

# Sex differences in postural orientation errors and association with objective and patient-reported function in patients with ACL injury: an exploratory cross-sectional study

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## ABSTRACT

**Objectives** There is limited research on sex differences in postural orientation (ie, alignment between body segments) in people with knee injury measured with a clinically applicable method. An understanding of the relationship between postural orientation and physical function may help guide decision making in rehabilitation. The aims were to evaluate (1) sex differences in visual assessment of Postural Orientation Errors (POEs) and (2) the association between POEs and objective and patient-reported physical function, in men and women with anterior cruciate ligament reconstruction (ACLR).

**Methods** Twenty-four women and 29 men (mean 26.7 (SD 6.5) years) with ACLR were included. Six POEs (lower extremity and trunk) were scored from a video of five tasks with varying difficulty to compute POE scores (total and subscores). Objective physical function was evaluated with the single-leg hop for distance and side hop. Patient-reported physical function was evaluated using patient-reported outcome measures (PROMs).

**Results** Women had significantly more POEs than men (median difference 5.5–25,  $p \leq 0.028$ ). More POEs were associated with shorter hop distance and fewer side hops in women ( $r_s = -0.425$  to  $-0.518$ ,  $p < 0.038$ ), but not in men ( $r_s < 0.301$ ,  $p > 0.05$ ). No associations were found between POE scores and PROMs, in either sex ( $r_s < -0.246$ ,  $p > 0.05$ ).

**Conclusions** Women with ACLR seem to have more POEs compared with men, indicating worse postural orientation. More POEs were associated with worse hop performance, suggesting that POE scores may be used as criteria for rehabilitation progression. The lack of associations between POE scores and PROMs indicate that these measures complement each other.

## INTRODUCTION

Clinical guidelines for rehabilitation after anterior cruciate ligament (ACL) injury suggest a goal-based approach. Specifically, progression in rehabilitation is based on evaluation of different aspects of patient-reported and objective physical function, for example, patient-reported outcome measures

## Key messages

### What is already known

- ▶ Women have shown to have worse postural orientation at the knee, measured with 3D kinematics, compared with men.

### What are the new findings

- ▶ Women with anterior cruciate ligament reconstruction (ACLR) had more Postural Orientation Errors (POEs) compared with men. To help design rehabilitation programmes to improve postural orientation in patients with an ACL injury, future studies need to investigate underlying modifiable factors for POEs, for example, muscle strength and muscle activation patterns, in men and women, respectively.
- ▶ POE scores were moderately to strongly associated with hop performance in women, but not in men. The POE subscale activities of daily living could be used in rehabilitation by clinicians to decide when patients can progress to more advanced exercises, such as jumping tasks.
- ▶ No associations between POEs and patient-reported outcome measures (PROMs) in this study could indicate that POEs do not reflect the patient's perceived knee function and knee quality. Assessment of POEs and PROMs may complement each other, and both could be used to evaluate a patient's knee function during rehabilitation after ACLR.

(PROMs), functional performance and movement quality.<sup>1 2</sup> Postural orientation is one aspect of movement quality, defined as the ability to maintain alignment between body segments during a static or dynamic task.<sup>3</sup> Postural orientation can be measured with either two-dimensional (2D) and 3D kinematics or visual assessment. The latter is a more feasible approach for the clinical setting. However, a systematic approach to visually assess postural orientation is needed to enable valid and reliable evaluations and to facilitate comparison between studies, but no such approach is included in current clinical

guidelines.<sup>1 2</sup> In recent cross-sectional studies, we evaluated measurement properties of a test battery for visual assessment of Postural Orientation Errors (POEs) of the lower extremity and trunk, during tasks of varying difficulty. The test battery showed good reliability and validity in patients with an ACL injury and ACL reconstruction (ACLR).<sup>4 5</sup> Thus, visual assessment of POEs can be used to assess postural orientation during the rehabilitation of ACL injuries.

Undesirable postural orientation, for example, greater 3D knee abduction, is suggested as a risk factor for sustaining both a first and second ACL injury.<sup>6 7</sup> Women have an increased risk of rupturing their ACL compared with men.<sup>8</sup> Thus, it is of importance to investigate sex differences in various measures of postural orientation, to guide rehabilitation progression for men and women, respectively. A systematic review<sup>9</sup> and recent cross-sectional study<sup>10</sup> observed worse postural orientation, that is, greater 3D knee abduction angle, in both women with an ACL injury and healthy women, compared with men. In contrast, no sex differences were observed for visual assessment of Knee Medial-to-Foot Position (KMFP).<sup>11</sup> However, whether sex differences are present in visual assessment of other POEs during daily and sport-specific activities in individuals with an ACL injury is unknown.

Hop performance and strength measures are often used as criteria for return to sport. However, these measures alone do not seem to provide sufficient information for a safe return to sport.<sup>12 13</sup> A combination of measures of objective physical function (eg, movement quality, strength and hop performance) and patient-reported functions are recommended in clinical guidelines to guide progression during ACL rehabilitation, and help with the decision regarding return to sport.<sup>1 2</sup> An understanding of the relationship between objective and patient-reported physical functions might help in better targeting the approach to rehabilitation, and possibly facilitate a safer return to sport/activity. For example, one cross-sectional study reported that quadriceps strength asymmetry was associated with greater movement asymmetry in the knee during landing, the authors, therefore, suggested that rehabilitation needs to focus on increasing quadriceps strength to improve knee biomechanics during landing.<sup>14</sup> To our knowledge, the association between visual assessment of movement quality and other measures of objective and patient-reported physical functions has only been examined in one cohort, including people with an ACL injury or ACLR.<sup>15 16</sup> Poorer movement quality (referred to as 'substitution patterns') was associated with worse patient-reported knee function and lower knee-specific activity, and worse hop performance.<sup>15 16</sup> Although several studies have observed sex differences in various measures of physical function, for example, hop performance,<sup>10</sup> PROMs<sup>17 18</sup> and postural orientation (3D knee kinematics),<sup>7 9 10</sup> there is limited research on whether associations between physical functions differ between men and women.

The aims of this study were to (1) evaluate sex differences in postural orientation assessed by visual observation of POEs, and (2) determine the association between POEs and hop performance and PROMs, respectively, in men and women undergoing rehabilitation after ACLR.

## METHODS

### Study design and patients

An invitation to participate in this cross-sectional study was sent out to all patients at the Department of Orthopaedics, Skåne University Hospital, Sweden, that had undergone an ACLR between June 2015 and March 2016 (n=165). Patients were included if they were between 18 and 39 years of age, >16 weeks postreconstruction, undergoing supervised physical therapy, and had progressed to jumping exercises with a change of direction in their rehabilitation. Patients who used crutches, had completed rehabilitation, had a medial collateral ligament injury grade 3, or other injuries or diseases overriding the knee injury symptoms were excluded.

All patients gave their written informed consent before participation. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (online supplemental appendix 1).<sup>19</sup> Patients were not involved in this study's design, conduct, reporting or dissemination plans.

### Procedures

Data were collected during a single session at Lund University, Sweden. During data collection, patients wore their own athletic shoes, shorts and sports bra (women).

### Functional tasks

Five tasks with increasing difficulty were performed according to Nae *et al*,<sup>4 5</sup> in the following order: (1) single-leg mini squat (SLS), (2) stair descending (SD), (3) forward lunge (FL), (4) single-leg hop for distance (SLHD) and (5) side hop (SH). The tasks were videorecorded from a frontal view (Oqus colour video camera (2c-series), 30 Hz, V.2.12, Gothenburg, Sweden).

### Postural Orientation Errors

POEs were visually assessed from the video-recordings by one physical therapist (JN). Each segment-specific POE was scored on a 3-point ordinal scale from 0 (good) to 2 (poor) with a validated, reliable scoring system (inter-rater reliability weighted K=0.31 to 0.9).<sup>4 5</sup> The Total POE score (the score of POEs within and across tasks), the POE subscale activities of daily living (ADL) (the POE scores within the SLS, SD and FL), the POE subscale Sport (the POE scores within the SLHD and SH), segment-specific POEs across tasks (the score of a segment-specific POE across tasks), and within-task POE scores (the score of segment-specific POEs within respective hop task) were calculated to a 0–100 scale (table 1; 0 represents good postural orientation and 100 poor postural orientation).

**Table 1** The test battery of tasks and POEs assessed within each task

Functional tasks	Ankle POE	Knee POEs		Thigh POE	Hip POE	Trunk POE	
	Foot pronation	Knee Medial-to-foot position	Femur medial to shank	Femoral valgus	Deviation of pelvis in any plane	Deviation of trunk in any plane	Calculation of the within-task POE score
Single-leg mini squat*	X	X	X	X	X	X	$\frac{\text{sum score}}{18} \times 100$
Stair descending*			X	X			$\frac{\text{sum score}}{6} \times 100$
Forward lunge*		X	X	X	X		$\frac{\text{sum score}}{12} \times 100$
Single-leg hop for distance		X	X	X	X		$\frac{\text{sum score}}{12} \times 100$
Side hop†		X (M,L)	X (M,L)	X (M,L)	X (M)	X (M)	$\frac{\text{sum score}}{24} \times 100$
Segment-specific POEs across tasks	N.C.	$\frac{\text{sum score}}{10} \times 100$	$\frac{\text{sum score}}{12} \times 100$	$\frac{\text{sum score}}{12} \times 100$	$\frac{\text{sum score}}{8} \times 100$	N.C.	
POE Subscale ADL	(Sum score of single-leg mini squat, stair descending and forward lunge)						$\frac{\text{sum score}}{36} \times 100$
POE Subscale Sport	(Sum score of single-leg hop for distance and side hop)						$\frac{\text{sum score}}{36} \times 100$
Total POE score							$\frac{\text{sum score}}{72} \times 100$

Calculation formulae for the within-task POE scores, segment-specific POEs across tasks and total POE score, included in the analysis.

\*These tasks are only included in the Total POE score and the POE subscale ADL in this study.

†The segment-specific POEs scored in medial and lateral landings, respectively.

ADL, activities of daily living; L, lateral landing; M, medial landing; N.C., not calculated; POEs, postural orientation errors.

### Hop performance

For the SLHD, hop distance was measured in centimetres from toe at take-off to heel at landing. The longest jump from three trials for the injured leg was used in the analysis. The SLHD is reliable (test-retest, intraclass correlation coefficient (ICC)<sub>2,1</sub>=0.92), and responsive to change through rehabilitation in patients with ACLR.<sup>20</sup> The SH was measured as the number of successful hops, on the injured leg, over two parallel lines, 30 cm apart,<sup>21</sup> during 30 s.<sup>22</sup> The SH has shown excellent test-retest reliability in people following ACLR (ICC=0.87).<sup>22</sup>

### Patient-reported outcome measures

Participants completed web-based versions of the following PROMs the week before physical testing: the Knee injury Osteoarthritis Outcome Score (KOOS),<sup>23</sup> the ACL-Quality of Life (ACL-QoL),<sup>24</sup> the Knee Self-Efficacy Scale (K-SES)<sup>25</sup> and the global knee function.<sup>26</sup> Subscales regarding knee function and knee QoL was chosen in PROMs with several subscales.

The KOOS subscales QoL and Functioning in Sport and Recreation (Sport/rec) were used in the analysis. KOOS is reported to be reliable (ICC<sub>2,1</sub>>0.75), valid against the Short Form-36 (SF-36), and responsive to change (effect sizes at 3 months 0.67–1.11, and 12 months 1.08–3.54).<sup>27 28</sup>

The ACL-QoL subscales 'recreational activities and sport participation or competition' and 'lifestyle' were used in the analysis. The Swedish version of the questionnaire has shown good test-retest reliability (ICC<sub>2,1</sub>=0.71–0.97), and is valid against KOOS QoL (r=0.87) and SF-36 (r=0.65–0.72).<sup>29</sup>

The K-SES subscale Present was used in the analysis. K-SES has shown good test-retest reliability (ICC=0.75) and is valid against SF-36 and KOOS.<sup>25</sup>

The global knee function is an estimation of the patients' global knee function on a visual analogue scale from 1 ('normal knee function') to 100 mm ('totally disabled').<sup>26</sup>

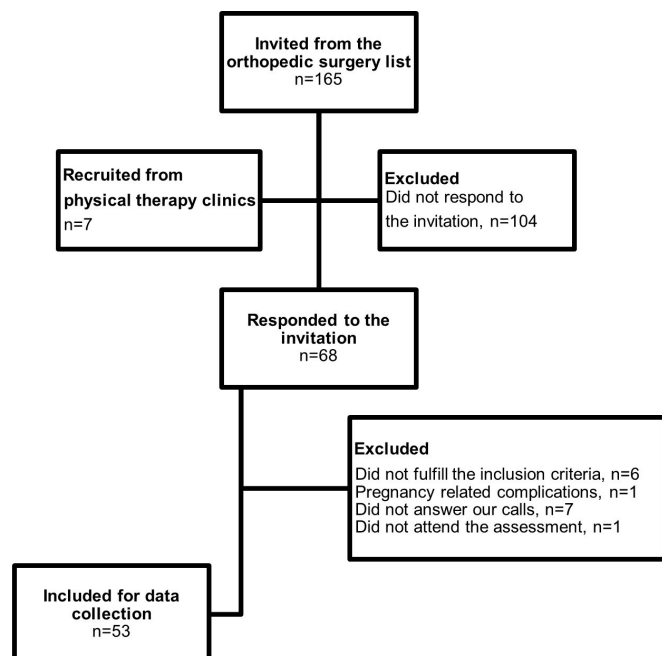
### Statistical analysis

This was an exploratory investigation and a secondary analysis of a dataset aimed to evaluate measurement properties of POEs,<sup>5</sup> thus, no a priori power calculation was performed. Complete cases were used for each analysis. Normality was assessed by inspecting histograms and the Kolmogorov-Smirnov test. All variables, except body mass index (BMI), were normally distributed.

Descriptive statistics were calculated for POE scores (median (quartiles)), hop performance and PROMs (mean (SD)) and for patient characteristics, for men and women separately. Mann-Whitney U test was used to evaluate any sex differences in ordinal data (POE scores) and BMI, independent sample t-tests were used to evaluate possible sex differences in continuous data (hop performance, PROMs, age, height, mass, time since surgery) and  $\chi^2$  test for nominal data (injury mechanism, injury occasion, graft type). Values of  $p \leq 0.05$  were considered statistically significant.

The Spearman's rank correlation coefficient was used to assess associations between postural orientation and hop performance and between postural orientation and PROMs. As hop performance, PROMs and postural orientation include different constructs, at most moderate associations were expected, and will thus be





**Figure 1** Flow chart over the recruitment process.

discussed. The following thresholds were applied:  $\geq 0.10$ – $0.29$  represents weak correlations,  $\geq 0.3$ – $0.49$  represents moderate correlations and  $\geq 0.5$  strong correlations.<sup>30</sup> Values of  $p \leq 0.05$  were considered statistically significant.

## RESULTS

Sixty-eight of the invited 165 participants agreed to participate, and 53 patients were finally included (figure 1). There were missing data for two participants regarding POE scores, and one participant did not respond to the PROMs.

### Descriptive data

Twenty-four women (46%), and 29 men (54%), with an ACLR, were included in this study. Women were significantly shorter and lighter than men. Women sustained their injury more often during training and men during the competition. All the other characteristics did not differ between sexes (table 2).

### Sex differences

Women had more POEs (ie, Total POE score, POE subscales and femoral valgus across tasks), jumped a shorter distance and performed fewer SH, compared with men ( $p < 0.05$ ). No sex differences were observed for any PROMs (table 3).

### Associations between postural orientation and hop performance

A higher score on the POE subscale ADL was significantly associated with shorter hop distance ( $-0.518$ ,  $p = 0.01$ ) and fewer SH ( $-0.425$ ,  $p = 0.038$ ), in women. No significant associations between POE scores and hop performance were observed in men. Non-significant associations above  $0.3$  were found between higher Total POE score and

shorter hop distance in women ( $r_s = -0.349$ ,  $p = 0.103$ ), and between higher within-task, POE score for the SLHD and longer hop distance in men ( $r_s = 0.3$ ,  $p = 0.112$ ) (table 4).

### Associations between postural orientation and PROMs

Associations were below  $0.3$  between POE scores and PROMs, for both men and women ( $r_s = 0.0001$  to  $-0.235$ ,  $p > 0.22$ ) (table 5).

## DISCUSSION

We found that women with ACLR displayed more POEs than men, indicating worse postural orientation and that POE scores were moderately to strongly associated with hop performance in women, but not in men. We found no association between POE scores and PROMs in either sex.

Women with ACLR exhibited more POEs than men in Total POE score, POE subscales and the segment-specific POE femoral valgus. This is consistent with previous studies on sex differences in movement quality, that is, that women have more landing errors<sup>31 32</sup> and greater knee abduction,<sup>7 9 10</sup> indicating worse movement quality than men. The Landing Error Scoring System (LESS) is a test battery in which movement patterns of the trunk, hip, knee and ankle are visually assessed and scored during the drop jump. Higher LESS scores have been reported in healthy women, and in women with an ACL injury, compared with men.<sup>31 32</sup> Because POEs were assessed in multiple tasks using postural orientation as a separate entity, compared with the LESS during one task using different constructs (eg, postural orientation, stance width, and stiff landing), our findings indicate that postural orientation more generally differs between sexes. Kinematic studies, using 3D analysis, have also reported that women have increased knee abduction compared with men, in both healthy<sup>9</sup> and populations with ACL injury.<sup>7 10</sup> Our findings and those previously reported, suggests that rehabilitation after ACLR, particularly in women, should have a strong focus on improving postural orientation.

There could be several possible modifiable and non-modifiable underlying factors for sex differences in postural orientation, but these are not well explored. One likely anthropometric, non-modifiable, factor is pelvic width. Women have a wider pelvis normalised to height than men,<sup>33</sup> and it has been reported that a wider pelvic width to femoral length ratio is associated with greater knee valgus during an SLS.<sup>34</sup> However, another study reported that pelvic width to femoral length ratio, in women, was not related to 3D hip adduction during running.<sup>35</sup> We did not measure pelvic width in our study. However, pelvic width could explain more femoral valgus POEs in women than men, as one of the reference points for femoral valgus POE is placed on the pelvis. A possible modifiable factor for sex differences in postural orientation could be sensorimotor function. Cronström *et al* reported that lower knee muscle strength and lower muscle activation of the trunk was associated with increased 3D knee abduction in women, but not in men.<sup>10</sup>

**Table 2** Characteristics of included patients

	Men (n=29)	Women (n=24)	Mean difference (95% CI)
Age*	27.1 (6.2)	26.3 (6.9)	-0.85 (-4.5 to 2.8)
Height (cm)*	179 (6.7)	167 (5.8)	-12.2 (-15.6 to -8.7)
Mass (kg)*	80.6 (12.7)	67.7 (9.2)	-12.9 (-19.2 to -6.7)
BMI†	24.1 (23.3–26.1)	23.5 (22.3–26.6)	P=0.211
Injury occasion‡			P=0.03
Match, n (%)	15 (51.7)	4 (16.7)	
Training, n (%)	9 (31)	13 (54.2)	
Other, n (%)	5 (17.2)	7 (29.2)	
Injury mechanism‡			P=0.653
Non-contact, n (%)	19 (65.5)	16 (66.7)	
Contact, n (%)	9 (31.0)	8 (33.3)	
Do not remember, n (%)	1 (3.4)	0 (0.0)	
Time since reconstruction (weeks)*	28.4 (6.3)	27 (6.7)	-1.49 (-5.1 to 2.15)
Type of graft‡			P=0.501
Hamstrings, n (%)	27 (93.1)	22 (91.7)	
Patellar, n (%)	2 (6.9)	1 (4.2)	
Donated, n (%)	0	1 (4.2)	
ACL revision surgery, n (%)	2 (6.9)	5 (20.9)	P=0.132
Associated injuries, n (%)	22 (75.9)	17 (70.8)	P=0.682
Bilateral ACL injury, n (%)	2 (6.9)	3 (12.5)	P=0.491
Meniscal injury, n (%)	10 (34.5)	14 (58.3)	P=0.595
Collateral ligament, n (%)	7 (24.1)	6 (25)	P=0.943
Cartilage, n (%)	8 (27.6)	3 (12.5)	P=0.182
Other, n (%)	1 (3.4)	2 (8.3)	P=0.448
Tegner activity level before injury†	8 (6–9)	8 (6–9) n=23	P=0.985
Tegner activity level at test session†	3 (2–4.5)	3 (3–4) n=23	P=0.962

\*Mean (SD).

†Median (quartiles) and Mann-Whitney U-test.

‡ $\chi^2$  test, significant difference in match and training.

ACL, anterior cruciate ligament; BMI, body mass index.

While there is some understanding of the sex differences and modifiable factors associated with knee abduction (one aspect of postural orientation),<sup>9 36</sup> further studies are needed to investigate underlying modifiable factors for other POEs, for example, muscle strength and muscle activation patterns, in men and women. Such information may help design rehabilitation programmes aimed at improving postural orientation in men and women after an ACL injury.

To our knowledge, our study is the first to report associations between postural orientation and hop performance in men and women, separately. The association between more POEs and shorter hop distance and fewer SH in women suggests improving postural orientation might contribute to improved hop performance. Such associations were not found in men indicating that other factors are important for hop performance in men. Only one previous study has reported that worse movement quality (visually assessed 'substitution patterns') was associated with worse hop performance in patients with an ACL injury or ACLR.<sup>16</sup>

However, in that study, men and women were not analysed separately, and the score includes different constructs (eg, postural orientation and body weight distribution), limiting the ability to compare findings between studies.

The only significant associations observed were between the POE subscale ADL and the hop tasks in women. However, it cannot be ruled out that a larger sample size could have resulted in more significant associations for both men and women. One possible explanation may be that good postural orientation during ADL tasks is a requirement for hop performance, indicating that good postural orientation in ADL tasks should be obtained before progression to jumping tasks in rehabilitation after ACLR. This reasoning is in line with practice guidelines for ACL injury treatment, that is, that progression from phase 1 (the acute postoperative phase) to phase 2 (initiating jumping tasks) occurs when the patient can perform phase 1 exercises with good movement quality.<sup>1 2</sup> Using the POE subscale ADL may help clinicians decide

**Table 3** Descriptive data for POE scores, hop performance, patient-reported outcome measures for men and women separately, and differences between men and women

POE scores	Men (n=29)	Women (n=24)	Mean difference (95% CI)	p-value
Total POE score*	20.5 (14–29)†	26 (21–33)†	NA	0.012
POE subscale ADL*	15.5 (11–24.25)†	25 (14.75–32.5)	NA	0.012
POE subscale sport*	25 (12.5–34.5)	31 (28–36)†	NA	0.028
KMFP across tasks*	10 (0–20)	20 (10–20)‡	NA	0.106
Femur medial to shank across tasks*	42 (25–65)†	50 (42–69)‡	NA	0.053
Femoral valgus*	29 (17–48)†	54 (33–58)‡	NA	0.001
Deviation of pelvis in any plane*	37.5 (25–50)	50 (37.5–50)‡	NA	0.294
<b>Hop performance</b>				
SLHD§ longest jump (cm)	121 (36)	91 (29)	–29.8 (–48.0 to –11.7)	0.002
SH§ no of hops (n)	45 (16)	31 (18)	–14.8 (–24.4 to –5.2)	0.003
<b>Patient-reported outcome measures</b>				
KOOS sport/rec§	58 (21.9)	59 (24.8)†	0.9 (–12.1 to 13.9)	0.890
KOOS QoL§	48 (19.8)	50 (14.7)†	1.8 (–8.2 to 11.7)	0.723
ACL-QoL subscale Recreational activities and sport participation§	38 (16.1)	38 (20.3)†	0.4 (–9.8 to 13.5)	0.944
ACL-QoL subscale life style§	48 (18.7)	53 (17.5)†	4.1 (–6.1 to 14.3)	0.426
K-SES subscale present§	6.7 (1.5)	7.1 (1.9)†	0.5 (–0.5 to 1.4)	0.345
Global knee function§	44 (21.8)	35 (18.8)†	–9.2 (–20.5 to 2.1)	0.115

\*Median (quartiles) and Mann-Whitney U-test.

†One subject did not complete all tasks/PROMs.

‡Two subjects did not complete all tasks.

§Mean (SD) and independent sample t-test.

ACL, anterior cruciate ligament; ADL, activities of daily living; KMFP, Knee Medial to Foot Position; KOOS, Knee injury and Osteoarthritis Outcome Score; K-SES, Knee Self-Efficacy Scale; NA, not applicable; POE, Postural Orientation Error; PROMs, patient-reported outcome measures; QoL, quality of life; SH, side hop; SLHD, single leg hop for distance.

when patients can progress to more advanced exercises, such as jumping tasks. However, future longitudinal studies are needed to investigate the responsiveness of POE scores during different phases of rehabilitation

before specific POE scores can be suggested as criteria for progression in rehabilitation.

The moderate association (although non-significant) between higher within-task POE score for the SLHD and

**Table 4** Spearman's rank correlation coefficient ( $r_s$ ) between postural orientation scores and hop performance during the single-leg hop for distance and side hop, in men and women separately

POE scores	Hop performance							
	Single-leg hop for distance Longest jump injured leg (cm)				Side hop No of hops, injured leg (n)			
	Men, n=29		Women, n=24		Men, n=29		Women, n=24	
	$r_s$	p-value	$r_s$	p-value	$r_s$	p-value	$r_s$	p-value
Total POE score	–0.024*	0.903	<b>–0.349*</b>	0.103	–0.178*	0.364	–0.267*	0.219
POE Subscale ADL	–0.013*	0.946	<b>–0.518</b>	0.010	–0.204*	0.297	<b>–0.425</b>	0.038
POE Subscale Sport	–0.067	0.732	–0.144*	0.511	–0.079	0.685	–0.106*	0.629
Within-task POE score Single-leg hop for distance	<b>0.301</b>	0.112	–0.120	0.577	NA			
Within-task POE score side hop	NA				–0.177	0.359	–0.048*	0.827

$r$  values  $\geq 0.3$  are indicated in bold.

\*One subject did not complete all tasks.

ADL, activities of daily living; NA, not applicable; POE, postural orientation error;  $r_s$ , Spearman's rank correlation coefficient.

**Table 5** Spearman's rank correlation coefficient ( $r_s$ ) between different postural orientation scores and patient-reported outcome measures separately in men and women

PROMs	POE scores					
	Total POE score		POE subscale ADL		POE subscale sport	
	$r_s$	P value	$r_s$	P value	$r_s$	P value
KOOS sport/rec						
Men (n=29)	-0.179*	0.68	0.0001*	0.999	-0.235	0.22
Women (n=22)	-0.093	0.363	-0.148	0.5	-0.145	0.52
KOOS QoL						
Men (n=29)	0.022*	0.912	0.092*	0.643	0.007	0.972
Women (n=23)	0.120*	0.594	-0.014	0.949	0.184	0.412
ACL-QoL subscale Sport†						
Men (n=29)	-0.112*	0.572	-0.019*	0.922	-0.124	0.523
Women (n=23)	0.092*	0.685	0.019	0.932	0.054	0.812
ACL-QoL subscale Life style						
Men (n=29)	0.020*	0.918	0.032*	0.874	0.013	0.947
Women (n=22)	0.216	0.335	0.057	0.796	0.142	0.53
K-SES subscale Present						
Men (n=29)	0.045*	0.82	0.066 <sup>a</sup>	0.74	0.037	0.85
Women (n=22)	0.046	0.839	0.021	0.925	-0.145	0.52
Global knee function						
Men (n=29)	-0.086*	0.665	-0.099*	0.615	-0.096	0.622
Women (n=23)	-0.177*	0.431	0.081	0.712	-0.246*	0.27

\*One subject did not complete all tasks.

†ACL-QoL subscale Recreational activities and sport participation.

ACL, anterior cruciate ligament; ADL, activities of daily living; KOOS, Knee injury and Osteoarthritis Outcome Score; K-SES, Knee Self-Efficacy Scale; POE, postural orientation error; PROMs, patient-reported outcome measures; QoL, quality of life;  $r_s$ , Spearman's rank.

longer hop distance in men showed the reverse relationship compared with women, indicating that a greater hop distance increases the demands on postural orientation in men. A cross-sectional study reported that men with ACL injury had worse movement quality, in terms of reduced 3D hip abduction, during a drop-jump despite having a normal physical function (strength and hop LSI  $\geq 90\%$ ), compared with healthy controls.<sup>37</sup> The authors suggested that kinematic analysis, in addition to muscle strength and hop performance, could provide further insight into the decision of return to sport.<sup>37</sup> Further studies could evaluate whether a visual assessment of POEs could be a valuable tool for such kinematic analysis. A prospective study suggests that altered neuromuscular control at the hip and knee during landing tasks is a risk factor for reinjury.<sup>6</sup> Whether more POEs when achieving good hop performance could constitute a risk factor for a future injury needs to be further studied.

The lack of associations between POE scores and PROMs could indicate that POEs do not reflect the patient's perceived knee function and knee quality. Assessment of POEs and PROMs may complement each other and provide a more complete picture about the patient's knee function, as suggested in rehabilitation practice and return to sport guidelines.<sup>1</sup> Inconsistent

findings are reported in cross-sectional studies in patients with lower extremity injury or disorder, where some observed no association between aspects of movement quality and PROMs.<sup>38,39</sup> In contrast, others noted that worse movement quality was associated with worse PROMs.<sup>15,16</sup> Longitudinal studies indicate that aspects of movement quality, that is, landing asymmetry in knee and trunk flexion,<sup>40</sup> and worse 'substitution patterns',<sup>15</sup> were associated with worse future PROMs.<sup>15,40</sup> The predictive ability of POE scores to determine future PROMs is a subject for further study.

### Strengths and limitations

This study is the first to investigate sex differences in a test battery for the visual assessment of POEs as a separate entity. Visual assessment of POEs has shown good validity and reliability in previous studies,<sup>4,5</sup> indicating that it is clinically feasible. Systematic reviews suggest that hop performance and muscle strength as criteria for return to sport may not be sufficient to identify those at risk of reinjury.<sup>12,13</sup> Further studies could evaluate whether a clinical assessment of visual assessment of POEs, in addition to muscle strength and hop performance, would add value to the criteria for progressing rehabilitation and determining return to sport.



Our exploratory study was the first step to investigate sex differences in POEs, and despite the moderate sample size, significant differences were observed between men and women, except for the segment-specific POE scores across tasks (KMFP, femur medial to shank, and deviation of pelvis in any plane). Possible confounding factors, such as height and mass, were not adjusted due to the sample size. Thus, this study's results need to be interpreted with caution, and a larger sample is needed to verify the result and adjust for possible confounding factors. The present study was a secondary analysis from a study where the primary aim was to evaluate the measurement properties of POEs.<sup>5</sup> Therefore, we had no predefined hypothesis on sex differences. Consequently, this was an advantage for the aim of this study because sex was unlikely to be subject to assessor bias.

## CONCLUSIONS

We observed more POEs in women compared with men, indicating worse postural orientation in women. The association between more POE scores and worse hop performance suggests that POE scores may be used as criteria for rehabilitation progression. The lack of associations observed between POE scores and PROMs indicate that these measures complement each other.

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