

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

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2 Figure Skaters

4

ABSTRACT

6 **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
8 making lumbopelvic-hip endurance, strength, and neuromuscular control imperative.

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

Design: Cross-sectional study.

12 **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)
14 performed the Y-balance test, single leg squat (SLS), single leg squat jump (SLSJ), and unilateral hip bridge endurance test.

16 **Main Outcome Measures:** Normalized reach difference (% of leg length) and composite scores
(((Anterior + Posteromedial + Posterolateral)/Limb length x 3) x100) were calculated for Y-
18 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
20 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
22 independent t-tests were performed between groups and sex. Paired t-tests were used to analyze limb differences.

24 **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
26 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
28 with either test.

Conclusions: Females performed better on the Y-balance and unilateral hip bridge tests.
30 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
32 contributing factors to distal overuse injuries.

Key Words: figure skating; hip; neuromuscular control

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36 **Key Points:**

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

44 **Introduction**

46 The lumbopelvic-hip complex has traditionally been investigated as a means of
47 understanding low back pain, which is a costly and highly prevalent condition for many
48 individuals, including athletes.¹ The connection between core function and lower extremity
49 injury, both acute and chronic, has been proposed, as both a cause of injury and a means of
50 intervention.² While there are links in collegiate athletes,³ dancers,⁴ and even young figure
51 skaters⁵ between proprioception, stability, and injury, there is a gap in the literature for elite-level
52 figure skaters. Poor performance on dynamic balance tasks, such as the Y-balance test, has been
53 associated with increased risk of injury.⁶ In division I athletes and high school basketball players,
54 a decreased reach distance and asymmetry between limbs in the anterior direction was associated
55 with lower extremity injuries.^{6,7} When looking at elite female basketball players, posteromedial
56 and overall composite scores from the Y-balance test increased following neuromuscular training
57 leading to increased neuromuscular control and decreased distal injuries throughout the season.⁸
58 Strength, balance, power, and flexibility are only a few of the requirements while training and
59 competing as a figure skater. As skaters advance in technical difficulty, the intensity of training
60 and physical demands also increase. Due to the rise in physical demand, lower extremity injuries
61 are common in elite figure skaters.⁹ Many of those injuries, including patellofemoral pain² and
62 lumbar spine injury,¹⁰ have been linked to dysfunction of the lumbopelvic-hip complex and core
63 in other athletic populations.¹

64 Males and females have a documented disparity in contribution from the lumbopelvic-hip
65 complex during lower extremity movement, which can be predictive of future acute and chronic
66 lower extremity injury.¹⁰ Proximal hip musculature dysfunction, notably of the gluteus maximus
67 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
68 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,
70 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
72 increased incidence of low back pain and injury.

Differences in physiological characteristics based on landing and non-landing limbs may
74 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,
76 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
78 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
80 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
82 landings, such as increased lateral trunk flexion, may contribute to injuries such as
patellofemoral knee pain.

84 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
86 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.
88 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

90 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
92 landing and non-landing limbs of the individual athlete were not dependent on sex.

Methods

94 *Study Design*

This was a descriptive, cross-sectional study that compared lumbopelvic-hip endurance
96 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
98 participated in senior qualifying international competitions (considered “elite”). The variables
assessed included, Y-balance test performance, SLS and single leg squat jump (SLSJ)
100 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
102 deemed the protocol exempt and de-identified data were shared for statistical analysis only.

Participants

104 Forty members of the United States Figure Skating International Selection Pool ($23.21 \pm$
4.31) (20 females and 20 males) participated in this study. All skaters who participated were
106 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
108 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
110 reported.

Testing Procedures

112 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
114 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,
116 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
118 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
120 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
122 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
124 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
126 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
128 same examiner that administered all of the testing.

Participants performed 5 SLS, barefooted, with rest time between trials. During each
130 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
132 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,
134 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
136 displacement upon landing from the single leg jump. Two female participants did not complete
the task due to time restraints.

138 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
140 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
142 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
144 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
146 hold times were recorded in seconds for both limbs. Time was recorded using a standard athletic
stopwatch (seconds).

148 *Data Analysis*

Descriptive statistics were calculated from the recorded characteristics for all
150 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
152 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
154 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
156 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

158 between sex and discipline. Paired t-tests were used to analyze limb differences. Cohen's *d* effect
160 sizes between sexes were calculated for the Y-balance composite scores and unilateral hip bridge
endurance hold times.

Results

162 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
164 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
166 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
168 females maxed out at 120 seconds and 3 of these females maxed out at 120 seconds bilaterally
(Table 2).

170 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
172 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

174 The purpose of this study was to compare lumbopelvic-hip endurance and neuromuscular
176 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
178 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
180 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.

182 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
184 endurance and dynamic balance, however male skaters demonstrated limb asymmetry on hip
endurance.

186 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
188 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
190 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
192 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
194 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
196 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
198 dorsiflexion without the familiar support of the skating boot may lead to reduced anterior reach
performance in figure skaters.¹³

200 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
202 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

204 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
206 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.

208 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
210 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
212 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
214 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
216 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
218 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
220 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
222 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
224 performance of highly technical elements requiring increased landing stability, such as multiple
quadruple jumps.

226 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
228 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
230 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
232 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
234 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
236 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
238 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 hip²⁴ specifically
240 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
242 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
244 stabilization. This may also play a role in increasing rates of chronic low back injuries in figure
skating.²⁵

246 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,
248 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
250 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
252 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,
254 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,
256 including dorsiflexion/plantarflexion and lack of achilles flexibility, which may correlate with Y-
balance test performance.

258 **Conclusion**

The purpose of this study was to compare lumbopelvic-hip endurance and neuromuscular
260 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
262 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,
264 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
266 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
268 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
270 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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346

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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.

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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.

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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.

Online First