Osteoarthritis and Cartilage 27 (2019) 580–585

Osteoarthritis and Cartilage

The star excursion balance test is a reliable and valid outcome measure for patients with knee osteoarthritis

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ARTICLE INFO

Article history:
Received 20 August 2018
Accepted 29 November 2018

Keywords:
Star excursion
Validity
Reliability
Neuromuscular control

SUMMARY

Objectives: Despite the recognized importance of neuromuscular exercises, there is currently no widely accepted clinical outcome measure focused on neuromuscular control for patients with knee osteoarthritis (OA). The purposes of the present study were to investigate the test-retest reliability, concurrent validity and longitudinal validity of the star excursion balance test (SEBT) in patients with knee OA.
Design: 74 patients performed the SEBT on two sessions within 7 days, and on a third session after completing 12 weeks of a home exercise program focused on neuromuscular control. A subgroup of 37 performed the SEBT while in the field of view of a motion capture system to estimate concurrent validity. The SEBT was recorded in cm and also normalized to leg length (LL). Participants also completed the 40 m fast-paced walk test and patient-reported outcomes before and after the exercise program.
Results: Intraclass correlation coefficients (95% confidence intervals) were 0.94 (0.91 to 0.96) and 0.93 (0.89 to 0.96) and standard errors of measurement were ±2.68 cm and ±3.05%LL for raw and normalized composite scores, respectively. The minimum detectable change at the 95% confidence level for the composite score was 7.44 cm and 8.45%LL. Correlations between observer and motion capture measures were very high (Pearson $r > 0.96$). There was a significant increase in SEBT following the exercise program (standardized response mean = 0.74). The change in SEBT had low correlations with changes in 40 m walk times ($r = 0.26$) and pain ($r = 0.28$).
Conclusion: The SEBT has suitable measurement properties for use in patients with knee OA.

Introduction

Neuromuscular control involves coordinated muscle activity to produce a desired movement and maintain functional joint stability during the movement[1]. Neuromuscular control of the knee is compromised in individuals with knee osteoarthritis (OA), and exercise programs that focus on neuromuscular control have become a mainstay of rehabilitation for these patients[2,3]. These programs often combine resistance training for the knee and hip musculature, standing balance and postural control exercises, and especially functional movements such as stepping or lunging while maintaining alignment and stability[1,4]. While many performance-based outcome measures for knee OA exist they typically aim to quantify functional abilities such as walking, sit to stand, and stair climbing, rather than directly assessing neuromuscular control[5]. Despite its accepted importance, there is no widely adopted clinical tool to monitor patient progress in improving neuromuscular control of the knee[1–3].

We propose that the Star Excursion Balance Test (SEBT) may be a suitable outcome measure of neuromuscular control in patients with knee OA. The SEBT is a challenging dynamic task that requires adequate neuromuscular control of the stance leg to maintain balance and maximize reach distance with the opposite limb[6]. The

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https://doi.org/10.1016/j.joca.2018.11.012
1063-4584/

task is similar to some of the exercises suggested in neuromuscular exercise programs for knee OA[1]. The SEBT requires participants to maintain a single leg stance and reach with the opposite leg as far as possible along a line marked on the ground[6,7]. The participant makes a light touch at maximal reach, returns to the centre, and repeats this for all eight directions of the star with the maximum reach providing the measure of performance[8].

Previous studies evaluating the measurement properties of the SEBT are encouraging. Adequate reliability, known groups validity and longitudinal validity have been demonstrated in samples of healthy participants, and in patients with lower extremity injuries, including anterior cruciate ligament tear and chronic ankle instability[9–12]. Additionally, significant changes in aspects of the SEBT have been observed in patients with knee OA after completing a 6-week lower extremity exercise program[13]. The measurement properties of the SEBT in patients with knee OA, however, remain largely unknown. If clinicians and researchers are to use the SEBT to evaluate change in neuromuscular control in individual patients with knee OA undergoing treatments, then further information is required.

The purposes of the present study were to investigate the: 1) test-retest reliability, 2) concurrent validity of observer measurements compared to a 3D motion capture system, and 3) longitudinal validity of the SEBT in response to 12 weeks of home exercise. We hypothesized that reliability and concurrent validity correlation coefficients would be excellent (Intraclass correlation coefficient, ICC>0.75), SEBT scores would improve significantly ($p < 0.05$) following neuromuscular exercise with at least a small-to-moderate effect size (standardized response mean, SRM>0.35) and improvements in the SEBT would be significantly associated ($p < 0.05$) to improvements in the 40 m fast paced walk test and patient-reported outcome measures (including the Knee Injury and Osteoarthritis Outcome Scores (KOOS) and other numeric ratings of pain), albeit with only low-to-moderate correlation coefficients (Pearson $r < 0.5$)[14].

Methods

Study design

Participant recruitment and testing involved six physiotherapy clinics, with a subgroup of participants ($n = 37$) tested in a movement analysis laboratory. Test session one (T1) and test session two (T2) were completed at least 24 h apart and within 1 week to assess test-retest reliability. A motion capture system was used during T1 for the subgroup to assess concurrent validity. A third test session (T3) was completed after 12 weeks of home exercise to assess longitudinal validity (Fig. 1).

Participants

Potential participants were patients referred to a physiotherapist for the treatment of knee OA. The presence of knee OA was confirmed by the physiotherapist using the Altman classification criteria (knee pain with at least three of six clinical findings including age greater than 50 years, morning stiffness less than 30 min, crepitus, bony tenderness on the joint, bony enlargement, and lack of palpable warmth)[15]. Patients were excluded if they had previous joint replacement, inflammatory or infectious arthritis in either lower extremity, neurological or medical disorder affecting balance or mobility, inability to read English, psychiatric illness that limited informed consent, or the inability to stand on one limb for 5 s. Participants provided written informed consent. This study was approved by the institution's Health Science Research Ethics Board.

Outcome measures

The SEBT was performed at all test sessions using all eight directions of the star[6]. The participant's age, height, weight and leg length (anterior superior iliac spine to the ipsilateral medial malleolus) were measured at the first test session. The Knee Injury and Osteoarthritis Outcome Score (KOOS) and the 40 m fast paced walk test were also assessed at the first and last test sessions. The KOOS questions were rated from zero to four and transformed to a score of 100 where higher scores indicated less pain and greater function and quality of life[16]. The 40 m Fast Paced Walk Test measured the time required for patients to walk four sets of 10 m distances between cones[5]. Patients also rated pain in their knee using an 11-point numeric rating scale (NRS) immediately before and after completing the SEBT. The NRS ranged from 0 to 10, with 0 representing no pain and 10 representing the worst pain possible.

The SEBT was performed on eight lines taped to the floor, each at 45° to each other with centimeters marked to determine reach distance (Fig. 2). All participants performed the test barefoot. The participant was positioned with their stance leg at the centre of the

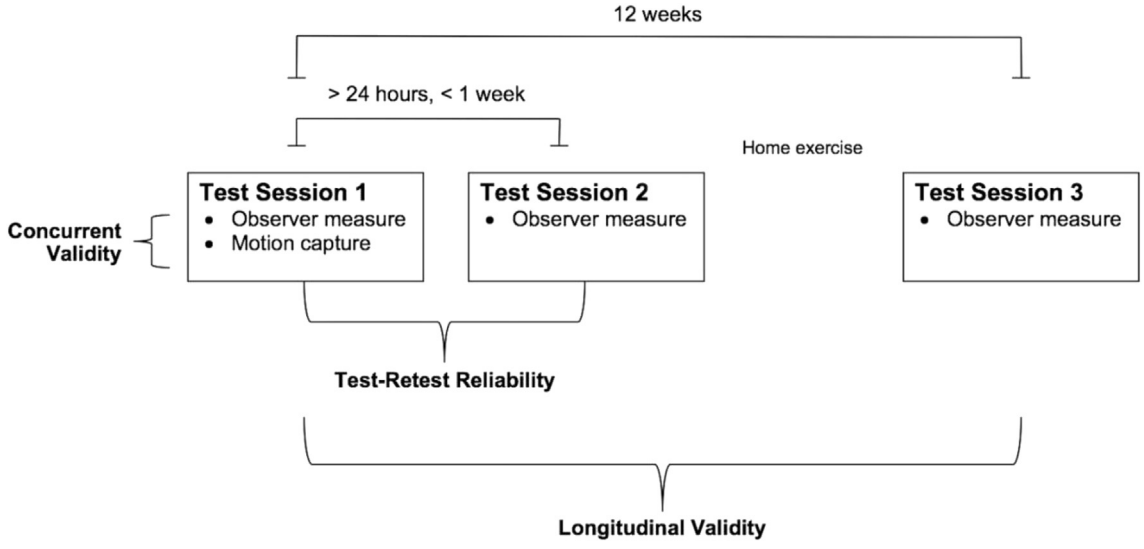

Fig. 1. Study design.

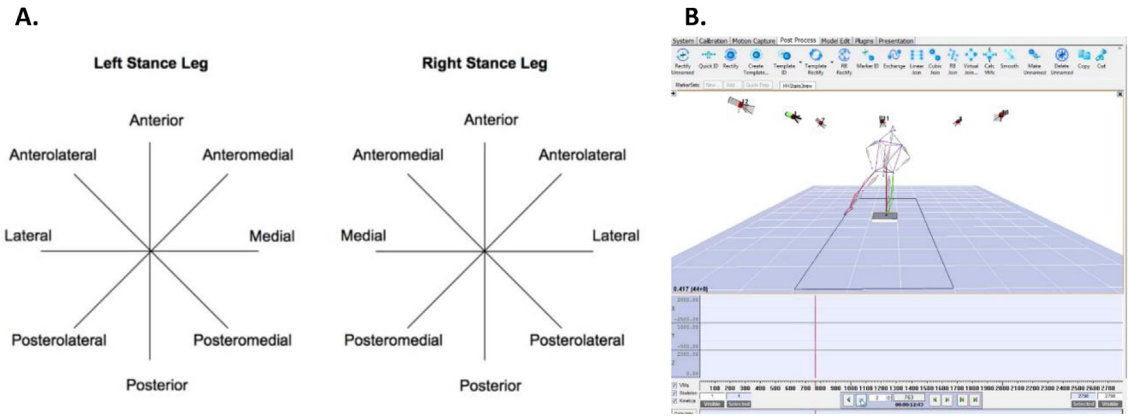

Fig. 2. A) The star excursion balance test set-up for the left and right stance legs. B) A patient completing testing as seen with the motion capture software used to calculate the maximum reach distances.

star, with the first medial cuneiform and arch of the foot over the centre mark. The participant was instructed to reach with the opposite leg as far as possible in the specified direction while maintaining balance on the stance leg and keeping the knee in line over the toe. They made a light touch with their toe at the maximal reach, and returned to the original double leg stance position. A tester observed and recorded the maximal reach distance for each trial from where the toe tapped on a tape marked in centimeters on the ground. They also monitored the participant to ensure they had their hands on their hips, their stance foot did not move, they did not put considerable support in the reaching leg, they did not lose balance or touch down other than the reach, and they maintained an appropriate position of the stance limb with the knee in line with the toe. No further postural instructions were given and trials were discarded and repeated if any of these instructions were not completed appropriately. All participants received verbal and visual instructions before completing the SEBT. One practice trial was performed in each direction on each stance leg.

The test direction order was performed as follows, relative to stance leg: anterior (AN), anteromedial (AM), medial (ME), posteromedial (PM), posterior (PO), posterolateral (PL), lateral (LA), and anterolateral (AL). Two trials were recorded consecutively for each test direction and the average was calculated to be used in analyses. All participants performed the SEBT on their unaffected (less symptomatic) leg first and then on their affected leg. In a subgroup ($n = 37$), a 12-camera motion capture system and motion capture software (Cortex, Motion Analysis Corporation, Santa Rosa, CA) were used to provide a gold standard assessment of the participants' maximal reach distances during the SEBT. Twenty-six markers were applied according to a modified Helen Hayes marker set[17]. A fixed virtual marker was created on the centre of the force plate and both toe virtual markers were created using the participant's foot length, the original marker set and the known anatomical offsets. The SEBT was then performed, with the first of the two trials in each direction being recorded by the motion capture system. Marker data were captured at a rate of 60 frames per second.

Neuromuscular exercise program

Following testing on the second session, all participants were instructed how to perform a home program of strengthening and balancing exercises similar to those included in neuromuscular exercise programs for knee OA[1]. Patients were instructed to complete the exercises at home three times a week for 12 weeks. We did not attempt to measure adherence. The exercise program began with range of motion and stretching exercises, followed by knee and hip strengthening exercises (e.g., step ups, forward lunges, chair stands, and clam shells), followed by two-legged and single-limb standing balance exercises. Maintaining alignment of the stance knee over the stance foot was emphasized. If participants experienced unusual pain or discomfort, we suggested that they stop the exercises and try again the following day.

Statistical analyses

The mean of two SEBT trials was calculated for each direction separately and for the mean of all eight directions. Data were normalized to leg length (LL) by dividing the mean reach by lower limb length and multiplying by 100%. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 24 (IBM Corp, Armonk, NY).

Test-retest reliability was assessed using the ICC with a two-way random model for absolute agreement (ICC 2,1)[18]. The standard errors of measurement (SEMs) were calculated to estimate the error associated with an individual's score. This was calculated from the square root of the mean square error term from the analysis of variance (ANOVA)[19]. The z value for 95% confidence (1.96) was used to calculate the error associated with an individual's SEBT change score (i.e., the minimal detectable change (MDC) at 95% confidence, where $MDC = SEM \times 1.96 \times \sqrt{2}$)[20]. Concurrent validity was estimated using the raw data (distances) from the first trial of each direction in the subgroup of participants tested with the motion capture system. Analysis graphs from the motion capture software were used to calculate the distance between the centre of the force plate and the virtual toe marker at touchdown to determine the overall distance reached. Concurrent validity was estimated for each direction by calculating the association between the observer's measurement of maximum reach and the motion capture maximum reach measurement using Pearson correlation coefficients (r). To investigate longitudinal validity, paired *t*-tests were used to compare SEBT scores before and after the exercise program (i.e., T1 and T3). Standardized response means were also calculated. Pearson correlation coefficients were then calculated to investigate the association between the change in normalized SEBT score, the change in the 40 m fast paced walk test times, the change in the five KOOS domains, and the change in the pain NRS.

A sample size of 74 provided 80% power (two-sided alpha = 0.05) to detect an ICC $\geq$0.75 with confidence interval width of 0.2[21]. Using a paired *t*-test, 64 participants provided 80% power

Table I
Participant demographics

Objective	Test–Retest reliability	Concurrent validity	Longitudinal validity
Number of participants	$n = 74$	$n = 37$	$n = 66$
Sex, male/female	41/33	29/8	35/31
Age, years	57.7 ± 8.8	58.0 ± 8.4	57.3 ± 8.9
BMI, kg/m^2	29.5 ± 5.6	29.0 ± 4.8	29.7 ± 5.7
Leg length, cm	88.2 ± 5.7	90.3 ± 4.3	88.0 ± 5.9
Days Between Test 1 and 2	5.4 ± 2.5	6.2 ± 2.6	5.4 ± 2.4
Days Between Test 1 and 3	–	81.0 ± 8.0	81.7 ± 18.6
KOOS at Baseline			
Pain	61.2 ± 17.8	58.6 ± 15.1	60.3 ± 18.4
Symptoms	54.8 ± 15.4	58.2 ± 15.9	54.4 ± 15.7
ADL	68.9 ± 17.8	67.5 ± 18.3	68.0 ± 18.2
Sport/Rec	39.4 ± 22.7	38.9 ± 21.9	39.5 ± 23.3
QOL	38.6 ± 21.2	35.5 ± 20.5	38.0 ± 21.3

Abbreviations: BMI, body mass index; KOOS, Knee Injury and Osteoarthritis Outcome Score; ADL, function in daily living; Sport/Rec, function in sport and recreation; QOL, knee related quality of life.
*Values are mean ± SD.

Table II
Means and standard deviations for SEBT scores on test sessions 1, 2 and the change between test sessions. ICC point estimates and 95% confidence intervals with the corresponding standard error of measurement and minimum detectable change (95% level of confidence) for the composite reach score raw data and normalized to leg length. ($n = 74$)

Affected leg	Test 1	Test 2	Mean change	ICC (95% CI)	± SEM	MDC95
Raw (cm)	60.95 ± 10.46	61.03 ± 11.47	0.09 ± 3.80	0.94 (0.91, 0.96)	2.68	7.44
Normalized (%LL)	69.03 ± 10.75	69.16 ± 12.01	0.12 ± 4.31	0.93 (0.89, 0.96)	3.05	8.45

Abbreviations: ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC95, minimum detectable change at the 95% confidence level.

(two-sided alpha = 0.05) to detect an effect size ≥0.35 following the exercise program[22]. We recruited 74 participants to account for approximately 15% dropout.

Results

Seventy-four patients participated in the first two test sessions and 66 of those participants completed the third test session (Table I). Eight participants were lost to follow-up (1 had lower limb realignment surgery, four had scheduling difficulties, three experienced musculoskeletal injuries outside of testing). A sub-group of 37 participants also completed testing in a biomechanics lab to assess concurrent validity.

The composite raw score ICC estimate of 0.94 (95% CI 0.91, 0.96) and composite normalized score ICC estimate of 0.93 (95% CI 0.89, 0.96) indicated excellent test-retest reliability (Table II). The SEMs were ±2.68 cm and ±3.05%LL for the raw and normalized composite scores, respectively. The MDC95 was 7.44 cm and 8.45%LL. The motion capture measurements and the observer measurements of reach for both stance legs were highly correlated in all directions ($r \geq 0.96$).

At test session 3, the composite normalized reach on the affected leg (73.07 ± 12.28 %LL) had significantly improved ($p < 0.0001$) with a mean change of 4.46% of LL (95% CI 2.97, 5.95) (Table III). The SRM for the composite normalized reach was 0.74. Low, statistically significant correlations were observed for the change in composite normalized score and the change in 40 m walk times and pain (Table IV). Very low, non-significant ($p > 0.10$) correlations were observed for the change in composite normalized score and the change in KOOS subscales.

Discussion

Test-retest reliability

The present ICCs (Table II) indicate excellent test-retest reliability of the SEBT in patients with knee OA. The ICC is a measure of relative reliability, calculated as a ratio of the variability between patients to the total variability, and represents the ability of a test to distinguish between patients[19,23]. These findings therefore suggest the SEBT is an appropriate tool to use in studies comparing groups of patients with knee OA, such as investigations of interventions intended to improve neuromuscular control.

Additionally, the present SEMs indicate reasonable measurement error. The SEM is a measure of absolute reliability, expressed in the same units as the original measurement, and can be used to describe measurement error in an individual patient's SEBT score[19,20,23]. The present SEMs are only slightly higher than SEMs previously reported for healthy adults and recreational athletes[13,24]. Importantly, the SEM enables the clinician to consider the error associated with an individual patient's performance. For example, given the SEM of 3%LL for the composite normalized score on the affected stance leg, a typical patient's true score on one test session of 69%LL could vary from 63 to 75 %LL simply due to measurement error (i.e., SEM * 1.96 = ± 6). Moreover, the SEM enables the calculation of the MDC and can be used to help monitor

Table III
Composite reach scores as raw data and normalized to leg length for test 1 and test 3 including the mean change and the standardized response means. ($n = 66$)

Affected leg	Test 1 reach	Test 3 reach	Mean change (95% CI)	*p*-value	SRM
Raw (cm)	60.46 ± 10.40	64.39 ± 11.83	3.93 (2.63, 5.24)	<0.0001	0.74
Normalized (%LL)	68.61 ± 10.57	73.07 ± 12.28	4.46 (2.97, 5.95)	<0.0001	0.74

Abbreviations: SRM, standardized response mean.

Table IV
Correlation between the SEBT, 40 m fast-paced walk test, KOOS subscales, and patient reported pain at test 1 and test 3, and the change from test 1 to test 3. Pearson r and *p* values are presented. ($n = 66$)

	40 m Walk	KOOS Pain	KOOS Symptoms	KOOS ADL	KOOS Sport/Rec	KOOS QOL	Pain NRS
Normalized SEBT, T1	−0.61	0.37	0.28	0.27	0.31	0.26	−0.23
Normalized SEBT, T3	−0.57	0.27	0.37	0.29	0.39	0.29	−0.17
	40 m Walk Change	**KOOS Pain Change**	**KOOS Symptoms Change**	**KOOS ADL Change**	**KOOS Sport Rec Change**	**KOOS QOL Change**	**Pain NRS Change**
Normalized SEBT Change	0.26	0.08	0.18	0.14	0.14	0.12	0.28
P values	0.04	0.55	0.14	0.25	0.27	0.33	0.03

Abbreviations: KOOS, Knee Injury and Osteoarthritis Outcome Score; ADL, function in daily living; Sport/Rec, function in sport and recreation; QOL, knee related quality of life; NRS, numeric rating scale; SEBT, star excursion balance test; T1, first test session; T2, second test session.

change (improvement or deterioration) in a patient's neuromuscular control[20]. Based on the present MDC95 of 8.45%LL (i.e., SEM * 1.96 *$\sqrt{2}$ = 8.45%LL), an individual's score would have to change by at least that amount between test sessions to be confident a true change had occurred. In other words, for the typical patient who scored 69%LL on the first test, we can be very confident that a true improvement has occurred if that individual's score is 77.45 %LL or higher on a subsequent occasion (as 95% of stable patients would change by less than 8.45%LL). When expressed in centimeters, the average patient in our study had a LL of approximately 88 cm, and the MDC95 is 7.4 cm.

Concurrent validity

The present motion capture measurements and the observer measurements of reach for both legs were highly correlated in all directions of the SEBT ($r \geq 0.96$). These results are consistent with a previous study examining the concurrent validity of motion capture and observer reach measurement when assessing the anteromedial, medial, and posteromedial directions of the SEBT[25]. These findings suggest the described very simple procedure using tape on the floor provides a highly accurate measure of distance reached. Similar future studies may benefit from calculating kinematics and kinetics during the SEBT to investigate specific mechanisms that patients use while reaching, and provide other measures of postural control for these patients.

Longitudinal validity

The SEBT improved significantly ($p < 0.0001$) after 12 weeks of home exercise and the SRM of 0.74 suggests this change can be described as moderate-to-large (Table III). This finding is consistent with another study evaluating patients with knee OA undergoing exercise and supports the longitudinal validity of the SEBT for use in patients with knee OA[13]. Notably, although some correlation coefficients were statistically significant, the associations between the change in SEBT score and the change in 40 m walk performance, KOOS scores and pain NRS were quite low. We anticipated this finding as it suggests these outcome measures assess quite different constructs. Previous research has consistently indicated patient-reported measures are poorly correlated with performance-based tests[14,26,27], suggesting both are important for monitoring patient function[27].

The specific testing methods used in the present study should be considered when generalizing its results, particularly when interpreting a patient's score with the present MDC values, which reflect performance based on the mean of two SEBT trials following one practice trial. Additionally, while the observed improvements in the SEBT following a home neuromuscular exercise support its longitudinal validity, the size of this improvement is likely to differ for supervised exercise program and/or the monitoring of adherence.

Overall, the present findings are consistent with our hypotheses, suggesting appropriate test-retest reliability, concurrent and longitudinal validity of the SEBT for patients with knee OA and support its use in research and clinical settings.

Contributions

Conception and design: Kanko, Birmingham.

Collection and assembly of data: Kanko, Gillanders, Lemmon, Chan, Postic.

Analysis and interpretation of the data: Kanko, Birmingham, Gillanders, Lemmon, Chan, Postic.

Drafting and approval of the article: Kanko, Birmingham, Bryant, Gillanders, Lemmon, Chan, Postic, Giffin.

Competing interests

None.

Funding

This study was supported in part by the Canada Research Chairs Program (Birmingham), the Canadian Institutes of Health Research, the Arthritis Society of Canada, and the University of Western Ontario Bone & Joint Institute.

Role of the funding source

Sponsors provided salary support and operating funds and had no involvement in data analysis or interpretation.

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