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The Lumbopelvic-Hip Complex Contribution During Lower Extremity Screening Tests in Elite Figure Skaters

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Context: Figure skating requires power and stability for takeoff and landing from multirotational jumps and various on-ice skills. Repetitive forces may cause overuse injuries distally, making lumbopelvic-hip endurance, strength, and neuromuscular control imperative.

Objective: To compare lumbopelvic-hip endurance and neuromuscular control in elite figure skaters between sexes and landing and nonlanding limbs using common screening tests.

Design: Cross-sectional study.

Setting: US Olympic and Paralympic Training Center.

Patients or Other Participants: Forty elite figure skaters (20 women, 20 men; age = 23.2 ± 4.3 years) performed the Y-balance test, single-legged squat (SLS), single-legged squat jump (SLSJ), and unilateral hip-bridge endurance test (40 right [R] landing limbs, length = 169.1 ± 12.2 cm).

Main Outcome Measure(s): Normalized reach difference (% of leg length) and composite scores [(anterior + posteromedial + posterolateral)/(limb length × 3) × 100] were calculated for the Y-balance test. Skaters held the unilateral hip bridge until failure with a maximum allotted time of 120 seconds. They performed 5 SLSs and 5 SLSJs while barefoot with the contralateral limb held behind them to mimic a landing position. Both tests were scored by the number of times the patella moved medially to the first ray (medial knee displacement [MKD]). Multivariate analyses of variance with post hoc independent *t* tests were conducted between sexes and groups. Paired *t* tests were used to analyze limb differences.

Results: Women had a larger composite Y-balance score (R = 10.8% of leg length, $P = .002$; left = 10.5%, $P = .001$) and hip-bridge hold time (R = 26.4 seconds, $P = .004$; left = 28.2 seconds, $P = .002$) for both limbs compared with men. Men held the hip-bridge longer on their landing limb. Six skaters performed worse on their nonlanding limb during the SLS, and 11 skaters had no MKD with either the SLS or SLSJ.

Conclusions: Women performed better on the Y-balance and unilateral hip bridge tests. Increased MKD for some skaters during the SLS and SLSJ may have indicated hip-abductor weakness. Understanding the proximal lumbopelvic-hip variables during takeoff and landing may elucidate contributing factors to distal overuse injuries.

Key Words: neuromuscular control, Y-balance test, hip-bridge test

Key Points

- Women demonstrated greater unilateral hip-bridge hold times and composite Y-balance scores than their male counterparts.
- Both men and women performed similarly bilaterally on single-legged tests, whereas men held the unilateral hip bridge longer using their landing limbs.
- Similar bilateral scores may indicate symmetry between the landing and nonlanding limbs on single-legged tasks.

The lumbopelvic-hip complex has traditionally been investigated as a means of understanding low back pain, which is a costly and highly prevalent condition for many individuals, including athletes.[1] The connection between core function and lower extremity injury, both acute and chronic, has been proposed, both as a cause of injury and as a means of intervention.[2] Although links were evident among proprioception, stability, and injury in collegiate athletes,[3] dancers,[4] and even young figure skaters,[5] a gap in the literature exists for elite-level figure skaters. Poor performance on dynamic balance tasks, such as the Y-balance test, has been associated with an increased risk of injury.[6] In National Collegiate Athletic Association Division I athletes and high school basketball players decreased reach distance and between-limbs asymmetry in the anterior direction was associated with lower extremity injuries.[6,7] Among elite female basketball players, posteromedial and overall composite scores on the Y-balance test increased after neuromuscular training (leading to increased neuromuscular control) and distal injuries decreased throughout the season.[8] Strength, balance, power, and flexibility were only a few of the requirements while training and competing as a figure skater. As skaters advanced in technical difficulty, the intensity of training and physical

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demands also increased. Due to the rise in physical demands, lower extremity injuries were common in elite figure skaters.[9] Many of the injuries, including patellofemoral pain[2] and lumbar spine injury,[10] have been linked with dysfunction of the lumbopelvic-hip complex and core in other athletic populations.[1]

Men and women have a documented disparity in the contribution of the lumbopelvic-hip complex during lower extremity movement, which can predict future acute and chronic lower extremity injury.[10] Proximal hip musculature dysfunction, notably of the gluteus maximus and medius, has led to increased frontal-plane projection angles in women during single-legged squat (SLS) screening and decreased hip-abduction and hip-extension force.[11] These sex differences in hip activation are particularly important in singles figure skating because on landing, a large proportion of the ground reaction forces are attenuated at the proximal joints, such as the hip and back, due to the lack of ankle mobility in the skating boot. Without appropriate hip strength, more forces would be attenuated at the trunk, which may lead to an increased incidence of low back pain and injury.

Differences in physiological characteristics based on landing and nonlanding limbs may drive various muscle-activation patterns from the lumbopelvic-hip complex between men and women. Women had greater activation of the transverse abdominis, vastus lateralis, vastus medialis, and gluteus maximus than men during roller skating jumps, which are very similar to jumps in figure skating.[12] Greater control may have been required of the landing limb as opposed to the nonlanding limb in order to provide stability as a skater landed from various skills. However, muscle fatigue can affect hip, knee, and ankle biomechanics, which could have resulted in figure skaters compensating with increased lateral trunk flexion toward their landing limb after they made contact with the ice.[12] Compensatory movement patterns during landings, such as increased lateral trunk flexion, may contribute to injuries such as patellofemoral pain.

It is important to understand and identify the cause of compensatory behavior to better treat the problem and, we hope, avoid injury. Therefore, the purpose of our study was to compare lumbopelvic-hip endurance and lower extremity performance in elite male and female figure skaters using common screening tests for their landing and nonlanding limbs. We expected to find increased lumbopelvic-hip endurance and stability in the skater's landing limbs due to the repetitive dynamic loading of the landing limb compared with the nonlanding limb. We also hypothesized that men would perform better than women in endurance and stability testing of the lower extremity. However, we expected that the differences between the landing and nonlanding limbs of the individual athlete would not depend on sex.

METHODS

Study Design

In this descriptive, cross-sectional study, we compared lumbopelvic-hip endurance and neuromuscular control between male and female elite skaters with respect to their landing and nonlanding limbs. Recruits were senior (highest)-level skaters who participated in senior qualifying international competitions (ie, were considered elite). The variables assessed were Y-balance test performance, SLS and single-legged squat jump (SLSJ) performance bilaterally, and hold time for a unilateral hip bridge. All procedures were part of annual testing by US Figure Skating. The University of Central Florida Institutional Review Board deemed the protocol exempt, and deidentified data were shared for statistical analysis only.

Participants

Forty members of the US Figure Skating International Selection Pool (20 women, 20 men; age = 23.21 ± 4.31 years) participated in this study. All skaters who participated were invited to attend the camp based on their performance at qualifying events. Inclusion criteria were senior-level skaters with no current injury interfering with training. Individuals were excluded if they presented with any of the following: a current lower leg injury affecting on-ice training, trunk or neck injury, or concussion within the previous 6 months. Individual injuries to the skaters who were excluded were not reported.

Testing Procedures

Participants reported to the Olympic and Paralympic Training Center in Colorado Springs to complete a single testing session in the following order: Y-balance test, SLS, SLSJ, and unilateral hip bridge.[13] One examiner (L.S.) tested 1 participant at a time. All 40 skaters performed the Y-balance test 3 times on each limb, reaching as far as possible in the anterior, posterolateral, and posteromedial directions. The participant stood on a single leg and used the contralateral foot to push a block from a Y-balance kit. The evaluator demonstrated proper form and instructed the participant to keep the heel of the standing leg down throughout the test. Each person completed 3 practice rounds before testing in each of the 3 directions. The test was performed barefoot to eliminate additional balance and stability contributions from shoes. Proper form included keeping hands on the hips, maintaining balance, fully returning to the starting position, keeping the heel of the test foot on the floor, and not placing weight on the reaching foot at any point during the test. If any of these items were not executed correctly, the trial was stopped and repeated after the individual rested; legs were alternated to reduce fatigue. Limb length was measured (in cm) from the anterior-superior iliac spine to the distal aspect of the medial malleolus using a measuring tape.[13] The reach distance of both limbs in each direction was then recorded by the same examiner who administered all testing.

Participants performed 5 SLSs, barefooted, with rest time between trials. During each SLS, they were instructed to keep their hands on their hips while the contralateral foot remained lifted approximately 6 in (15.24 cm) off the ground behind them to mimic the figure-skating landing position. The test score was based on the number of squats performed in which the midline of the patella moved medially to the first ray, resulting in medial knee displacement (MKD).[14] Each person performed the SLSJ 5 times, jumping as high as possible on a single leg and landing in a squatting position. The score was based on visual inspection of MKD on landing from the jump. Two female participants did not complete the task due to time restraints.

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Table 1. Participant Demographics

Demographics	All Participants (n = 40)	Men Only (n = 20)	Women Only (n = 20)
Age, y	23.21 ± 4.31	24.55 ± 4.92	21.87 ± 3.18
Height, cm	169.08 ± 12.19	179.15 ± 7.51	159.00 ± 5.92
Leg length, cm, right	87.12 ± 5.88	91.45 ± 4.50	82.79 ± 3.35
Landing limb, right	40	20	20
Skating discipline	12 singles, 15 pairs, 13 dance	6 singles, 8 pairs, 6 dance	6 singles, 7 pairs, 7 dance

The unilateral hip bridge was conducted with the participant lying supine with arms across the chest, hook lying, and feet flat on the table.[15] When the examiner instructed the skater to assume the start position, the individual extended 1 knee while keeping the other flexed with the foot flat on the table. Then he or she lifted the hips and buttocks off the table to maintain a straight line along the lateral thigh up to the thorax and was asked to maintain this position until failure, with a maximum of 120 seconds allowed. The trial end if this form was not maintained or if the athlete chose to discontinue the trial for any reason and lowered the body to the table. This procedure was repeated with the other knee extended after a rest period, and hold times were recorded in seconds for both limbs, using a standard athletic stopwatch.

Data Analysis

We calculated descriptive statistics from the recorded characteristics for all participants, which included age, sex, height, landing leg, leg length, and skating discipline. Distance (cm) reached in the Y-balance test, number of SLSs and MKD, number of SLSJs and MKD, and length of time (seconds) for unilateral hip bridges were recorded for each participant bilaterally. The Y-balance test reach distances (cm) were averaged across trials for all 3 directions and used to compute the absolute differences between limbs, normalized differences between limbs (% leg length), and the composite score [composite score (%) = (anterior + posteromedial + posterolateral)/(limb length × 3) × 100]. We determined the composite score using the average of all 3 reach distances while accounting for leg length.[6,13] Multivariate analyses of variance with post hoc independent *t* tests were performed for sex and discipline. Paired *t* tests were conducted to analyze limb differences. We calculated Cohen *d* effect sizes between sexes for the Y-balance composite scores and unilateral hip-bridge endurance hold times.

RESULTS

Demographics of the participants are listed in Table 1. Each person identified the right limb as their landing limb (n = 40). The female composite scores for all 3 reach distances were 10.77% higher than the men for the right limb ($d = 1.07$; 95% CI = 0.40, 1.73; $P = .004$) and 10.47% higher for the left limb ($d = 1.13$; 95% CI = 0.46, 1.79; $P = .002$). Women held the unilateral hip bridge 26.4 seconds longer than men ($d = 0.98$; 95% CI = 0.33, 1.64; $P = .022$), but the women's right and left hold times did not differ ($P > .05$). Men held for 5.80 seconds longer using the right leg ($P = .02$). Four women held for the full (maximum) 120 seconds, and 3 of these held for 120 seconds bilaterally (Table 2).

On 5 SLS trials, 70% of the combined men and women did not show MKD on the right side (Table 3). Only 35% of the men and 44% of the women had no MKD during the right SLSJ. The MKD did not differ by sex, landing limb, or discipline.

DISCUSSION

The purpose of our study was to compare lumbopelvic-hip endurance and neuromuscular control in elite male and female figure skaters using common functional tests in relation to their landing and nonlanding limbs. When performing the unilateral hip bridge, women held for 26.4 seconds longer; 4 women held for the full 120 seconds (Table 2). Women had higher Y-balance composite scores for both limbs, although neither men nor women displayed between-limbs differences. No differences were found between sex, limbs, or discipline when performing the SLS or SLSJ. Only 11 skaters demonstrated no MKD on the SLS or SLSJ. These results suggested that female figure skaters outperformed male figure skaters in hip endurance and dynamic balance and that male skaters demonstrated limb asymmetry in hip endurance.

Functional tests have often been used to measure injury risk and performance, but thresholds varied for specific populations.[16,17] Functional tests were most effective when they reflected the skills required of the sport and were performed as a battery of tests, providing a better understanding of the athlete's whole picture.[16,18] Few off-ice functional assessments are commonly used to comprehensively evaluate figure skaters; we conducted the Y-balance test, SLS, SLSJ, and unilateral hip bridge. The Y-balance test has been investigated previously in figure

Table 2. Y-Balance and Unilateral Hip Bridge Endurance Results

	Landing (R)			Nonlanding limb (L)		
	Men	Women	*P* value[a]	Men	Women	*P* value[a]
Composite Y-balance score, %	105.86 ± 10.94	116.3 ± 9.21	.002	106.79 ± 10.09	117.26 ± 8.44	.001
Anterior	63.46 ± 8.27	66.99 ± 5.95		65.43 ± 6.71	68.56 ± 6.15	
Posteromedial	114.86 ± 9.64	114.54 ± 8.41		114.99 ± 8.75	115.01 ± 7.11	
Posterolateral	111.20 ± 8.48	107.68 ± 8.28		111.54 ± 7.00	107.27 ± 7.78	
UHBE, s	60.8 ± 27.07	87.19 ± 26.71	.022	54.99 ± 26.25	83.23 ± 28.29	.002

Abbreviations: L, left leg; R, right leg; UHBE, unilateral hip bridge endurance.

[a] $P < .05$.

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Table 3. Medial Knee Displacement Frequency Across 5 Trials for Single-Leg Squat and Single-Leg Squat Jump Results

	SLS (R)		SLS (L)		SLSJ (R)		SLSJ (L)	
Frequency	M (n = 20)	W (n = 20)	M (n = 20)	W (n = 20)	M (n = 20)	W (n = 18)	M (n = 20)	W (n = 18)
0	14	14	18	16	7	8	5	8
1	1	4	1	0	2	0	4	1
2	2	0	0	1	4	1	6	3
3	0	1	1	2	5	2	2	2
4	0	1	0	0	1	2	2	1
5	3	0	0	1	1	5	1	3
P value	1.0		.60		.86		.32	

Abbreviations: L, left leg; M, men; R, right leg; SLS, single-leg squat; SLSJ, single-leg squat jump; W, women.

skaters because of the importance of the dynamic balance in the landing position (posterolateral reach). Decreased posterolateral reach could place excessive power demands on the takeoff limb.[13] Unlike the skating position, which lifts the heel in the boot so the ankle is slightly plantar flexed, we required participants to keep their heels on the ground during Y-balance testing. Neuromuscular control might have been significantly affected by lifting of the stance-leg heel, which is often due to muscular imbalances and lack of ankle range of motion.[7] Skating boots restrict ankle movement and dorsiflexion; lacking the familiar support of the skating boot may have led to reduced anterior-reach performance in figure skaters.[13]

Both male and female figure skaters tended to perform better on the Y-balance test on their nonlanding limb, indicating greater dynamic stability on that limb (Table 2). More than half of all figure skaters lacked dorsiflexion mobility while wearing skating boots.[19] The nonlanding limb may have required slightly more dorsiflexion for some takeoff positions, leading to more mobility. Greater dorsiflexion, knee flexion, and hip flexion at takeoff followed by triple extension (extension at the ankle, knee, and hip) allowed for greater vertical jump height.[20] The ability to generate maximal power from the nonlanding limb while leaning on an edge, either forward or backward, requires maximal stability from the nonlanding ankle to maintain the edge while jumping.

Elite figure skaters in our study held the unilateral hip bridge for a longer period of time than nonskaters.[15] The number of female participants who were able to hold the unilateral hip bridge for the maximum allotted time of 120 seconds could have indicated greater hip endurance in women compared with men. A longer hold time on the unilateral hip bridge reflected greater endurance, increased muscle activation, and limb stability.[15] This could have suggested poor muscle activation in the male skaters, specifically affecting the lumbar multifidus, erector spinae muscles, gluteus maximus, and gluteus medius.[13] Muscle weakness could have altered the position and stability of the pelvis and may have subsequently contributed to poor neuromuscular control at the hip and low back pain.[21] Further, reduced hip external-rotator and extensor strength were predictors of poor isometric performance.[22] Male skaters held the unilateral hip bridge longer on the landing limb than the nonlanding limb. The landing limb had an increased need for stability in order to support the high angular velocity during jumps and overcome the forces of jump landings.[12] In contrast, the nonlanding limb required more power generation to optimize jump height. Although both legs must be stable and strong, the specific demands may have led to asymmetry. Male skaters may have had asymmetric stability in the lumbopelvic-hip complex and greater endurance, favoring the landing limb, which may have been due to performance of highly technical elements requiring increased landing stability, such as multiple quadruple jumps.

Although female figure skaters may have had greater hip endurance, they may have been lacking hip strength. A lack of strength at the knee, including the quadriceps and hamstrings, and in the low back and core could have contributed to the increased MKD during single-legged dynamic movements. The majority of athletes had no MKD on the SLS; however, participants performed significantly worse on the SLSJ (Table 3). This may have been the result of the SLS task being too easy for this elite sample and the SLSJ being somewhat less familiar as an off-ice functional task. The SLSJ mimicked the possible neuromuscular control needed during landing from a jump. During takeoff, the anterior chain is primarily activated to produce enough torque and power to perform multiple rotational jumps.[12] This is the opposite of the landing phase, in which the movement is very quick, not allowing time to alter the amount of dorsiflexion in the ankle and resulting in landing forces moving up the kinetic chain to the hip and lumbar spine. A stiffer position at landing required the hip and trunk to attenuate more of the forces. Gluteal muscle strength is particularly important for controlled single-legged landings.[23] The gluteus medius is one of the main stabilizers of the hip,[24] specifically during static single-legged tasks such as the SLS. A lack of gluteus medius strength may have been a contributing factor to the increased MKD during jump landings, suggesting that improving hip strength may lead to improved performance on the SLSJ. Furthermore, a lack of gluteal strength at landing may have led to increased spinal musculature activation to provide stabilization. This may also play a role in increasing rates of chronic low back injuries in figure skating.[25]

As a unique study used to investigate an understudied population such as elite figure skaters, the current research had some limitations. This study was conducted on a small, specific sample and the results may have limited application to a more general athletic population. Elite athletes spend a disproportionate amount of time practicing when compared with other athletic populations, predisposing them to injuries, specifically those of the back and lower extremity.[10,13] Participants in this study may have had an injury history, which could have been a contributing factor to any decreased performance; we did not collect information on injury history. Future researchers should focus on injury prevalence in the core, low back, and lower extremity and the implications for functional performance

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in this population. Another limitation was that we did not have information about joint range of motion, including dorsiflexion-plantar flexion and Achilles flexibility, which may correlate with Y-balance test performance.

CONCLUSIONS

The purpose of our study was to compare lumbopelvic-hip endurance and neuromuscular control in male and female elite figure skaters in relation to their landing and nonlanding limbs using common functional tests. Women had a greater Y-balance test composite score than men and were able to reach farther on their landing limb, while men were able to reach farther on their nonlanding limb. Overall, female skaters had greater endurance in the unilateral hip bridge, while men exhibited asymmetric endurance, favoring their landing limb. Male and female elite figure skaters demonstrated good alignment on the SLS; however, they did have MKD during the SLSJ. Altered hip adduction and abduction coactivation change the alignment at the knee; these alterations, collectively with ankle stiffness and a lack of dorsiflexion mobility, could have led to MKD. Altered biomechanics, along with strength deficits in the hip musculature, may have resulted in more force attenuation at the spinal musculature and chronic low back injuries from overuse and repetitive jump landings during practice.

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