzer Mode, flight time was determined from video data (Figure 1). Flight time is defined as the time, measured in thousandths of a second, from when the blade of the takeoff foot leaves the ice to when the blade of the landing foot makes contact with the ice (14). Following the trials, subjects were asked to rate their on-ice jump performance of all waltz jumps on a scale of 1 (poor) to 10 (best). This number was recorded on a scale printed on the subjects' data sheets.



A

B

Figure 1. Waltz Jump: take-off (A), and landing (B)

Statistical Analysis

Statistical analyses were completed with IBM® SPSS® (Version 20.0.0) software. All data was tested for normality and homogeneity of variance before statistical tests were performed. A one-way ANOVA was used to determine if any significant differences existed between groups for descriptive characteristics and pre-test measurements. A one-way ANOVA with repeated measures was performed to ensure no significant differences for anthropometric characteristics within groups from pre- to post-test. To determine the effects of the plyometric training program, a two-way ANOVA with repeated measures for time (pre-test vs. post-test) was performed. Significance was accepted at the $p \leq 0.05$ level. All results are reported as means and standard deviations.

RESULTS

Results of the one-way ANOVA indicated that there were no significant differences between the intervention and control groups for descriptive or anthropometric characteristics from pre- to post-training (Table 1). Additionally, there were no significant differences between the groups for the outcome variables prior to training. Body mass and body fat percentage within groups did not significantly change from pre- to post-test.

The outcome measures are reported as means and standard deviations from pre- to post-test for the intervention and control groups (Table 3). The group x time interaction for off-ice vertical jump height within subjects indicated a significant effect (F = 17.0, p = 0.001, η^2_ρ = 0.586). The plyometric training group increased vertical jump height by 5.4%, while the control group decreased vertical jump from pre- to post-test. Standing long jump distance significantly increased by 26% in the plyometric training group (F = 31.0, p < 0.001, η^2_ρ = 0.721), while it decreased in the control group. The group x time interaction for on-ice flight time was significant (F = 11.6, p = 0.007, η^2_ρ = 0.538). Flight time in the plyometric training group increased by 0.029 seconds, an 8.0% increase, while the flight time of the control group decreased by 0.016 seconds, a 4.0% decrease. There were no significant differences (p = 0.101) from pre- to post-training for the self-reported jump evaluation.

Table 3. Off-Ice and On-Ice Jump Performance Outcomes After Plyometric Training

	Plyometric Training (n=6)		Control (n=8)	
	Pre	Post	Pre	Post
Off-ice Vertical Jump (cm)	47.6 ± 16.6	50.2 ± 16.9*	43.3 ± 5.7	42.2 ± 5.2
Standing Long Jump (cm)	151.0 ± 45.6	190.5 ± 46.9*	168.9 ± 31.8	161.8 ± 26.4
On-ice Flight Time (ms)	0.362 ± 0.066†	0.391 ± 0.056*†	0.368 ± 0.087‡	0.352 ± 0.085‡
Self-Evaluation (1-10)	5.4 ± 2.4†	7.2 ± 1.9†	5.7 ± 2.6‡	5.6 ± 2.0‡

*p < 0.05 (Significance within group, pre vs. post); † n=5; ‡ n=7

A secondary analysis was conducted with the removal of the subjects who did not train on-ice (n=2 in intervention and n=2 in control group). Manual inspection of individual data revealed that the two subjects in the intervention group improved all outcome measures, while the two subjects in the control group experienced decreases in all outcome measures. Following the same statistical procedures as above, the group x time interactions remained significant for off-ice vertical jump height (p = 0.028), off-ice standing long jump (p < 0.001), and on-ice flight time (p = 0.007).

The one male skater was recognized to be an outlier. Having removed this data from analysis, off-ice vertical jump height (p = 0.004) and off-ice standing long jump (p < 0.001) remained statistically significant, while on-ice flight time did not (p = 0.077).

DISCUSSION

The purpose of this study was to examine the effects of a six-week sport specific plyometric training program on jump performance in collegiate figure skaters. As was hypothesized, individuals who participated in the plyometric program significantly improved their on-ice flight time, off-ice vertical jump height, and off-ice standing long jump distance. There was no significance noted for on-ice self-reported jump evaluation.

Several figure skating professionals (14, 27, 28) have recommended the use of plyometric training in the sport, but this is the first study, to the researcher's knowledge, to evaluate the effects of plyometric training on jump performance in figure skaters. In addition to increasing power, plyometric training has the potential to improve the elastic component of the muscle-tendon complex, whole muscle and single fiber contractile performance, muscle hypertrophy, and muscle geometry (21). Neuromuscular adaptations to plyometrics include increases in motor unit recruitment, as well as changes in activation strategies or stretch-reflex excitability (21). Hewett et al. (10) discovered that plyometric training decreased landing forces and lowered hip abduction and adduction moments in female athletes. For figure skaters, changes that occur from off-ice plyometric training may also translate to on-ice jumping, thus improving on-ice muscle strategies and landing mechanics. As observed from the secondary analysis, plyometric training may have the potential to prevent detraining in skaters during the off-season, but these observations warrant further investigation.

On-ice jump performance is challenging to capture due to the three-dimensional and rotational components of jumps, not to mention the need for motion analysis systems compatible to an ice surface. Subjects in the training group only increased flight time by 0.029 seconds. While this would seem to be a relatively small improvement, an increase of a few hundredths of a second is sufficient time to gain 10 to 20 degrees of rotation, depending on the rotational velocity of the skater, according to King (14). Thus, this small improvement may mean the difference in success or failure when attempting higher revolution jumps. The naked eye may not be able to identify the change in flight time, but video analysis can capture this change, as demonstrated in the present study.

The plyometric training program utilized in this research was based on the six-week program developed by Hewett et al. (10), consisting of light to moderate exercises and a progression sufficient enough for subjects to become accustomed to plyometrics. This progression was adapted to figure skating to create the training program used in this study. The current plyometric program was also designed following recommendations from two meta-analyses (20, 30) that exclusively evaluated the effect of plyometric training on vertical jump height in adults. One major difference between the recommendations from the meta-analyses and the present study was related to intensity. Low to moderate intensity exercises were included in this plyometric training program to promote safe, low-impact landings, but high intensity exercises have previously produced the greatest gains in jump height (30). As hypothesized, the improvements in vertical jump height observed in the present study are consistent with the findings of previous studies, however, the plyometric training group in the present study did not increase vertical jump height (5.4%) as much as was observed (10%) by Hewett and researchers (10). The subjects in the study by Hewett et al. were adolescent volleyball players, while the subjects of the present study were college-aged skaters. Perhaps, younger individuals have enhanced adaptations to plyometric training. The smaller increase may also be explained by incorporating the horizontal and/or rotational components instead of focusing solely on vertical height. Based on the results of the meta-analysis by Saez-Saez de Villarreal and researchers (30), 10-week programs with two sessions per week produced the greatest effects in vertical jump height. The present study resulted in gains in both on-ice and off-ice outcomes after only six weeks. Markovic (20) identified that most of the studies lacking increased findings in vertical jump performance did not implement plyometrics for greater than eight weeks, however, several plyometric training programs that lasted less than eight weeks have produced mixed results of vertical jump height. Female collegiate dancers have increased their vertical jump height after six (5) and seven weeks (8) of plyometric training. Athletes of another aesthetic sport, rhythmic gymnastics, increased their vertical jump height by 16.2% after four weeks of plyometric exercises in the pool (12). On the contrary, six weeks of plyometric training did not result in significant increases in collegiate female athletes (6). Luebbers et al. (19) found that vertical jump increases were greater in their sample of college-aged men that participated in seven weeks of plyometric training versus their sample that only participated in a four-week program. In contrast to the recommendations, the program designed for the present study demonstrated that vertical jump height can be improved with a six-week plyometric training program with only two sessions per week consisting of low to moderate intensity exercises.

Off-ice standing long jump was also assessed, as figure skating jumps require horizontal movement. Few studies have evaluated standing long jump after plyometric training, which may be attributed to a majority of researchers placing focus on volleyball and basketball, sports that depend on vertical jumping. Michailidis et al. (23) assessed standing long jump distance after a 12-week plyometric training program in preadolescent male soccer players. The subjects who participated in the plyometric program, which consisted of low to moderate intensity exercises, increased standing long jump distance by 4.2% at post-testing. Another study (13), which assessed effects of plyometric training in prepubescent boys, resulted in no training effect on standing long jump. Researchers of both studies expected to see greater gains in standing long jump and accounted findings to the exclusion of long jumping exercises in the plyometric training program. In the present study, immense gains (26%) in standing long jump distance

were observed. This large increase was likely attributed to the inclusion of exercises that incorporated horizontal movement into the plyometric training program. Because figure skating jumps require horizontal propulsion, the implementation of horizontal plyometric exercises could promote sport-specific improvements.
The self-reported jump evaluation was created in an attempt to capture subjects' perceived improvements of their waltz jumps after the plyometric training program. The waltz jump is one of the first jumps introduced to beginner-level figure skaters. Many participants in this study represented middle to high levels of figure skating, having already mastered single and double revolution jumps, which are much more difficult than the waltz jump. They most likely mastered the waltz jump, a one-half revolution jump, early in their skating careers. Measuring on-ice outcomes during higher level jumps may be more appropriate for higher level skaters, and more detailed on-ice evaluation could be created to further examine subjective feedback of jumping performance.

Lastly, skating training alone for the six-week time frame was not enough to increase jump performance in collegiate figure skaters. Aleshinsky with fellow figure skating researchers and professionals (4) stressed the importance of off-ice strength and conditioning to maximize performance in the sport, and Poe et al. (26, 27, 28) has specifically recommended plyometric training for skaters. Unfortunately, many coaches and figure skaters disregard these recommendations and opt to spend numerous hours on the ice attempting jumps. It is a common belief among coaches that greater time spent on-ice produces better skaters. However, if skaters do not have the adequate power to master jumps off-ice, they may actually be wasting time practicing those jumps on-ice. Through the present study, plyometric training has been shown to improve on-ice and off-ice jump performance in collegiate figure skaters.

There are several limitations associated with this study in regards to small sample size and lack of randomization. Due to lack of randomization, we cannot be fully confident that group differences are attributable to the training program, rather than the different populations from which they are drawn. External validity is also limited as the skaters represented different levels of figure skating. Our results may not be generalizable to males since our sample only included one male participant. Future researchers should conduct randomized controlled trials with a larger sample of figure skaters for greater statistical power and homogeneity of age, gender, and experience. Lastly, additional biomechanical research is needed to enhance cost-effective analysis of on-ice jump performance, particularly using digital cameras with higher frame rates through which flight time can be more accurately measured.

In conclusion, the findings support the use of plyometric training programs to increase on-ice flight time, off-ice vertical jump height, and off-ice standing long jump. The plyometric exercises utilized were low to moderate intensity, time-efficient, and feasible in skating rinks. Video analysis, used to record flight time, was simple to use directly on the ice. The on-ice flight time results are presented with great enthusiasm, as this is the first study to evaluate a plyometric training intervention in figure skating. Therefore, coaches and figure skaters could benefit from implementing plyometric training when they desire to improve on-ice flight time, off-ice vertical jump height, and standing long jump distance.

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