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

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ABSTRACT

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

Objective: The purpose was to compare lumbopelvic-hip endurance and neuromuscular control in elite figure skaters between sex and limbs using common screening tests.

Design: Cross-sectional study.

Setting: U.S. Olympic and Paralympic Training Center.

Participants: Forty elite figure skaters (23.2±4.3years, 169.1±12.2cm, 20F, 40R landing limb) performed the Y-balance test, single leg squat (SLS), single leg squat jump (SLSJ), and unilateral hip bridge endurance test.

Main Outcome Measures: Normalized reach difference (% of leg length) and composite scores (((Anterior + Posteromedial + Posterolateral)/Limb length x 3) x100) were calculated for Y-balance test. Skaters held the unilateral hip bridge until failure with a maximum allotted time of 120s. Participants performed 5 SLS and SLSJ, barefooted 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)). MANOVA with post-hoc independent t-tests were performed between groups and sex. Paired t-tests were used to analyze limb differences.

Results: Females had a larger composite Y-balance score (R:+10.8, p=.002; L:+10.5,p=.001) and hip bridge hold time (R:+26.4sec, p=.004; L:+28.2sec,p=.002) on both limbs compared to males. Males held the hip bridge longer on their landing limb. During the SLS and SLSJ, 6 skaters performed worse on their non-landing limb during the SLS, and 11 skaters had no MKD with either test.

Conclusions: Females performed better on the Y-balance and unilateral hip bridge tests. Increased MKD for some skaters in the SLS and SLSJ may indicate hip abductor weaknesses. Understanding proximal lumbopelvic-hip variables during take-off and landing may elucidate contributing factors to distal overuse injuries.

Key Words: figure skating; hip; neuromuscular control

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Key Points:

1. Females demonstrated greater unilateral hip bridge hold times and composite Y-balance scores than their male counterparts.
2. Both males and females performed similarly bilaterally on single leg tests, while males held the unilateral hip bridge longer on their landing limbs.
3. Similar bilateral scores may indicate symmetry between landing and non-landing limbs on single-leg tasks.

Introduction

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, as both a cause of injury and a means of intervention.[2] While there are links in collegiate athletes,[3] dancers,[4] and even young figure skaters[5] between proprioception, stability, and injury, there is a gap in the literature for elite-level figure skaters. Poor performance on dynamic balance tasks, such as the Y-balance test, has been associated with increased risk of injury.[6] In division I athletes and high school basketball players, a decreased reach distance and asymmetry between limbs in the anterior direction was associated with lower extremity injuries.[6,7] When looking at elite female basketball players, posteromedial and overall composite scores from the Y-balance test increased following neuromuscular training leading to increased neuromuscular control and decreased distal injuries throughout the season.[8] Strength, balance, power, and flexibility are only a few of the requirements while training and competing as a figure skater. As skaters advance in technical difficulty, the intensity of training and physical demands also increase. Due to the rise in physical demand, lower extremity injuries are common in elite figure skaters.[9] Many of those injuries, including patellofemoral pain[2] and lumbar spine injury,[10] have been linked to dysfunction of the lumbopelvic-hip complex and core in other athletic populations.[1]

Males and females have a documented disparity in contribution from the lumbopelvic-hip complex during lower extremity movement, which can be predictive of 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 females during a single leg squat (SLS) screening, decreased hip abduction, and hip extension force output.[11] These sex differences in hip activation are particularly important in singles figure skating because at 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 of the forces will be attenuated at the trunk, which may lead to increased incidence of low back pain and injury.

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

It is important to understand and identify the cause for compensatory behavior to better treat the issue and hopefully avoid detrimental injury. Therefore, the purpose of this study was to compare lumbopelvic-hip endurance and lower extremity performance using common screening tests in male and female elite figure skaters in relation to their landing and non-landing 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 to the non-landing limb. We also hypothesized that males would perform better than females in endurance and stability testing of the lower extremity. However, we expected that the differences between the landing and non-landing limbs of the individual athlete were not dependent on sex.

Methods

Study Design

This was a descriptive, cross-sectional study that compared lumbopelvic-hip endurance and neuromuscular control between male and female elite skaters with reference to their landing and non-landing limbs. Skaters in this study were senior level (the highest level) who participated in senior qualifying international competitions (considered "elite"). The variables assessed included, Y-balance test performance, SLS and single leg squat jump (SLSJ) performance bilaterally, and their hold time for a unilateral hip bridge. All procedures were part of annual testing with United States Figure Skating. The XXXX Institutional Review Board deemed the protocol exempt and de-identified data were shared for statistical analysis only.

Participants

Forty members of the United States Figure Skating International Selection Pool (23.21± 4.31) (20 females and 20 males) participated in this study. All skaters who participated were invited to attend the camp based on performance at qualifying events. Inclusion criteria included senior level skaters with no current injury interfering with training. Individuals were excluded if they presented with any of the following: current lower leg injury impacting on-ice training, trunk or neck injury, or a concussion within the previous six months. Individual injuries 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 (XX) tested one participant at a time. All 40 participants performed the Y-balance test three times on each limb, reaching in the anterior, posterolateral, and posteromedial directions. This task was performed by the participant standing on a single leg and reaching the contralateral foot pushing a block from a Y-balance kit. The evaluator demonstrated proper form and instructed the participants to keep the heel of their standing leg down throughout the test. Each participant completed 3 practice rounds before testing in each of the 3 directions. The test was performed barefoot to eliminate additional balance and stability contribution from shoes. The proper form included keeping hands on their hips, maintaining balance, fully returning to starting position, keeping the heel of the test foot on the floor, and not placing weight in the reaching foot at any point during the test. If any of this was not performed correctly the trial was stopped and repeated with rest and alternating legs in between to reduce fatigue. Participants would reach as far as possible in three directions. Limb length was measured 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 that administered all of the testing.

Participants performed 5 SLS, barefooted, with rest time between trials. During each SLS, individuals were instructed to keep their hands on their hips while their contralateral foot remained lifted approximately 6 inches off the ground behind them to mimic the figure skating landing position. The score was based on the number of squats performed where the midline of their patella moved medially to their first ray, resulting in medial knee displacement.[14] The SLSJ, was performed by each participant jumping 5 times as high as they could on a single leg and landing in a squatted position. They were scored based on visual inspection of medial knee displacement upon landing from the single leg jump. Two female participants did not complete the task due to time restraints.

The unilateral hip bridge was performed with the participant lying supine with their arms across their chest, hook-lying, and feet flat on the table.[15] When the examiner instructed the participant to get into the start position, the participant extended one knee while keeping the other flexed with their foot flat on the table. Then they lifted their hips and buttocks off the table to maintain a straight line along the lateral thigh up to the thorax. Individuals were asked to maintain this position until failure with a maximum of 120-seconds allowed. The trial would end if they could not keep this form or if they chose to discontinue the trial for any reason and lowered down to the table. This was repeated with the other knee extended after a rest period and hold times were recorded in seconds for both limbs. Time was recorded using a standard athletic stopwatch (seconds).

Data Analysis

Descriptive statistics were calculated from the recorded characteristics for all participants, which included, age, sex, height, landing leg, leg length (cm), and skating discipline. Distance reached in the Y-balance test, number of SLS with medial knee displacement, number of SLSJ with medial knee displacement, and length of time for unilateral hip bridges (seconds) were recorded for each participant bilaterally. Y-balance test reach distances were averaged across trials for all 3 directions and were used to calculate the absolute difference between limbs (cm), normalized differences between limbs (% leg length), and the composite score. The composite score was calculated using the average of all 3 reach distances while accounting for leg length.[6,13] MANOVA with post-hoc independent t-tests were performed between sex and discipline. Paired t-tests were used to analyze limb differences. Cohen's *d* effect sizes between sexes were calculated for the Y-balance composite scores and unilateral hip bridge endurance hold times.

Results

Demographics of the participants tested are listed in Table 1. Each participant indicated their right limb as their landing limb (n=40). The female composite scores for all 3 reach distances were 10.77 larger than males on the right limb (p=.004, d=1.07 (.40-1.73)) and 10.47 larger on the left (p=.002, d=1.13 (.46-1.79)). Females held the unilateral hip bridge 26.4s longer than the males (p=.022, d=.98 (.33, 1.64)). Females did not differ between their right and left unilateral hip bridge hold times (p>.05). Males held 5.80s longer on their right leg (p=.02). Four females maxed out at 120 seconds and 3 of these females maxed out at 120 seconds bilaterally (Table 2).

Out of 5 SLS trials, 70% of the combined males and females did not have medial knee displacement on the right side (Table 3). Only 35% of the males and 44% of the participating females had no medial knee displacement on the right SLSJ. There was no significant difference in medial knee displacement by discipline, sex, or landing limb.

Discussion

The purpose of this study was to compare lumbopelvic-hip endurance and neuromuscular control in elite figure skaters using common functional tests in males and females in relation to their landing and non-landing limbs. When performing the unilateral hip bridge, females had 26.4 seconds longer hold times, with four females holding the unilateral hip bridge for the full 120 seconds (Table 2). Females had larger Y-balance composite scores on both limbs, although neither males nor females had limb differences in Y-balance composite scores. No significant differences were found between sex, discipline, or limbs when performing the SLS or SLSJ. Only 11 skaters demonstrated no medial knee displacement on the SLS or SLSJ. The results of the current study suggest that female figure skaters outperform male figure skaters on hip endurance and dynamic balance, however male skaters demonstrated limb asymmetry on hip endurance.

Functional tests are often used to measure injury risk and performance, but thresholds vary based on specific populations.[16,17] Functional tests are the most effective when they reflect the skills required of the sport and performed as a battery giving a better understanding of the whole picture for the athlete.[16,18] There are few off-ice functional assessments that are commonly used for comprehensive evaluation of figure skaters; this study used the Y-balance test, unilateral hip bridge, and the SLS. The Y-balance test has been studied previously in figure skaters because of the important of the dynamic balance in the landing position (posterolateral reach). Decreased posterolateral reach can place excessive power demands on the take-off limb.[13] Unlike the skating position, which lifts the heel in the boot so the ankle is slightly plantarflexed, we required participants to keep their heel on the ground during Y-balance testing. Neuromuscular control can be significantly affected when lifting the heel of the stance leg, often due to muscular imbalances and lack of range of motion in the ankle.[7] Skating boots restrict ankle movement and dorsiflexion without the familiar support of the skating boot may lead 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 non-landing limb, which indicates greater dynamic stability on that limb (Table 2). Over half of all figure skaters lack dorsiflexion mobility in skating boots.[19] The non-landing limb may require slightly more dorsiflexion for some take-off positions, leading to more mobility. Greater dorsiflexion, knee flexion, and hip flexion at take-off followed by triple extension (extension at the ankle, knee, and hip) allows for greater vertical jump height.[20] The ability to generate maximal power from the non-landing limb while leaning on an edge, either forward or backward, requires maximal stability from the non-landing ankle to maintain the edge while jumping.

Elite figure skaters in the current study were able to hold the unilateral hip bridge for a longer period of time when compared to non-skaters.[15] The number of female participants who were able to hold the unilateral hip bridge for the maximum allotted time of 120 seconds, could be indicative of greater hip endurance in females when compared with males. A longer hold time on the unilateral hip bridge reflects greater endurance, increased muscle activation, and limb stability.[15] This could suggest poor muscle activation in male skaters, specifically in the lumbar multifidus, erector spinae muscles, gluteus maximus and gluteus medius.[13] Muscle weakness could alter the position and stability of the pelvis and may subsequently contribute to poor neuromuscular control at the hip and low back pain.[21] Further, reduced hip external rotator and extensor strength are predictors of poor isometric performance.[22] Male skaters held the unilateral hip bridge longer on the landing limb in comparison to their non-landing limb. The landing limb has an increased need for stability in order to support the high angular velocity during jumps and to overcome the forces from jump landings.[12] In contrast, the non-landing limb requires more power generation to optimize jump height. Although both legs must be stable and strong, the specific demands may lead to asymmetry. Male skaters may have asymmetrical stability in the lumbopelvic-hip complex and greater endurance, favoring the landing limb, which may be due to performance of highly technical elements requiring increased landing stability, such as multiple quadruple jumps.

Although female figure skaters may have greater hip endurance, they may be lacking hip strength. Lack of strength at the knee, including the quadriceps and hamstring, along with low back and core could be contributing factors to the increased amount of demonstrated medial knee displacement during single leg dynamic movements. The majority of athletes had no medial knee displacement on the SLS, however skaters in this study performed significantly worse on the SLSJ (Table 3). This may be the result of the SLS task being too easy for this elite sample and the SLSJ is somewhat less familiar as an off-ice functional task. The SLSJ mimics the possible neuromuscular control needed during landing from a jump. During take-off, the anterior chain is mainly activated to produce enough torque and power to perform multiple rotational jumps.[12] This is opposite of the landing phase, where the movement is very quick, not allowing time to alter the amount of dorsiflexion in the ankle resulting in landing forces moving up the kinetic chain to the hip and lumbar spine. A stiffer position at landing requires the hip and trunk to attenuate more of the forces. Gluteal muscle strength is particularly important for controlled single leg landings.[23] The gluteus medius is one of the main stabilizers of the hip[24] specifically during static single leg tasks such as the SLS. Lack of gluteus medius strength may be a contributing factor to the increased medial knee displacement during jump landings, suggesting that improving hip strength may lead to improved performance on the SLSJ. Furthermore, lack of gluteal strength at landing may lead 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, there were some limitations in the current study. This study was conducted on a small, specific sample, and may have limited application to a more general athletic population. Elite athletes spend a disproportionate amount of time practicing when compared to other athletic populations predisposing them to injuries specifically those of the back and lower extremity.[10,13] Participants in this study may have had a prior injury history, which could have been a contributing factor to any decreased performance. We did not collect information on prior injury history in this sample. Future research should focus on injury prevalence to the core, low back, and lower extremity and its implications for functional performance in this population. Another limitation in the current study was that we did not have information about joint range of motion, including dorsiflexion/plantarflexion and lack of achilles flexibility, which may correlate with Y-balance test performance.

Conclusion

The purpose of this study was to compare lumbopelvic-hip endurance and neuromuscular control in elite figure skaters using common functional tests in males and females in relation to their landing and non-landing limbs. Females had a greater Y-balance test composite score when compared with males. When comparing between limbs, females were able to reach farther on their landing limb while males were able to reach farther on their non-landing limb. Overall, females skaters had greater endurance on the unilateral hip bridge, while males exhibited asymmetrical endurance, favoring their landing limb. Male and female elite figure skaters demonstrated good alignment on SLS, however did have medial knee displacement during the SLSJ. Altered hip adduction and abduction co-activation change the alignment at the knee; these alterations collectively with ankle stiffness and lack of dorsiflexion mobility could lead to medial knee displacement. These altered biomechanics along with strength deficits in the hip musculature may lead to more force attenuation at the spinal musculature and chronic low back injuries from overuse and repetitive jump landings during practice.

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Table 1. Participant demographics.

	All participants (N=40)	Males only (N=20)	Females only (N=20)
Age (yrs)	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)	87.12±5.88 R	91.45±4.50 R	82.79±3.35 R
Landing Limb	40 R	20 R	20 R
Discipline	12 Singles, 15 Pairs, 13 Dance	6 Singles, 8 Pairs, 6 Dance	6 Singles, 7 Pairs, 7 Dance

cm, centimeter; yrs, years; R, Right.

Table 2. Y-balance and unilateral hip bridge endurance results.

	Landing (R)		Non-landing limb (L)	
	M	**F**	**M**	**F**
Composite Y-Balance Score	105.86±10.94	116.3±9.21	106.79±10.09	117.26±8.44
	p=.002*		p=.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	60.8± 27.07s	87.19±26.71s	54.99±26.25s	83.23±28.29s
	p=.022*		p=.002*	

*p<.05

M, Male; F, Female; R, Right; L, Left; UHBE, Unilateral Hip Bridge Endurance; s, seconds.

Table 3. Medial knee displacement frequency across 5 trials for single leg squat and single leg squat jump results.

Frequency	SLS - Right		SLS - Left		SLSJ - Right		SLSJ - Left	
	M (n=20)	F (n=20)	M (n=20)	F (n=20)	M (n=20)	F (n=18)	M (n=20)	F (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	

*p<.05

M, Male; F, Female; SLS, single leg squat; SLSJ, single leg squat jump.