The Impact of Early Specialization on Ice Hockey Goaltender Hip Kinematics

Supplementary materials: https://doi.org/10.6084/m9.figshare.25749147.v1
For correspondence: meg.harrington@mail.utoronto.ca

Margaret S. Harrington[1], Courtney A. Hlady[2], and Timothy A. Burkhart[1]

[1]Faculty of Kinesiology and Physical Education, University of Toronto, Toronto, ON, Canada
[2]Department of Physical Therapy, University of Toronto, Toronto, ON, Canada

Please cite as: Harrington, M.S., Hlady, C.A., & Burkhart, T.A. (2024). The impact of early specialization on ice hockey goaltender hip kinematics. *SportRχiv*.

ABSTRACT

The purpose of this cross-sectional study was to compare hip kinematics between early specialized (ES) and not early specialized (NES) ice hockey goaltenders. This study included 13 ES and 13 NES goaltenders. Kinematics were quantified during common goaltender tasks (i.e., butterfly drops, power and butterfly slides) on a custom slide board using Theia3D markerless technology. The maximum and minimum hip flexion, adduction, and internal rotation angles were determined. The concurrent hip angles in the two other planes at these maximum and minimum positions were also extracted (e.g., adduction and internal rotation at maximum flexion). For discrete data, groups were compared using independent t-tests or Mann-Whitney U tests ($\alpha = 0.05$), dependent on normality. Statistical parametric mapping was used to compare the groups' hip angles over time. The ES goaltenders moved with increased hip internal rotation and abduction at lower hip flexion angles but with less internal rotation and abduction at higher flexion. Neither of the groups reached the expected extreme ranges of flexion, adduction, or internal rotation typically associated with the mechanical bony impingement of FAIS. The ES goaltenders may minimize large magnitudes of combined flexion and internal rotation or abduction as a pain avoidance mechanism in hips with FAIS or labral tears, or they developed advantageous hip control strategies to avoid abnormal hip contact mechanics that contribute to the development of these pathologies. This study also suggests that hip joint loading throughout internal rotation and abduction may be influential in goaltenders' increased risk of intra-articular hip injuries.

KEY POINTS

Findings Early specialized goaltenders minimized the combination of flexion and internal rotation or abduction during several tasks. Early and not early specialized goaltenders achieved ranges of motion that would correspond with increased labral strain but not the mechanical bony impingement associated with FAIS.

Implications Loading of hip joint structures at sub-maximal ranges of motion is an important consideration for future research on intra-articular hip injuries. When recommending to avoid early sports specialization based on injury risk, consideration of other sports participation should be made to avoid overloading specific structures.

Caution This cross-sectional design does not establish a causal relationship between early specialization, kinematics, and hip injuries.

INTRODUCTION

Approximately 69% of elite ice hockey goaltenders experience hip and groin issues,[1] with 36% of these resulting in altered training or performance.[1] Intra-articular hip injuries, such as femoroacetabular impingement syndrome (FAIS) and labral tears, are of particular concern, with incidence rates of 1.97 per 1000 player-game hours.[2] It has been suggested that the risk of intra-articular hip injuries in goaltenders is associated with repetitive loading of the joint structures at extreme ranges of motion, such as internal rotation during hip flexion (e.g., the butterfly position).[2–5]

Sport specialization in hockey has been correlated with more severe cam morphologies associated with FAIS[6] and poorer perceived hip and groin pain and function.[7] Sports specialization can be broadly defined as year-round participation in a single sport to focus on skill development in that specific sport.[8] Across hockey positions, goaltenders are one of the most sport-specialized.[9] It is suggested that increased cumulative loading, particularly pre-puberty, increases the risk of intra-articular hip injuries in early sport specialized goaltenders.[10] While sport specialization may negatively impact neuromuscular control and movement patterns,[8] the biomechanics of early specialized (ES) and not early specialized (NES) goaltenders have not been quantified.

Therefore, the purposes of this study were to: i) compare hip kinematics between ES and NES goaltenders during dynamic goaltending tasks; and ii) determine the relationship between hip kinematics and self-reported athletic hip function. We hypothesized that the ES goaltenders would demonstrate more hip flexion, adduction, and internal rotation, which corresponds with the potential for bone-on-bone impingement related to FAIS. In addition, more flexion, adduction, and internal rotation would correlate with poorer self-reported athletic hip function.

METHODS

Participants

Currently active goaltenders (at least once per week) between the ages of 16 and 25 years were recruited. Participants were excluded if they had: i) previous lower extremity or back surgery; ii) a lower extremity or back injury (excluding the hip or groin region) in the past six months; iii) a current hip or groin injury that prevented full participation in hockey training and competition; or iv) a concussion in the past six months. Participants signed an informed consent form to participate in the study before taking part.

A three-point sport specialization questionnaire was used that asked whether, before grade nine of high school, participants quit other sports to focus on hockey, trained more than eight months of the year in hockey, and considered ice hockey more important than other sports.[8] Responses were assigned one (yes) or zero (no) points,[8] and specialization status was categorized as low (0-1 points) or moderate to high (2-3 points).[8] Participants reported at what age they started playing hockey as full-time goaltenders. Hockey Canada's recent development pathway recommends that players should not specialize as goaltenders if they are under nine years old.[11] Therefore, for this study, goaltenders were categorized as ES if they began playing hockey as a goaltender full-time before the age of nine years and were rated as moderate to high specialization by grade nine.

Years of goaltender experience and current and highest level of hockey participation were categorized as recreational (e.g., house league), minor league (e.g., U18 B-AAA, Junior C-A), or major league competitive (e.g., major junior, college, professional). Participants also completed the Kerlan-Jobe Orthopaedic Clinic (KJOC) Athletic Hip Score to measure their subjective athletic hip and groin function.[12] The KJOC questionnaire asked participants to report current hip or groin trouble, previous treatment received for their hip or groin, and missed game or practice time in the last year due to a hip injury.[12]

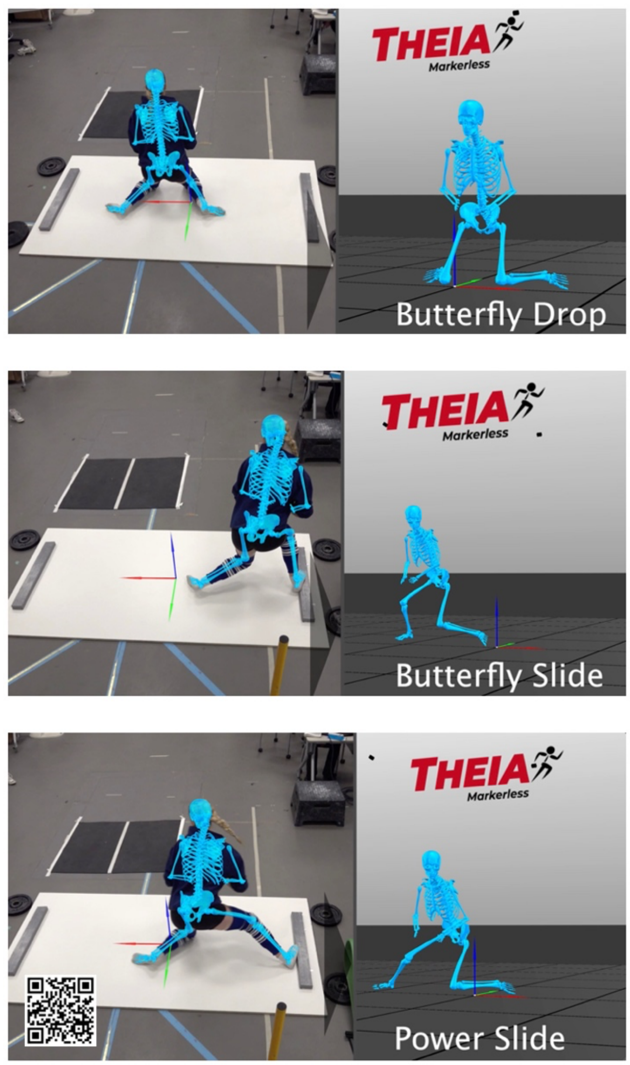

FIGURE 1. Participant performing a butterfly drop, butterfly slide, and power slide on slide board with skeletal model overlay generated using Theia3D. To watch the video of the tasks, scan QR code or access with this link: https://youtu.be/BsBN6NPs5gE

Sample size calculation.

A sample size calculation was performed using G*power statistical software (G*Power; Kiel Germany) based on data from similar kinematic studies that compared hip kinematics between athletes and non-athletes (13) and between healthy controls and athletes with a hip disorder (14). A two-tailed independent t-test with power and alpha set at 0.80 and 0.05, respectively was used. The calculations suggested that a sample size of 10 and 13 would be sufficient to achieve significant differences between groups with large effect sizes (1.38 and 1.19, respectively). Therefore, we collected data from a total of 26 participants (13 per group).

Data Collection

Eight synchronized Sony RX0 II cameras (Sony Corporation, Japan) collected two-dimensional video data at a frame rate of 120 Hz for markerless motion analysis. The tasks were performed on a custom slide board (122x244 cm, gloss-finish laminate sheet) to allow for the simulated performance of on-ice tasks (FIGURE 1). Participants performed the goaltending tasks while wearing knee pads covered with hockey socks to prevent discomfort during kneeling positions.

Each participant performed three trials of: i) butterfly drop – starting in the standing ready position, drop into the butterfly; ii) butterfly slide – starting in the standing ready position with their foot against the bumper to push off of, slide laterally; and iii) power slide – participants began in a half-butterfly position with the foot of their knee-up leg against the bumper, were then instructed to push off the bumper to slide laterally. Each task ended with the participant in the butterfly position and the slides were completed in the direction of both their catcher and blocker side (FIGURE 1). Participants were instructed to perform the tasks as fast and comfortably as possible and to maintain control throughout (i.e., facing forward).

Data Processing

The videos were processed using Theia3D software (Theia Markerless Inc., Canada) and imported into Visual3D (C-Motion Inc., USA), where the data were filtered with a generalized, cross-validatory spline function (predicted mean squared error of 10 mm^2).[13,14] Inverse kinematic analysis was used to calculate 3D hip joint angles over time. An automatic, velocity-based threshold of ±0.1 m/s for the pelvis segment (in the primary direction of movement) was established to identify the initiation and completion of the movement cycle for all trials.[15] The kinematics were time-normalized to 100% of the movement cycle.

For each trial, and both hips, the minimum and maximum flexion, adduction, and internal rotations were extracted. In addition, the concurrent hip angles in the two other planes at the time of the maximum and minimum angles were extracted. For example, at maximum hip flexion, the corresponding hip adduction angle and internal rotation angles were retrieved. This allowed for analysis of the relationship between hip motion in each plane at the end ranges of motion. The discrete data were averaged across each participant's three trials for statistical analysis.

Statistical Analysis

Normality of the data was checked by examining the Shapiro-Wilk tests and the skewness and kurtosis *Z*-scores.[16] Differences between the ES and NES groups' continuous participant characteristics were evaluated using independent *t*-tests or Mann-Whitney *U* tests, dependent on normality. In addition, Chi-Square analyses or Fisher's exact tests, based on expected counts, were used to determine differences between the groups for categorical data. Independent *t*-tests or Mann-Whitney *U* tests were also used to determine statistically significant differences in the hip kinematics between the groups at each of the maximum and minimum angles, as well as the concurrent hip angles in the other two planes at these time points. Post-hoc effect sizes were quantified for both independent *t*-tests (Cohen's *d;* small <0.2, medium <0.5, large <0.8)[17] and the Mann-Whitney *U* statistics (small <0.3, medium <0.5, large >0.8)[17] and all discrete statistical analyses were performed in SPSS (V.29; IBM Corporation, USA) with alpha set at 0.05.

Statistical parametric mapping (SPM) was used to compare joint angles over the task cycles (averaged across each participant's three trials) between the ES and NES groups.[18] The SPM analyses were performed in MATLAB (V.2022a, MathWorks Inc., USA) and statistical significance was achieved when the output SPM{t} exceeded the critical threshold (p <0.05).

A multivariate linear regression, with a forward selection approach, was used for exploratory analysis to determine the variables that best estimated the KJOC scores. The biomechanical inputs were maximum flexion, adduction, and internal rotation angles, and the concurrent angles in the other two planes at each maximum.[3] Additional input variables were sex, age, anthropometrics, years of experience, current level, and highest level of play. Multi-collinearity was assessed using the tolerance (>0.1) and variance inflation factor (VIF) (<10) for each variable in the final model.[19]

TABLE 1 Participant characteristics

	Early Specialized	Not Early Specialized	*p*
Participants, n	13	13	
Sex, n			
Female	2	4	0.645
Male	11	9	
Age, y	19.2 (2.5)	19.7 (2.3)	0.568
Body mass, kg	75.5 (12.4)	72.8 (13.1)	0.739
Height, m	1.76 (0.12)	1.75 (0.11)	0.607
Body mass index, kg/m^2	24.3 (3.0)	23.7 (3.2)	0.798
Experience, y	12.5 (2.1)	8.7 (2.7)	<0.001*
Current Level, n			
Recreational	3	5	0.010*
Competitive - Minor	10	3	
Competitive - Major	0	5	
Highest Level, n			
Recreational	0	1	0.020*
Competitive - Minor	13	7	
Competitive - Major	0	5	
KJOC Athletic Hip Score	86.8 (11.7)	76.3 (18.9)	0.103
Prev. hip/groin treatment, n	5	4	1.00
Missed iced in last year, n	0	2	0.480
Current hip/groin trouble, n	3	2	1.00

Data refers to frequency or mean (SD). *Significant difference determined by independent *t*-tests for continuous data or Chi-Square analyses for categorical. KJOC: Kerlan-Jobe Orthopaedic Clinic.

Results

Participants

Twenty-six goaltenders were included in this study. There were no statistical differences between the groups with respect to age, body mass, height, body mass index, or proportion of males and females (TABLE 1). There was a significant difference in respect to years of experience as a goaltender, with the ES group having 3.8 years more experience than the NES group (*p* <0.001, *d* = 1.58). The proportion of goaltenders' levels of competition was significantly different between ES and NES groups for both current level (*p* = 0.010) and highest level of play (*p* = 0.020) (TABLE 1). There were no significant differences between the groups for the KJOC, frequencies of previous hip treatment, missed ice time, or current hip trouble (TABLE 1).

Maximum and Minimum Hip Angles

The ES group demonstrated 5.9° of additional blocker-side hip flexion during the butterfly slide toward the catcher side (*p* = 0.047, *d* = 0.83) and 8.2° greater minimum catcher-side hip flexion angles during the power slide towards the catcher direction (*p* = 0.029, *r* = -0.43) (TABLE 2). There was 3.5° less blocker-side minimum hip adduction during the power slide in the blocker direction for the ES compared to the NES groups (*p* = 0.033, *r* = -0.42).

Concurrent 3D Hip Angles

With respect to the concurrent kinematics at maximum hip flexion, there was 5.2° less blocker-side hip internal rotation at maximum hip flexion in the ES compared to the NES group (*p* = 0.031, *d* = 0.90) during the butterfly drop (TABLE 2). In addition, during the butterfly slide to the catcher side, the ES group had significantly lower internal rotation at maximum blocker-side hip flexion by 3.2° (*p* = 0.041, *d* = 0.85).

At minimum flexion during the butterfly slide to the blocker side, the ES group demonstrated significantly greater catcher-side hip internal rotation compared to the NES group by 4.5° (*p* = 0.048, *d* = 0.82) (TABLE 2). Furthermore, at minimum hip flexion, the ES group had greater blocker-side hip abduction during the butterfly slide to the blocker side by 4.7° (*p* = 0.023, *d* = 0.95) and the power slide to the catcher side by 7.8°, (*p* = 0.028, *d* = 0.92), and 9.5° greater catcher-side hip abduction during the butterfly slide to the catcher side (*p* = 0.021, *d* = 0.97).

During the butterfly slide to the blocker side, the ES group had 16.3° greater catcher-side hip flexion at maximum adduction compared to the NES group (*p* = 0.032, *d* = 0.89). There was also significantly greater blocker-side hip abduction at maximum internal rotation for the ES versus the NES group by 10.4° (*p* = 0.016, *d* = 1.02) during the butterfly slide to the blocker side.

Table 2 Mean (SD) concurrent hip angles (°) at end ranges for catcher side and blocker side hips. Early specialized (ES) and not early specialized (NES) goaltenders performed sides laterally to both the catcher direction (CD) and blocker direction (BD).

		Flexion (+)		Adduction (+)		Internal Rotation (+)	
		Blocker hip	Catcher hip	Blocker hip	Catcher hip	Blocker hip	Catcher hip
At max flexion							
Butterfly	ES	60.8 (11.1)	61.1 (11.0)	-15.8 (4.3)	-17.2 (5.7)	**6.0 (5.8)[a]**	7.0 (5.9)
	NES	54.4 (11.4)	55.0 (11.9)	-13.0 (7.8)	-16.9 (7.4)	**11.2 (5.7)**	7.4 (4.7)
Butterfly slide (CD)	ES	**76.6 (8.5)[a]**	53.4 (14.9)	-9.3 (4.4)	-15.5 (6.3)	**6.7 (2.9)[a]**	10.3 (4.4)
	NES	**70.7 (5.3)**	53.8 (12.2)	-8.4 (4.4)	-15.7 (5.8)	**10.0 (4.5)**	9.1 (4.3)
Butterfly slide (BD)	ES	55.0 (10.2)	75.9 (8.2)	-14.5 (6.7)	-10.3 (3.8)	7.6 (5.2)	8.1 (3.4)
	NES	52.7 (15.5)	74.4 (7.9)	-12.9 (10.4)	-12.8 (7.2)	11.0 (8.2)	6.1 (3.7)
Power slide (CD)	ES	72.6 (13.9)	50.1 (8.6)	-8.6 (9.5)	-15.9 (7.4)	9.0 (7.3)	16.8 (6.4)
	NES	68.6 (10.6)	47.6 (12.1)	-3.6 (7.0)	-14.1 (10.1)	10.2 (5.3)	13.7 (6.5)
Power slide (BD)	ES	49.4 (7.6)	73.5 (10.4)	-11.0 (7.0)	-12.0 (9.0)	13.7 (8.2)	11.3 (5.0)
	NES	48.9 (13.0)	75.0 (7.9)	-10.8 (9.3)	-6.8 (4.1)	14.0 (5.8)	8.9 (4.9)
At min flexion							
Butterfly	ES	39.2 (7.1)	39.1 (6.6)	-6.8 (5.4)	-10.8 (5.0)	19.1 (5.1)	19.1 (5.4)
	NES	36.5 (9.1)	37.7 (9.1)	-5.7 (6.6)	-9.6 (4.1)	17.2 (7.8)	15.2 (7.1)
Butterfly slide (CD)	ES	41.3 (6.7)	34.7 (9.0)	-13.8 (7.9)	**-30.9 (8.2)[a]**	14.8 (6.1)	17.4 (5.4)
	NES	34.9 (11.5)	29.6 (10.4)	-8.8 (5.2)	**-21.4 (11.2)**	13.6 (6.3)	13.6 (7.9)
Butterfly slide (BD)	ES	32.5 (6.7)	41.0 (6.8)	**-30.2 (3.4)[a]**	-13.8 (6.5)	15.1 (7.2)	**17.2 (3.8)[a]**
	NES	28.5 (10.8)	35.0 (10.5)	**-25.5 (6.1)**	-10.8 (6.5)	14.9 (6.3)	**12.7 (6.8)**
Power slide (CD)	ES	39.0 (7.4)	**41.7 (7.7)[a]**	**-12.4 (10.3)[a]**	-15.5 (8.4)	16.1 (6.8)	16.0 (6.4)
	NES	33.4 (13.5)	**33.4 (10.8)**	**-4.6 (6.2)**	-10.6 (5.9)	14.7 (8.8)	13.6 (7.2)
Power slide (BD)	ES	40.0 (9.1)	42.8 (8.1)	-9.4 (6.3)	-12.0 (4.2)	13.0 (6.9)	15.7 (6.0)
	NES	31.8 (11.8)	35.9 (12.8)	-11.0 (6.9)	-7.8 (6.2)	14.4 (5.9)	16.2 (6.1)
At max adduction							
Butterfly	ES	43.1 (10.0)	45.2 (13.7)	-5.8 (5.4)	-9.8 (5.0)	17.1 (7.1)	15.6 (8.5)
	NES	40.9 (7.9)	40.7 (10.0)	-3.0 (6.3)	-7.2 (4.7)	16.4 (6.0)	14.7 (4.9)
Butterfly slide (CD)	ES	64.7 (18.8)	42.7 (10.4)	-4.2 (3.3)	-8.3 (5.1)	5.4 (6.5)	14.9 (5.0)
	NES	55.3 (15.9)	40.4 (12.8)	-3.7 (3.5)	-6.2 (4.6)	8.2 (6.0)	14.3 (7.5)
Butterfly slide (BD)	ES	44.2 (7.2)	**65.0 (16.8)[b]**	-3.9 (7.6)	-6.1 (3.9)	13.4 (5.8)	6.9 (5.9)
	NES	43.0 (15.4)	**48.6 (19.6)**	-1.5 (5.8)	-6.8 (5.2)	13.3 (6.4)	9.9 (6.0)
Power slide (CD)	ES	57.9 (20.5)	46.6 (8.9)	-1.7 (6.0)	-4.6 (3.8)	11.1 (7.1)	16.3 (4.7)
	NES	55.5 (14.1)	38.5 (10.9)	1.4 (4.6)	-2.6 (3.0)	13.0 (5.3)	14.0 (6.6)
Power slide (BD)	ES	45.4 (9.3)	60.9 (15.4)	0.3 (5.3)	-6.5 (6.3)	14.2 (7.3)	13.8 (6.7)
	NES	41.5 (14.5)	58.1 (22.3)	0.8 (3.9)	-3.0 (3.9)	13.5 (5.4)	11.9 (4.3)
At min adduction							
Butterfly	ES	58.9 (12.1)	56.8 (8.9)	-17.6 (4.0)	-19.7 (4.6)	6.3 (5.8)	7.8 (7.0)
	NES	50.5 (14.7)	51.9 (14.7)	-16.1 (4.4)	-18.8 (4.5)	8.6 (5.6)	7.4 (5.2)
Butterfly slide (CD)	ES	58.4 (7.6)	36.3 (8.6)	-27.4 (6.8)	-32.6 (6.8)	17.0 (5.5)	16.5 (6.1)
	NES	54.7 (7.2)	34.0 (10.8)	-28.9 (7.4)	-29.6 (3.8)	18.5 (5.2)	12.4 (4.6)
Butterfly slide (BD)	ES	34.9 (6.1)	59.2 (7.1)	-31.9 (3.8)	-30.5 (7.7)	15.1 (6.6)	15.9 (4.7)
	NES	32.3 (13.1)	57.3 (6.5)	-29.6 (4.1)	-30.6 (6.3)	12.5 (6.1)	12.5 (7.5)
Power slide (CD)	ES	50.9 (6.2)	45.5 (8.2)	-29.9 (10.9)	-27.0 (6.5)	18.7 (5.4)	16.8 (6.3)
	NES	50.5 (9.1)	42.3 (11.6)	-28.5 (4.6)	-27.1 (5.0)	20.8 (5.8)	10.5 (9.4)
Power slide (BD)	ES	45.3 (8.2)	54.9 (6.6)	**-22.7 (4.1)[b]**	-33.5 (8.7)	12.2 (8.0)	17.1 (5.7)
	NES	41.3 (11.7)	55.9 (7.8)	**-26.1 (3.5)**	-30.0 (5.1)	8.3 (6.4)	16.3 (8.4)

Continued

Table 2 Continued

		Flexion (+)		Adduction (+)		Internal Rotation (+)	
		Blocker hip	Catcher hip	Blocker hip	Catcher hip	Blocker hip	Catcher hip
At max internal rotation							
Butterfly	ES	41.9 (8.3)	43.3 (7.3)	-6.8 (5.2)	-11.6 (5.1)	19.7 (5.0)	20.4 (4.7)
	NES	38.4 (8.7)	40.2 (9.4)	-5.0 (6.7)	-9.0 (4.7)	18.5 (6.2)	16.7 (5.7)
Butterfly slide (CD)	ES	50.9 (10.4)	41.6 (10.0)	-23.6 (9.7)	-19.8 (8.7)	19.2 (5.1)	20.0 (5.3)
	NES	48.7 (12.9)	39.8 (12.3)	-21.9 (10.1)	-16.5 (9.1)	21.4 (4.6)	18.3 (5.7)
Butterfly slide (BD)	ES	37.3 (8.0)	48.4 (8.7)	**-23.8 (11.0)[b]**	-20.1 (7.4)	19.5 (4.5)	21.2 (4.4)
	NES	38.5 (9.2)	47.3 (11.3)	**-13.4 (9.4)**	-18.1 (8.8)	19.8 (5.0)	17.7 (6.0)
Power slide (CD)	ES	49.2 (11.9)	46.0 (8.1)	-22.7 (10.4)	-16.2 (6.0)	21.6 (5.3)	20.5 (5.6)
	NES	46.5 (10.2)	41.0 (11.8)	-19.7 (8.7)	-14.5 (8.5)	24.1 (7.0)	17.9 (6.8)
Power slide (BD)	ES	45.4 (8.6)	50.2 (6.9)	-10.1 (5.3)	-19.3 (7.6)	18.2 (6.6)	23.0 (5.1)
	NES	42.7 (13.8)	46.0 (11.5)	-8.9 (6.6)	-14.4 (7.8)	19.0 (5.7)	23.1 (6.6)
At min internal rotation							
Butterfly	ES	58.9 (12.5)	57.9 (14.0)	-16.0 (4.0)	-16.8 (6.7)	4.5 (5.1)	2.9 (3.4)
	NES	50.0 (14.5)	49.5 (9.8)	-14.3 (6.3)	-16.0 (6.7)	7.1 (5.0)	5.5 (4.5)
Butterfly slide (CD)	ES	63.5 (12.4)	48.5 (15.9)	-8.7 (5.6)	-18.2 (10.6)	0.7 (4.3)	8.1 (3.4)
	NES	55.5 (15.6)	43.6 (14.7)	-8.0 (3.7)	-17.2 (9.0)	3.8 (3.9)	5.7 (5.0)
Butterfly slide (BD)	ES	48.6 (12.3)	66.0 (11.8)	-14.2 (11.0)	-9.1 (5.3)	6.4 (5.6)	3.7 (3.5)
	NES	45.9 (17.4)	63.5 (15.2)	-14.8 (10.3)	-12.6 (6.2)	6.4 (6.1)	3.4 (3.4)
Power slide (CD)	ES	63.6 (21.3)	45.5 (8.1)	-6.8 (7.8)	-14.6 (7.9)	6.7 (6.8)	12.9 (5.9)
	NES	56.0 (20.0)	39.8 (12.4)	-4.3 (5.8)	-18.5 (11.1)	8.1 (6.5)	8.2 (8.0)
Power slide (BD)	ES	44.0 (9.0)	63.9 (17.6)	-15.7 (8.6)	-10.1 (8.6)	10.0 (8.0)	9.0 (4.5)
	NES	39.5 (11.7)	69.3 (16.7)	-19.8 (8.4)	-8.0 (6.1)	6.5 (5.6)	7.2 (4.4)

Significant difference (bold) between groups at $P < 0.05$ determined with independent *t*-test ([a]) or Mann-Whitney *U* test ([b]).

Hip Angles Across Movement Cycles

There was a significant increase in the catcher-side hip internal rotation in the ES compared to the NES group between 58-70% of the butterfly drop movement cycle ($p = 0.032$) (FIGURE 2F). In addition, during the butterfly slide to the catcher side, the ES group had significantly less blocker-side hip internal rotation compared to the NES group between 9-17% of the cycle ($p = 0.040$) (FIGURE 2I) and significantly more catcher-side hip abduction between 54-62% of the movement ($p = 0.036$) (FIGURE 2K). There were no significant differences between groups for the power slide to the catcher side (FIGURE 2) or the butterfly slide and power slide to the blocker side (see SUPPLEMENTAL FILE 1, FIGURE S1 and S2).

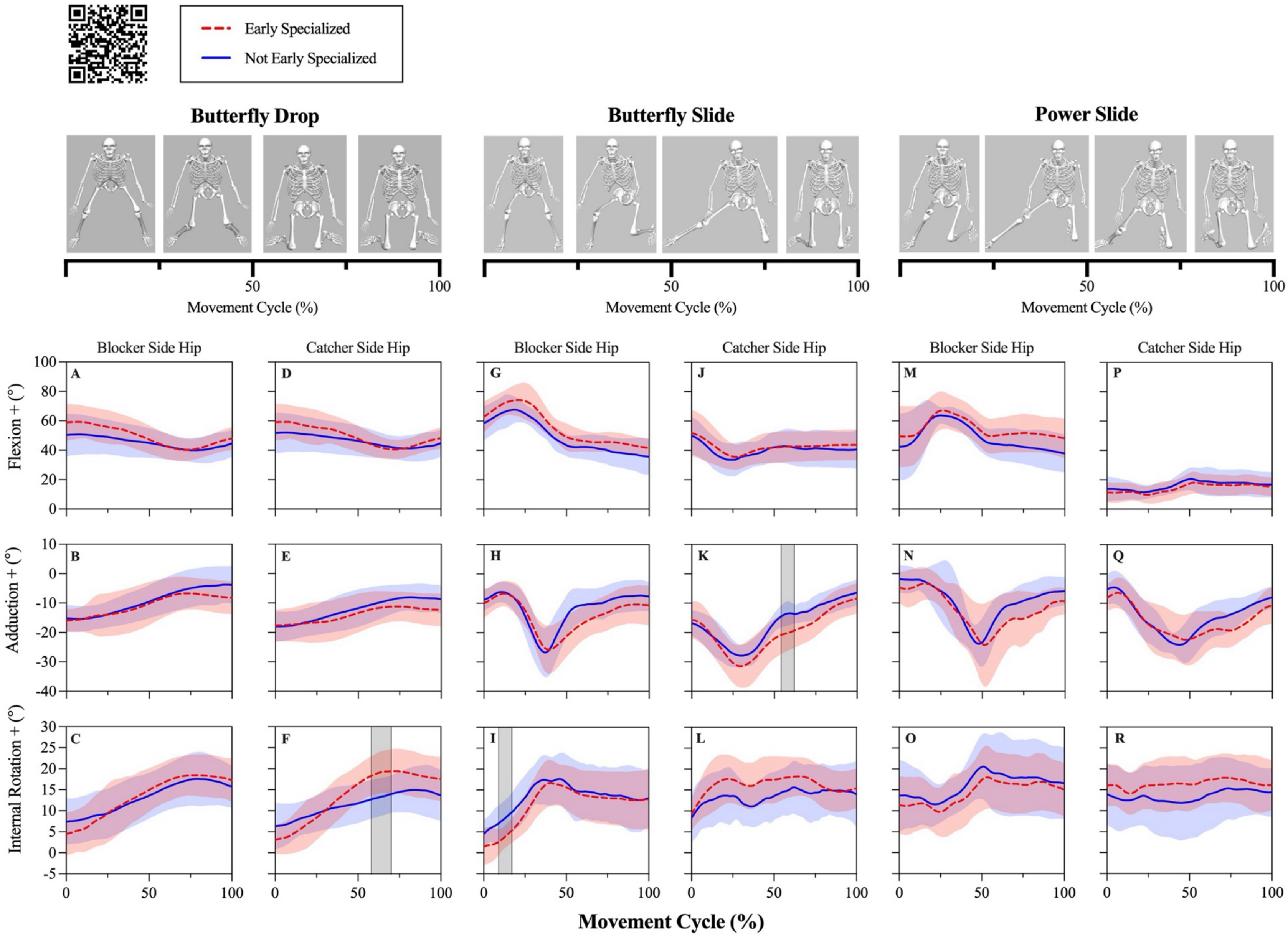

FIGURE 2. Mean (SD) hip angles for butterfly drop (A-F), butterfly slide to catcher side (G-L), and power slide to catcher side (M-R) with movement cycle examples. Gray columns indicate significant difference using statistical parametric mapping. To watch the animated figure, scan QR code or access with this link: https://youtu.be/Z5EPXae7cGE?feature=shared

Self-Perceived Athletic Hip Function

A five-variable multivariate linear regression model was identified that best estimated the KJOC athletic hip score (R^2 = 0.846; F(5,20) = 28.47, p <0.001; Tolerance = 0.57-0.93, VIF = 1.25-1.69) (TABLE 3). Maximum catcher-side hip abduction during the power slide to the blocker side, blocker-side hip internal rotation at maximum flexion during the butterfly slide to the catcher side, playing major competitive hockey as the highest level of competition, and years of experience as a goaltender were negatively correlated with the KJOC scores (TABLE 3). Blocker-side hip adduction at maximum internal rotation during the butterfly slide to the blocker side was positively correlated with the KJOC.

Table 3 Regression results of goaltender characteristics and hip biomechanics on KJOC Athletic Hip Score.

Variable	B [95% CI]	SE	β	p	Tolerance	VIF	*Adj. R^2*
(Constant)	83.31 [65.50, 101.13]	8.54		< 0.001			0.846
Highest level – major competition	-30.40 [-39.21, -21.59]	4.22	-0.75	< 0.001	0.57	1.76	
Power slide (BD) max catcher hip abduction	-1.01 [-1.39, -0.63]	0.18	-0.45	< 0.001	0.93	1.07	
Butterfly slide (BD) blocker hip adduction at max IR	0.36 [0.08, 0.64]	0.13	0.25	0.014	0.72	1.38	
Years of experience	-1.24 [-2.15, -0.32]	0.44	-0.23	0.011	0.89	1.12	
Butterfly slide (CD) blocker hip IR at max flexion	-0.98 [-1.78, -0.18]	0.38	-0.25	0.019	0.67	1.50	

KJOC: Kerlan-Jobe Orthopaedic Clinic; BD: blocker direction; IR: internal rotation; CD: catcher direction; B: unstandardized coefficients; CI: confidence interval; SE: standard error for B; β: standardized coefficients; VIF: variance inflation factor; adj: adjusted.

Discussion

This study aimed to compare hip kinematics between ES and NES goaltenders and to determine if there is a relationship between hip kinematics and self-reported athletic hip function. The most important finding of this study was that the ES goaltenders moved with greater hip internal rotation and abduction at lower hip flexion angles but with lower internal rotation and abduction at a higher hip flexion compared to the NES group. In addition, neither of the groups demonstrated the expected end ranges of flexion, adduction, or internal rotation typically associated with the mechanical bony impingement of FAIS.

There were inverse relationships between hip flexion and internal rotation, as well as flexion and abduction in ES goaltenders. They demonstrated significantly greater internal rotation and abduction angles compared to the NES group when hip flexion angles were lower. However, the ES group showed less internal rotation and abduction angles at higher hip flexion angles. These results may indicate that the ES group are minimizing the combined flexion and internal rotation or abduction as a pain avoidance mechanism in hips with intra-articular pathologies.[20] However, this may also be an indication that these goaltenders have developed improved hip joint control during these movements to minimize the abnormal hip contact mechanics that contribute to the development of these pathologies.[21,22] This theory of avoidance vs. adaption and the range of motion the goaltenders displayed raises questions about the role of extreme motions and bony impingement in intra-articular hip injuries in goaltenders.

In the current investigation, the goaltenders did not approach the expected end ranges of motion that would cause bone-on-bone impingement, which has traditionally been associated with the development and progression of FAIS.[23,24] The current results are consistent with previous work that quantified on-ice kinematics during skating, butterfly save, and recovery.[3] Previous studies have shown that impingement occurs at 36° of internal rotation when the hip is flexed and abducted to 35° and 10°, respectively.[25] In neutral adduction, bony impingement occurred with an average of 48° of internal rotation at 45° of flexion and 29° of internal rotation at 90° of flexion.[26] The mean maximum internal rotation achieved by the goaltenders in the current study was 23° at 50° of flexion and 19° of abduction for the ES and 24° at 47° of flexion and 20° of abduction for the NES goaltenders. Given that the goaltenders were not achieving the end-ranges of motion, it is likely that the mechanical limitations did not cause the movement pattern differences shown between the groups.

Loading of the hip joint structures at sub-maximal ranges of motion may play an important role in a goaltenders' increased risk of intra-articular hip injuries. Previous research has demonstrated that combined abduction and internal rotation at 90° of flexion result in the greatest anterior labrum strain compared to other hip positions.[27] Labral strains have also been demonstrated to increase when hip abduction is between 20° and 40°.[28] Thus, ES goaltenders may have adapted motion strategies that minimize the combination of flexion and internal rotation or abduction, to reduce loading on the labrum, a commonly injured structure in goaltenders.[2]

The exploratory regression analysis supported the importance of internal rotation and abduction. Decreased self-reported athletic hip function scores were associated with increased hip internal rotation at maximum flexion during the butterfly slide and increased hip abduction during the power slide. In addition to the biomechanics, other goaltender characteristics corresponded with hip function. For example, higher competition level and years of experience negatively correlated with hip function. Both of these scenarios often require more intense and frequent training which can increase the cumulative stress on the hip, and may explain the correlation with poorer hip function scores.

Research and Policy Implications

The research presented here suggests that goaltending movements likely increase the stresses experienced by the labrum, cartilage, and joint capsule ligaments and transfer them onto the bony attachments. In addition, premature bony impingement at extreme ranges of motion may not be the primary risk factor for intra-articular hip injuries and symptoms, as suggested previously. Therefore, when avoiding early specialization based on injury risk, careful attention should also be paid to the additional sports and activities that NES athletes participate in to ensure the movement patterns are diverse enough to avoid overloading specific structures. The exploratory regression analysis also highlights the importance of considering a multi-variate approach to researching athlete injury risk.

Strengths and Limitations

The current study is among the first to investigate the effect of early sport specialization on how goaltenders move and how this is linked to hip function. The novel use of markerless motion capture of goaltending tasks simulated on a slide board overcame challenges of traditional marker-based techniques (e.g., markers falling off or being occluded by protective equipment) and generated new insights into the kinematic demands of goaltender movements.

There are several limitations to acknowledge. Only active goaltenders were included, which may have excluded goaltenders who stopped playing due to injuries. Also, it is important to note there are different early specialization classification systems may affect categorization. The method used in this study is consistent with established literature,[8] Hockey Canada guidelines,[11] and a recent consensus statement.[29] Furthermore, clinical measures of hip and groin function (e.g., mobility tests, medical imaging) were not performed; thus, we cannot determine whether the kinematic differences may be related to the presence of hip pathologies. Lastly, we need to establish the generalizability of the tasks simulated on the slide board to on-ice kinematics.

Conclusion

The inverse relationships between hip flexion and internal rotation, and flexion and abduction in ES goaltenders suggest that they may have developed strategies to deal with potential pathological changes of the hip joint structures. However, it is unclear whether this is a pain avoidance mechanism in hips with FAIS or labral tears, or if they developed advantageous hip control strategies to avoid abnormal hip contact mechanics that contribute to the development of these pathologies. Finally, this study showed that the goaltenders did not approach their expected end ranges of motion, suggesting that hip joint loading throughout internal rotation and abduction may also be influential in goaltenders' increased risk of intra-articular hip injuries.

Contributions

Conceptualization: MSH and TAB. Methodology: MSH. Software: MSH. Formal analysis: MSH, Investigation: MSH and CAH. Resources: MSH, CAH, and TAB. Data curation: MSH. Writing – original draft: MSH. Writing – review & editing: MSH, CAH, and TAB. Visualization: MSH. Supervision: MSH and TAB. Project administration: MSH and TAB. Funding acquisition: TAB.

Acknowledgements

We would like to thank Sachin Raina for promoting this study and helping to acquire funding for this work. We also would like to thank Anna May for assistance with data collection. Lastly, we would like to thank all the coaches and hockey organization members that supported us in recruiting participants.

This research was funded by Maple Leaf Sports & Entertainment (72086009) the Natural Sciences and Engineering Research Council of Canada (RGPIN-2019-05340). CAH was supported by a University of Toronto Research Excellence Award in natural sciences and engineering.

Data and Supplementary Material Accessibility

Data are available upon reasonable request to the corresponding author.

REFERENCES

1. Wörner T, Clarsen B, Thorborg K, Eek F. Elite Ice Hockey Goalkeepers Have a High Prevalence of Hip and Groin Problems Associated With Decreased Sporting Function: A Single-Season Prospective Cohort Study. *Orthop J Sports Med* 2019;7: 2325967119892586.
2. Epstein DM, McHugh M, Yorio M, Neri B. Intra-articular hip injuries in national hockey league players: A descriptive epidemiological study. *Am J Sports Med* 2013;41:343-8.
3. Whiteside D, Deneweth JM, Bedi A, Zernicke RF, Goulet GC. Femoroacetabular impingement in elite ice hockey goaltenders: Etiological implications of on-ice hip mechanics. *Am J Sports Med* 2015;43:1689-97.
4. Doran C, Pettit M, Singh Y, Sunil Kumar KH, Khanduja V. Does the Type of Sport Influence Morphology of the Hip? A Systematic Review. *Am J Sports Med* 2022;50:1727-41.
5. Stull JD, Philippon MJ, Laprade RF. "at-Risk" Positioning and Hip Biomechanics of the Peewee Ice Hockey Sprint Start. *Am J Sports Med* 2011;39 Suppl:29S-35S.
6. Nguyen M, Bixby S, Yen YM, Miller P, Stracciolini A. Moderate and High Sport Specialization Level in Ice Hockey Athletes Is Associated With Symptomatic Cam Deformity. *Sports Health* 2023;15:753-9.

7. Sheppard M, Nicknair J, Goetschius J. Early sport specialization and subjective hip and groin dysfunction in collegiate ice hockey athletes. *J Athl Train* 2020;55:232-7.
8. Jayanthi NA, Labella CR, Fischer D, Pasulka J, Dugas LR. Sports-specialized intensive training and the risk of injury in young athletes: A clinical case-control study. *Am J Sports Med* 2015;43:794-801.
9. Winans M, Biese KM, Rudek G, Renner MN, Stamm JM, Bell DR. The Association of Sport Specialization With Youth Ice Hockey Position and Youth Ice Hockey Parents' Perceptions of Sport Specialization. *Int J Athl Ther Train* 2023;28:303-7.
10. Philippon MJ, Ho CP, Briggs KK, Stull J, Laprade RF. Prevalence of increased alpha angles as a measure of cam-type femoroacetabular impingement in youth ice hockey players. *Am J Sports Med* 2013;41:1357-62.
11. Hockey Canada. Goaltending Pathway 2022-2023. 2022. Available: https://www.hockeycanada.ca/en-ca/hockey-programs/players/essentials/positions-skills/goaltenders [Accessed 01 Jan 2024].
12. Papaliodis DN, Banffy MB, Limpisvasti O, *et al*. The Development and Validation of a Subjective Assessment Tool for the Hip in the Athletic Population. *Am J Sports Med* 2017;45:2517-23.
13. Jónasson P, Thoreson O, Sansone M, *et al*. The morphologic characteristics and range of motion in the hips of athletes and non-athletes. *J Hip Preserv Surg* 2016;3:325-32.
14. Vasavada K, Ross KA, Lott A, *et al*. Characterizing femoroacetabular impingement in professional Nordic Skiers. *Phys Sportsmed* 2023;51:285-90.
15. Zin MAM, Rambely AS, Ariff NM, Ariffin MS. Smoothing and differentiation of kinematic data using functional data analysis approach: An application of automatic and subjective methods. *Appl Sci (Basel)* 2020;10:2493.
16. Woltring HJ. A Fortran package for generalized, cross-validatory spline smoothing and differentiation. *Adv Eng Softw* 1986;8:104-14.
17. Ghoussayni S, Stevens C, Durham S, Ewins D. Assessment and validation of a simple automated method for the detection of gait events and intervals. *Gait Posture* 2004;20:266-72.
18. Ghasemi A, Zahediasl S. Normality tests for statistical analysis: A guide for non-statisticians. *Int J Endocrinol Metab* 2012;10:486-9.
19. Field A. *Discovering Statistics Using IBM SPSS Statistics.* 5th ed. Sage Publications; 2018.
20. Pataky TC. Generalized n-dimensional biomechanical field analysis using statistical parametric mapping. *J Biomech* 2010;43:1976-82.
21. Kim JH. Multicollinearity and misleading statistical results. *Korean J Anesthesiol* 2019;72:558-69.
22. Diamond LE, Dobson FL, Bennell KL, Wrigley T V., Hodges PW, Hinman RS. Physical impairments and activity limitations in people with femoroacetabular impingement: A systematic review. *Br J Sports Med* 2015;49:230-42.
23. Barfield JW, Oliver GD. Sport specialization and single-legged-squat performance among youth baseball and softball athletes. *J Athl Train* 2019;54:1067-73.
24. Reiman MP, Matheson JW. Restricted hip mobility: clinical suggestions for self-mobilization and muscle re-education. *Int J Sports Phys Ther* 2013;8:729-40.

25. Ganz R, Parvizi J, Beck M, Leunig M, Nötzli H, Siebenrock KA. Femoroacetabular Impingement: A Cause for Osteoarthritis of the Hip. *Clin Orthop Relat Res* 2003;417:112-20.
26. Griffin DR, Dickenson EJ, O'Donnell J, *et al*. The Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement. *Br J Sports Med* 2016;50:1169-76.
27. Patel R V., Han S, Lenherr C, Harris JD, Noble PC. Pelvic Tilt and Range of Motion in Hips With Femoroacetabular Impingement Syndrome. *J Am Acad Orthop Surg* 2020;28:e427-e432.
28. Han S, Owens VL, Patel RV, *et al*. The continuum of hip range of motion: From soft-tissue restriction to bony impingement. *J Orthop Res* 2020;38:1779-86.
29. Safran MR, Giordano G, Lindsey DP, *et al*. Strains Across the Acetabular Labrum during Hip Motion: A Cadaveric Model. *Am J Sports Med* 2011;39 Suppl:92S-102S.
30. Ollivier M, Le Corroller T, Parratte S, Chabrand P, Argenson JN, Gagey O. Mechanical strains passing through the acetabular labrum modify its shape during hip motion: an anatomical study. *Knee Surg Sports Traumatol Arthrosc* 2017;25:1967-74.
31. Bell RD, Snedden TR, Biese KM, *et al*. Consensus definition of sport specialization in youth athletes using a Delphi approach. *J Athl Train* 2021;56:1239-51.