Simplifying the Star Excursion Balance Test: Analyses of Subjects With and Without Chronic Ankle Instability

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Study Design: Case control study.
Objectives: The objectives of this study are: (1) to perform factor analyses on data from the 8 components of the star excursion balance test (SEBT) in subjects with and without chronic ankle instability (CAI) in an effort to reduce the number of components of the SEBT, (2) to assess the relationships between performance of the different reach directions using correlation analyses, and (3) to determine which components of the SEBT are most affected by CAI.
Background: The SEBT is a series of 8 lower-extremity–reaching tasks purported to be useful in identifying lower extremity functional deficits.
Methods and Measures: Forty-eight young adults with unilateral CAI (22 males, 26 females; mean ± SD age, 20.9 ± 3.2 years; mean ± SD height, 173.6 ± 11.1 cm; mean ± SD mass, 80.1 ± 22.1 kg) and 39 controls (23 males, 16 females; mean ± SD age, 20.7 ± 2.4 years; mean ± SD height, 174.1 ± 12.9 cm; mean ± SD mass, 75.1 ± 18.6 kg) performed 3 trials of the 8 tasks with each of their limbs. Separate exploratory factor analyses were performed on data for involved limbs of the CAI group, uninvolved limbs of the CAI and control groups, and both limbs of the CAI and control groups. Pearson product moment correlations were calculated to identify the relationships between the different reach directions. A series of eight 2 × 2 analyses of variance were calculated to determine the influence of group (CAI, control) and side (involved, uninvolved) on performance of the 8 tasks.
Results: For all 3 factor analyses, only 1 factor in each analysis produced an eigenvalue greater than 1 and the posteromedial reach score was the most strongly correlated task with the computed factor ($\alpha > .90$), although all 8 tasks produced alpha scores greater than .67. Bivariate correlations between specific reach directions ranged from .40 to .91. Subjects with CAI reached significantly less on the anteromedial, medial, and posteromedial directions when balancing on their involved limbs compared to their uninvolved limbs and the side-matched limbs of controls.
Conclusions: The posteromedial component of the SEBT is highly representative of the performance of all 8 components of the test in limbs with and without CAI. There is considerable redundancy in the 8 tasks. The anteromedial, medial, and posteromedial reach tasks may be used clinically to test for functional deficits related to CAI in lieu of testing all 8 tasks. There is a need for a hypothesis-driven study to confirm the results of this exploratory study. *J Orthop Sports Phys Ther 2006;36:131-137.*

Key Words: *dynamic postural control, functional testing, lower extremity*

Chronic ankle instability (CAI) is a frequent consequence after lateral ankle sprain and it is estimated that approximately 40% of individuals suffering an initial ankle sprain will develop longstanding ankle dysfunction.[20] The etiology of CAI has been attributed to pathological joint laxity, sensorimotor deficits, or a combination of both entities.[11] Several authors have speculated that sensorimotor deficits are the primary cause of CAI and should be the primary target of conservative intervention strategies.[11,15,22] This has led to the search for clinical tests that may be used to assess for sensorimotor deficits related to CAI. Such tests may also be used as objective markers of improvement with rehabilitation.

Functional assessment techniques, such as variations on the Romberg test[4-6] and various hopping[2,17,24] and agility[1,17] tests, have been reported in the ankle instability literature. The inability to maintain quiet stance during single-leg standing has consistently

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been shown to be associated with ankle instability[4-6]; however, the sensitivity of these assessments has been questioned in patients with CAI.[13] Docherty et al[2] demonstrated a relationship between side-to-side and figure-8 hop test performance and the level of self-reported ankle dysfunction. However, others[1,17,24] have not found various hopping and agility tasks to differ significantly between those with and without CAI.

One functional test that may hold promise in detecting deficits related to CAI is the star excursion balance test (SEBT). The SEBT is a clinical test purported to detect functional performance deficits associated with lower extremity pathology in otherwise healthy individuals.[3,7-12,14,18-20] The SEBT consists of a series of lower extremity reaching tasks in 8 directions that challenge subjects' postural control, strength, range of motion, and proprioceptive abilities. The farther a subject can reach with 1 leg while balancing on the opposite leg, the better functional performance they are deemed to have. The ability to reach farther with a limb requires a combination of better balance, strength, and motion on the contralateral stance limb.[12] Tests are performed separately while balancing on the right and left limbs.

The SEBT has been shown to have strong intratester and intertester reliability.[12,14] Once subject learning effects have been controlled for, intraclass correlation coefficients ranging from .85 to .96 for intratester reliability and from .81 to .93 for intertester reliability have been reported.[12] The SEBT has also been shown to be sensitive in the detection of functional deficits associated with CAI.[8,19] Olmsted et al[19] found that subjects with unilateral CAI reached significantly less far on their involved limbs compared to their uninvolved limbs and to the side-matched limbs of a control group. In their analysis, reach distances from all 8 directions of the SEBT were averaged together.[19] Reach deficits have also been shown to be exacerbated between subjects with and without CAI after lower-extremity–fatiguing exercise.[8] These deficits are accompanied by reduced knee and hip motion, but not ankle motion, in the sagittal plane, suggesting that CAI may be related to performance deficits in the entire affected extremity.[8] Performance on the SEBT have also been shown to increase after 4 weeks of supervised rehabilitation in subjects with CAI.[9] These findings indicate the utility of the SEBT as a clinical test for assessing sensorimotor deficits related to CAI.

A potential limitation, however, to using the SEBT in clinical practice is that performance of a functional test battery consisting of 3 trials each of 8 different reach directions on each limb may be very time consuming. While Earl and Hertel[3] observed some statistically significant differences in muscle activation patterns and lower extremity joint range of motion during execution of the 8 different reaches, there is likely redundancy in the performance factors that these reaches are measuring.

The purposes of our exploratory study were (1) to perform a series of factor analyses on performance data of the 8 components of the SEBT from subjects with and without CAI in an effort to reduce the number of components of the SEBT necessary to detect functional deficits, (2) to assess the relationships between performance of the different reach directions using correlational analyses, and (3) to determine which components of the SEBT are most affected by CAI.

METHODS

Subjects

Forty-eight young adults (22 males, 26 females; mean ± SD age, 20.9 ± 3.2 years; mean ± SD height, 173.6 ± 11.1 cm; mean ± SD mass, 80.1 ± 22.1 kg) with self-reported unilateral CAI and 39 young adults (23 males, 16 females; mean ± SD age, 20.7 ± 2.4 years; mean ± SD height, 174.1 ± 12.9 cm; mean ± SD mass, 75.1 ± 18.6 kg) without CAI volunteered to participate. Subjects completed a survey and a follow-up interview with a research team member regarding their ankle injury history to determine if they met the inclusion or exclusion criteria. Subjects were considered to have unilateral CAI if they (1) had a history of at least 1 ankle sprain on the involved ankle requiring medical care, (2) reported more than 3 episodes of the ankle giving way on the involved side in the past 12 months, (3) had no history of fracture or surgery to the involved ankle, and (4) had no history of ankle sprain, fracture, or surgery on the uninvolved limb. All subjects self-reported to be free of any lower extremity injury, including ankle sprain, within 6 weeks of study participation. Subjects were recruited in kinesiology classes and through flyers posted in the athletic facilities at the main campus of the Pennsylvania State University. All subjects read and signed an informed consent form approved by the University's biomedical review board prior to participation.

Procedures

The SEBT was performed with the subject standing barefoot at the center of a grid laid on the floor with 8 lines extending at 45° increments from the center of the grid (Figure 1). A "crosshairs" was drawn at the center of the grid. The length and width of the stance foot were measured and the foot was meticulously placed so that the geometric center of the foot aligned with the intersection of the crosshairs. Subjects maintained a single-leg stance while reaching with the contralateral leg to touch as far as possible along the chosen line. Subjects touched the furthest

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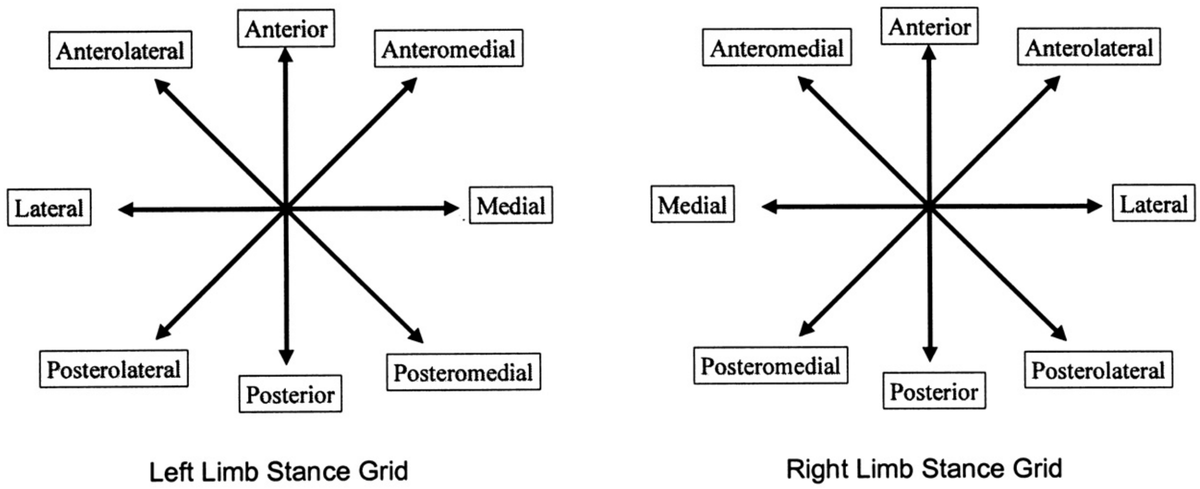

FIGURE 1. The testing grid for the star excursion balance test. The directions are labeled based on the reach direction in reference to the stance limb.

point possible on the line with the most distal part of their reach foot. The reach foot touched the furthest point on the line as lightly as possible so that the reach leg did not provide considerable support in the maintenance of upright posture. Subjects then returned to a bilateral stance while maintaining their equilibrium. The examiner marked the point touched along the line and then manually measured the distance in cm from the center of the grid to the touch point with a tape measure. Reach distances were then normalized to subjects' leg length, which was measured from the anterior superior iliac spine to the distal tip of the medial malleolus.[7] The stance foot could not move from its starting position for a valid trial; but, if this occurred, the stance foot was repositioned at the center of the grid prior to the next trial.

The 8 lines were labeled: anterolateral (AL), anterior (ANT), anteromedial (AM), medial (MD), posteromedial (PM), posterior (PO), posterolateral (PL), and lateral (LAT). The 8 lines were named according to the direction of reach in relation to the stance leg. Half of the subjects began by performing the right-leg stance tests first, while the other half began by first performing the left-leg stance tests. The order of reach directions was assigned using a Latin square to avoid order effects from contaminating the data.[23] Each subject performed 6 practice trials in each of the 8 directions on each leg followed by 5 minutes of rest before recording began.[12] Subjects then performed 3 trials in each direction on each limb. Ten seconds of rest were provided between individual reach trials.

FIGURE 2. The posteromedial reach of the Star Excursion Balance Test performed while balancing on the left limb.

Statistical Analysis

The mean of the normalized reach distances for the 3 trials in each direction were calculated and served as the dependent measures. Three exploratory factor analyses were performed on the performance data from (1) involved limbs of the CAI group (n = 48), (2) the uninvolved limbs of the CAI group and both limbs from the control group (n = 126), and (3) both limbs of both groups (n = 174). Three separate analyses were performed in an effort to determine if the underlying constructs of the contribution of the individual directions differed with and without pathology. For each factor analysis, a maximum likelihood factor extraction was performed and the resulting eigenvalues were examined to identify the

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TABLE 1. Alpha values for each direction in relation to the single-factor solution identified for each of the factor analyses.

CAI Limbs (n = 48)*		Healthy Limbs (n = 126)†		All Limbs (n = 174)‡	
Reach Direction	**α**	**Reach Direction**	**α**	**Reach Direction**	**α**
Posteromedial	.95	Posteromedial	.97	Posteromedial	.96
Medial	.91	Posterior	.94	Posterior	.93
Posterior	.90	Posterolateral	.91	Posterolateral	.90
Anterior	.86	Anteromedial	.84	Medial	.85
Posterolateral	.86	Medial	.83	Anteromedial	.84
Anteromedial	.86	Anterior	.81	Anterior	.83
Anterolateral	.79	Anterolateral	.79	Anterolateral	.79
Lateral	.67	Lateral	.79	Lateral	.77

Abbreviation: CAI, chronic ankle instability.
* CAI limbs represent the involved limbs of the CAI group.
† Healthy limbs represent the uninvolved limbs of the CAI group and both limbs of the control group.
‡ All limbs represent both limbs of both groups.

number of underlying factors in each data set. The computed factors represent composite scores based on the interrelationships between the individual items (in this case, reach directions) that are strongly interrelated. Those computed factors resulting in eigenvalues greater than 1.0 were retained in the model.[23] Each factor retained in the model represents a unique underlying construct being measured by the items that load most strongly to a given factor. For each factor retained, the loading value (α) of each of the 8 reach directions was examined. Alpha values can range from zero to 1.0, with a higher value representing a stronger association between the individual item and the computed factor.[23]

Bivariate correlations between the different reach measures in CAI (n = 48) and healthy limbs (n = 126) samples were assessed with Pearson product moment correlation coefficients to explore the strength of the relationships between the individual reach directions. Correlation coefficients close to zero are considered weak, those close to 0.5 moderate, and those close to 1.0 strong.[16]

Lastly, a series of 8 mixed-model 2 × 2 analyses of variance (ANOVAs) were performed to examine potential differences in reach performance in each of the 8 directions related to the between-factor (group: CAI, control) and the within-factor (limb: involved, uninvolved) effects. For each control subject, side matching to the CAI group was performed so that 1 limb was assigned as "sham involved" and 1 as "sham uninvolved." This was performed in a manner so that an equal proportion of right and left limbs were classified as involved and uninvolved in the CAI group and as sham involved and sham uninvolved in the control group. This side-matching procedure was undertaken to control for any influence that limb dominance may have had on reach performance. We were interested in identifying significant group-by-side interactions in an effort to determine the influence of CAI on SEBT performance. We hypothesized that reach distances on the CAI-involved limbs would be significantly less than the reach distances performed on the CAI-uninvolved limbs and both limbs from the control group for at least some of the reach directions, but we did not have a clear indication of the specific directions in which this would occur. In the presence of significant interactions, Tukey's HSD tests were performed to assess for significant differences in reach performance between all possible pairs of means. The significance level was set a priori at $P < .05$ for all analyses.

RESULTS

There were no statistically significant differences in the age, height, or body mass of subjects in the CAI and control groups.

Factor Analyses

For each of the 3 factor analyses performed, a 1-factor solution was identified (Table 1). In each case, the PM reach direction was most strongly related to the computed factor. The PM direction appears to be the reach direction most representative of performance of reaches in all 8 directions in our subjects with and without CAI.

For the limbs with CAI, a 1-factor model was identified with the factor having an eigenvalue of 6.1. The second best factor had an eigenvalue of 0.9. The loading of each reach direction to the 1-factor model revealed that the PM reach was the most strongly related (α = .95). However, all 8 directions had alpha values of greater than .67, suggesting considerable redundancy among the 8 directions.

For the healthy limbs, a 1-factor model was also identified with the factor having an eigenvalue of 6.2. The next best factor had an eigenvalue of 0.7. The PM reach again loaded highest (α = .97) and all 8 directions had alpha values of greater than .79.

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TABLE 2. Pearson product moment correlations (*r*) of reach performance in the 8 different directions for limbs with chronic ankle instability (n = 48). All *r* values are significant ($P < .05$).

	AM	MD	PM	PO	PL	LAT	AL
ANT	.91	.80	.78	.74	.66	.40	.91
AM		.80	.77	.74	.66	.46	.82
MD			.90	.75	.74	.66	.73
PM				.89	.84	.65	.69
PO					.90	.62	.64
PL						.77	.61
LAT							.43

Abbreviations: AL, anterolateral; AM, anteromedial; ANT, anterior; LAT, Lateral; MD, medial; PL, posterolateral; PM, posteromedial; PO, posterior.

TABLE 3. Pearson product moment correlations (*r*) of reach performance in the 8 different directions on the uninvolved limbs of the unilateral CAI group and both limbs of the control group (n = 126).

	AM	MD	PM	PO	PL	LAT	AL
ANT	.88	.67	.76	.73	.68	.55	.87
AM		.73	.80	.74	.71	.61	.81
MD			.83	.75	.70	.65	.65
PM				.92	.87	.75	.72
PO					.89	.74	.70
PL						.84	.68
LAT							.59

Abbreviations: AL, anterolateral; AM, anteromedial; ANT, anterior; LAT, Lateral; MD, medial; PL, posterolateral; PM, posteromedial; PO, posterior.

For the analysis of all limbs combined, a 1-factor solution was again identified with the factor having an eigenvalue of 6.2. The next best factor had an eigenvalue of 0.8. The PM reach again loaded highest (α = .97) and all 8 directions had alpha values of greater than .77.

Correlations

The Pearson product moment correlations among the reach directions revealed *r* values between 0.43 and 0.91 for the involved limbs (Table 2) and between 0.55 and 0.92 for the uninvolved limbs (Table 3). All bivariate correlations were statistically significant ($P < .05$).

ANOVAs

Means and standard deviations for all SEBT data are in Table 4. Significant group-by-side interactions were found for the AM, MD, and PM reach directions ($P < .05$) (Figures 3-5). For each of these directions, post hoc testing revealed that the reach distances of the involved limbs of the CAI group were significantly less than those of their contralateral limbs and the side-matched sham-involved limbs of the control subjects ($P < .05$). With the exception of the MD direction ($P < .05$), there were no significant side-to-side differences in the control group. Additionally, there were no significant differences between the uninvolved limbs of the CAI group and the side-matched sham-involved limbs of the control group. There were no significant main effects found between the CAI and control groups for any of the reach directions.

DISCUSSION

The primary findings of our study were: (1) the PM reach direction appears to be most representative of the overall performance of the SEBT in limbs with and without CAI; (2) there was considerable redundancy in performance of the different reach directions of the SEBT; and (3) the AM, MD, and PM

TABLE 4. Means and standard deviations of normalized reach distances (reach distance in cm/leg length in cm). CAI subjects had unilateral instability. For the control group, one limb was assigned as "sham involved" and one as "sham uninvolved" so that an equal proportion of right and left limbs were classified as involved and uninvolved in both the CAI and control groups.

	CAI Subjects (n = 48)		Healthy Controls (n = 39)			
	Involved Limbs	Uninvolved Limbs	Involved Limbs	Uninvolved Limbs	Group-by-Side Interaction (*P* Value)	Group Main Effect (*P* Value)
ANT	0.76 ± 0.12	0.79 ± 0.11	0.79 ± 0.12	0.80 ± 0.11	.16	.50
AM	0.80 ± 0.10	0.82 ± 0.09	0.84 ± 0.10	0.82 ± 0.12	.005*	.38
MD	0.85 ± 0.10	0.88 ± 0.09	0.89 ± 0.09	0.87 ± 0.09	<.0005*	.59
PM	0.85 ± 0.13	0.89 ± 0.13	0.90 ± 0.13	0.90 ± 0.13	.03*	.34
PO	0.82 ± 0.14	0.84 ± 0.15	0.86 ± 0.15	0.88 ± 0.14	.75	.22
PL	0.79 ± 0.12	0.81 ± 0.12	0.81 ± 0.13	0.83 ± 0.13	.39	.41
LAT	0.67 ± 0.11	0.70 ± 0.12	0.71 ± 0.13	0.71 ± 0.15	.07	.46
AL	0.69 ± 0.10	0.71 ± 0.10	0.72 ± 0.09	0.73 ± 0.11	.20	.27

Abbreviations: AL, anterolateral; AM, anteromedial; ANT, anterior; CAI, chronic ankle instability; LAT, lateral; MD, medial; PL, posterolateral; PM, posteromedial; PO, posterior.
* Significant at $P < .05$.

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directions were able to identify significant reach deficits associated with CAI.

For each of the 3-factor analyses, a 1-factor solution was identified and the PM reach direction was most strongly related to the computed factor in each case. The PM direction appears to be most representative of performance of all 8 tasks in our sample. It must be noted, however, that all reach directions had alpha values of at least .67 in relation to the single-factor solutions. The combination of the 1-factor solutions and the strong loading of each reach task to the single composite factors suggests tremendous redun-

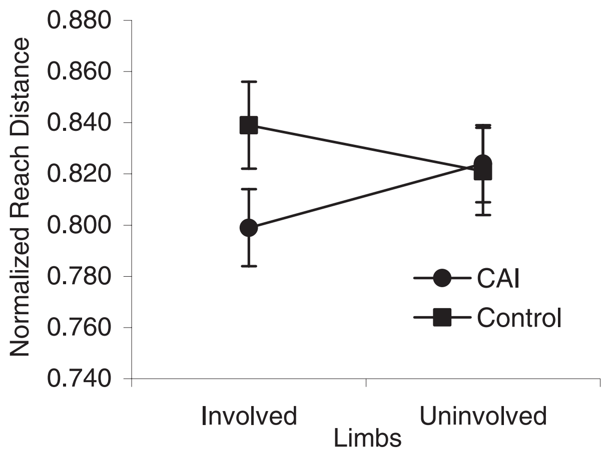

FIGURE 3. There was a significant group-by-side interaction for the anteromedial reach direction ($F_{1,85}$ = 8.32, *P* = .005). Tukey's HSD post hoc testing revealed that the chronic ankle instability (CAI) group reached significantly less far when balancing on their involved limbs compared to their contralateral uninvolved limbs and both the "sham involved" and "sham uninvolved" limbs of the control group. Error bars represent SE ($P<.05$).

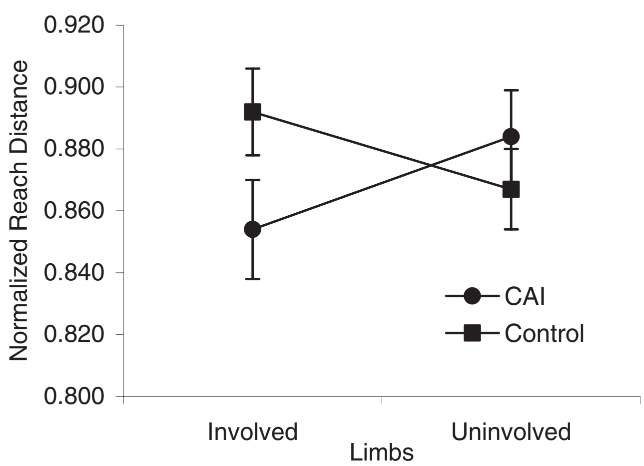

FIGURE 4. There was a significant group-by-side interaction for the medial reach direction ($F_{1,85}$ = 13.29, $P<.0005$). Tukey's HSD post hoc testing revealed that the chronic ankle instability (CAI) group reached significantly less far when balancing on their involved limbs compared to their contralateral uninvolved limbs and the side-matched "sham involved" limbs of the control group. Unexpectedly, there was also a significant side-to-side difference between limbs in the control group. Error bars represent SE ($P<.05$).

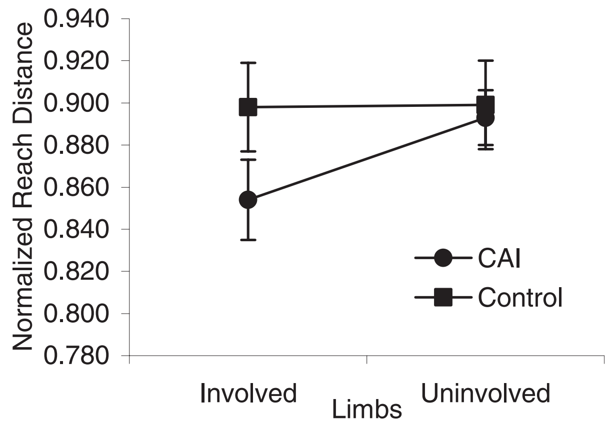

FIGURE 5. There was a significant group-by-side interaction for the posteromedial reach direction ($F_{1,85}$ = 4.97, *P* = .03). Tukey's HSD post hoc testing revealed that the chronic ankle instability (CAI) group reached significantly less far when balancing on their involved limbs compared to their contralateral uninvolved limbs and both the "sham involved" and "sham uninvolved" limbs of the control group. Error bars represent SE ($P<.05$).

dancy between the different reach directions and should indicate to clinicians that not all 8 directions of the SEBT need to be performed when assessing for functional performance deficits related to CAI.

The correlations between reach distances in the different directions were generally strong and, at worst, moderate. These results, coupled with those of the factor analyses, demonstrate that the different reach directions capture redundant aspects of lower extremity functional performance.

The results of the ANOVAs revealed significant side-by-group interactions for the AM, MD, and PM directions. For each of these 3 directions, the involved limbs of the CAI group were associated with less reach distance than the group's own contralateral limbs and the side-matched sham-involved limbs of the control group. The AM, MD, and PM directions were sensitive in detecting functional performance differences related to CAI both within limbs of individuals with unilateral CAI and between subjects with and without CAI. The magnitude of the significant differences ranged from 4% to 5% of leg length between CAI involved limbs and side-matched sham-involved limbs in controls, and from 2% to 4% within the involved and uninvolved limbs of the CAI group. It appears that the AM, MD, and PM reach directions may be used clinically to test for functional deficits related to CAI in otherwise healthy young adults in lieu of testing all 8 reach directions. Previously, reach deficits associated with CAI have been demonstrated in the literature with performance in all 8 directions averaged together.[19] The clinical implication of these 3 significant directions all containing a medial reach components is not clear and warrants further study. Lastly, in regard to the ANOVAs, we must acknowledge the risk of alpha inflation due to the explor-

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atory nature of our study as our use of 8 separate analyses may have increased our chance of making a type I error.

The most important clinical application of our findings is that performance of all 8 reach directions of the SEBT is unnecessary when testing patients with CAI for functional performance deficits. This will save considerable time for clinicians and patients. Based on these data, we recommend that a protocol encompassing the AM, MD, and PM reach directions be utilized to detect deficits related to CAI. A hypothesis-driven study is needed to confirm the findings of this exploratory study. Further research is also needed to determine the minimum clinically important difference for the SEBT related to CAI, if the SEBT is useful in other age groups (our study was limited to young adults), and to identify which reach directions are most appropriate for detecting functional deficits related to other lower extremity pathologies such as anterior knee pain.

CONCLUSION

Performance of all 8 reach directions of the SEBT is likely unnecessary when evaluating for functional deficits related to CAI because of considerable redundancy among the reach directions. The PM reach direction distances were most strongly associated with the performance of all the reach directions in subjects with and without CAI. However, the PM, AM, and MD directions were all able to identify statistically significant differences between limbs with and without CAI.

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