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# A new approach of the Star Excursion Balance Test to assess dynamic postural control in people complaining from chronic ankle instability

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## A B S T R A C T

The purpose of this study was to quantitatively and qualitatively assess dynamic balance with accuracy in individuals with chronic ankle instability (CAI). To this aim, a motion capture system was used while participants performed the Star Excursion Balance Test (SEBT). Reached distances for the 8 points of the star were automatically computed, thereby excluding any dependence to the experimenter. In addition, new relevant variables were also computed, such as absolute time needed to reach each distance, lower limb ranges of motion during unipodal stance, as well as absolute error of pointing. Velocity of the center of pressure and range of variation of ground reaction forces have also been assessed during the unipodal phase of the SEBT thanks to force plates. CAI group exhibited smaller reached distances and greater absolute error of pointing than the control group ( $p < 0.05$ ). Moreover, the ranges of motion of lower limbs joints, the velocity of the center of pressure and the range of variation of the ground reaction forces were all significantly smaller in the CAI group ( $p < 0.05$ ). These reduced quantitative and qualitative performances highlighted a lower dynamic postural control. The limited body movements and accelerations during the unipodal stance in the CAI group could highlight a protective strategy. The present findings could help clinicians to better understand the motor strategies used by CAI patients during dynamic balance and may guide the rehabilitation process

*Keywords:*  
Ankle instability  
Dynamic balance  
Kinematics

## 1. Introduction

Lateral ankle sprain is one of the most frequent sports related injuries and it can represent up to 45% of injuries in sports with high risk such as basketball [1]. This traumatic mechanism can happen during specific sport movements [2] and even during activities of daily living [3]. After a first ankle sprain, involving collateral lateral ligaments, residual symptoms can appear with an occurrence that could be estimated up to 73% [4,5]. Among these residual symptoms, repeated episodes of lateral instability could appear and induce recurrent sprains [6]; these episodes often define chronic ankle instability (CAI). This pathology is mainly

characterized by ankle “giving-way”, which corresponds to an ankle joint disrobement during its loading [5], as well as by an alteration of the proprioceptive system [5,6] that can contribute to a decline in neuromuscular control and induce an altered postural control [7]. In order to properly diagnose CAI, self-reported questionnaires, such as Foot and Ankle Ability Measure (FAAM) and FAAM Sport [8] are often used to complete the subjective information given by the feeling of an ankle “giving-way”.

Postural control may be classified as either static, with the aim to maintain a base of support with minimal movement, or dynamic, with the aim to maintain a stable base of support while completing a prescribed movement. Altered static postural control in the presence of CAI has not been systematically demonstrated thanks to classical measures such as center of pressure velocity [9–11]. It was hypothesized that this absence of consensus could be explained by a lack of sensitivity of these measures and that is why more efficient variables should be used to better characterize CAI during static balance assessment [12,13]. Although dynamic postural control has already been investigated in this population [4,12,14–19], this ability should be even more precisely studied,

especially because more complex functional tasks may allow for better identification of postural deficits. A common test used to quantify dynamic balance is the Star Excursion Balance Test (SEBT) [20], which goal is to maintain single leg stance while reaching maximal distance with the extremity of contralateral limb in each direction of a star materialized on the floor. This test is a series of eight lower-extremity-reaching tasks purported to be more useful and relevant in identifying lower extremity functional deficits than tests involving only quiet standing. The SEBT indeed requires both lower extremity balance, strength, coordination, flexibility and proprioception [21] and is mainly used as a functional screening tool to assess dynamic stability, monitor rehabilitation progress, assess deficits following a lower extremity injury, identify athletes at high risk for lower limb injury [21,22], and identify chronic ankle instability [4].

The metrological properties of the SEBT can however be discussed because since this balance test is dynamic and manually assessed, difficulty can occur in attempting to accurately measure the farthest reached point [4,14,15], which can constitute a strong limitation of the SEBT use. Besides, the SEBT is so far limited to measurements obtained only in a position reached at the end of the investigated movements. Beyond these observations, clinicians need further information to properly understand motion dysfunctions related to CAI. Investigations of generated movements during dynamic balance tests are thus necessary. Within this framework, a quantitative and qualitative method for measuring dynamic balance can be developed. A more accurate and reliable way to assess reach distances would be then to use an optoelectronic cameras system, which is becoming more and more widespread in clinical centers and motion analysis laboratories. In addition, the use of such equipment also allows to investigate how the movement is performed and, notably, can give information about (1) the time needed to reach the target, (2) the accuracy of the pointing task and (3) the range of motion (ROM) of the lower limb joints.

The main aim of the present study was to assess dynamic balance with accuracy in CAI sufferers thanks to the contribution of movement analysis laboratory tools. It could be assumed that a good dynamic postural stability would imply a greater reached distance as well as a longer time to perform the task and would induce a better pointing accuracy. Use of optoelectronic cameras and force platforms could also increase the knowledge about the motor strategy used by CAI sufferers during SEBT procedure.

## 2. Methods

### 2.1. Participants

A total of 34 adults were recruited for this study: 17 adults with unilateral CAI (7 women and 10 men) constituted the CAI group (age  $27.8 \pm 8.4$  years; height  $1.73 \pm 0.09$  m; body mass  $74.0 \pm 19.5$  kg) and 17 adults without CAI (5 women and 12 men) constituted the control (CTRL) group (age  $28.8 \pm 9.8$  years; height  $1.76 \pm 0.08$  m; body mass  $70.9 \pm 11.5$  kg). Each participant had a specific medical consultation with a sport medicine doctor to assess instability degree of both ankles thanks to specific examination of the lower limbs. Participants were also asked to complete the FAAM and FAAM Sport questionnaires to assess their subjective instability felt during activities of daily living and during sports activities, respectively. The clinical examination also allowed excluding neurologic pathologies. In addition, each participant had to report no history of bone fracture or surgery of the lower limbs in the past 4 years. Further exclusion criteria were ankle pain and swelling. To be included in the CAI group, participants had to report a history of at least one sprain older than 4 months at the unstable ankle as well as a history of at least 3 episodes of “giving-way” on the same ankle in the

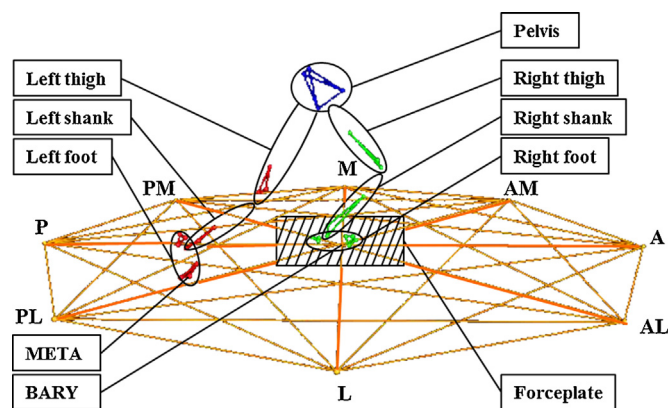
past year. To be included in the CTRL group, participants had to be free of severe ankle sprain and had to never report any feeling of ankle “giving-way”. Since unilateral instability affected 13 dominant limbs, defined as the limb used to kick a ball, and 4 non-dominant limbs in the CAI group, 13 dominant limbs and 4 non-dominant limbs have been examined in the CTRL group. In each group, there were 5 left limbs and 12 right limbs investigated. These limbs corresponded to the “stance limb” during the SEBT. All volunteers gave written informed consent to participate in the study and all procedures complied with the Declaration of Helsinki and were approved by the local Ethics Committee.

### 2.2. Materials

A motion capture system (Vicon Motion Systems Ltd., Oxford, UK) with eight cameras (Vicon<sup>®</sup> MX40) captured the spatial location of retro-reflective markers with a sample rate of 100 Hz. Eight retro-reflective markers were used to materialize the extremities of an 8-pointed star, placed at 1.5 m of the barycenter of the star (BARY). These markers defined the anterior (A), antero-medial (AM), medial (M), postero-medial (PM), posterior (P), postero-lateral (PL), lateral (L) and antero-lateral (AL) targets (Fig. 1). The reaching directions were actually named based on the stance limb. A 30 retro-reflective markers biomechanical model was used in this study to quantify lower limb kinematics. It was based on ISB recommendations [23] and it allowed to quantify hips, knee and ankle kinematics in sagittal, frontal and transverse planes. An AMTI<sup>®</sup> force-plate (AMTI; Watertown, MA), with a sample rate of 100 Hz, was used to quantify spatio-temporal and dynamic parameters under foot during the unipodal stance phase of the experimental procedure.

### 2.3. Procedures

Once participants were equipped with all the markers in the movement analysis laboratory, they had to perform the SEBT. It began in a bipodal stance with the stance foot placed on the BARY. Then, the non-tested foot left the floor. Consequently, participants stood in a single limb stance on the tested-limb. While keeping balance on the tested limb, objectives for the participant were twofold: (1) to point with the extremity of the non-tested foot (touchpoint) as far as possible and (2) to align as precisely as possible the retro-reflective marker placed on the head of the third metatarsal bone (META) with the target marker defining the tip of



**Fig. 1.** Set up configuration of the Star Excursion Balance Test (SEBT) using motion capture. Representation of the assessment of the right ankle in the postero-lateral (PL) direction. Image partly obtained from Nexus<sup>®</sup> software. Other directions of the star: A: anterior, AM: antero-medial, M: medial, PM: postero-medial, P: posterior, L: lateral and AL: antero-lateral; BARY: barycenter of the star, META: head of the third metatarsal bone.

the star (Fig. 1). After each pointing task, the non-tested foot returned to its initial position, reassuming a bipodal stance.

According to previous recommendations [24], participants performed four non-recorded trials as familiarization, and then one trial per direction was recorded. The recorded trial was redone in the following cases: (1) the participant performed a support transfer on the non-stance limb; (2) the stance foot removed from BARY; (3) the participant was unable to maintain single limb balance during the whole test. Based on previous research [25], maximal reached SEBT distance was expressed as a percentage of leg length (distance), with leg length corresponding to the distance between the anterior superior iliac spine and the ipsilateral medial malleolus measured in the anatomical reference position via the motion capture system.

#### 2.4. Data processing

Distance was considered as the maximum excursion of the non-tested leg at touchpoint divided by leg length. The recorded touchpoint was defined as the point where the distance between BARY and META was the longest and the position of META along the vertical axis was the lowest. The absolute error of pointing was determined as the angle between the vector defined by BARY and META and the vector defined by BARY and the target point. Balance time was defined as the time interval between toe-off and touchpoint. During this time interval, 3D ground reaction force ranges of variation (DeltaFx, DeltaFy, DeltaFz) and center of pressure velocity were examined. Center of pressure velocity (VCoP) was considered as the mean value of instantaneous displacement velocity of the center of pressure; the medio-lateral component (VCoP-ML) and the antero-posterior component (VCoP-AP) were also computed. DeltaFx, DeltaFy and DeltaFz were considered as the difference between the maximal force and the minimal force along the medio-lateral, antero-posterior and

vertical axis, respectively, during the time interval previously described. Hip, knee and ankle ranges of motion (ROM) were also calculated. These different data had been automatically computed with Matlab<sup>®</sup> software (The Mathworks, Natick, USA).

#### 2.5. Statistical analysis

Statistical tests were performed with Statistica<sup>®</sup> software (StatSoft, Tulsa, USA). Data are reported as means  $\pm$  SD in text, figures and tables. Normality of the data was checked using the Kolmogorov–Smirnov test and equality of variances was verified by the Levene test. Unpaired Student *t*-tests were performed to compare groups' characteristics and FAAM and FAAM Sports results of the two groups. The impacts of group (CAI vs CTRL) and SEBT direction (A, AM, M, PM, P, PL, L, AL) on distance, error, VCoP, ROM, balance time and on ground reaction variations were analyzed by means of two-way analysis of variance (group  $\times$  direction,  $2 \times 8$ ) with repeated measures on one factor (direction). When a significant main effect was found, a least significant differences Tukey post hoc test was used to identify the significant differences among the selected means. For all analyses, the level of significance was set at  $p < 0.05$ .

### 3. Results

#### 3.1. Participants characteristics

There was no significant difference between each group for age ( $p = 0.75$ ), height ( $p = 0.33$ ) and body mass ( $p = 0.58$ ). Average number of ankle sprains was  $4.6 \pm 3.0$  and average number of ankle "giving-way" was  $19.6 \pm 16.1$  in the past year for CAI participants.

Regarding the self-reported questionnaires, the score for FAAM was  $92.7 \pm 5.5$  for CAI group and  $100.0 \pm 0.0$  for CTRL group

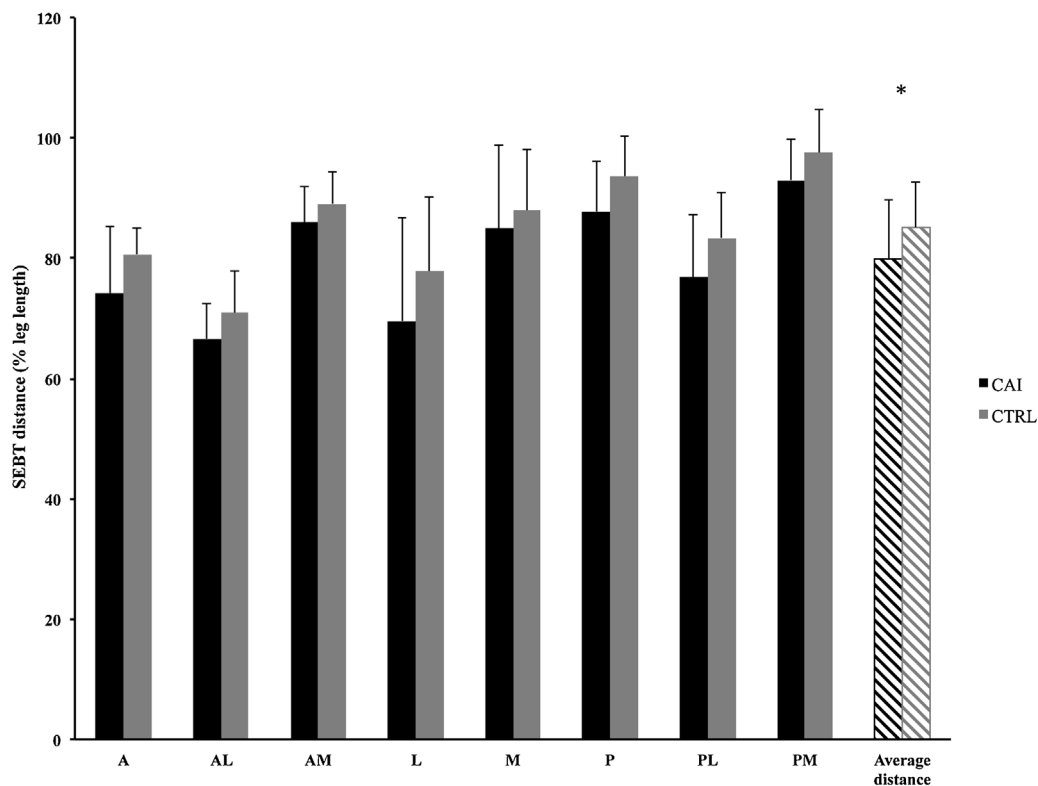


Fig. 2. Reached distances at SEBT. CAI: chronic ankle instability group, CTRL: control group. \* highlighted a group effect ( $p < 0.05$ )

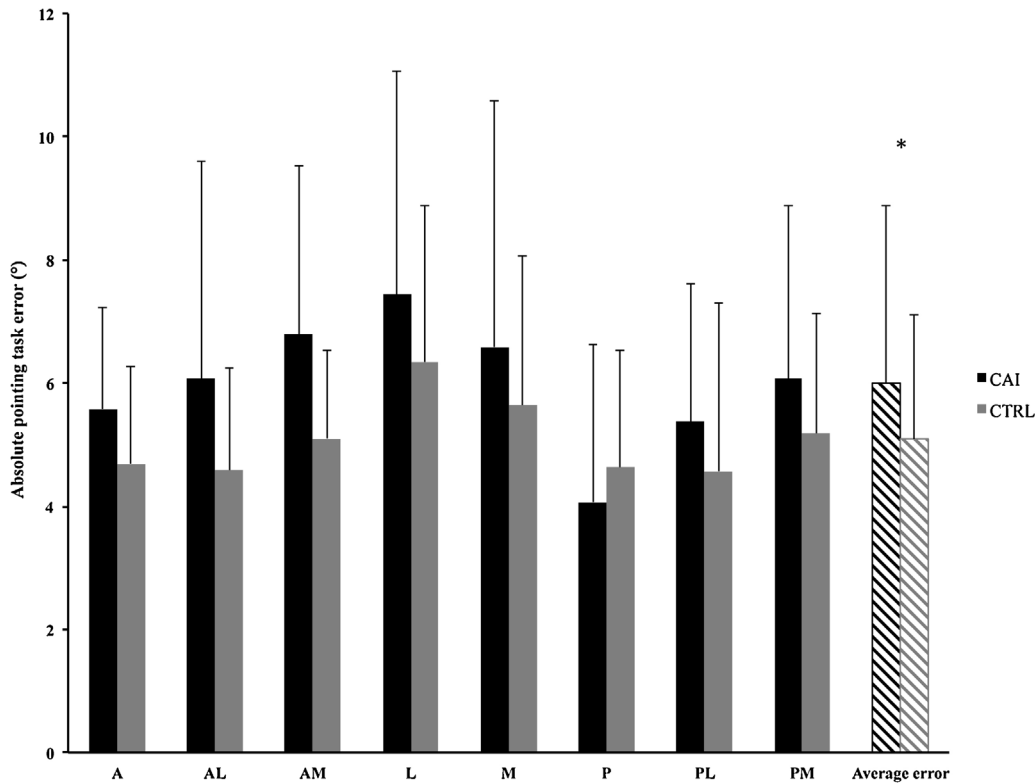


Fig. 3. Absolute pointing task error at SEBT. CAI: chronic ankle instability group, CTRL: control group. \* highlighted a group effect ( $p < 0.05$ )

( $p < 0.001$ ), and the score for FAAM Sports was  $83.1 \pm 12.4$  for CAI group and  $100.0 \pm 0.0$  for CTRL group ( $p < 0.001$ ).

### 3.2. SEBT performance

A group effect was shown for reached distances ( $F_{1,32} = 7.655$ ,  $p = 0.009$ ). Tukey post hoc revealed a shorter reached distance for CAI participants compared to CTRL ones ( $79.9 \pm 9.9\%$  of lower limb length for CAI group and  $84.7 \pm 7.6\%$  for CTRL group, Fig. 2).

A group effect was shown for absolute error of pointing task ( $F_{1,32} = 6.418$ ,  $p = 0.02$ ). Tukey post hoc revealed an increased error for CAI participants ( $6.0 \pm 2.9^\circ$  vs  $5.1 \pm 2.0^\circ$ , Fig. 3).

### 3.3. Spatio-temporal parameters

Spatio-temporal parameters results were presented in Table 1. A group effect was shown for VCoP ( $F_{1,32} = 8.871$ ,  $p = 0.006$ ) and Tukey post hoc revealed a decreased VCoP for CAI participants compared to CTRL ones ( $11.6 \pm 2.3 \text{ cm s}^{-1}$  vs  $13.6 \pm 2.7 \text{ cm s}^{-1}$ ). A group effect was also noted for VCoP-ML ( $F_{1,32} = 36.587$ ,  $p < 0.001$ ) with a decreased VCoP-ML for CAI participants compared to CTRL ones ( $4.9 \pm 1.6 \text{ cm s}^{-1}$  vs  $6.4 \pm 1.6 \text{ cm s}^{-1}$ ). No significant group effect was noted for VCoP-AP ( $F_{1,32} = 3.358$ ,  $p = 0.07$ ).

No group effect was shown for balance time ( $F_{1,32} = 2.357$ ,  $p = 0.13$ ).

Table 1

Experimental data computed during unipodal stance of Star Excursion Balance Test procedure. CAI: chronic ankle instability group, CTRL: control group, VCoP: center of pressure velocity, ML: medio-lateral, AP: antero-posterior, ROM: range of motion, DeltaFx: range of variation of medio-lateral ground reaction force, DeltaFy: range of variation of antero-posterior ground reaction force, DeltaFz: range of variation of vertical ground reaction force.

Variable	CAI	CTRL	p-value
Distance (% leg length)	$79.9 \pm 9.9$	$84.7 \pm 7.6^*$	0.009
Pointing task absolute error (°)	$6.0 \pm 2.9$	$5.1 \pm 2.0^*$	0.02
Balance time (s)	$1.4 \pm 0.4$	$1.9 \pm 0.5$	0.13
VCoP ( $\text{cm s}^{-1}$ )	$11.6 \pm 2.3$	$13.6 \pm 2.7^*$	0.006
VCoP-ML ( $\text{cm s}^{-1}$ )	$4.9 \pm 1.6$	$6.4 \pm 1.6^*$	<0.001
VCoP-AP ( $\text{cm s}^{-1}$ )	$9.4 \pm 2.3$	$10.6 \pm 2.697$	0.07
Ankle flexion/extension ROM (°)	$13.9 \pm 4.2$	$15.3 \pm 3.9$	0.45
Ankle pronation/supination ROM (°)	$5.4 \pm 2.6$	$7.4 \pm 3.0^*$	0.008
Ankle adduction/abduction ROM (°)	$4.7 \pm 1.9$	$5.8 \pm 1.9^*$	0.04
Knee flexion/extension ROM (°)	$33.0 \pm 9.9$	$39.0 \pm 11.6$	0.18
Knee adduction/abduction ROM (°)	$2.8 \pm 1.3$	$3.8 \pm 1.5$	0.07
Knee medial/lateral rotation ROM (°)	$8.3 \pm 3.4$	$9.8 \pm 3.9^*$	0.03
Hip flexion/extension ROM (°)	$29.8 \pm 19.8$	$34.7 \pm 20.5$	0.14
Hip adduction/abduction ROM (°)	$14.4 \pm 5.2$	$15.6 \pm 5.6$	0.38
Hip medial/lateral rotation ROM (°)	$16.3 \pm 8.8$	$19.9 \pm 9.4^*$	0.007
DeltaFx ( $\text{N kg}^{-1}$ )	$0.055 \pm 0.018$	$0.067 \pm 0.020^*$	<0.001
DeltaFy ( $\text{N kg}^{-1}$ )	$0.055 \pm 0.016$	$0.067 \pm 0.021^*$	0.002
DeltaFz ( $\text{N kg}^{-1}$ )	$0.212 \pm 0.076$	$0.218 \pm 0.077^*$	0.80

\* highlighted a group effect ( $p < 0.05$ ).

### 3.4. Kinetics

Kinetics results were presented in Table 1. A group effect was shown for DeltaFx ( $F_{1,32} = 16.031$ ,  $p < 0.001$ ) and for DeltaFy ( $F_{1,32} = 10.622$ ,  $p = 0.002$ ). Tukey post hoc revealed a decreased DeltaFx for CAI participants compared to CTRL participants ( $0.055 \pm 0.018 \text{ N kg}^{-1}$  vs  $0.067 \pm 0.020 \text{ N kg}^{-1}$ ) and a decreased DeltaFy for CAI participants compared to CTRL participants ( $0.055 \pm 0.016 \text{ N kg}^{-1}$  vs  $0.067 \pm 0.021 \text{ N kg}^{-1}$ ).

### 3.5. Kinematics

Kinematics results were presented in Table 1. A group effect was shown for ankle Pronation/Supination (PS) ROM ( $F_{1,32} = 7.995$ ,  $p = 0.008$ ). Tukey post hoc revealed a decreased ankle PS ROM for CAI participants compared to CTRL participants ( $5.4 \pm 2.6^\circ$  vs  $7.4 \pm 3.0^\circ$ ).

A group effect was shown for hip medio-lateral rotation (MLr) ROM ( $F_{1,32} = 8.428$ ,  $p = 0.007$ ), for knee MLr ROM ( $F_{1,32} = 4.893$ ,  $p = 0.03$ ) and for ankle AdAb ROM ( $F_{1,32} = 4.726$ ,  $p = 0.04$ ). In the CAI group compared to CTRL group, Tukey post hoc revealed a decreased hip MLr ROM ( $16.3 \pm 8.8^\circ$  vs  $19.9 \pm 9.3^\circ$ ), a decreased knee MLr ROM ( $8.3 \pm 3.4^\circ$  vs  $9.8 \pm 3.9^\circ$ ) and a decreased ankle AdAb ROM ( $4.7 \pm 1.9^\circ$  vs  $5.8 \pm 1.9^\circ$ ).

## 4. Discussion

The main result of this study was the shorter reached distances for people complaining from CAI compared to CTRL participants. The average distance for the 8 directions was 80% of leg length for CAI group and 85% of leg length for CTRL group. The efficiency of this test to detect lower extremities injuries had already been proved [26] and some authors had also noted significant differences between people complaining CAI and control population in at least one direction of the star [4,14–16,22]. Investigating the directions of the Y-balance test<sup>®</sup>, namely investigating anterior, postero-medial and postero-lateral directions, revealed to be effective in detecting deficits in reached distances ( $F_{1,32} = 5.331$ ,  $p = 0.028$ ), confirming the findings of Plante and Wikstrom [16] but not the results of Martínez-Ramírez, who showed no significant differences [18]. It has also been suggested that to study CAI, the medial directions of the star only could be investigated to identify significant reached distances deficits [17]. Statistical analysis of these directions did not reveal any significant difference between groups in the present study ( $F_{1,32} = 1.785$ ,  $p = 0.19$ ). Therefore, in the aim to simplify the procedure of the SEBT, it might be more relevant to use the Y-balance test<sup>®</sup> instead of the medial directions.

Use of movement laboratory tools seemed to be relevant to quantify reached distances at SEBT and to assess dynamic postural control. Indeed, the velocity of the center of pressure was significantly lower in CAI group than in CTRL group, especially for the medio-lateral component with an average value of  $4.9 \text{ cm s}^{-1}$  for CAI group and  $6.4 \text{ cm s}^{-1}$  for CTRL group. This result could indicate that body movement above the stance foot was smaller for CAI participants. This hypothesis was validated thanks to assessment of lower limb ROM, which were significantly decreased in CAI group, for ankle PS ROM, for ankle AdAb ROM, for hip MLr ROM and for knee MLr ROM. These results showed that participants complaining from CAI reduced their ROMs particularly in frontal and transverse planes and then minimized medio-lateral constraints at the ankle joint and consequently limited stresses on lateral ligaments. The decreased values of DeltaFx and DeltaFy observed in CAI group ( $0.055 \text{ N kg}^{-1}$  vs  $0.067 \text{ N kg}^{-1}$ , for the two variables) were consistent with this reasoning, since it implied a reduction in body accelerations during unipodal stance

[27]. All of these results could highlight an adaptation of the central nervous system, which programmed protective motor command based on the past experiences of ankle “giving-way” or lateral instability. This motor adaptation would limit the risk of ankle instability that could be induced by wide whole body movements or accelerations.

Despite the lack of statistically significant difference between groups for balance time ( $F_{1,32} = 1.058$ ,  $p = 0.31$ ), there was a systematic trend to a shorter time needed to perform the test and a higher movement velocity in the CAI group. It has already been shown that during targeted reaching tasks with upper limbs, a small decrease in the movement time led to a great decrease in the accuracy of the movement [28]. The existence of this relationship at the lower limbs was also suggested [20] and could then partly explain the higher pointing error observed in CAI participants during the SEBT ( $6.0^\circ$  for CAI and  $5.1^\circ$  for CTRL;  $p = 0.02$ ). In addition, a shorter unipodal balance time could illustrate a worse stability in individuals with CAI [29]. Since proprioceptive afferences play an important role during SEBT [21], these various alterations highlighted in the CAI group could be due to a proprioceptive degradation already described in this population [5]. Notably, it has already been shown that a proprioceptive rehabilitation program increased reached distances in SEBT [30].

## 5. Conclusion

The aim of this study was to assess the relevance of movement analysis tools to compute reached distances automatically during SEBT procedure, and to show if this method could discriminate people complaining from CAI from asymptomatic individuals. Considering the 8 directions of the star, results showed that CAI participants reached shorter distances than CTRL. Moreover, a reduction to the 3 “Y-balance” directions was a relevant procedure simplification and would be less time consuming for the experimenters. Use of optoelectronic cameras and force platform, and their associated variables such as the velocity of the center of pressure, the lower limb ROMs and ranges of variation of ground reaction forces, also indicated that people suffering from CAI employed a protective strategy, limiting the movements and accelerations of the whole body during unipodal stance phase of SEBT. Establishing this strategy could highlight a deteriorated postural control in this population. The present findings could help clinicians to better understand the motor strategies used by CAI patients during dynamic balance and may guide the rehabilitation process.

## Conflict of interest

There was no conflict of interest regarding this study among any of the authors.

## References

- [1] Anandacoomarasamy A, Barnsley L. Long term outcomes of inversion ankle injuries. *Br J Sports Med* 2005;39:e14. <http://dx.doi.org/10.1136/bjism.2004.011676> [discussion e14].
- [2] Kristianslund E, Bahr R, Krosshaug T. Kinematics and kinetics of an accidental lateral ankle sprain. *J Biomech* 2011;44:2576–8. <http://dx.doi.org/10.1016/j.jbiomech.2011.07.014>.
- [3] Slaven EJ, Mathers J. Management of chronic ankle pain using joint mobilization and ASTYM<sup>®</sup> treatment: a case report. *J Man Manip Ther* 2011;19:108–12. <http://dx.doi.org/10.1179/2042618611Y.0000000004>.
- [4] Olmsted LC, Garcia CR, Hertel J, Shultz SJ. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *J Athl Train* 2002;37:501–6.
- [5] Freeman AR, Dean RE. The etiology and prevention of functional instability of the foot. *J Bone Jt Surg* 1965;47:678–85.
- [6] Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train* 2002;37:364–75.

- [7] McKeon PO, Hertel J. Spatiotemporal postural control deficits are present in those with chronic ankle instability. *BMC Musculoskelet Disord* 2008;9:76.
- [8] Martin RL, Ph D, Irrgang JJ, Burdett RG, Ped C. Evidence of validity for the foot and ankle ability measure (FAAM). *Foot Ankle Int* 2005;968–83.
- [9] Ross SE, Linens SW, Wright CJ, Arnold BL. Balance assessments for predicting functional ankle instability and stable ankles. *Gait Posture* 2011;34:539–42.
- [10] Isakov E, Mizrahi J. Short reports: is balance impaired by recurrent sprained ankle? *Br J Sports Med* 1997;31:65–7.
- [11] Brown CN, Mynark R. Balance deficits in recreational athletes with chronic ankle instability. *J Athl Train* 2007;42:367–73.
- [12] Hertel J, Olmsted-Kramer LC. Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait Posture* 2007;25:33–9. <http://dx.doi.org/10.1016/j.gaitpost.2005.12.009>.
- [13] McKeon PO, Hertel J. Ankle instability, Part I: Can deficits be detected. *J Athl Train* 2008;43:293–304.
- [14] 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.
- [15] Hoch MC, Staton GS, Medina McKeon JM, Mattacola CG, McKeon PO. Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. *J Sci Med Sport* 2012;15:574–9. <http://dx.doi.org/10.1016/j.jsams.2012.02.009>.
- [16] Plante JE, Wikstrom EA. Differences in clinician-oriented outcomes among controls, copers, and chronic ankle instability groups. *Phys Ther Sport* 2013;14:221–6. <http://dx.doi.org/10.1016/j.ptsp.2012.09.005>.
- [17] Hertel J, Braham RA, Hale SA, Olmsted-kramer LC. Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther* 2006;36:131–7.
- [18] Martínez-Ramírez A., Lecumberri P, Gómez M, Izquierdo M. Wavelet analysis based on time–frequency information discriminate chronic ankle instability. *Clin Biomech (Bristol Avon)* 2010;25:256–64. <http://dx.doi.org/10.1016/j.clin-biomech.2009.11.004>.
- [19] Terada M, Harkey MS, Wells AM, Pietrosimone BG, Gribble PA. The influence of ankle dorsiflexion and self-reported patient outcomes on dynamic postural control in participants with chronic ankle instability. *Gait Posture* 2014;40:193–7. <http://dx.doi.org/10.1016/j.gaitpost.2014.03.186>.
- [20] Kinzey SJ, Armstrong CW. The reliability of the star-excision test in assessing dynamic balance. *J Orthop Sports Phys Ther* 1998;27:356–60. <http://dx.doi.org/10.2519/jospt.1998.27.5.356>.
- [21] Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the Star Excursion Balance Test. *North Am J Sport Phys Ther* 2009;4:92–9.
- [22] Gribble, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train* 2012;47:339–57. <http://dx.doi.org/10.4085/1062-6050-47.3.08>.
- [23] Wu G. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—Part I: Ankle, hip, and spine. *J Biomech* 2002;35:543–8. <http://dx.doi.org/10.1006/rtp.2002.1549>.
- [24] Robinson RH, Gribble PA. Support for a reduction in the number of trials needed for the star excursion balance test. *Arch Phys Med Rehabil* 2008;89:364–70. <http://dx.doi.org/10.1016/j.apmr.2007.08.139>.
- [25] Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Meas Phys Educ Exerc Sci* 2003;7:89–100. [http://dx.doi.org/10.1207/S15327841MPEE0702\\_3](http://dx.doi.org/10.1207/S15327841MPEE0702_3).
- [26] 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. <http://dx.doi.org/10.2519/jospt.2006.2244>.
- [27] Gillet C, Duboy J, Barbier F, Armand S, Jeddi R, Lepoutre F-X, et al. Contribution of accelerated body masses to able-bodied gait. *Am J Phys Med Rehabil* 2003;82:101–9. <http://dx.doi.org/10.1097/01.PHM.0000046629.78324.28>.
- [28] Keele SW, Posner MI. Processing of visual feedback in rapid movements. *J Exp Psychol* 1968;77:155–8.
- [29] Hurvitz EA, Richardson JK, Werner RA, Ruhl AM, Dixon MR. Unipedal stance testing as an indicator of fall risk among older outpatients. *Arch Phys Med Rehabil* 2000;81:587–91. <http://dx.doi.org/10.1053/mr.2000.6293>.
- [30] Peres M, Cecchini L, Pacheco I, Moré Pacheco A. Efeitos do treinamento proprioceptivo na estabilidade do tornozelo em atletas de voleibol. *Rev Bras Med Esporte* 2014;20:146–50.