Original Research

Extended Version of a Test Battery for Visual Assessment of Postural Orientation Errors: Face Validity, Internal Consistency, and Reliability

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[Nae J, Creaby MW, Ageberg E. Extended version of a test battery for visual assessment of postural orientation errors: face validity, internal consistency, and reliability. *Phys Ther.* 2020;100:1542–1556.]

Published Ahead of Print: May 13, 2020
Accepted: May 3, 2020
Submitted: September 3, 2019

Objective. Undesirable postural orientation may be a risk factor for a second anterior cruciate ligament (ACL) injury. The purpose of this study was to evaluate face validity, internal consistency, and interrater reliability of an extended version of a previous test battery for visual assessment of postural orientation errors (POEs) in patients during the late phase of rehabilitation following ACL reconstruction (ACLR) (ie, when they have initiated jumping exercises).

Methods. This study used a cross-sectional design. Fifty-three patients (45% women) in the late phase of ACLR rehabilitation performed 5 functional tasks of varying difficulty. POEs of the lower extremity and trunk were visually assessed from video and scored on a scale from 0 (good) to 2 (poor).

Results. The side-hop and 2 new POEs (femur medial to shank, femoral valgus) were added to the test battery after expert focus group discussions. Internal consistency was calculated for all tasks (α = .712–.823). Interrater reliability showed fair to substantial agreement for femur medial to shank and femoral valgus during all tasks ($K = 0.31$–0.815) and almost perfect agreement for side-hop (intraclass correlation coefficient = 0.88).

Conclusions. The good internal consistency and reliability after adding side-hop, femur medial to shank, and femoral valgus suggests that this test battery is a suitable tool to quantify postural orientation throughout ACLR rehabilitation.

Impact. This test battery for visual assessment of POEs was evaluated in a heterogeneous group of patients in different phases of ACLR battery and can be used in clinical practice to measure POEs in patients with ACLR, including in the late phase of rehabilitation to return to sport. This study encourages research on more demanding tasks and additional POEs to cover the entire rehabilitation period after ACL injury or reconstruction.

Patients who return to sports with undesirable postural orientation after an anterior cruciate ligament (ACL) reconstruction (ACLR) may have an increased risk for future ACL injury.[1,2] Postural orientation is the ability to maintain alignment between body segments and the environment during a static or dynamic task.[3] Visual assessment of postural orientation errors (POEs) is 1 way to evaluate postural orientation.[4] In a previous study, we evaluated a test battery for visual assessment of POEs during functional tasks and recommended that this test battery be used as a complement to other common measures of physical function (ie, strength and hop performance).[4] Evaluation of physical function should be on a regular basis, from acute to late phases of rehabilitation to guide and monitor progress and to aid the physical therapist in the decision-making of the athlete's return to sport.[5] A recent cross-sectional study showed that altered postural orientation of the lower extremity, measured with 2-dimensional (2D) kinematics, was present 6 to 8 months post-ACLR in the injured leg during the single-leg hop for distance (SLHD), even though the limb symmetry index was classified as normal (ie, >90%).[6] This supports the use of both hop test performance and postural orientation to obtain a more comprehensive picture of the patient's physical function.

Our previous test battery included assessment of POEs at the foot, knee, hip, and trunk during the performance of the single-leg mini squat (SLS), stair descending, forward lunge, and SLHD.[4] We found that this test battery was valid in a heterogeneous group with a wide time span since ACL injury or ACLR (ie, they were in different phases in their rehabilitation).[4] The tasks used for assessing POEs might not necessarily be the same in the acute and late phases of rehabilitation. In the acute phase of rehabilitation, the main goals are to reduce joint effusion and restore range of motion.[5] In the intermediate and late phases of rehabilitation, the athlete has initiated jumping exercises and heavy strength training with the goal to restore strength and hop symmetry, with adequate postural orientation.[5] More demanding tasks may be needed in the late phases to increase the sensitivity to detect POEs, especially for an athletic population. In our previous test battery, only 1 jumping task, in the sagittal plane, was included.[4] However, since a common mechanism of an ACL injury is a cutting maneuver,[7] it could be argued that detection of POEs in such a challenging task, with change of direction, might be needed for an athletic population in the late phases of rehabilitation.

Further consideration of the face validity of the scoring system may also be appropriate. For example, the knee-medial-to-foot position (KMFP) (which is included in the original test battery[4]) has shown low sensitivity to detect high-risk movement patterns with visual assessment compared with 2D[8] and three-dimensional (3D) kinematics.[9] Thus, additional or other lower extremity POEs may be needed.

The present study is a refinement and further development of our previous test battery for assessing POEs,[4] where we have added a cutting task and additional lower extremity POEs. The aim was to evaluate the face validity, internal consistency, and interrater reliability of this extended version of the test battery in a cohort of ACLR in the late phase of rehabilitation.

Methods

Study Design

This study was cross-sectional and followed the STROBE guidelines (http://www.strobe-statement.org).

Participants

In our previous study, patients at different phases of rehabilitation were included. Some of them (n = 10) were at too early a stage in their rehabilitation to perform jumping exercises, yielding missing data for the jumping task.[4] Therefore, in the present study, we included patients with ACLR in the late phase of rehabilitation at a stage where they had initiated jumping exercises. We recruited patients at the Department of Orthopedics, Skåne University Hospital, Sweden. All patients that had undergone an ACLR between June 1, 2015 and March 15, 2016 (n = 165) received an invitation to participate in this study. In addition, advertisement about the study was posted at sports injury clinics in Skåne, Sweden. Inclusion criteria were (1) at least 16 weeks post-ACLR, (2) age between 18 and 40 years, (3) undergoing supervised physical therapy, and (4) have initiated jumping exercises, including change of direction in their rehabilitation. Exclusion criteria were (1) use of crutches, (2) had finalized their rehabilitation, (3) had a medial collateral ligament injury grade 3, or (4) had other injuries or diseases overriding the symptoms of the knee injury. Data collection was performed from February to August in 2016, and each patient participated at 1 occasion. Fifty-three patients (mean = 27 years, SD = 6.5 years, 45% women) in the late phase of rehabilitation after an ACLR were included (mean = 28 weeks, SD = 6.5 weeks post-reconstruction) (Tab. 1; Fig. 1).

All patients gave their written informed consent prior to participation. The study was approved by the Regional Ethical Review Board in Lund, Sweden (2015/8).

Procedures

Body weight was obtained with a digital weighting scale. All the other patient characteristics, including the Tegner activity score[10] and the Knee injury and Osteoarthritis Outcome score,[11] were obtained via a web-based questionnaire sent out prior to data collection. Data were collected on the ACLR leg according to below described

Table 1.
Characteristics of Included Patients (N = 53)[a]

Variable	Value
Age, mean (SD)	26.7 (6.5)
Women/men, n (%)	24/29 (45/55)
Height (cm), mean (SD)	174 (8.7)
Weight (kg), mean (SD)	75 (13)
Body mass index, kg/m^2, mean (SD)	24.7 (3.2)
Injured knee, right/left (%)	21/32 (40/60)
Time since reconstruction (wk), mean (SD)	28 (6.5)
Type of graft	
Hamstrings, n (%)	49 (92.5)
Patellar, n (%)	3 (5.7)
Other, n (%)	1 (1.9)
ACL revision surgery, n (%)	6 (11)
Associated injuries, n (%)	39 (74)
Bilateral ACL, n (%)	5 (9)
Meniscal injury, n (%)	33 (62)
Collateral ligament, n (%)	13 (25)
Cartilage, n (%)	11 (21)
Other, n (%)	3 (6)
Tegner activity level before injury, median (quartiles)	8 (6–9)
Tegner activity level at test session, median (quartiles)	3 (2.25–4)
KOOS subscales (n = 52), mean (SD)	
Pain	60 (12.1)
Symptoms	83 (11.9)
Function in daily living	95 (7.9)
Function in sport/recreation	59 (23)
Knee-related QoL	49 (17.6)

[a]ACL = anterior cruciate ligament; KOOS = Knee injury and Osteoarthritis Outcome Score; QoL = quality of life.

methods. Patients wore their personal athletic shoes, shorts, and sports bra (women).

Face Validity

A focus group met to discuss the face validity for the need of additional tasks and POEs to contribute new content to the construct of postural orientation. The group consisted of 2 physical therapists with 8 to 15 years of clinical experience, 1 with a master's degree (J.N.), and 1 with a doctoral degree (E.A.), and 1 exercise scientist with a doctoral degree specializing in biomechanics (M.W.C.). All were part of the focus group in the original study.[4]

The side-hop (SH) and the square hop were discussed as relevant tasks for assessing POEs in cutting movements. The SH was chosen as the cutting task to be added to the original test battery. The need for new lower extremity POEs was discussed by the focus group based on limitations with the visual assessment of KMFP. The femur medial to shank and the femoral valgus were added to the existing test battery to engender a more comprehensive assessment of lower extremity POEs. The rationale is provided in Figure 2. The focus group discussed the results of each analysis and whether the result appeared to reflect the construct to be measured.

Functional Tasks

The following tasks were used, with tasks 1 to 4 included in the first study[4] and task 5 added in the present study: (1) SLS, (2) stair descending, (3) forward lunge (FL), (4) SLHD, and (5) SH. Each participant performed all tasks on the injured leg, using shoes, at 1 occasion. Up to 3 practice trials were permitted for each task. A video camera (1920 × 1080 pixels; 30 Hz; Qualisys motion capture system, Gothenburg, Sweden) recorded the execution of the tasks in the frontal plane.

Single-leg Mini Squat

The SLS has previously been described[12] and was modified in this study to obtain 60 degrees of knee flexion and performed without finger-tip support. The patient was standing in front of a bench adjusted to ensure that the depth of the squat was approximately 60 degrees. The patient was instructed to stand on 1 leg, with arms alongside the body, and flex the knee until they lightly touched the bench with their buttocks, and then return to

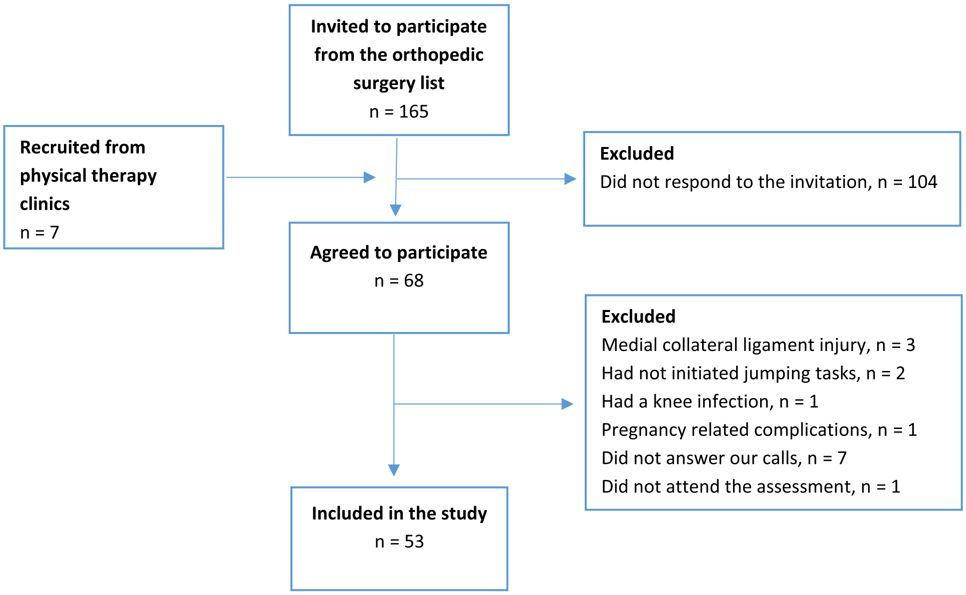


Figure 1.
Flowchart of the recruitment process.

extension. The task was repeated 5 times. POEs were assessed during the entire movement from starting position to knee flexion and during the return to full knee extension.

Stair Descending

The stair descending was performed according to Pfeifer et al[13] but modified to use a 30-cm high step board. The patient was standing on a step board with arms alongside the body. The patient stepped down with the non-injured leg and took a few steps on the floor, and returned to starting position. The task was repeated 5 times. POEs were assessed on the loading leg from starting position until the foot left the step board.

Forward Lunge

The FL was performed according to Alkjaer et al.[14] The patient was standing with the feet hip-width apart on the floor and took a long stride forward with the ACLR leg, flexed the knee to approximately 90°, and pushed back to starting position by extending the front leg. The task was repeated 3 times. The front leg was assessed for POEs from the first contact with the floor until maximum knee flexion.

Single-leg Hop for Distance

The SLHD was modified with arms free.[15] The patient was standing on 1 leg behind a marked line, with the other leg lifted from floor by flexing the knee. The patient jumped forward as far as possible, with arm swing allowed, taking off and landing on same foot; the task was approved if the balance was maintained for 3 seconds after landing. The task was repeated until 3 approved landings were achieved. POEs were assessed from first contact with the floor and approximately 3 seconds after landing.

Side-Hop

The participant performed the SH by standing on the test leg beside 2 parallel lines, 30 cm apart,[16] lifting the contralateral leg from the ground and arms alongside the body. Instructions were to hop on the test leg from side to side (ie, in the frontal plane) over the lines 7 times at a self-selected pace, commencing with a hop lateral to the test leg. POEs were assessed when the patella reached its lowest point (maximum knee flexion) during 3 medial and 3 lateral landings, whereof the last landing was not assessed.

Postural Orientation Errors

Postural orientation was assessed from video recordings by 1 physical therapist (J.N.) with 8 years of clinical experience. Five segments/joints were included in the assessment (ankle POE, knee POEs, thigh POE, hip POEs, and trunk POEs). Six segment-specific POEs were visually assessed, including POEs 1 to 4 from the original test battery[4] and POEs 5 to 6 added in the present study: (1) foot pronation, (2) KMFP, (3) deviation of pelvis in any plane, (4) deviation of trunk in any plane, (5) femur medial to shank, (6) femoral valgus. For each task, 4 to 6 segment-specific POEs were visually assessed (see detailed description in Figure 3).

The femur medial to shank was developed in this study to represent postural orientation of the knee by including

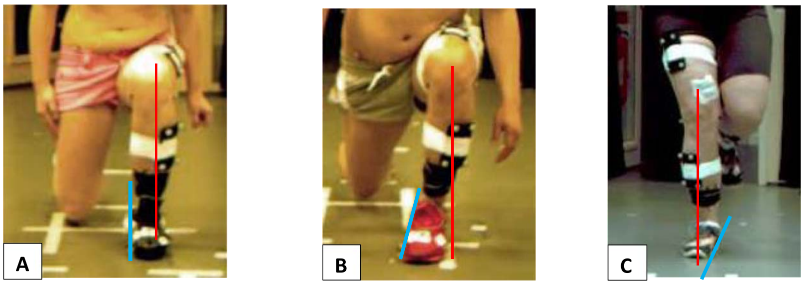
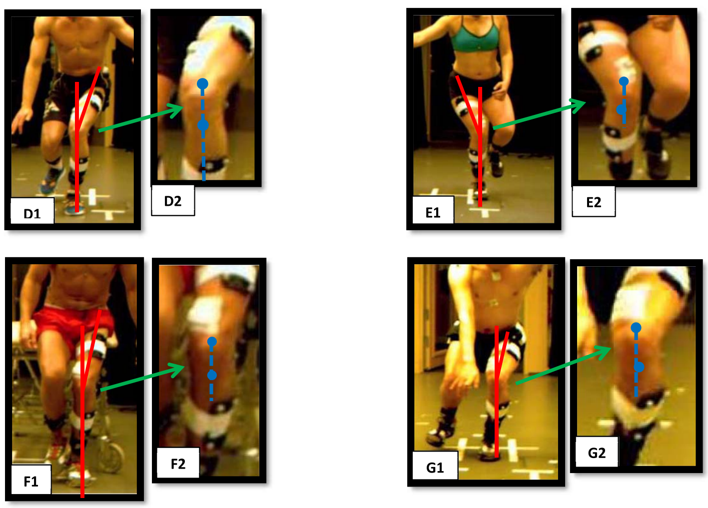
<table>
<tr><th colspan="2">Add a Cutting Task to the Test Battery</th></tr>
<tr><td>Current limitation</td><td>The current test battery includes 1 hop task, the single-leg hop for distance; however, a common mechanism of an anterior cruciate ligament (ACL) injury is a cutting maneuver. More demanding tasks are needed to increase the sensitivity to detect postural orientation errors (POEs) in the late phases of ACL rehabilitation.</td></tr>
<tr><td>Possible solution</td><td>Adding a cutting maneuver, the side hop, to the test battery.</td></tr>
<tr><td>Rationale for chosen solution</td><td>The focus group argued that the side hop is easier to assess in the frontal plane on-video than the square hop, and it has been reported that the side hop has better ability to discriminate between injured and uninjured sides in number of hops in patients with ACL injury, compared with the square hop.[23]</td></tr>
<tr><th colspan="2">Adding new lower extremity POEs</th></tr>
<tr><td>Current limitation</td><td>Visual assessment of knee medial-to-foot position (KMFP) has shown low sensitivity to detect high-risk movement patterns, such as knee abduction angle in 2D[8] and 3D.[9] Knee abduction represents the rotation of the shank in the frontal plane of the thigh, and one reason why the KMFP may not reflect knee abduction could be that the distal reference point is located on the foot and not on the shank. Thus, a KMFP could be the result of ankle kinematics rather than knee kinematics due to the involvement of 2 separate joints (knee and foot) which may produce independent movements of the reference points (patella and second toe). Photos A-C below show different foot positions (blue line) when the knee is scored as knee-over-foot position (KOFP) (red line) (note that a knee lateral to the foot, as in photo B, is scored as a KOFP).


Photo A represents a neutral foot position. Photo B represents an adducted foot position, resulting in a greater distance between patella and the medial border of the foot, thus less likely a KMFP. Photo C represents an abducted foot position, resulting in a smaller distance between patella and the medial border of the foot, thus increased likelihood of a KMFP.</td></tr>
<tr><td>Possible solution</td><td>Adding new lower extremity POEs to the test battery, the femur medial to shank, and the femoral valgus.</td></tr>
<tr><td>Rationale for chosen solution</td><td>The knee can be poorly positioned according to the new lower extremity POEs but still be rated as "good" with the KMFP assessment (see Photos D-G below). Adding the POEs for femur medial to shank and the femoral valgus might engender a more comprehensive assessment of lower extremity POEs, compared with the KMFP assessment alone. The reference points used for assessing the new POEs are located on the segments adjacent to the tibiofemoral joint that they target (thigh and shank), increasing the likelihood that these POEs represent knee and thigh kinematics.


See Photos D-G for different executions and scorings of femoral valgus (red) and femur medial to shank (blue) when the knee is scored as KOFP. The photos showing femur-medial-to-shank assessments are enlarged (Photos D2-G2) to the right of the original photos (D1-G1). Photo D shows femoral valgus rated as "Poor" and femur medial to shank rated as "Fair." Photo E shows femoral valgus rated as "Poor" and femur medial to shank rated as "Poor." Photo F shows femoral valgus rated as "Fair" and femur medial to shank rated as "Fair." Photo D shows femoral valgus rated as "Fair" and femur medial to shank rated as "Poor."</td></tr>
</table>

Figure 2.
Face validity result and focus group discussions leading up to changes in the test battery. 2D = 2-dimensional; 3D = 3-dimensional.

reference points at the segments above and below the knee joint (ie, the distal femur and tibial tuberosity). Femoral valgus[17] was included as another POE of the lower extremity (ie, the frontal plane orientation of the thigh).

Scoring

Each segment-specific POE was scored on a 3-point ordinal scale from 0 to 2,[4] where 0 represents good postural orientation (ie, no signs of POEs), 1 represents fair postural orientation (ie, minimal signs of POEs), and 2 represents poor postural orientation (ie, clear signs of POEs). If a patient performs a task in a way that it does not have any similarities to the expected execution, this represents very poor postural orientation (score of 3). In such cases, a maximum within-task POE score was given (ie, number of POEs in that task times 3). A missing value was given in cases when a patient declined to do a test or tried but stopped for reasons other than undesirable postural orientation (eg, fear or pain). A segment-specific POE was given the score fair or poor when it occurred at least 3 out of 5 times in tasks performed with 5 repetitions (SLS, stair descending) and at least 2 out of 3 times for tasks performed with 3 repetitions (FL, SLHD, SH). In the event if 1 of each category was scored, the score of fair was given.

The scoring system was modified in the current study by transforming the score to a percentage scale (from 0 to 100) for the within-task POE scores, 2 subscales (ADL and Sport), and the total POE score. Zero represents good postural orientation and 100 represents poor postural orientation. For the SH, 2 separate within-task POE scores were calculated, 1 for each landing direction (ie, medial and lateral). However, for the percentage scale, the medial and lateral scores were added together to a single within-task POE score for the SH. The transformation formula for the percentage scale for within-task POE scores is as follows:

$$\text{Within task POE score} = \frac{\text{Sum of all segment specific POE scores within a task}}{\text{Maximum possible within task POE score}} \times 100$$

The total POE score is calculated as follows:

$$\text{Total POE score} = \frac{\text{Sum of all segment specific POEs}}{\text{Maximum possible total POE score}} \times 100$$

Two subscales were created in this study: subscale ADL and subscale Sport. The subscale ADL includes the SLS, stair descending, and FL, and the subscale Sport includes the SLHD and SH. The score for each subscale is calculated as follows:

$$\text{Subscale score} = \frac{\text{Sum of all segment specific POEs within the subscale}}{\text{Maximum possible subscale score}} \times 100$$

Segment-Specific POEs	Functional Tasks in Which Each POE Is Assessed*	Scoring of "0" Good (no POE)†	Scoring of "1" Fair (minor POE)†	Scoring of "2" Poor (major POE)†
Foot pronation	SLS	The absence of pronation of the medial arch of the foot, navicular bone and the medial malleolus indicates no POE	A slight position of pronation of the medial arch of the foot, navicular bone and the medial malleolus indicates a minor POE	A clear position of pronation of the medial arch of the foot, navicular bone and the medial malleolus indicates a major POE
KMFP	SLS SD FL SLHD SH	Mid-point of patella is in line with or lateral to the second toe	Mid-point of patella is placed medial to the second toe	Mid-point of patella is clearly placed medial to the big toe
Deviation of pelvis in any plane	SLS SD FL SLHD SH	The absence of pelvis into lateral deviation, pelvic tilt and/or rotation of pelvis respectively indicates no POE	A slight position of the pelvis into lateral deviation, pelvic tilt and/or rotation of pelvis respectively indicates minor POE	A clear position of the pelvis into lateral deviation, pelvic tilt and/or rotation of pelvis respectively indicates major POE
Deviation of trunk in any plane	SLS SD SLHD SH	The absence of a trunk position into forward lean, lateral lean and/or rotation indicates no POE	A slight position of the trunk into forward lean, lateral lean and/or rotation indicates minor POE	A clear position of the trunk into forward lean, lateral lean and/or rotation indicates major POE
Femur medial to shank	**SLS** **SD** **FL** **SLHD** **SH**	Mid-point of medial and lateral femoral condyles is lateral to tibial tuberosity	Mid-point of medial and lateral femoral condyles is in-line with tibial tuberosity	Mid-point of medial and lateral femoral condyles is medial to tibial tuberosity
Femoral valgus (the angle created by the intersection of a longitudinal line and a line from mid-point patella toward ASIS)	**SLS** **SD** **FL** **SLHD** **SH**	The absence of femoral valgus indicates no POE	A slight position of femoral valgus indicates minor POE	A clear position of femoral valgus indicates major POE

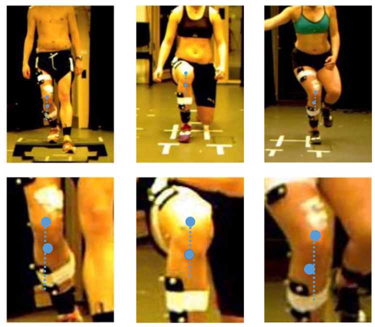
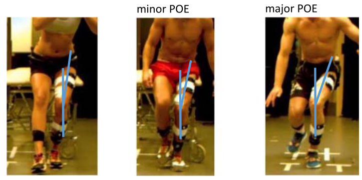



Figure 3.
Detailed description of the visual assessment of the segment-specific postural orientation errors (POEs). Foot pronation, knee medial-to-foot position (KMFP), deviation of pelvis in any plane, and deviation of trunk in any plane are previously described.[4] Photos to illustrate the POEs added in the present study are provided. ASIS = anterior superior iliac spine; FL = forward lunge; SD = stair descending; SH = side-hop; SLHD = single-leg hop for distance; SLS = single-leg mini squat. *POEs assessed in each task before the internal consistency analysis. †In cases where one of each category was scored (0, 1, 2), a score of 1 was given. If 2 scores were scored equally frequent, the highest of the 2 was assigned (eg, 0, 0, 1, 1, 2 would yield a score of 1).

Thirty-one participants were visually assessed by a second physical therapist with 22 years of clinical experience for evaluation of interrater reliability for the new POEs in all tasks, for all POEs within the SH, and the within-task POE score for the SH.

The COSMIN guidelines (https://www.cosmin.nl/) were followed to evaluate measurement properties of the additional parts of the test battery.

Statistical Analysis

Descriptive data were calculated as median (quartiles) for the within-task POE scores, POE subscores, and total POE score.

Internal consistency (Cronbach's alpha [α]) was analyzed for both the original version and the extended version of the test battery to explore if any task or POEs should be excluded from the test battery. An α between .7 and .95 was considered adequate to be maintained in the test battery. The next step in the analysis for tasks with an α of <.7 was to explore whether exclusion of segment-specific POEs would increase the α value >.7. A segment-specific POE was excluded from a task if the α value increased with exclusion of that specific POE and if the corrected item-total correlation between a POE and the within-task POE score was <0.3.[18] The item-total correlation value is an indicator of whether items (ie, segment-specific POEs in this study) correlate with the total score[18] (ie, the within-task POE score). A high item-total correlation value for each segment-specific POE indicates that the segment-specific POEs are good contributors to the construct of the within-task POE score, whereas values <0.3 indicate that the segment-specific POEs do not contribute to the construct of the within-task POE score.[18] Thus, segment-specific POEs <0.3 were excluded from the test battery.

Interpretability (floor and ceiling effects) was not analyzed in the present study, because improvements in postural orientation may be exhibited over time responsiveness (eg, a person may have POEs in the early phase but not in the late phase of rehabilitation). Thus, more floor effects of segment-specific POEs may be present in a population in the late phase, as in the current study, compared with our previous study.[4] Therefore, exclusion of POEs based on floor effects was deemed not relevant in the present study.

Interrater reliability was calculated using quadratic weighted kappa for segment-specific POEs. Intra class correlation ($ICC_{2,1}$) coefficient was calculated for within-task POE scores because weighted kappa was not possible to calculate due to too many zeros in the data. The following thresholds were used for weighted kappa (K) and ICC: <0.00 indicated poor agreement, 0.00 to 0.20 slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.80 substantial agreement, and 0.81 to 1.00 almost perfect agreement.[19] Percent agreement was calculated for segment-specific POEs in cases when weighted kappa was not possible to calculate.

Role of the Funding Source

The funder played no role in the design, conduct, or reporting of this study.

Results

Reliability: Internal Consistency

First, the Cronbach's α of the original test battery was evaluated, showing α values ranging from .07 to .597, representing poor internal consistency (Appendix 1). Second, the Cronbach's α was evaluated for the extended version of the test battery. After the deletion of some POEs from some tasks, due to item-total correlation values <0.3 for the extended version of the test battery stair descending (ie, deviation of trunk in any plane, deviation of pelvis in any plane, KMFP), SLHD (deviation of trunk in any plane), and SH lateral landing (deviation of trunk in any plane, deviation of pelvis in any plane), the α values for all tasks ranged from .712 to .823, representing good internal consistency (Appendix 2). The total POE score had an α value of .749 (Appendix 2, step 4).

Reliability: Interrater Reliability

The femur medial to shank and the femoral valgus showed fair to substantial agreement between raters (K = 0.31–0.81). The within-task POE score for the SH showed substantial to almost perfect agreement between raters (ICC = 0.789–0.907) (Tab. 2).

Final Test Battery

The final test battery includes the following tasks: SLS, stair descending, FL, SLHD, and SH, and the following segment-specific POEs: pronation of the foot, KMFP, femur medial to shank, femoral valgus, deviation of pelvis in any plane, and deviation of trunk in any plane. The median (quartiles) for the total POE score was 25% (17–31) and ranged between 17% and 33% (0–44) for each within-task POE score. See Table 3 for detailed description about which segment-specific POEs to assess in each task, together with the calculation formulas for the percentage scale and the median (quartiles) for each within-task POE score, subscales ADL and Sport, and the total POE score. A scoring file (Excel file) can be found as Supplementary Material.

Discussion

The final test battery, consisting of 5 tasks (SLS, stair descending, FL, SLHD, and SH) and 6 segment-specific POEs (foot pronation, KMFP, femur medial to shank, femoral valgus, deviation of pelvis in any plane, and deviation of trunk in any plane), had high internal consistency and good reliability. These results suggest that

Table 2.
Interrater Reliability for the Additional Segment-Specific POEs and for the Within-Task POE Score for the SH[a]

Interrater	SLS N = 31 Median (Quartiles)	Stair Descending N = 31 Median (Quartiles)	FL N = 31 Median (Quartiles)	SLHD N = 31 Median (Quartiles)	SH Lateral Landing N = 29 Median (Quartiles)	SH Medial Landing N = 29 Median (Quartiles)	SH (Medial + Lateral Landings) Median (Quartiles)
KMFP							
Tester 1					1 (1–1)	0 (0–0)	
Tester 2					1 (0–1)	0 (0–0)	
Weighted kappa (95% CI)					0.417 (0.018–0.816)	N.A.	
Percent agreement[b]					N.A.	96.5%	
Femur medial to shank							
Tester 1	1 (0–1)	1 (0–1)	1 (1–2)	1 (1–1)	1 (0.5–2)	1 (1–2)	
Tester 2	1 (0–1)	1 (1–1)	1 (1–1)	1 (0–1)	1 (0–1)	1 (1–2)	
Weighted kappa (95% CI)	0.631 (0.295–0.81)	0.492 (0.09–0.894)	0.314 (0.065–0.523)	0.547 (0.202–0.893)	0.31 (0.06–0.559)	0.655 (0.437–0.874)	
Femoral valgus							
Tester 1	1 (0–1)	1 (0–1)	1 (0–1)	1 (0–2)	0 (0–1)	1 (0–1)	
Tester 2	1 (0–1)	1 (0–1)	1 (0–1)	1 (0–2)	0 (0–0)	1 (0–1)	
Weighted kappa (95% CI)	0.753 (0.475–1.0)	0.638 (0.18–1.0)	0.724 (0.412–0.867)	0.668 (0.441–0.896)	0.815 (0.422–1)	0.78 (0.607–0.952)	
Deviation of pelvis in any plane							
Tester 1						1 (0–1)	
Tester 2						0 (0–1)	
Weighted kappa (95% CI)						0.505 (0.171–0.838)	
Deviation of trunk in any plane							
Tester 1						0 (0–1)	
Tester 2						0 (0–0.5)	
Weighted kappa (95% CI)						0.628 (0.22–1.0)	
Within-task POE score N = 30							
Tester 1					2 (1–4)	3 (1.75–5.25)	6.5 (2.75–8)
Tester 2					2 (1–3)	2 (1–5)	4.5 (2–8)
ICC (95% CI)[b]					0.798 (0.617–0.898)	0.903 (0.807–0.953)	0.88 (0.763–0.941)

[a]CI = confidence interval; FL = forward Sorward lunge; ICC = intraclass Intraclass correlation coefficient; KMFP = Knee Medial-to-Foot Position; N.A. = not applicable; kappa was not able to be calculated because of too many zeros; POE = postural orientation error; SH = side hop; SLHD = single-leg hop for distance; SLS = single-leg mini squat.
[b]Percent agreement/ICC was calculated because weighted kappa was not possible to calculate due to too many zeros.

this test battery can be used to measure POEs in patients with ACLR in the late phase of rehabilitation.

Athletes in sports that involve cutting maneuvers have an increased risk of ACL injury.[20,21] However, the original test battery for assessing POEs did not include any task encompassing cutting movements.[4] Therefore, the relevance of including a cutting task was discussed in the focus group (face validity), and the SH was added to the original test battery. The SH has previously been used in test batteries for evaluating hop performance in patients with ACL injury[22,23] and in the present study also for visual assessment of postural orientation in patients with ACLR in the late phase of rehabilitation. Good internal consistency and good interrater reliability were observed for the SH, supporting the use of this task in the construct of postural orientation and as an additional task in the original test battery for visual assessment of POEs.[4]

With regard to face validity, the visual scoring of the KMFP from the original test battery was questioned by the focus group in that the KMFP may be the result of knee and/or

Table 3.
Final Test Battery of Tasks and POEs Assessed Within Each Task[a]

Functional Tasks	Ankle POE	Knee POEs		Thigh POE	Hip POEs	Trunk POEs	Within-Task POE Score	Median (Quartiles)
	Foot Pronation	KMFP	Femur Medial to Shank	Femoral Valgus	Deviation of Pelvis in Any Plane	Deviation of Trunk in Any Plane		
SLS	X	X	X	X	X	X	$\frac{\text{sum score}}{18} x\, 100$	17 (11–28)
SD			X	X			$\frac{\text{sum score}}{6} x\, 100$	25 (0–33)
FL		X	X	X	X		$\frac{\text{sum score}}{12} x\, 100$	25 (8–33)
SLHD		X	X	X	X		$\frac{\text{sum score}}{12} x\, 100$	33 (25–44)
SH lateral landing		X	X	X			$\frac{\text{sum score}}{24} x\, 100$	27 (17–33)
SH medial landing		X	X	X	X	X		
Subscale ADL	(Sum score of the SLS, SD, and FL)						$\frac{\text{sum score}}{36} x100$	19 (11–28)
Subscale sport	(Sum score of the SLHD and SH)						$\frac{\text{sum score}}{36} x100$	31 (19–35)
Total POE score							$\frac{\text{sum score}}{72} x100$	25 (17–31)

[a]ADL = activities of daily living; FL = forward lunge; KMFP=Knee Medial-to-Foot Position; POE = postural orientation error; SD = stair descending; SH = side hop; SLHD = single-leg hop for distance; SLS = single-leg mini-squat.

ankle kinematics due to the location of the reference points on segments separated by 2 joints (knee and ankle). The validity of the KMFP as a knee POE might be affected by this, which could mean that no POEs in the original test battery[4] evaluate the knee specifically. Therefore, the femur medial to shank and the femoral valgus were added as new lower extremity POEs to the original test battery.[4] We assume that these POEs may represent lower extremity kinematics better than the KMFP, since the reference points are located just above and below the joint, or on the segment, they target. However, future validity studies on the association between POEs and 3D kinematic variables are needed to determine which POE/POEs best represent/s knee kinematics.

A strength of the femur medial to shank is that the reference points are located above and below the knee joint (mid-point of femur condyles and tibial tuberosity), thus representing the knee specifically and possibly better representing knee abduction (ie, the rotation of the shank segment in the frontal plane of the thigh segment). However, the short distance between the reference points could be seen as a limitation, as the rater needs to pause and zoom-in the recording, making the assessment of the femur medial to shank more time consuming compared with the other POEs. To ease the assessment and improve the reliability between raters, the tibial tuberosity could be marked on the participant with tape or ink before the recording.

Our study is the first to our knowledge to include visual assessment of femoral valgus as a lower extremity POE. Creaby et al reported that 2D femoral valgus predicted greater peak 3D hip adduction during running in healthy males and suggested that 2D femoral valgus could be used as a potential clinical criterion to assess frontal plane orientation at the hip.[17] We found substantial to almost perfect interrater agreement for the femoral valgus in all tasks. Thus, visual assessment of femoral valgus from video recordings is reliable to use during the SLS, stair descending, FL, SLHD, and SH. However, 1 limitation is that intrarater reliability was not evaluated. This should be evaluated in future studies because it is important to determine measurement error for different test occasions within the same rater. Good internal consistency was noted for both the femur medial to shank and the femoral valgus, supporting the addition of these POEs to the original test battery[4] for a more comprehensive assessment of lower extremity postural orientation. The extended version of the test battery showed higher internal consistency compared with the original test battery, indicating that the extended version, including an additional jumping task and new POEs, is more suitable to use throughout the ACLR rehabilitation, including the late phase. The use of a homogenous population is a strength in this study; however, the results cannot be generalized to other lower extremity injuries. Thus, further studies are needed to evaluate the internal consistency of the test battery in other populations with knee injury (eg, in patients with patellofemoral pain syndrome).

Deviation of the trunk in any plane showed low item-total correlation values (<0.3) in some tasks, indicating that the trunk did not contribute to the construct under study.[18] This resulted in deletion of the trunk deviation in any plane from the stair descending and the SLHD in the extended version of the test battery compared with the original study[4] as well as from the SH lateral landing. The addition of the femur medial to shank and the femoral valgus could implicate a shift in the construct of postural orientation toward the lower extremity, which might be 1 reason for the low item-total correlation values for the deviation of trunk in any plane. Another reason could be that visual assessment from video recordings is not sufficient to measure trunk deviation in any plane. A camera in the sagittal plane and/or 3D assessment may be needed for more accurate evaluation of trunk movements. Further studies may reveal whether the trunk will contribute to the construct of within-task POE scores in the early phase of ACLR. Although the assessment of KMFP has been questioned,[8,9] the KMFP remained as a POE in all tasks, except in the stair descending, after the internal consistency analysis.

This study was conducted from a 2D perspective. Previous studies indicate that 2D measures do not necessarily describe the actual movement in 3D.[12,17] Ageberg et al showed that visual assessment of the KMFP was valid against 2D knee abduction but that the actual movement in 3D was due to an internal rotation of the hip.[12] Another study showed that 2D femoral valgus could predict 3D hip adduction.[17] Thus, a next step in the evaluation of the test battery for visual assessment of POEs is construct validity by determining the association between each segment-specific POE and 2D and 3D kinematic variables, respectively. Also, the responsiveness to change of POEs through rehabilitation needs to be investigated to prove the utility of the test battery for patients with ACL injury during different phases of rehabilitation as well as evaluate the predictive ability of the test battery (such as re-injury).

Conclusion

The extended version of the test battery includes the addition of the side-hop, the femur medial to shank, and the femoral valgus for a more comprehensive assessment of lower extremity POEs in patients with ACLR in the late phase of rehabilitation. Good internal consistency and reliability were observed for this extended version. The results suggest that the test battery presented here can be used in future studies and in clinical practice to measure POEs in patients with ACLR, including in the late phase of rehabilitation to return to sport.

Author Contributions and Acknowledgments

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The authors gratefully acknowledge Lund University Humanities Lab for providing a test facility for data collection.

Ethics Approval

This study was approved by the Regional Ethical Review Board in Lund, Sweden (2015/8). All patients gave their written informed consent prior to participation.

Funding

This study was funded by a grant from the Skåne Regional Council, Lund University (E.A.).

Disclosures and Presentations

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

DOI: 10.1093/ptj/pzaa092

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Appendix 1.

Table A1.
Cronbach's Alpha for Within-Task POEs and Item-Total Correlation for Segment-Specific POEs within a Task for Original Test Battery[a]

Task/POE	Cronbach α	Corrected Item-Total Correlation	Cronbach α if Item Deleted
SLS (n = 53)			
Within-task POE	.597		
Deviation of trunk in any plane		0.309	.580
Deviation of pelvis in any plane		0.576	.339
KMFP		0.294	.589
Foot pronation		0.373	.533
SD (n = 52)			
Within-task POE	.462		
Deviation of trunk in any plane		0.515	−.122
Deviation of pelvis in any plane		0.343	.275
KMFP		0.052	.628
FL (n = 53)			
Within-task POE	.07		
Deviation of pelvis in any plane		0.042	–
KMFP		0.042	–
SLHD (n = 53)			
Within-task POE	.448		
Deviation of trunk in any plane		0.229	.436
Deviation of pelvis in any plane		0.540	−.269
KMFP		0.106	.589
Total POE score			
SLS	.579	0.405	.474
SD		0.401	.474
FL		0.396	.481
SLHD		.257	.597

[a]FL = forward lunge; KMFP=Knee Medial-to-Foot Position; POEs = postural orientation errors; SD = stair descending; SLHD = single-leg hop for distance; SLS = single-leg mini squat.

Appendix 2.

Table A2.
Step 1 of Cronbach Alpha for Within-Task POEs and Item-Total Correlation for Segment-Specific POEs within a Task[a]

Task/POE	Cronbach α		Corrected Item-Total Correlation		Cronbach α if Item Deleted	
SLS (n = 53)						
Within-task POE	.712					
Deviation of trunk in any plane			0.251		.728	
Deviation of pelvis in any plane			0.502		.654	
Femoral valgus			0.473		.664	
KMFP			0.491		.677	
Femur medial to shank			0.600		.617	
Foot pronation			0.414		.683	
SD (n = 52)						
Within-task POE	.612					
Deviation of trunk in any plane			0.284		.599	
Deviation of pelvis in any plane			0.351		.573	
Femoral valgus			0.448		.512	
KMFP[b]			0.249		.612	
Femur medial to shank			0.532		.459	
FL (n = 53)						
Within-task POE	.733					
Deviation of pelvis in any plane			0.550		.658	
Femoral valgus			0.703		.554	
KMFP			0.245		.792	
Femur medial to shank			0.423		.597	
SLHD (n = 53)						
Within-task POE	.687					
Deviation of trunk in any plane*			0.159		.756	
Deviation of pelvis in any plane			0.585		.567	
Femoral valgus			0.584		.572	
KMFP			0.405		.654	
Femur medial to shank			0.405		.559	
SH (n = 51)	Lateral	Medial	Lateral	Medial	Lateral	Medial
Within-task POE	0.635	0.822				
Deviation of trunk in any plane			0.199	0.526	0.659[b]	0.811
Deviation of pelvis in any plane			0.392	0.727	0.580	0.752
Femoral valgus			0.596	0.696	0.488	0.762
KMFP			0.291	0.507	0.632	0.823
Femur medial to shank			0.500	0.682	0.518	0.768

[a]FL = forward lunge; KMFP=Knee Medial-to-Foot Position; POE = postural orientation errors; SD = stair descending; SH = side-hop; SLHD = single-leg hop for distance; SLS = single-leg mini squat.
[b]POEs excluded from further analyses.

Table A3.
Step 2 of Cronbach Alpha for Within-Task POEs and Item-Total Correlation for Segment-Specific POEs within a Task After the Deletion of 1 POE[a]

Task/POE	Cronbach α		Corrected Item-Total Correlation		Cronbach α if Item Deleted	
SD (n = 52)						
Within-task POE	.612					
Deviation of trunk in any plane*			0.263		.628	
Deviation of pelvis in any plane			0.410		.530	
Femoral valgus			0.423		.520	
Femur medial to shank			0.482		.472	
SLHD (n = 53)						
Within-task POE	.756					
Deviation of pelvis in any plane			0.455		.762	
Femoral valgus			0.672		.629	
KMFP			0.527		.716	
Femur medial to shank			0.585		.682	
SH (n = 51)	Lateral	Medial	Lateral	Medial	Lateral	Medial
Within-task POE	0.659	0.822				
Deviation of trunk in any plane				0.526		0.811
Deviation of pelvis in any plane			0.203	0.727	0.720[b]	0.752
Femoral valgus			0.564	0.696	0.522	0.762
KMFP			0.401	0.507	0.619	0.823
Femur medial to shank			0.612	0.682	0.454	0.768

[a]KMFP=Knee Medial-to-Foot Position; POE = postural orientation errors; SD = stair descending; SH = side-hop; SLHD = single-leg hop for distance; SLS = single-leg mini squat.
[b]POEs excluded from further analyses.

Table A4.
Step 3 of Cronbach Alpha for Within-Task POEs and Item-Total Correlation for Segment-Specific POEs within a Task After the Deletion of a Second POE[a]

Task/POE	Cronbach α		Corrected Item-Total Correlation		Cronbach α if Item Deleted	
SD (n = 52)						
Within-task POE	.628					
Deviation of pelvis in any plane*			0.234		.816	
Femoral valgus			0.585		.326	
Femur medial to shank			0.542		.378	
SH (n = 51)	Lateral	Medial	Lateral	Medial	Lateral	Medial
Within-task POE	0.720	0.823				
Deviation of trunk in any plane				0.526		0.811
Deviation of pelvis in any plane				0.727		0.752
Femoral valgus			0.434	0.696	0.749	0.762
KMFP			0.554	0.507	0.615	0.823
Femur medial to shank			0.661	0.682	0.469	0.768

[a]KMFP = Knee Medial-to-Foot Position; POE = postural orientation errors; SD = stair descending; SH = side-hop.

Table A5.
Step 4 and Final Results of Cronbach Alpha for Within-Task POEs and Item-Total Correlation for Segment-Specific POEs within a Task[a]

Task/POE	Cronbach α		Corrected Item-Total Correlation		Cronbach α if Item Deleted	
SLS(n = 53)						
Within-task POE	.712					
Deviation of trunk in any plane			0.251		0.728	
Deviation of pelvis in any plane			0.502		0.654	
Femoral valgus			0.473		0.664	
KMFP			0.491		0.677	
Femur medial to shank			0.600		0.617	
Foot pronation			0.414		0.683	
SD (n = 52)						
Within-task POE	.816					
Femoral valgus			0.690		NA	
Femur medial to shank			0.690		NA	
FL (n = 53)						
Within-task POE	.733					
Deviation of pelvis in any plane			0.550		0.658	
Femoral valgus			0.703		0.554	
KMFP			0.245		0.792	
Femur medial to shank			0.423		0.597	
SLHD (n = 53)						
Within-task POE	.756					
Deviation of pelvis in any plane			0.455		0.762	
Femoral valgus			0.672		0.629	
KMFP			0.527		0.716	
Femur medial to shank			0.585		0.682	
SH (n = 51)	Lateral	Medial	Lateral	Medial	Lateral	Medial
Within-task POE	0.720	0.823				
Deviation of trunk in any plane				0.526		0.811
Deviation of pelvis in any plane				0.727		0.752
Femoral valgus			0.434	0.696	0.749	0.762
KMFP			0.554	0.507	0.615	0.823
Femur medial to shank			0.661	0.682	0.469	0.768
Total POE score (n = 51)						
SLS	0.749		0.345		0.757	
SD			0.552		0.697	
FL			0.551		0.691	
SLHD			0.589		0.678	
SH			0.563		0.686	

[a]FL = forward lunge; KMFP=Knee Medial-to-Foot Position; POE = postural orientation errors; SD = stair descending; SH = side-hop; SLHD = single-leg hop for distance; SLS = single-leg mini squat.