

Postural Control and Lower Extremity Contribution During Star Excursion Balance Test in Athletes with Chronic Ankle Instability

Chin-Yang Chen¹ Ar-Tyan Hsu¹ Lan-Yuan Guo² Cheng-Feng Lin^{1,*} Yi-An Chen¹

Objective: To investigate postural control strategy in athletes with and without chronic ankle instability (CAI) during Star Excursion Balance Test (SEBT) and to determine the possible contributing factors to the reaching distance of SEBT. **Design:** Controlled laboratory study. **Setting:** Motion Analysis Laboratory. **Methods:** Fifteen subjects with CAI and 15 uninjured age-matched athletes performed eight directional leg-reaching tasks of the SEBT. Eight infrared video cameras and one Kistler force plates were used to record the markers trajectories and ground reaction force, respectively. Reaching distance of eight directions, the displacement of anterior-posterior and medial-lateral center of pressure (COP), joint angle of the ankle, knee, and hip at maximum reaching distance, muscle strength of the ankle and knee joint muscles were measured. **Results:** The CAI group had significantly smaller ankle plantar flexor strength and reaching distance in the posterior-lateral, posterior, posterior-medial, anterior-medial, and medial directions of the SEBT but had greater knee and hip flexion angle in the anterior-lateral and lateral directions. The passive range of motion of ankle dorsiflexion positively correlated with reaching distance in the majority of testing directions in both groups. The CAI group had significantly greater anterior-posterior COP displacement in the anterior-lateral direction of reaching but significantly smaller medial-lateral COP displacement in the posterior direction of reaching than the control group. **Conclusion:** Athletes with CAI had inferior performance in SEBT to those without. The ankle, knee, and hip angles in the sagittal plane at peak reaching distance and the flexibility of calf muscle contributed to the performance of the SEBT. (FJPT 2011;36(4):263-273)

Key Words: Dynamic postural control, Chronic ankle instability, Star excursion balance test.

¹ Department of Physical Therapy, National Cheng Kung University, Tainan, Taiwan

² Department of Sports Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan

Correspondence to: Cheng-Feng Lin, Department of Physical Therapy, National Cheng Kung University, No. 1, University Rd., Tainan 70101, Taiwan.

Tel: 886-6-235-3535#5911 E-mail: connie@mail.ncku.edu.tw

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INTRODUCTION

Ankle sprain has the highest injury rate found in the basketball and volleyball players during games.^{1,2} Individuals with ankle sprain may suffer from recurrent ankle sprain and complain about ankle “giving way” during activities,³ and this phenomenon is called as “ankle instability”. About 40-75% of those with lateral ankle sprain develop into chronic ankle instability. The impaired proprioception, neuromuscular control, strength deficits, pathologic laxity, and arthrokinematic restrictions are proposed as contributors to chronic ankle instability (CAI).⁴

The decreased neuromuscular control may be a reason of recurrent ankle sprain in individuals with CAI. Studies showed that subjects with functional ankle instability decreases static postural stability.^{3,5,6} However, no sufficient evidence to prove the relationship between ankle instability and decreased postural stability.⁷ Postural stability relies on three major sensory inputs which are visual, vestibular, and somatosensory systems. When the ligament is injured, somatosensory system may be injured and other sensory receptors may compensate the mechanoreceptor defect of the injured ligament.⁸ It is thus difficult to identify whether the CAI subjects have the deficit in the postural control or not.

Evaluation of ankle instability status through static postural sway or ankle proprioception test is insufficient.⁹ Thus, the star excursion balance test (SEBT), a test containing eight-direction single-leg reaching, was used to evaluate the dynamic postural control in subjects with ankle instability.^{10,11} The longer reaching distance in each direction is the better dynamic postural control of the performer. Finding of these two previous studies showed that less reaching distance and decreased hip and knee joint angles were found in the CAI group than control group during SEBT or in the condition after fatigue.^{10,11} However, they only measured the reaching distance and joint angles in the sagittal plane. A more complete understanding of dynamic postural control should be provided with changes of center of pressure (COP) and joint angles in other planes. This test has also been used to evaluate dynamic postural control for predicting lower extremity injury¹² and the intra-tester and inter-tester reliability of this test have already been established.¹³ In addition, a previous study indicated the CAI subjects present decreased hip and knee joint motion in the sagittal plane during

the SEBT.¹⁰

Although the SEBT is a convenient clinical tool to evaluate dynamic postural control, it is not well understood how the CAI affects the performance of SEBT. To our knowledge, little study discussed the center of pressure between the CAI and healthy subjects in performing SEBT. Measurement of COP has been often used as an interpretation of postural control.^{14,15} Therefore, investigation of COP during SEBT gives us information about how an individual executes the test and measuring COP has advantage than the reaching distance because COP parameters can be quantified in different directions as well as different determinants. Furthermore, how the injured ankle joint affects the CAI subjects on executing the SEBT is unclear.

The purposes of this study were to investigate the postural control strategy in terms of reaching distance, and kinematics of the ankle, knee, and hip joints between the CAI subjects and healthy subjects during the SEBT. In addition, possible factors that may affect the reaching distance of the SEBT would be determined via a correlational analysis. We hypothesized that subjects with CAI had poor dynamic postural control and decreased reaching distance in the SEBT with smaller ankle, knee, and hip joint motion. We also hypothesized that the ankle dorsiflexion, knee and hip flexion angle would contribute to the reaching distance.

METHODS

Participants

Fifteen healthy subjects (control group) and fifteen subjects with chronic ankle instability (CAI group) between the ages of 18 and 28 years were recruited from campus (Table 1.). The inclusion criteria of subjects in the CAI group were: (1) having at least one acute ankle sprain that resulted in swelling, pain and protected weight bearing and/or immobilization of the injured ankle; (2) having often complained of ankle “giving way” during sports activity and at least sprained their ankles twice within the past six year; (3) having suffered from recurrent ankle sprain at least one time in the past six months, and (4) having the Cumberland Ankle Instability Tool (CAIT) score less than 27. The inclusion criteria of the age-matched control group were having regular exercise at least three times per week, and the exercise required regularly jump-landing

Table 1. Mean (SD) of subjects characteristics and muscle strength

Group	CAI	Control	<i>p</i> -value
Testing leg (R, L)	9R, 6L	12R, 3L	NA
Gender (Female, Male)	6F, 9M	7F, 8M	NA
Age (year)	21.6 (2.4)	21.5 (2.6)	0.943
Height (cm)	166.8 (7.1)	164.5 (7.4)	0.388
Weight (kg)	62.6 (7.9)	59.2 (9.6)	0.300
CAIT	18.1 (5.0)	30.0 (0.0)	0.001 [*]
	Muscle strengths (lb)		
Ankle plantarflexors	247.6 (60.9)	288.9 (46.7)	0.041 [*]
Ankle dorsiflexors	231.6 (44.9)	258.3 (44.9)	0.107
Ankle evertors	140.5 (36.0)	157.4 (22.2)	0.137
Ankle invertors	163.1 (52.0)	183.1 (27.6)	0.205
Knee flexors	218.3 (47.6)	222.7 (38.2)	0.791
Knee extensors	259.6 (48.0)	272.0 (58.2)	0.529

^{*}: Significant difference between CAI and Control groups

CAI: chronic ankle instability; CAIT: Cumberland Ankle Instability Tool

tasks such as basketball and volleyball game. The subjects in the control group should not have any sport injury or joint instability in the lower extremity. Subjects were excluded from either group if they had a history of serious orthopedic injury (except for the ankle instability in the CAI group) that would affect their regular sports performance such as running speed or jumping height. Subjects with acute inflammation in the ankle joint were also excluded from the CAI group.

Basic Measurements

Each subject completed a questionnaire containing basic data, previous sport-related injury history, and one assessment tool, Cumberland Ankle Instability Tool (CAIT). The CAIT contains 9 items describing the instability condition about the injured foot during daily activities and grades the severity of instability between 0 and 30.¹⁶ The higher CAIT score means greater stability of the ankle joint. The subject was identified as with unstable ankle and increased the injury risk if the CAIT score below 27.5 (specificity was 74.7%, and sensitivity was 82.9%).¹⁶ Both active range of motion (AROM) and passive range of motion (PROM) of ankle dorsiflexion, plantarflexion, inversion and eversion were measured. The ankle joint flexibility was represented with PROM of ankle dorsiflexion. The maximum muscle strength of the ankle plantarflexors, dor-

siflexors, invertors, evertors, and knee extensors and flexors were measured three times of each muscle with a hand-held dynamometer (Hoggan, West Jordan, UT, USA) at each standard position by the same investigator.¹⁷ The average of three maximum muscle strength measurements of each muscle was reported. The medial longitudinal arch angle and rearfoot-to-leg angle were used to evaluate the foot type of each participant in a standing position.¹⁸ The medial longitudinal arch angle was the obtuse angle between the lines connecting medial malleolus to navicular tuberosity and medial malleolus to first metatarsal head. The rearfoot-to-leg angle was the acute angle formed by the longitudinal bisecting line of the calcaneus and the distal one third of the leg. A pronated foot was defined by the rearfoot-to-leg angle greater than 9° and the medial longitudinal arch angle less than 134°. A supinated foot was determined if the rearfoot-to-leg angle was less than 3° and the medial longitudinal arch angle was greater than 150°.¹⁸

Instruments

Eight infrared video cameras (Eagle Digital RealTime System, Motion Analysis Corporation, USA) were used to record the trajectories of markers. One Kistler force plate (Type 9281B, Kistler Instrument Corporation, Switzerland) was used to collect the ground reaction force in order to calculate the

COP. The Eagle Digital RealTime System with eight cameras collected the markers data at a sample rate of 100 frames/second. The analog data were collected at a sampling rate of 1000 frames/second. The videographic data were up-scaled to 1000 frames/second to synchronize with the analog data.

Marker Placement

A total of 35 markers were attached on the bilateral lower extremities. The foot segment was defined with four anatomical markers placed on the lateral and medial malleoli, and the 1st and 5th metatarsal heads. The shank segment was defined with four anatomical markers on the lateral and medial epicondyles of femur, lateral and medial malleoli, and one tracking marker at the midpoint of lateral shank. Two anatomical markers on the lateral and medial epicondyles of femur and one tracking marker on the midpoint between the ipsilateral ASIS and lateral epicondyle of femur defined the thigh segment. The pelvis segment was defined with the anatomical markers placed on the bilateral ASIS, and the mid-point of the bilateral PSIS. In addition, one marker was placed on the distal end of 2nd toe to calculate the reaching distance.

Experimental Procedure

Before the data collection, the experimental procedure was introduced to each participant. After understanding all the procedure, the participants were given a consent form approved by the University Hospital Institutional Review Board. Each subject was screened by a licensed physical therapist before he or she participated in this study. The written consent form was obtained if they satisfied with the inclusion criteria. Each subject was asked to wear a pair of shorts during anthropometric measurement and data collection. Each subject was asked to warm up for 5 to 10 minutes before data collection. The warm-up included stretch of lower extremities, ROM exercise, and vertical jump. After the warm-up, the reflective markers were attached to bony landmarks of the lower limbs.

Each subject was given time to practice SEBT to ensure they know how to perform this task correctly. Subjects needed to obey following rules during the SEBT: (1) standing the unstable foot (CAI group) or dominant foot (control group) on the center of grid formed by 8 lines, (2) keeping their hands on the waist during the test, (3) keeping the heel of the supporting leg on the ground at all times, (4) maintaining single-leg stand-

ing in reaching and returning phases, and (5) reaching as far as possible by moving leg along the line. Eight leg-reaching directions including anterior (A), anterior-lateral (AL), lateral (L), posterior-lateral (PL), posterior (P), posterior-medial (PM), medial (M), anterior-medial (AM) were measured (Figure 1.). Each subject performed three successful trials of reaching for each direction and then the averaged reaching distance from these three trials were reported. The trial was discarded and recollected as long as subjects lost balance or disobeyed one of the above rules. The maximum reaching distance at each direction was recorded and then normalized to the supporting leg length of the corresponding subject. The COP displacements were defined as the maximum distance between the COP moving point and the reference point, crossed by the longitudinal axis of 2nd metatarsal bone and the line connecting 1st and 5th metatarsal heads. All data reduction was processed through Visual 3D-3.9 (C-Motion, MD, USA) and MatLab7.1 (Mathwork, Natick, MA, USA).

Statistical Analysis

The independent t test was used to determine the statistical differences between groups. The parameters tested included normalized reaching distance of eight directions, displacements of the anterior-posterior and medial-lateral COP, three-dimensional joint angles of the ankle, knee, and hip at maximum reaching distance, AROM and PROM of the ankle joint, and the muscle strength of the ankle and knee joint muscles. Pearson product-moment correlations were used to determine the bivariate relationships between normalized reaching distance of each direction and three-dimensional joint angle at maximum reaching distance, the PROM, the muscle strength, and the medial longitudinal arch angle and rearfoot-to-leg angle in the pooled dataset of two groups. The significant level for all analyses was set at $p < 0.05$. All statistical analyses were performed using SPSS 14.0 computer program (SPSS for Windows, Chicago, IL, USA).

RESULTS

The CAI group had smaller ankle plantar flexor strength than that of the control group ($p = 0.041$; 95% CI = -18.264 to -0.406) (Table 1.). No group differences in AROM ($0.60 < p$

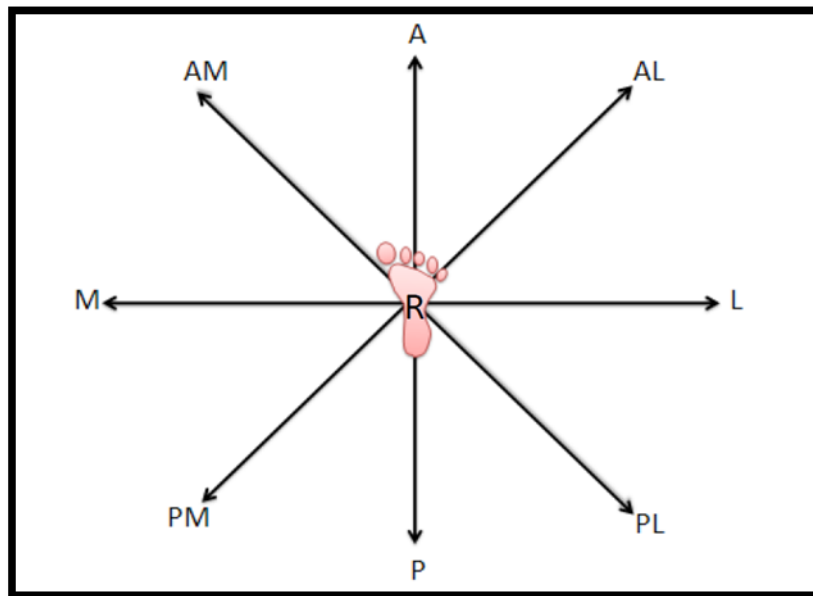


Figure 1. Eight directions of the SEBT

A: anterior; AL: anterior-lateral; L: lateral; PL: posterior-lateral; P: posterior; PM: posterior-medial; M: medial; AM: anterior-medial

< 0.98) and PROM ($0.31 < p < 0.84$) of ankle plantarflexion, dorsiflexion, inversion, and eversion were found. Similarly, no group differences in the medial longitudinal arch angle (CAI: $140.5^\circ \pm 8.3^\circ$, control: $138.8^\circ \pm 7.7^\circ$; $p=0.558$) and rearfoot-to-leg angle (CAI: $6.7^\circ \pm 2.0^\circ$, control: $7.1^\circ \pm 2.5^\circ$; $p=0.579$) were found.

The reaching distance of the control group was longer in the PL ($p=0.018$; 95% CI=-0.214 to -0.021), P ($p=0.002$; 95% CI=-0.183 to -0.044), PM ($p=0.003$; 95% CI=-0.149 to -0.032), M ($p < 0.001$; 95% CI=-0.120 to -0.039), and AM ($p=0.005$; 95% CI=-0.095 to -0.017) directions of the SEBT compared with that of the CAI group (Figure 2.). The average reaching distance of eight directions was also greater in the control group than the CAI group (CAI: 0.73 ± 0.06 vs. control: 0.80 ± 0.06 ; $p=0.005$; 95% CI=-0.117 to -0.023).

The CAI subjects had greater knee flexion angle in AL ($p=0.036$; 95% CI=-29.162 to -1.089) and L ($p=0.005$; 95% CI=-12.953 to -2.574) directions of the SEBT than the control subjects (Table 3a). The CAI subjects had greater hip flexion angle in AL ($p=0.024$; 95% CI=1.955 to 25.010) and L ($p=0.032$; 95% CI=0.586 to 11.608) directions of the SEBT than the control subjects (Table 2a.). No significant group differences

were found in the knee and hip joint angles in the frontal and transverse planes (Table 2a.) and ankle joint angles in the three planes at maximum reach distance of SEBT. (Table 2b.)

The displacement of anterior-posterior COP trajectory was larger in AL ($p=0.010$; 95% CI=0.023 to 0.152) direction in the CAI group than the control group (Figure 3a.). The displacement of medial-lateral COP trajectory was smaller in P ($p=0.017$; 95% CI=-0.102 to 0.010) direction in the CAI group than the control group (Figure 3b.).

No significant correlation was found between the medial longitudinal arch angle and the reaching distance in every direction ($0.117 < p < 0.839$). Also, no significant correlation was found between the rearfoot-to-leg angle and the reaching distance in each direction ($0.525 < p < 0.962$). The ankle and knee muscle strength tested ($0.168 < p < 0.928$) also had no significant correlation with the reaching distance in each direction. In addition, the PROM of ankle dorsiflexion was positively correlated with normalized reaching distance in the A ($r=0.564$; $p=0.001$), AL ($r=0.512$; $p=0.004$), L ($r=0.396$; $p=0.030$), PL ($r=0.391$; $p=0.033$), P ($r=0.391$; $p=0.032$), PM ($r=0.404$; $p=0.027$), and AM ($r=0.443$; $p=0.014$) directions. The ankle dorsiflexion angle significantly correlated with the

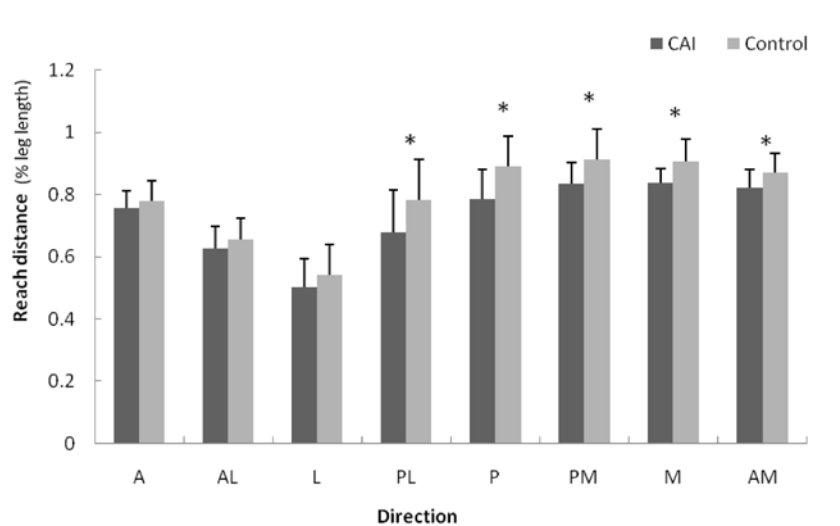


Figure 2. Normalized reach distances in the SEBT (normalized to the leg length)
 **p*<0.05: Significant difference between CAI and control groups.

Table 2a. Knee and hip joint angles at maximum reach distance (degrees)

Knee	Flexion(+)		Adduction(+)		Internal rotation(+)	
	CAI	Control	CAI	Control	CAI	Control
A	58.6(19.9)	57.8(18.6)	10.1(10.2)	11.5(10.1)	-4.3(8.8)	-7.7(8.0)
AL	43.2(18.6)*	28.0(18.9)	4.0(8.4)	5.8(7.8)	4.8(8.8)	4.7(11.9)
L	7.9(8.2)*	0.1(5.4)	1.7(3.2)	3.5(2.3)	15.1(11.0)	15.7(9.8)
PL	31.9(14.9)	36.8(17.9)	20.1(9.4)	25.8(8.3)	-25.3(13.2)	-29.5(10.2)
P	44.5(13.8)	53.0(18.7)	17.1(8.6)	21.6(7.6)	-15.8(12.0)	-17.5(9.0)
PM	56.5(16.2)	59.6(28.8)	13.4(12.2)	11.6(13.2)	-11.8(10.8)	-12.1(9.4)
M	61.6(20.7)	70.0(20.2)	12.3(9.6)	9.3(14.8)	-13.8(11.0)	-12.9(9.5)
AM	56.0(18.1)	65.7(18.4)	12.4(9.6)	12.3(12.4)	-13.4(10.4)	-12.5(9.3)
Hip	Flexion(+)		Adduction(+)		Internal rotation(+)	
A	27.2(19.8)	22.7(13.1)	15.5(6.4)	17.8(6.2)	16.7(11.7)	19.0(8.5)
AL	26.0(18.0)*	12.5(12.2)	18.5(5.0)	18.3(5.8)	16.5(10.5)	17.4(7.6)
L	18.5(9.0)*	12.4(5.1)	19.1(5.4)	20.4(5.6)	8.1(9.7)	8.2(9.9)
PL	60.0(15.8)	65.2(15.1)	16.5(5.2)	14.0(11.1)	7.3(12.0)	8.6(8.9)
P	68.5(12.6)	76.4(15.3)	12.4(5.3)	12.2(8.2)	11.4(10.6)	13.1(9.6)
PM	55.7(18.1)	65.7(16.0)	1.9(11.4)	3.8(8.1)	14.4(10.9)	18.5(11.4)
M	35.3(22.2)	40.3(18.5)	4.1(9.3)	2.7(10.0)	14.6(10.7)	19.5(9.7)
AM	20.6(17.6)	22.7(16.5)	11.5(6.1)	13.4(9.0)	14.7(12.1)	19.7(8.3)

**p*<0.05: Significant difference between CAI and control groups

CAI: chronic ankle instability; A: anterior; AL: anterior-lateral; L: lateral; PL: posterior-lateral; P: posterior; PM: posterior-medial; M: medial; AM: anterior-medial

reaching distance in every direction except for the L direction (Table 3.). The knee flexion angle and hip flexion angle significantly correlated with the reaching distance in the PL, P, PM, and M directions (Table 3.).

DISCUSSION

Normalized reaching distance in SEBT

In general, the CAI group had shorter reaching distance

Table 2b. Ankle joint angle at maximum reach distance (degrees)

	Dorsiflexion(+)		Adduction(+)		Eversion(+)	
	CAI	Control	CAI	Control	CAI	Control
A	25.6(8.0)	28.1(8.9)	-9.2(4.0)	-7.7(3.8)	-3.1(3.0)	-2.5(4.0)
AL	15.2(7.4)	11.2(8.5)	-3.3(4.5)	-2.6(3.1)	5.7(5.9)	6.4(5.2)
L	-3.6(4.8)	-5.5(3.2)	0.7(4.7)	1.5(3.6)	12.9(8.2)	11.8(7.7)
PL	14.8(8.5)	19.2(9.1)	-10.1(5.0)	-9.5(4.7)	-5.9(6.2)	-3.3(3.5)
P	15.4(6.9)	20.6(9.0)	-11.8(4.0)	-11.8(5.8)	-7.1(5.8)	-5.8(4.0)
PM	21.6(7.1)	25.7(7.2)	-12.7(5.0)	-11.4(5.1)	-8.1(5.6)	-6.7(3.5)
M	28.4(8.5)	32.4(8.7)	-12.5(4.9)	-10.5(5.7)	-8.3(4.8)	-7.3(3.5)
AM	27.7(9.0)	32.9(7.8)	-12.1(5.4)	-9.9(5.6)	-7.5(4.8)	-6.1(4.6)

CAI: chronic ankle instability; A: anterior; AL: anterior-lateral; L: lateral; PL: posterior-lateral; P: posterior; PM: posterior-medial; M: medial; AM: anterior-medial

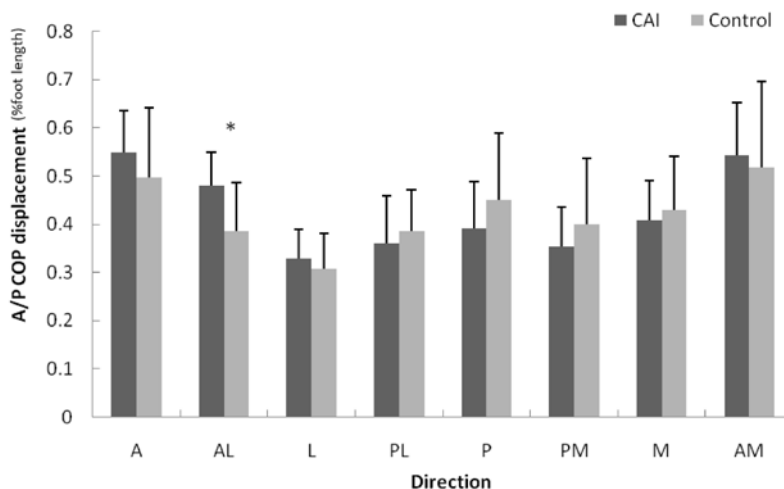


Figure 3a. Normalized anterior-posterior COP displacement in the SEBT (normalized to the foot length)

* $p < 0.05$: Significant difference between CAI and control groups.

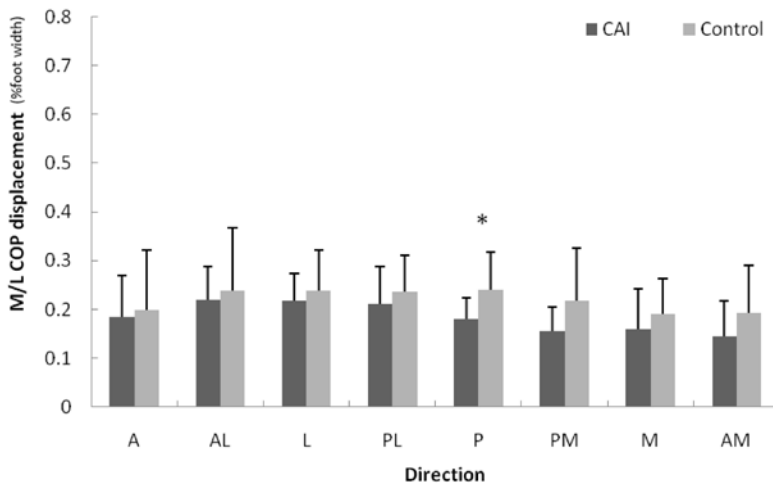


Figure 3b. Normalized medial-lateral COP displacement in the SEBT (normalized to the foot width)

* $p < 0.05$: Significant difference between CAI and control groups.

Table 3. Correlation between normalized reach distance and joint angle at maximum reach distance

Distance	Ankle Dorsiflexion	Knee Flexion	Hip Flexion
A	0.760*	0.691*	0.342
AL	0.404*	0.305	-0.006
L	-0.311	-0.034	-0.355
PL	0.545*	0.523*	0.802*
P	0.551*	0.648*	0.732*
PM	0.601*	0.288	0.683*
M	0.602*	0.653*	0.433*
AM	0.740*	0.671*	0.265

* $p < 0.05$

in several directions than the control group. Our findings supported that the CAI subjects had poor dynamic postural control. The deficits in the postural control in the CAI subjects might result from the earlier ankle sprain that may have damaged influential components for postural control such as neuromuscular control, proprioception, joint configuration or muscle strength.⁴ Studies have presented that the postural control deficits exist in the individuals after ankle sprain.^{19,20} Our findings also showed that the reaching distance was possibly affected by the decreased strength of the ankle plantarflexor in the CAI subjects even though significant correlation between strength of plantarflexors and reaching distance was not found. The reaching distance and plantarflexors strength were both smaller in the CAI group than the control group. The ankle plantarflexors contracted eccentrically during reaching phase of the SEBT as the tibia advanced. Therefore, the reaching distance may be decreased if the CAI subjects have weak ankle plantarflexors. Moreover, the non-significant correlation can be explained with different types of contraction during reaching phase (eccentric contraction) and during muscle strength test (concentric contraction).

The CAI group had significantly shorter reaching distance only in the AM, M, PM, P, and PL directions when compared with the controls. Two reasons may explain these findings. One is the decreased muscle strength of ankle plantarflexors in the CAI subjects as mentioned previously. The other is that these directions may put lateral ligaments in a more stressful position than other directions do. Subjects used a strategy with greater ankle dorsiflexion in these directions to reach for the maximum distance. According to our results, positive correlation between

ankle dorsiflexion angle and the normalized reaching distance were found during the AM, M, PM, P and PL reaching. Since CAI subjects had weaker plantarflexors, it is thus difficult to control the ankle joint in these directions. Based on the ankle joint angle at the maximum reaching distance, subjects demonstrated greater ankle abduction angle (over 10°) in the AM, M, PM, P, and PL directions. This result suggested that the foot segment would rotate externally relative to the shank segment. This twist movement of the ankle joint would stress the ligament. A cadaveric study presented that the lateral ankle ligaments have greater strain when a greater ankle dorsiflexion angle combined with external rotation are applied on the cadaver foot.²¹ This finding supports why the CAI group had shorter reaching distance in these directions.

Joint angle during SEBT

During SEBT, subjects who performed with greater ankle, knee, and hip joint angles would reach longer distance. We found the CAI group had significantly greater knee and hip flexion angles in the AL and L directions, but had no significant group difference in the reaching distance in these two directions. In the AL and L directions, subjects extended the reaching leg and crossed the supporting leg for maximum reaching. The range of motion in the hip adduction, instead of the balance control ability in supporting leg, may be one main limitation to retrieve more distance. In addition, the hip and knee angle were not significant correlated to the reaching distance in the AL and L directions. This combined results suggested that the CAI group flexed their knee and hip to maintain balance for achieving the similar reaching distance as control group in

these directions. As previous study showed, subjects with ankle inversion injury and with ankle hypermobility changes the proximal muscle recruitment pattern in response to perturbations.²² Our findings implied that the proximal joints do present the compensatory movement for maintaining postural stability in the AL and L directions. The increased proximal joint angles, such as the hip and knee joints, suggested that the unstable distal joint (ankle joint) may induce a compensatory strategy at the proximal joints (knee or hip joint).

COP

The CAI subjects presented a smaller COP displacement in the medial-lateral direction in each reaching direction. This reduced COP displacement in the medial-lateral direction also corresponds to the injury mechanism of ankle sprain. Because ankle sprain or ankle instability often occurs to the lateral ankle ligament and the COP would be medial to the subtalar joint axis and increased the supination moment that predisposes ankle to ankle sprain.⁴ The reduced COP displacement in the medial-lateral direction might be a way to avoid overstress on the lateral ligament. In addition, a stiffer ankle joint, pronated or supinated foot were usually assumed as compensatory change to stabilize the COM above the base of support.⁴ Due to lack of capability in accurately controlling ankle motion, the CAI subjects tried to immobilize the COM over the limit of stability that resulted in a decreased medial-lateral displacement of COP trajectory.

The CAI subjects presented larger anterior-posterior COP displacement in the reaching task that involved shifting weight forwards (A, AL, AM) but shorter anterior-posterior COP displacement in the reaching task that involved shifting weight backwards (P, PL, PM). The larger anterior-posterior COP displacement in the directions involving weight-transfer forwards may be contributed from greater knee and hip flexion angles during those directions. Greater knee and hip flexion angles during reaching could bring COP forward, though the reaching distance may not be necessarily longer. Therefore, large COP displacement in the anterior-posterior direction may not be reflective of poor postural control. In addition, the CAI subjects may also grasp the floor with their toes to stabilize the foot when they shifted the COP to the forefoot. Those strategies may increase the anterior-posterior COP displacement in the direction consisting weight shifting forward.

Factors associated with reaching distance

Moderate to high correlations between reaching distance and the flexion angle of ankle, knee, and hip joints in majority of directions indicated the importance of the lower extremity joints in contributing to this task. The greater ankle dorsiflexion, knee flexion, and hip flexion angles, the lower height the COM is. The lower COM increased the postural stability and thus enhanced the reaching distance. This finding was supported by a study with a stepwise regression analysis.²³ Their results revealed that hip and knee flexion angles account for 62 to 95% of variance in reaching distances of SEBT for 20 healthy subjects. However, in our finding, the ankle dorsiflexion angle did not correlate well with the reaching distance in the L direction only. The discrepancy in this may be due to characteristics of the task requisition in the L direction. During the reaching phase of the L direction, the reaching leg needs to cross the supporting leg. Therefore, subjects often place their ankle, knee, and hip joints in a more extended position.

The PROM of ankle dorsiflexion has a positive correlation with reaching distance in the majority of directions. In a previous study, the raw reaching distance of SEBT has been shown to be positively correlated to the body height and leg length, but not to foot type or ROM of ankle dorsiflexion and hip external and internal rotation.²⁴ In our study, the reaching distance was normalized to the leg length. This explained that the positive correlation between ankle dorsiflexion angle and normalized reaching distance should not come from the variability of leg length but the flexibility of triceps surae. The PROM of ankle dorsiflexion is usually used to evaluate the flexibility of triceps surae. Poor muscle flexibility and postural control have been shown as contributing factors to CAI.²⁵ Based on our results, poor ankle flexibility might affect the dynamic postural control and thus further affected performance of the SEBT.

Limitations

Several limitations of our study need to be acknowledged. Gender difference and diverse physical activity levels may affect the performance of SEBT. Future study should minimize the influence from these factors. In addition, we cannot be sure that the injured side in the CAI group was the dominant side. Comparison between the injured side in the CAI group and dominant side in the Control group may lead to discrepancy in their performance. Further study should control the effect of

dominant and non-dominant side on the performance of SEBT. Finally, the reliability and validity of the SEBT was not developed in the current study. Future investigation should involve constructing the reliability and validity of the SEBT.

CONCLUSION

The CAI subjects had poor dynamic postural control and shorter reaching distance during SEBT. However, the reaching distance may be associated with the strength of calf muscles in both groups. In addition, performance (reaching distance) of the SEBT was positively correlated with the hip, knee, and ankle angles in the sagittal plane and also with the flexibility of calf muscle. Therefore, evaluation of SEBT should consider the flexibility of lower extremity muscles and the joint motions of the ankle, knee, and hip joints. According to our finding of COP displacement in the anterior-posterior direction as well as knee and hip joint motions, training program should focus on the directions of anterior-lateral and lateral to enhance their ability of dynamic postural control.

REFERENCES

- Agel J, Palmieri-Smith RM, Dick R, Wojtys EM, Marshall SW. Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train* 2007;42:295-302.
- Dick R, Hertel J, Agel J, Grossman J, Marshall SW. Descriptive epidemiology of collegiate men's basketball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004. *J Athl Train* 2007;42:194-201.
- Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br* 1965;47:678-85.
- Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train* 2002;37:364-75.
- Tropp H, Odenrick P. Postural control in single-limb stance. *J Orthop Res* 1988;6:833-9.
- Tropp H, Odenrick P, Gillquist J. Stabilometry recordings in functional and mechanical instability of the ankle joint. *Int J Sports Med* 1985;6:180-2.
- Riemann BL. Is there a link between chronic ankle instability and postural instability? *J Athl Train* 2002;37:386-93.
- Akbari M, Karimi H, Farahini H, Faghizadeh S. Balance problems after unilateral lateral ankle sprains. *J Rehabil Res Dev* 2006;43:819-24.
- Wikstrom EA, Tillman MD, Chmielewski TL, Borsa PA. Measurement and evaluation of dynamic joint stability of the knee and ankle after injury. *Sports Med* 2006;36:393-410.
- Gribble PA, Hertel J, Denegar CR, Buckley WE. The effects of fatigue and chronic ankle instability on dynamic postural control. *J Athl Train* 2004;39:321-9.
- Gribble PA, Hertel J, Denegar CR. Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. *Int J Sports Med* 2007;28:236-42.
- Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther* 2006;36:911-9.
- Kinzey SJ, Armstrong CW. The reliability of the star-excursion test in assessing dynamic balance. *J Orthop Sports Phys Ther* 1998;27:356-60.
- McKeon PO, Ingersoll CD, Kerrigan DC, Saliba E, Bennett BC, Hertel J. Balance training improves function and postural control in those with chronic ankle instability. *Med Sci Spor Exerc* 2008;40:1810-9.
- Cloak R, Nevill AM, Clarke F, Day S, Wyon MA. Vibration training improves balance in unstable ankles. *Int J Sports Med* 2010;31:894-900.
- Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The Cumberland ankle instability tool: A report of validity and reliability testing. *Arch Phys Med Rehabil* 2006;87:1235-41.
- Hislop HJ, Montgomery J. Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination, 7th ed. Philadelphia: WB Saunders; 2002.
- Tsai LC, Yu B, Mercer VS, Gross MT. Comparison of different structural foot types for measures of standing postural control. *J Orthop Sports Phys Ther* 2006;36:942-53.
- Hertel J. Sensorimotor deficits with ankle sprains and chronic ankle instability. *Clin Sports Med* 2008;27:353-70.
- McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, part I: Can deficits be detected with instrumented testing. *J Athl Train* 2008;43:293-304.
- Colville MR, Marder RA, Boyle JJ, Zarins B. Strain measurement in lateral ankle ligaments. *Am J Sports Med* 1990;18:196-200.
- Beckman SM, Buchanan TS. Ankle inversion injury and hypermobility: Effect on hip and ankle muscle electromyography onset latency. *Arch Phys Med Rehabil* 1995;76:1138-43.
- Robinson RH, Gribble PA. Kinematic predictors of performance on the Star Excursion Balance Test. *J Sport Rehab* 2008;17:347-57.
- Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Meas Phys Educ Exerc Sci*, 2003;7:89-100.
- Hubbard TJ, Kramer LC, Denegar CR, Hertel J. Contributing factors to chronic ankle instability. *Foot Ankle Int* 2007;28:343-54.

慢性踝關節不穩定運動員執行星型平衡測試的姿勢控制和下肢關節影響

陳進陽¹ 徐阿田¹ 郭藍遠² 林呈鳳^{1,*} 陳怡安¹

目的：本研究目的為探討正常與慢性腳踝不穩定的受測者執行星型平衡測試 (Star Excursion Balance Test) 時，姿勢控制的策略以及可能影響星型平衡測試碰觸距離的因子。**方法：**十五位慢性腳踝不穩定和十五位經過年齡配對的正常運動員參與本研究，並使用單腳碰觸八種不同方向。在動作測試執行過程中，使用了八台紅外線攝影機和一塊力板紀錄了運動學和地面反作用力的資料，以分析八個方向伸腳可及的距離、壓力中心內外和前後的位移量以及在最大碰觸距離時，膝關節、踝關節和髌關節的關節角度。另外，也量測踝關節和膝關節的肌力。**結果：**研究結果顯示，慢性腳踝不穩定組在蹠屈肌群的肌力和伸腳可及的距離大致都顯著小於健康組，且在前外側和外側方向的膝關節和髌關節都有較大的彎曲角度；兩組的腳踝被動背屈角度都和伸腳可及距離有正相關，在執行前外方向星型平衡測試時，慢性腳踝不穩定組有較大的壓力中心前後位移，但是在執行正後方向時，卻有較小的壓力中心內外位移。**結論：**慢性腳踝不穩定的運動員執行星型平衡測試的表現比正常運動員差，且運動員在執行星型平衡測試的表現和腳伸到最遠距離時的最大踝關節、膝關節和髌關節的矢狀面關節角度及小腿肌肉的柔軟性有正相關。(物理治療 2011;36(4):263-273)

關鍵詞：動態控制、慢性腳踝不穩定、星型平衡測試

¹ 台南市成功大學物理治療學系

² 高雄市高雄醫學大學運動醫學系

通訊作者：林呈鳳 成功大學物理治療學系 70101 台南市大學路一號

電話：(06)235-3535 轉 5911 E-mail: connie@mail.ncku.edu.tw

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