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PHYSICAL AND PHYSIOLOGICAL CHARACTERISTICS OF FEMALE ARTISTIC ROLLER SKATERS BASED ON DISCIPLINE AND LEVEL OF EXPERTISE

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Abstract

Introduction. In artistic roller skating, athletes use shoes fitted with small wheels to be used in rinks. The sport consists of seven disciplines characterized by different physical demands. Roller skaters are judged on content and manner of performance, and this includes the skater's ability to do jumps, spins, and footwork. To date, no study has analyzed the different physical qualities in artistic roller skaters based on their skating discipline and skating level. Thus, the purpose of this study was to compare the body composition, flexibility, balance, reactive strength, maximal strength and aerobic capacity based on skating discipline and skating level. ***Material and methods.*** A total of 108 female athletes from the three individual disciplines (figures, freestyle, and solo dance) and three different levels (elite, sub-elite, and non-elite) volunteered to participate in this study. All subjects completed the sit-and-reach, front split, Y-Balance, countermovement jump, squat jump, drop jump, isometric mid-thigh pull and 20-metre multistage shuttle roller skate tests. Six multivariate analyses of variance were performed to identify differences between disciplines and levels. Statistical significance was set at $p < 0.05$. ***Results.*** The findings showed that freestyle skaters have less body fat, and higher levels of reactive and maximal strength than figure and solo dance skaters. Elite skaters demonstrate greater values of flexibility, balance, strength and aerobic capacity compared to their sub-elite and non-elite counterparts. ***Conclusions.*** The results of this study showed that there are differences between elite and non-elite athletes and between skating disciplines. Strength and conditioning professionals should take that into consideration when training these athletes.

Key words: body composition, strength, balance, flexibility, aerobic capacity, figure skating

Introduction

The sport of artistic roller skating is governed by the Fédération Internationale de Roller Sports (FIRS) and consists of seven disciplines: figures, freestyle (also called "free"), solo dance, pairs, couple dance (also called "dance"), show and precision. Figures, freestyle and solo dance are individual disciplines, pairs and couple dance are pairs disciplines, and show and precision are considered group disciplines.

Figures is a discipline for both sexes where athletes must perform circles drawn on the ground which the skater, from a stationary position, travels only on one foot, making figures according to a pre-defined plan that represents the specific difficulties of this discipline. Like in ice skating, freestyle programs are performed with a choreography appropriate to the music, during which athletes have to perform several jumps and spins combined with harmonious gestures. In the solo dance competition, athletes perform various elements such as dance, turns and footwork sequences. These individual skills become increasingly difficult in competitive skating as, for example, freestyle skaters must be able to consistently perform jumps with three rotations in the air [1] and, at the same time, these athletes need to have high levels of aerobic and anaerobic endurance [2]. As the elements of the sport get more demanding, the injury risk also gets higher. Freestyle, dance and pairs skaters are amongst those who have multiple injuries, especially in lower limb joints, such as ankles and hips, during their careers [3]. Not only can these differences be observed between disciplines but also between levels of expertise [3]. These disparities between levels of expertise and disciplines/positions can drive professionals to build more specific injury prevention and strength and conditioning programs. Similar studies have already been done in other sports such as football [4] and basketball [5], with the authors observing differences in strength, power, speed and agility between playing positions and levels of expertise.

Three studies examined the anthropometric profile of different genders of elite artistic roller skaters [1, 6, 7] and one study examined aerobic capacity of young female elite artistic roller skaters [2]. However, there is still no data on other physical qualities such as maximal strength, reactive strength, rate of force development, balance and flexibility. Also, there is no comparison between disciplines and levels of expertise.

Consequently, the purpose of this study was to compare the body composition, flexibility, balance, reactive strength, maximal strength and aerobic capacity performance based on an individual skating discipline and skating level.

Material and methods

Experimental Approach to the Problem

A descriptive, cross-sectional study was used to compare performance measures in female artistic roller skaters based on their skating discipline and skating level. The independent variables in this study were skating discipline (figures, freestyle and solo dance) and skating level (elite, sub-elite and non-elite). The dependent variables included body composition, flexi-

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bility, balance, reactive strength, maximal strength and aerobic capacity. Skating level in this study was defined based on the current levels by discipline of Portuguese Skating Federation. Thus, skating levels are categorized from the highest to the lowest competitive level: (1) elite; (2) sub-elite (level V or IV); and (3) non-elite (level III, II or I). To reach elite level, the athlete had to represent the national team on at least one occasion in the past two seasons, or the athlete had to have at least one appearance in the national championship in the past two seasons. According to the Portuguese Skating Federation, level IV athletes compete with each other to see who goes to the national championship. For this reason, athletes at this level who do not qualify for the national championship are classified as sub-elite.

Subjects

A total of 108 athletes (age, 15.5 ± 3.0 years; body weight, 52.0 ± 10.2 kg; body height, 156.8 ± 7.3 cm) from 7 different Portuguese clubs volunteered to participate in this study. The subjects, with the help of their coaches, self-reported their skating discipline (figures, freestyle or solo dance). The athletes' maturation was not analyzed. All the subjects and their parents or guardians were informed about the possible risks of the investigation before giving written informed consent to participate. All procedures were approved by the ethics committee of the University of Lisbon, Faculty of Human Kinetics, and were conducted in accordance with the declaration of Helsinki for human studies of the World Medical Association [8].

Procedures

The subjects took part in a single testing session wearing athletic shoes and comfortable clothing. The fundamental principle when sequencing various tests is that one test should not affect the performance of the next one so tests that might produce fatigue should be the last ones to be administered and vice-versa [9]. With this is mind, the sequence of the tests was as follows: (1) anthropometrics and body composition tests (i.e., body height, body mass, leg length, body skinfolds and body circumferences); (2) flexibility tests (i.e., sit-and-reach and front split); (3) balance test (i.e., Y-Balance); (4) reactive strength tests (i.e., countermovement jump (CMJ), squat jump (SJ) and drop jump from 15 cm (DJ15) and 35 cm (DJ35); (5) maximal strength, rate of force development (RFD) and impulse (IMP) test (i.e., isometric mid-thigh pull (IMTP)) and; (6) aerobic capacity test (i.e., 20-metre multistage shuttle roller skate).

After the anthropometrics and body composition tests, the athletes completed seven dynamic active stretching exercises: straight leg march, butt kicks, carioca, high knees, reverse lunge with twist, power shuffle (step slide) and jogging with squats. Due to the negative acute effects of static stretching on performance [10], after the front split test, the athletes performed a more specific warm-up of five exercises to better prepare for the remaining session: easy skip with arm swings, skip for distance using arms to drive forward, skip for height using arms to drive upward, backward run and lateral low shuffle.

The evaluators were certified by the NSCA, as these were the guidelines that were followed. All the subjects had 5-10 minutes to familiarize with all testing procedures where the assessors explained the common faults of each test and the correct way to execute each one.

Anthropometrics and body composition tests

The subjects were barefoot for all measurements. For body mass, a calibrated scale (BC-731, Tanita, Japan) was used, while for body height, a stadiometer (SECA 213, China) was applied. Leg length was measured with a measuring tape and it was defined as the distance from the anterior superior iliac spine (ASIS) to the medial malleolus of the skater's right leg [11]. Body skinfolds (i.e., front thigh, triceps, subscapular and abdominal) and body circumferences (i.e., waist and hip) were measured accordingly with the NSCA guidelines [9]. Body skinfolds were measured with a skinfold caliper (Classic, XFit, Portugal), while body circumferences were measured with a measuring tape (SECA 201, China). Moreover, several other variables were derived: a) body mass index (BMI) was calculated as weight (kg) divided by height in squared meters (m^2); b) fat-free mass (FFM) was calculated according to the method already described elsewhere [12]; c) body fat (BF) was calculated as weight (kg) minus FFM (kg); d) waist-to-hip ratio (WHP) was calculated as waist circumference (cm) divided by hip circumference (cm).

Flexibility tests

The subjects were barefoot for all measurements. The sit--and-reach test was administered in a box that had a slide ruler attached to the top. Keeping the knees locked, the participants kept the bare feet against the box and then pushed the slide as far as possible. This final position was held for 2 seconds. Previous researchers noted good reliability for the sit-and-reach assessment [13]. The result was normalized by leg length in cm. The front split was completed next to a 2-meter tape measure secured to the floor. The subject lowered into a full-split position with one leg forward and the other leg behind and externally rotated. Total distance from the front leg lateral malleolus to the rear leg (opposite leg) lateral malleolus was measured using the tape measure on the floor. The result was normalized by leg length in cm.

Balance test

The Y-Balance Test (YBT) was completed on a commercially available device (Functional Movement Systems, Inc., Chatham, VA) which has good to excellent intrarater reliability [14]. Two methods of defining performance were included (i.e., normalized reach distance and composite score) to ensure differences between disciplines and levels are well identified. The composite score for all three average reach distances (anterior, posteromedial and posterolateral) was calculated using the equation already applied elsewhere [11]. The test was conducted according to the procedures already published before [15].

Reactive strength tests

Two trials were recorded for each jump (i.e., CMJ, SJ, DJ15, and DJ35) using free software, open hardware equipment (Chronojump Boscosystem, Barcelona, Spain) with a minimum of 60-second rest between trials. In line with previous research, all the subjects were instructed to perform maximal effort jumps with hands remaining on hips throughout to limit the influence of the upper body on jump performance [16]. For SJ, the subjects were instructed to remain still in the squat position for 3 seconds and not to perform any countermovement before jumping. The variables measured for these jumps analyses were jump height from 15 cm (JH15) and 35 cm (JH35), eccentric utilization ratio (EUR) (i.e., the ratio between CMJ and SJ jumping height), contact time from 15 cm (CT15) and 35 cm (CT35), and reactive strength index from 15 cm (RSI15) and 35 cm (RSI35), calculated as JH, in meters, divided by CT, in seconds. Acceptable reliability had previously been reported for these types of tests [17] and for this specific contact platform [18].

Table 1. Within-session reliability (intraclass correlation coefficients [ICC] and coefficients of variation [CoV]) obtained from all trials of the physical performance tests.

	Sit and reach	Front split	CMJ	SJ	DJ15	DJ35	IMTP
ICC (95% CI)	0.99 (0.93-0.99)	0.99 (0.86-0.99)	0.98 (0.94-0.99)	0.97 (0.91-0.99)	0.89 (0.67-0.96)	0.93 (0.67-0.98)	0.98 (0.93-0.99)
CoV (%)	0.83	1.51	1.89	2.91	4.10	6.33	5.45

CI = confidence interval; CMJ = countermovement jump; SJ = squat jump; DJ15 = drop jump from 15 cm; DJ35 = drop jump from 35 cm; IMTP = isometric mid-thigh pull

Maximal strength test

For the IMTP test, in line with previous research, the subjects were positioned with feet hip width apart, the bar was positioned at midthigh, the torso upright with neutral spine, and knee and hip angles near 140° [19]. After familiarization, 2 maximal effort trials were recorded from each subject with a minimum of 90-second rest between each trial to ensure sufficient recovery. Each trial was collected for 8 seconds, which included a 3-second countdown and the subjects pulling on the bar for 5 seconds. An isoinertial dynamometer that consists of a cable extension linear position transducer (Chronojump Boscosystem, Barcelona, Spain), with a sampling rate of 80 Hz, attached to the barbell interfaced with a personal computer was used. Peak force (PF), relative peak force (RPF), calculated as PF divided by FFM, peak RFD (PRFD) and IMP were reported.

Aerobic capacity test

For the 20-metre multistage shuttle roller skate test, the participants were required to skate between two lines, 20 m apart, with the same protocol described elsewhere [20]. The subjects started skating at 8.5 km · h^{-1} and increased their speed by 0.5 km · h^{-1} each minute. Speed was dictated by an audio signal from a computer using software developed for this purpose. Before the test, all the subjects performed 5 minutes of skating on the test track at 7.5 km · h^{-1}. The results were expressed as the number of laps completed, speed (km/h) of the last stage completed and total time from the start to the point of volitional exhaustion or disqualification.

Statistical Procedures

Statistical analyses were performed using the Statistical Package for Social Science (V. 27.0, SPSS Inc., Chicago, IL). Intraclass correlation coefficients (ICCs) were conducted to determine the reliability of reactive strength, change of direction and sprint testing methods within sessions. Interpretation of these values was conducted using Portney and Watkins [21] ranges, whereby values of > 0.75 indicate good reliability, values ranging from 0.5 to 0.75 imply moderate reliability and values < 0.5 suggest poor reliability. Variability in the data was assessed via the calculation of coefficients of variation (CoVs); this analysis of absolute reliability provides information regarding within-trial variability expressed as a percentage. Descriptive statistics are shown as means ± standard deviations unless stated otherwise. Six multivariate analyses of variance were performed on groupings of dependent variables (body composition, flexibility, balance, reactive strength, maximal strength and aerobic capacity) to investigate differences between skating discipline and skating level. Post hoc testing was accomplished using Tukey's test. Mean differences (MDs) and magnitudes of the standardized effects were calculated for all significant differences using Cohen's d with associated 95% confidence intervals (CI) and interpreted using thresholds of 0.2, 0.5, 0.8 for small, moderate and large, respectively [22]. An effect size (ES) of ± 0.2 was considered the smallest worthwhile effect with an effect size of < 0.2 considered to be trivial. The effect was deemed unclear if its 95% confidence interval overlapped the thresholds for small positive and negative effects. Effect size is independent of sample size and since many subgroups are heterogenous, the authors decided to report it. Statistical significance was set at $p < 0.05$ for all analyses.

Results

All within-session measures of reliability are reported in table 1. All parameters demonstrated good within-session reliability, ranging from 0.89-0.99 for all the variables. Of all tests, DJ35 demonstrated the greatest variability within trials (CoV = 6.33).

There were significant differences in age and BMI based on skating discipline. Freestyle skaters were younger than figure skaters (MD = -2.42 years [CI: -4.08, -0.76]; p = 0.002, d = 0.84 large [CI: -1.48, -0.20]) and had a lower BMI compared with solo dance skaters (MD = -1.78 kg/m^2 [CI: -3.41, -0.15]; p = 0.029, d = 0.63 moderate [CI: -1.25, -0.01]). There were no significant differences between skating levels for age, body height, body weight, BMI and leg length. All demographic data are presented in table 2.

Table 2. Participant demographics by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	N	Age (y)	Body height (cm)	Body weight (kg)	BMI (kg/m^2)	Leg length (cm)
Figures	26	17.1 ± 3.1†	159.0 ± 6.4	55.0 ± 10.1	21.6 ± 3.3	76.6 ± 3.1
Non-Elite	10	15.2 ± 2.5	156.4 ± 6.0	55.2 ± 12.3	22.4 ± 4.1	75.1 ± 3.2
Sub-Elite	7	18.4 ± 3.8	156.9 ± 5.1	55.2 ± 13.4	22.2 ± 3.8	78.5 ± 4.0
Elite	9	18.2 ± 2.2	163.6 ± 5.6	54.5 ± 3.8	20.4 ± 1.1	76.8 ± 1.3
Freestyle	51	14.7 ± 2.8	156.0 ± 8.2	49.4 ± 10.8	20.1 ± 3.0	77.0 ± 5.1
Non-Elite	17	13.3 ± 1.5	153.4 ± 7.2	46.3 ± 10.2	19.5 ± 3.3	76.9 ± 6.2
Sub-Elite	21	14.1 ± 1.9	156.8 ± 9.3	49.0 ± 11.3	19.7 ± 2.9	77.0 ± 4.9
Elite	13	17.4 ± 3.5	158.0 ± 7.4	54.4 ± 9.8	21.6 ± 2.6	77.1 ± 4.2
Solo Dance	31	15.7 ± 3.0	156.4 ± 6.3	53.7 ± 8.2	21.9 ± 2.7†	76.9 ± 3.3
Non-Elite	9	13.4 ± 1.1	153.4 ± 7.2	50.8 ± 8.5	21.4 ± 2.2	76.5 ± 3.3
Sub-Elite	11	16.1 ± 2.6	157.9 ± 4.7	55.4 ± 9.5	22.2 ± 3.4	76.6 ± 4.1
Elite	10	17.2 ± 3.5	157.3 ± 6.9	54.4 ± 6.0	22.0 ± 2.5	77.7 ± 2.4

BMI = body mass index. † Signals represent significant differences from freestyle discipline ($p < 0.05$).

Body Composition

There were significant differences in some body skinfolds and BF between disciplines. Freestyle skaters had a lower subscapular skinfold compared with figure skaters (MD = -2.24 mm [CI: -4.29, -0.18]; p = 0.029, d = 0.61 moderate [CI: -1.42, 0.19]) and solo dance skaters (MD = -2.19 mm [CI: -4.13, -0.25]; p = 0.023, d = 0.59 moderate [CI: -1.36, 0.19]). Freestyle skaters

also had a lower triceps skinfold compared with figure skaters (MD = -3.59 mm [CI: -6.12, -1.06]; p = 0.003, d = 0.82 large [CI: -1.80, 0.17]) and solo dance skaters (MD = -3.07 mm [CI: -5.47, -0.68]; p = 0.008, d = 0.68 moderate [CI: -1.67, 0.31]) and a lower front thigh skinfold compared with figure skaters (MD = -4.27 mm [CI: -7.09, -1.44]; p = 0.001, d = 0.83 large [CI: -1.96, 0.31]) and solo dance skaters (MD = -4.41 mm [CI: -7.07, -1.74]; p < 0.001, d = 0.88 large [CI: -1.96, 0.20]). Freestyle skaters had less body fat than figure skaters (MD = -2.28 kg [CI: -4.12, -0.43]; p = 0.011, d = 0.69 moderate [CI: -1.44, 0.07]) and solo dance skaters (MD = -2.14 kg [CI: -3.89, -0.40]; p = 0.012, d = 0.67 moderate [CI: -1.35, 0.02]). There were no significant differences in body circumferences and FFM between disciplines. Differences were found between elite and non-elite figure skaters for subscapular (MD = -3.91 mm [CI: -7.52, -0.30]; p = 0.032, d = 1.16 large [CI: -2.67,-0.35]) and abdominal skinfolds (MD = -6.42 mm [CI: -10.32, -2.52]; p = 0.001, d = 1.78 large [CI: -3.40, -0.16]) and between elite and sub-elite figure skaters for WHR (MD = -0.06 [CI: -0.11, -0.01]; p = 0.011, d = 1.87 large [CI: -1.89, -1.85]). Elite freestyle skaters had higher levels of FFM (MD = 8.74 kg [CI: 2.11, 15.36]; p = 0.007, d = 1.02 large [CI: -1.32, 3.37]) and a higher hip circumference (MD = 7.69 cm [CI: 0.91, 14.48]; p = 0.023, d = 0.90 large [CI: -1.77, 3.57]) compared to their non-elite counterparts. There were no significant differences regarding body composition between solo dance levels. All body composition data are presented in table 3.

Flexibility

There were no significant differences between disciplines in sit-and-reach and front split on the right and left leg. Elite figure skaters had significantly better results in sit-and-reach (MD = 0.11 [CI: 0.09, 0.21]; p = 0.030, d = 1.32 large [CI: 1.26, 1.36]) and in front split on the right leg (MD = 0.12 [CI: 0.00, 0.25]; p = 0.046, d = 1.23 large [CI: 1.18, 1.27]) than sub-elite figure skaters. All flexibility data are presented in table 4.

Table 4. Flexibility performance by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	Sit-and-reach (cm/leg length)	Front split – right leg (cm/leg length)	Front split – left leg (cm/leg length)
Figures	0.53 ± 0.09	1.98 ± 0.11	1.98 ± 0.10
Non-Elite	0.53 ± 0.06	1.95 ± 0.09	1.96 ± 0.08
Sub-Elite	0.47 ± 0.05*	1.92 ± 0.08*	1.93 ± 0.09
Elite	0.58 ± 0.11	2.04 ± 0.12	2.03 ± 0.12
Freestyle	0.52 ± 0.09	2.02 ± 0.15	2.02 ± 0.12
Non-Elite	0.51 ± 0.09	2.00 ± 0.18	2.00 ± 0.15
Sub-Elite	0.52 ± 0.08	2.01 ± 0.15	2.01 ± 0.13
Elite	0.55 ± 0.09	2.06 ± 0.09	2.06 ± 0.07
Solo Dance	0.55 ± 0.09	2.02 ± 0.11	2.05 ± 0.12
Non-Elite	0.51 ± 0.05	2.00 ± 0.09	2.06 ± 0.11
Sub-Elite	0.58 ± 0.09	2.05 ± 0.08	2.06 ± 0.08
Elite	0.55 ± 0.10	2.00 ± 0.16	2.02 ± 0.16

* – signals represent significant differences from elite level (p < 0.05).

Balance

Freestyle skaters performed better on the posterolateral reach for the right leg (MD = 6.90% [CI: 0.69, 13.11] p = 0.026, d = 0.70 moderate [CI: -1.51, 2.91]) and had a higher composite score for the same leg (MD = 5.13% [CI: 0.11, 10.14]; p = 0.044, d = 0.61 moderate [CI: -1.26, 2.48]) than athletes from the figures discipline. Elite figure skaters had better results in the anterior reach distance compared with their sub-elite counterparts for the left leg (MD = 8.64% [CI: 0.70, 16.58]; p = 0.031, d = 2.90 large [CI: 1.44, 4.36]). There were no significant differences between freestyle and solo dance skating levels. The YBT data are presented in Table 5.

Reactive Strength

Freestyle skaters jumped higher during DJ15 than solo dance skaters (MD = 3.23 cm [CI: 0.59, 5.86]; p = 0.012, d = 0.65 mod-

Table 3. Body composition variables by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	Body skinfolds (mm)				FFM (kg)	BF (kg)	Body circumferences (cm)		WHR
	SUB	TRI	ABD	THI			Waist	Hip	
Figures	10.9 ± 3.5†	19.0 ± 3.7†	11.6 ± 4.4	24.9 ± 4.6†	45.3 ± 7.2	9.7 ± 3.2†	69.1 ± 7.7	90.8 ± 7.0	0.76 ± 0.05
Non-Elite	12.8 ± 4.7‡	20.0 ± 4.7	15.2 ± 5.0‡	25.5 ± 6.0	44.7 ± 8.6	10.5 ± 4.1	70.1 ± 7.3	91.4 ± 9.1	0.77 ± 0.03
Sub-Elite	10.7 ± 1.6	19.4 ± 1.5	10.1 ± 1.7	25.1 ± 4.6	45.7 ± 9.8	9.5 ± 3.7	71.0 ± 12.1	88.8 ± 7.7	0.80 ± 0.06‡
Elite	8.9 ± 1.4	17.6 ± 3.6	8.8 ± 1.6	24.1 ± 2.9	45.6 ± 2.8	8.9 ± 1.2	66.6 ± 1.9	91.8 ± 3.2	0.73 ± 0.01
Freestyle	8.7 ± 3.7	15.4 ± 4.8	10.1 ± 4.6	20.7 ± 5.4	42.1 ± 7.8	7.4 ± 3.5	66.6 ± 6.8	86.9 ± 8.6	0.77 ± 0.04
Non-Elite	9.2 ± 5.0	15.9 ± 5.9	11.4 ± 5.7	20.9 ± 6.6	39.2 ± 6.6‡	7.1 ± 4.1	65.9 ± 6.9	84.1 ± 7.8‡	0.78 ± 0.03
Sub-Elite	8.5 ± 3.3	14.6 ± 4.7	10.1 ± 4.5	19.3 ± 4.7	42.0 ± 8.4	7.0 ± 3.4	66.1 ± 6.4	86.7 ± 9.2	0.76 ± 0.04
Elite	8.2 ± 2.1	16.0 ± 3.6	8.5 ± 2.3	22.5 ± 4.2	45.9 ± 7.0	8.5 ± 3.0	68.4 ± 7.6	90.8 ± 7.6	0.75 ± 0.05
Solo Dance	10.8 ± 3.5†	18.5 ± 4.3†	12.0 ± 3.8	25.1 ± 4.4†	44.2 ± 5.9	9.5 ± 2.6†	68.7 ± 5.1	90.9 ± 7.0	0.76 ± 0.03
Non-Elite	10.1 ± 2.3	18.3 ± 4.5	12.7 ± 4.2	22.6 ± 4.3	42.3 ± 5.7	8.5 ± 3.0	68.2 ± 4.4	88.0 ± 7.2	0.78 ± 0.02
Sub-Elite	12.2 ± 4.7	18.8 ± 4.4	13.3 ± 4.1	26.7 ± 4.8	44.9 ± 7.0	10.4 ± 2.9	70.1 ± 7.0	92.3 ± 7.1	0.76 ± 0.03
Elite	9.9 ± 2.0	18.2 ± 4.2	9.9 ± 1.8	25.4 ± 3.1	45.0 ± 4.7	9.3 ± 1.4	67.4 ± 2.2	91.9 ± 6.5	0.74 ± 0.04

SUB = subscapular; TRI = triceps; ABD = abdominal; THI = thigh; FFM = fat-free mass; BF = body fat; WHR = waist to hip ratio. † Signals represent significant differences from freestyle discipline (p < 0.05). ‡ Signals represent significant differences from elite level (p < 0.05).

Table 5. Y-Balance performance by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	Normalized reach distance (%)						Composite score (%)	
	Right leg			Left leg			Right leg	Left leg
	Anterior	Posteromedial	Posterolateral	Anterior	Posteromedial	Posterolateral		
Figures	70.38 ± 7.16	109.46 ± 7.90	107.55 ± 8.58*	68.76 ± 7.01	112.09 ± 8.51	109.84 ± 9.80	95.80 ± 6.13*	96.90 ± 6.83
Non-Elite	68.62 ± 7.29	107.27 ± 8.63	107.52 ± 13.31	67.53 ± 9.23	109.03 ± 9.96	109.64 ± 12.58	94.47 ± 7.57	95.40 ± 8.31
Sub-Elite	66.97 ± 4.41	110.30 ± 0.11	107.98 ± 3.80	64.67 ± 2.33†	112.75 ± 5.03	107.15 ± 2.85	95.08 ± 2.49	94.86 ± 3.09
Elite	74.98 ± 6.91	111.23 ± 10.06	107.26 ± 4.42	73.31 ± 3.70	114.97 ± 8.64	112.15 ± 10.18	97.83 ± 6.40	100.14 ± 6.53
Freestyle	73.06 ± 8.05	115.25 ± 13.02	114.45 ± 10.65	71.76 ± 7.54	118.53 ± 12.54	114.53 ± 12.34	100.92 ± 9.46	101.61 ± 9.60
Non-Elite	70.85 ± 9.11	113.97 ± 12.34	113.36 ± 11.05	69.48 ± 6.29	116.64 ± 11.42	113.19 ± 13.91	99.39 ± 9.34	99.77 ± 9.20
Sub-Elite	75.71 ± 7.46	116.13 ± 12.87	115.53 ± 10.29	74.28 ± 7.63	119.11 ± 11.32	115.07 ± 11.10	102.46 ± 8.75	102.82 ± 8.51
Elite	71.66 ± 6.73	115.52 ± 14.97	114.15 ± 11.40	70.69 ± 8.22	120.07 ± 16.12	115.42 ± 12.95	100.44 ± 10.30	102.06 ± 11.96
Solo Dance	69.64 ± 6.59	110.26 ± 12.50	109.12 ± 12.69	69.62 ± 6.39	113.63 ± 13.13	110.58 ± 12.71	96.34 ± 9.37	97.95 ± 9.63
Non-Elite	70.19 ± 6.31	108.48 ± 17.47	107.42 ± 10.95	70.34 ± 5.35	112.56 ± 12.65	110.84 ± 10.44	95.36 ± 11.39	97.91 ± 8.86
Sub-Elite	67.36 ± 5.46	110.13 ± 8.39	110.05 ± 12.58	68.09 ± 8.16	113.06 ± 10.64	109.82 ± 11.59	95.85 ± 7.40	96.99 ± 8.72
Elite	71.87 ± 7.76	112.01 ± 12.54	109.52 ± 15.25	70.82 ± 4.91	115.29 ± 17.01	111.27 ± 16.63	97.80 ± 10.35	99.12 ± 11.99

* – Signals represent significant differences from freestyle discipline ($p < 0.05$). † – Signals represent significant differences from elite level ($p < 0.05$).

erate [CI: -0.44, 1.73]) and they had a lower value for CT15 (MD = –0.06 s [CI: -0.09, -0.02]; $p < 0.001$, d = 1.01 large [CI: -1.03, -1.00]) and CT35 (MD = -0.05 s [CI: -0.08, -0.01]; $p = 0.003$, d = 0.76 moderate [CI: -0.77, -0.75]) compared with figure skaters. Freestyle skaters had a higher RSI15 than figure skaters (MD = 0.23 m/s [CI: 0.05, 0.41]; $p = 0.009$, d = 0.72 moderate [CI: 0.65, 0.79]) and solo dance skaters (MD = 0.25 m/s [CI: 0.08, 0.42]; $p = 0.002$, d = 0.84 large [CI: 0.78, 0.91]). The only significant difference between figure skating levels was in JH15, where elite athletes jumped higher than non-elite athletes (MD = 5.06 cm [CI: 0.91, 9.20]; $p = 0.015$, d = 1.40 large [CI: -0.37, 3.17]). Solo dance elite skaters jumped higher than their non-elite counterparts in SJ (MD = 4.60 cm [CI: 0.75, 8.45]; $p = 0.017$, d = 1.64 large [CI: 0.37, 2.90]), JH15 (MD = 9.77 cm [CI: 5.45, 14.08]; $p < 0.001$, d = 2.42 large [CI: 0.61, 4.24]), and JH35 (MD = 6.10 cm [CI: 2.51, 9.69]; $p = 0.001$, d = 2.03 large [CI: 0.68, 3.38]). Both elite (MD = 0.32 m/s [CI: 0.03, 0.61]; $p = 0.028$, d = 1.60 large [CI: 1.51, 1.69]) and sub-elite (MD = 0.28 m/s [CI: 0.00, 0.55]; $p = 0.048$, d = 1.15 large [CI: 1.04, 1.26]) solo dance skaters had higher RSI15 values than non-elite solo dance skaters. Non-elite solo dance skaters, on the other hand, had higher EUR values than sub-elite (MD = 0.25 [CI: 0.07, 0.42]; $p = 0.004$, d = 1.41 large [CI: 1.33, 1.48]) and elite (MD = 0.24 [CI: 0.06, 0.42]; $p = 0.009$, d = 1.29 large [CI: 1.21, 1.38]) solo dance skaters. Freestyle elite skaters jumped higher than their sub-elite counterparts in SJ (MD = 3.74 cm [CI: 0.32, 7.17]; $p = 0.029$, d = 0.87

Table 6. Reactive strength performance by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	CMJ (cm)	SJ (cm)	EUR	DJ15			DJ35		
				JH15 (cm)	CT15 (s)	RSI15 (m/s)	JH35 (cm)	CT35 (s)	RSI35 (m/s)
Figures	26.62 ± 4.47	23.86 ± 4.29	1.12 ± 0.07	24.03 ± 4.16	0.29 ± 0.06†	0.89 ± 0.31†	23.88 ± 4.49	0.27 ± 0.06†	0.94 ± 0.37
Non-Elite	24.34 ± 2.69	21.89 ± 2.69	1.11 ± 0.06	21.22 ± 2.68‡	0.28 ± 0.07	0.80 ± 0.23	21.66 ± 2.84	0.28 ± 0.07	0.85 ± 0.34
Sub-Elite	27.32 ± 6.81	23.98 ± 6.00	1.14 ± 0.08	25.16 ± 3.38	0.29 ± 0.06	0.93 ± 0.42	24.19 ± 5.42	0.29 ± 0.05	0.91 ± 0.48
Elite	28.61 ± 2.56	25.96 ± 3.55	1.11 ± 0.08	26.27 ± 4.55	0.29 ± 0.05	0.95 ± 0.31	26.11 ± 4.49	0.26 ± 0.06	1.05 ± 0.32
Freestyle	27.94 ± 4.83	25.31 ± 4.29	1.11 ± 0.11	24.37 ± 4.80	0.23 ± 0.06	1.12 ± 0.33	24.36 ± 4.30	0.23 ± 0.05	1.14 ± 0.37
Non-Elite	26.52 ± 4.59	24.13 ± 2.97‡	1.10 ± 0.08	23.30 ± 4.74	0.24 ± 0.08	1.03 ± 0.28	22.61 ± 3.35‡	0.24 ± 0.06	1.01 ± 0.32
Sub-Elite	27.54 ± 4.20	24.47 ± 3.79	1.13 ± 0.10	23.83 ± 4.95	0.23 ± 0.05	1.10 ± 0.36	23.51 ± 3.70	0.22 ± 0.05	1.13 ± 0.35
Elite	30.46 ± 5.44	28.21 ± 5.36	1.09 ± 0.14	26.64 ± 4.19	0.22 ± 0.05	1.25 ± 0.33	28.03 ± 4.36	0.22 ± 0.05	1.32 ± 0.41
Solo Dance	27.05 ± 3.40	23.42 ± 3.77	1.17 ± 0.19	21.14 ± 5.49†	0.25 ± 0.06	0.86 ± 0.28†	22.40 ± 3.94	0.25 ± 0.06	0.96 ± 0.34
Non-Elite	27.27 ± 3.37	20.69 ± 3.13‡	1.35 ± 0.27‡	15.00 ± 5.33‡	0.23 ± 0.02	0.65 ± 0.19‡	18.72 ± 2.87‡	0.27 ± 0.05	0.73 ± 0.21
Sub-Elite	26.18 ± 4.22	23.92 ± 3.95	1.10 ± 0.07§	22.73 ± 2.93	0.26 ± 0.07	0.93 ± 0.30§	23.16 ± 3.14	0.25 ± 0.08	1.06 ± 0.41
Elite	27.89 ± 2.19	25.29 ± 2.83	1.11 ± 0.09	24.77 ± 3.01	0.27 ± 0.06	0.97 ± 0.23	24.81 ± 3.42	0.24 ± 0.05	1.07 ± 0.23

CMJ = countermovement jump; SJ = squat jump; EUR = eccentric utilization ratio; DJ15 = drop jump from 15 cm; JH15 = jump height from 15 cm; CT15 = contact time from 15 cm; RSI15 = reactive strength index from 15 cm; DJ35 = drop jump from 35 cm; JH35 = jump height from 35 cm; CT35 = contact time from 35 cm; RSI35 = reactive strength index from 35 cm. † – Signals represent significant differences from freestyle discipline ($p < 0.05$). ‡ – Signals represent significant differences from elite level ($p < 0.05$). § – Signals represent significant differences from non-elite level ($p < 0.05$).

large [CI: -0.58, 2.32]) and in JH35 (MD = 4.52 cm [CI: 1.30, 7.73]; p = 0.004, d = 1.18 large [CI: -0.12, 2.47]). Freestyle elite skaters also jumped higher in SJ (MD = 4.08 cm [CI: 0.50, 7.66]; p = 0.022, d = 1.01 large [CI: -0.43, 2.45]) and in JH35 (MD = 5.42 cm [CI: 2.06, 8.77]; p = 0.001, d = 1.47 large [CI: 0.15, 2.79]) than freestyle non-elite skaters. There were no significant differences in CMJ between skating disciplines and skating levels. The reactive strength data are presented in table 6.

Maximal Strength

Freestyle skaters had higher levels of RPF compared to figure skaters (MD = 1.89 N/kg [CI: 0.17, 3.61]; p = 0.028, d = 0.61 moderate [CI: -0.07, 1.30]). Elite freestyle skaters had higher IMP values compared with non-elite freestyle skaters (MD = 778.28 N·s [CI: 42.74, 1513.81]; p = 0.036, d = 1.14 large [CI: -243.40, 245.68]). Elite solo dance skaters also had higher IMP values compared with their non-elite counterparts (MD = 760.01 N·s [CI: 29.33, 1490.70]; p = 0.040, d = 1.52 large [CI: -223.85, 226.88]). There were no significant differences in RFD between skating disciplines and skating levels. All data are in table 7.

Aerobic Capacity

There were significant differences between elite and non-elite freestyle skaters in the number of laps (MD = 12.26 [CI: 1.16, 23.36]; p = 0.027, d = 1.00 large [CI: -3.38, 5.38]), speed of the last stage completed (MD = 0.61 km/h [CI: 0.09, 1.13]; p = 0.019, d = 1.05 large [CI: 0.85, 1.26]), and total time on the test (MD = 1.20 min [CI: 0.11, 2.28]; p = 0.027, d = 1.01 large [CI: 0.58, 1.43]). There were no significant differences between disciplines and between figure and solo dance skating levels. The aerobic capacity data are presented in table 8.

Table 8. The 20-metre multistage shuttle roller skate test performance by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	Laps	Speed (km/h)	Time (min)
Figures	63.58 ± 17.58	11.90 ± 0.84	7.67 ± 1.66
Non-Elite	61.50 ± 20.97	11.70 ± 1.03	7.32 ± 2.17
Sub-Elite	65.43 ± 7.46	12.07 ± 0.19	7.79 ± 0.73
Elite	64.44 ± 20.51	12.00 ± 0.94	7.97 ± 1.64
Freestyle	71.41 ± 13.09	12.23 ± 0.62	8.36 ± 1.28
Non-Elite	66.35 ± 12.85*	11.97 ± 0.62*	7.86 ± 1.27*
Sub-Elite	71.05 ± 12.15	12.21 ± 0.56	8.33 ± 1.19
Elite	78.62 ± 12.43	12.58 ± 0.57	9.06 ± 1.18
Solo Dance	71.84 ± 17.05	12.19 ± 0.83	8.41 ± 1.67
Non-Elite	70.67 ± 8.85	12.11 ± 0.42	8.30 ± 0.86
Sub-Elite	66.25 ± 19.34	11.92 ± 0.97	7.81 ± 2.00
Elite	79.60 ± 18.24	12.60 ± 0.84	9.23 ± 1.56

* – signals represent significant differences from elite level (p < 0.05).

Discussion

The purpose of this study was to assess physical differences between individual skating disciplines and skating levels of female artistic roller skating athletes. The findings showed that freestyle skaters have less body fat and higher levels of reactive and maximal strength than figure and solo dance skaters. Elite skaters demonstrate greater values of flexibility, balance, strength and aerobic capacity compared to their sub-elite and non-elite counterparts.

Freestyle female skaters tend to have lower values of body skinfolds and BF compared with female figure and solo dance skaters. Athletes with lower BF [23] and lower values of skinfold thickness [24] have a higher vertical jump. This might be explained by the fact that heavier athletes need to produce more work, compared with lighter athletes, to move their bodies to achieve the same displacement of the jump [25]. Since freestyle skaters are the only ones that require to jump during their routines, this outcome was expected. Nevertheless, regardless of discipline, artistic female roller skaters tend to have low levels of BF and body skinfolds. This is because artistic merit is a component of scores in roller skating and this factor is greatly influenced by the athletes' physical characteristics, showing

Table 7. Isometric mid-thigh pull performance by skating discipline (Figures, Freestyle, and Solo Dance) and skating level (Non-Elite, Sub-Elite, and Elite).

	PF (N)	RPF (N/kg)	PRFD (N/s)	IMP (N·s)
Figures	693.75 ± 157.06	15.40 ± 3.03†	2745.45 ± 1848.12	3204.76 ± 821.29
Non-Elite	664.53 ± 157.03	15.00 ± 3.14	1863.37 ± 320.72	3121.64 ± 915.21
Sub-Elite	709.15 ± 177.44	15.45 ± 1.31	3735.17 ± 2445.42	3436.91 ± 1071.40
Elite	714.24 ± 147.17	15.80 ± 3.98	2955.74 ± 2047.76	3116.54 ± 489.98
Freestyle	727.05 ± 182.29	17.29 ± 3.16	3109.78 ± 1634.69	3142.31 ± 862.25
Non-Elite	696.25 ± 146.76	17.84 ± 2.76	3028.78 ± 1348.78	2796.27 ± 580.11‡
Sub-Elite	697.85 ± 190.20	16.66 ± 3.36	2678.38 ± 1188.43	3154.87 ± 966.86
Elite	814.48 ± 195.77	17.58 ± 3.39	3912.59 ± 2306.84	3574.55 ± 847.81
Solo Dance	714.20 ± 143.50	16.18 ± 2.70	3398.92 ± 2417.37	3030.46 ± 712.70
Non-Elite	704.85 ± 149.20	16.54 ± 2.23	2654.52 ± 879.33	2492.36 ± 341.15‡
Sub-Elite	710.07 ± 146.82	15.99 ± 3.46	2951.84 ± 2448.31	3249.10 ± 785.84
Elite	727.55 ± 149.01	16.10 ± 2.25	4605.38 ± 3004.56	3252.37 ± 653.36

PF = peak force; RPF = relative peak force; PRFD = peak rate of force development; IMP = impulse. † – Signals represent significant differences from freestyle discipline (p < 0.05). ‡ – Signals represent significant differences from elite level (p < 0.05).

that physical appearance has a major impact in this sport, like in ice figure skating [26]. Elite freestyle female skaters have higher values of FFM than non-elite freestyle skaters. There is a large correlation between FFM and vertical jump performance [27] and, therefore, an increase in leg muscle power should be expected in elite freestyle skaters compared with their non-elite counterparts. One study [6] found differences in body circumferences between artistic roller skating disciplines; however, the differences were between individual and pairs disciplines and the present study only focused on individual disciplines.

These athletes regularly practice flexibility from a young age, and this may explain why there are no significant differences between skating levels in the sit-and-reach and in the front split tests. These results are in line with one study with a sample of ice figure skating athletes [28]. Elite skaters of the figures discipline have higher values of flexibility and better results on YBT compared to their sub-elite counterparts. In this specific discipline, athletes must perform circles drawn on the ground which the skater, from a stationary position, travels only on one foot, making figures according to a pre-defined plan that represents the difficulties of this discipline. While performing these circles, the athletes' movement must have pace and rhythm without harming their body control and steadiness. These movements are like those performed on YBT and lower extremity flexibility was shown to be a factor contributing to larger scores on this test [29]. With this under consideration, to be part of the elite in this discipline, high levels of lower limb flexibility and balance are needed. Female freestyle skaters had higher values for posterolateral reach on the right leg than female figure skaters. One study with ice hockey players concluded that this reach is correlated with skating speed [30] and this might indicate that freestyle skaters are used to achieve higher speed velocities to better help them do their jumps, spins and footwork sequences. Nevertheless, more research is needed in this area to better understand if skating velocity is also correlated with posterolateral reach in artistic roller skating.

Freestyle skaters had a better value for RSI15 than figure and solo dance skaters. RSI was developed to measure how an athlete copes and performs during plyometric activities by measuring the muscle-tendon stress and their reactive jump capacity, and it demonstrates an athlete's ability to rapidly change from an eccentric motion into a concentric muscular contraction [31]. Freestyle skaters must perform combinations of various jumps during their routines. For a combination jump to be valid, there must not occur a complete break in the usual landing rhythm of one jump and the take-off of the next jump and for this to happen freestyle skaters must be reactive. This factor might also explain why freestyle skaters jumped higher during DJ15, compared with solo dance skaters, since they are used to jumping immediately after another jump. There were no differences between freestyle levels in CMJ. The axel is the most technically difficult jump of all artistic skating jumps, as jumping technique for single axel requires one and a half rotations in the air [32], and previous research on ice figure skating stated that there was no difference between single, double and triple axels height [33]. This might explain why there were no differences between levels in CMJ height. Still, there is a necessity to study if this outcome is also present in artistic roller skating. However, this study found that SJ height and JH35 were good performance indicators to separate the elite from the non-elite in the freestyle and solo dance disciplines. The SJ test is typically used to measure an athlete's explosive lower-body concentric power during the speed-strength spectrum [34] and indicates that elite skaters possess more concentric strength in their leg extensors, compared with non-elite skaters. This was the first study to evaluate EUR in artistic roller skating athletes and it was found that this variable is a good indicator to separate the elite from the non-elite in the solo dance discipline. EUR provides an insight into an athlete's slow stretch-shortening cycle ability [35], and the fact that non-elite solo dance skaters have a higher value in this variable possibly reflects the greater reliance on stretch shortening actions to better accomplish their movements during their routines. For this reason, and in line with what was said previously, non-elite solo dance skaters should focus on developing their lower-limb maximal strength capacity to improve their SJ performance.

The IMTP assesses performance qualities that are critical to most sporting actions such as strength and power and it was seen that the test can be administered in female young artistic roller skaters. This was the first study to assess PF, RFD and IMP through the IMTP test in female artistic roller skaters. It was found that freestyle skaters had higher values in RPF than skaters from the figures discipline. There are large correlations between RPF and jump height [36], and freestyle skaters are amongst those who jump higher. The IMP variable was another great performance indicator to differentiate elite from non-elite athletes in the disciplines of freestyle and solo dance. Impulse values have been associated with SJ performance [37] and it was already seen that this test is a good indicator to separate elite from non-elite skaters.

Elite freestyle skaters performed better on the 20-metre multistage shuttle roller skate test compared to their non-elite counterparts. Other studies in ice figure skating also reported differences between elite and non-elite skaters in tests such as the one-mile run [38] and the Cooper 12-minute test [39]. One study with artistic roller skaters stated that competition induces a greater cardiac stress when compared to non-competitive practice with the same skating program and that greater aerobic capacity would attenuate this greater cardiac stress during competitions [2]. Therefore, the current findings suggest the necessity of training aerobic capacity in artistic roller skating athletes to better prepare them for the higher stresses of competition.

Finally, it should be noted that there are some differences between chronological ages in different groups. Because of that, some results should be interpreted with caution since it is expected that mid- and post-peak height velocity (PHV) athletes have higher levels of maximal strength and peak power compared with their pre-PHV counterparts [40]. Nevertheless, the onset of PHV in females occurs approximately at 11 years of age [41].

Conclusions

Morphological characteristics are associated with success in high performance sport [42] and the results of this study show that artistic roller skating is a sport that favors lightness and leanness at elite levels. YBT has been used as a return to sport test [43]. Since this is the first study that uses this test in female artistic roller skating athletes, strength and conditioning professionals should consider these cut-off points when making baseline assessments or return to sport decisions after injury, rather than use age-based normative data for comparison. SJ and EUR are good performance indicators to separate the elite skaters from the rest. Female non-elite skaters should focus on developing their lower limb maximal strength capacity to better cope with the demands of their sport. Professionals should then start with a maximal strength training program before jumping into any power or plyometric routine. Since maximal strength is

an important training component in these athletes, being able to quantify this physical quality in roller skaters can give a performance and injury-risk advantage. Strength and conditioning professionals can use IMP to monitor differences between skating levels, and RPF can be used to monitor training adaptations related to jump height.

References

1. Vila H., Abraldes J.A., Rodríguez N., Ferragut C. (2015). Anthropometric and somatotype characteristics of world class male roller skaters by discipline. *The Journal of Sports Medicine and Physical Fitness* 55(7-8), 742-8. PMID: 26360965.
2. Medeiros A., Tonello L., Gasparini N., Foster C., Boullosa D. (2016). Lowered heart rate response during competition in figure skaters with greater aerobic fitness. *International Journal of Performance Analysis in Sport* 16(2), 581-9. DOI: 10.1080/24748668.2016.11868910
3. Dubravcic-Simunjak S., Kuipers H., Moran J., Pećina M., Simunjak B., Ambartsumov R. et al. (2008). Stress fracture prevalence in elite figure skaters. *Journal of Sports Science and Medicine* 7(3), 419-20. PMID: 24137091.
4. Young W.B., Newton R.U., Doyle T.L., Chapman D., Cormack S., Stewart G. et al. (2005). Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules Football: a case study. *Journal of Science and Medicine in Sport* 8(3), 333-45. DOI: 10.1016/s1440-2440(05)80044-1
5. Delextrat A., Cohen D. (2009). Strength, power, speed, and agility of women basketball players according to playing position. *Journal of Strength and Conditioning Research* 23(7), 1974-81. DOI: 10.1519/JSC.0b013e3181b86a7e
6. Vila Suárez H., Manchado C., Ferragut Fiol C. (2015). Anthropometry, body composition and domatotype characteristics of world class female roller skaters by discipline. *International Journal of Morphology* 33(3), 1130-5. DOI: 10.4067/S0717-95022015000300051
7. Vila Suárez M.E., Abraldes J.A., Rodríguez N., Manchado C., Ferragut C. (2013). The anthropometric profile of elite roller figure skaters. *Journal of Human Sport and Exercise* 8, 633-41. DOI: 10.4100/jhse.2013.8.Proc3.09
8. The World Medical Association (2009). Declaration of Helsinki - Ethical principles for medical research involving human subjects. *Jahrbuch Für Wissenschaft Und Ethik* 14(1), 233-238.
9. Haff G.G., Triplett N.T. (2015). *Essentials of strength training and conditioning*. Champaign, IL: Human Kinetics.
10. Behm D.G., Chaouachi A. (2011). A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology* 111(11), 2633-51. DOI: 10.1007/s00421-011-1879-2
11. Plisky P.J., Rauh M.J., Kaminski T.W., Underwood F.B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic & Sports Physical Therapy* 36(12), 911-9. DOI: 10.2519/jospt.2006.2244
12. Warner E.R., Fornetti W.C., Jallo J.J., Pivarnik J.M. (2004). A skinfold model to predict fat-free mass in female athletes. *Journal of Athletic Training* 39(3), 259-62. PMID: 15496996.
13. Ayala F., Sainz de Baranda P., De Ste Croix M., Santonja F. (2012). Reproducibility and criterion-related validity of the sit and reach test and toe touch test for estimating hamstring flexibility in recreationally active young adults. *Physical Therapy in Sport* 13(4), 219-26. DOI: 10.1016/j.ptsp.2011.11.001
14. Plisky P.J., Gorman P.P., Butler R.J., Kiesel K.B., Underwood F.B., Elkins B. (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports and Physical Therapy* 4(2), 92-9. PMID: 21509114.
15. Shaffer S.W., Teyhen D.S., Lorenson C.L., Warren R.L., Koreerat C.M., Straseske C.A. et al. (2013). Y-balance test: a reliability study involving multiple raters. *Military Medicine* 178(11), 1264-70. DOI: 10.7205/MILMED-D-13-00222
16. Barker L.A., Harry J.R., Mercer J.A. (2018). Relationships between countermovement jump ground reaction forces and jump height, reactive dtrength index, and jump time. *Journal of Strength and Conditioning Research* 32(1), 248-54. DOI: 10.1519/JSC.0000000000002160
17. Lloyd R.S., Oliver J.L., Hughes M.G., Williams C.A. (2009). Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. *Journal of Sports Sciences* 27(14), 1565-73. DOI: 10.1080/02640410903311572
18. Pagaduan J., Blas X.D. (2014). Reliability of countermovement jump performance on chronojump-boscosystem in male and female athletes. *Sport SPA* 10(2), 5-8.
19. Beckham G.K., Sato K., Santana H.A.P., Mizuguchi S., Haff G.G., Stone M.H. (2018). Effect of body position on force production during the isometric midthigh pull. *Journal of Strength and Conditioning Research* 32(1), 48-56. DOI: 10.1519/JSC.0000000000001968
20. Yagüe P., Del Valle M., Egocheaga J., Linnamo V., Fernández A. (2013). The competitive demands of elite male rink hockey. *Biology of Sport* 30, 195-9. DOI: 10.5604/20831862.1059211
21. Portney L.G., Watkins M.P. (2009). *Foundations of clinical research: applications to practice*. Upper Saddle River, NJ: Pearson/Prentice Hall.
22. Cohen J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Earlbaum Associates.
23. Dizon J., Grimmer-Somers K. (2010). Making Filipino taekwondo athletes internationally competitive: An international comparison of anthropometric and physiologic characteristics. *Journal of Science and Medicine in Sport* 12, e131-e2. DOI:10.1016/j.jsams.2009.10.273
24. Roschel H., Batista M., Monteiro R., Bertuzzi R.C., Barroso R., Loturco I. et al. (2009). Association between neuromuscular tests and kumite performance on the Brazilian karate national team. *Journal of Sports Science and Medicine* 8(3), 20-4. PMID: 24474882.
25. Reiser II R.F., Rocheford E.C., Armstrong C.J. (2006). Building a better understanding of basic mechanical principles through analysis of the vertical jump. *Strength and Conditioning Journal* 28(4), 70-80. DOI: 10.1519/00126548-200608000-00012
26. Monsma D.V., Malina R.M. (2005). Anthropometry and somatotype of competitive female figure skaters 11-22 years. Variation by competitive level and discipline. *Journal of Sports Medicine and Physical Fitness* 45(4), 491-500. PMID: 16446680.
27. Aouichaoui C., Trabelsi Y., Bouhlel E., Tabka Z., Dogui M., Richalet J.P. et al. (2012). The relative contributions of anthropometric variables to vertical jumping ability and leg power in Tunisian children. *Journal of Strength and Conditioning Research* 26(3), 777-88. DOI: 10.1519/JSC.0b013e31822a61a2
28. Slater L.V., Vriner M., Zapalo P., Arbour K., Hart J.M. (2016). Difference in agility, strength, and flexibility in competitive

figure skaters based on level of expertise and skating discipline. *Journal of Strength and Conditioning Research* 30(12), 3321-8. DOI: 10.1519/JSC.0000000000001452
29. Robinson R., Gribble P. (2008). Kinematic predictors of performance on the Star Excursion Balance Test. *Journal of Sport Rehabilitation* 17(4), 347-57. DOI: 10.1123/jsr.17.4.347
30. Krause D.A., Smith A.M., Holmes L.C., Klebe C.R., Lee J.B., Lundquist K.M. et al. (2012). Relationship of off-ice and on-ice performance measures in high school male hockey players. *Journal of Strength and Conditioning Research* 26(5), 1423-30. DOI: 10.1519/JSC.0b013e318251072d
31. Flanagan E.P., Ebben W.P., Jensen R.L. (2008). Reliability of the reactive strength index and time to stabilization during depth jumps. *Journal of Strength and Conditioning Research* 22(5), 1677-82. DOI: 10.1519/JSC.0b013e318182034b
32. Iwańska D., Mazurkiewicz A., Urbanik C. (2018). Biomechanics of the axel paulsen figure skating jump. *Polish Journal of Sport and Tourism* 25(2), 3-9. DOI: 10.2478/pjst-2018-0007
33. King D.L., Arnold A.S., Smith S.L. (1994). A kinematic comparison of single, double, and triple axels. *Journal of Applied Biomechanics* 10(1), 51-60. DOI: 10.1123/jab.10.1.51
34. Markovic G., Dizdar D., Jukic I., Cardinale M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research* 18(3), 551-5. DOI: 10.1519/00124278-200408000-00028
35. McGuigan M., Doyle T., Newton M., Edwards D., Nimphius S., Newton R. (2006). Eccentric utilization ratio: Effect of sport and phase of training. *Journal of Strength and Conditioning Research* 20(4), 992-5. DOI: 10.1519/R-19165.1
36. Nuzzo J.L., McBride J.M., Cormie P., McCaulley G.O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research* 22(3), 699-707. DOI: 10.1519/JSC.0b013e31816d5eda
37. Tran T.T., Lundgren L., Secomb J., Farley O.R., Haff G.G., Seitz L.B. et al. (2015). Comparison of physical capacities between nonselected and selected elite male competitive surfers for the National Junior Team. *International Journal of Sports Physiology and Performance* 10(2), 178-82. DOI: 10.1123/ijspp.2014-0222
38. Fischer L., Darby L., Morgan A., Tobar D. (2016). Physiological characteristics of youth synchronized skaters. *International Journal of Exercise Science* 9(3), 270-282.
39. Comuk N., Erden Z. (2012). The effect of muscular strength and endurance on technical skill in professional figure skaters. *Isokinetics and Exercise Science* 20(2), 85-90. DOI: 10.3233/IES-2012-0445
40. Meylan C.M., Cronin J.B., Oliver J.L., Hopkins W.G., Contreras B. (2014). The effect of maturation on adaptations to strength training and detraining in 11-15-year-olds. *Scandinavian Journal of Medicine & Science in Sports* 24(3), e156-64. DOI: 10.1111/sms.12128
41. Iuliano-Burns S., Mirwald R.L., Bailey D.A. (2001). Timing and magnitude of peak height velocity and peak tissue velocities for early, average, and late maturing boys and girls. *Amercian Journal of Human Biology* 13(1), 1-8. DOI: 10.1002/1520-6300
42. Claessens A.L., Veer F.M., Stijnen V., Lefevre J., Maes H., Steens G. et al. (1991). Anthropometric characteristics of outstanding male and female gymnasts. *Journal of Sports Sciences* 9(1), 53-74. DOI: 10.1080/02640419108729855
43. Boyle M.J., Butler R.J., Queen R.M. (2016). Functional movement competency and dynamic balance after anterior cruciate ligament reconstruction in adolescent patients. *Journal of Pediatric Orthopaedics* 36(1), 36-41. DOI: 10.1097/BPO.0000000000000402

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