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ESCOLA SUPERIOR DE SAÚDE

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Static and Dynamic Postural Control of the Ankle during the performance of the Y Balance Test and Leg Stance Test in Subjects with and without Chronic Ankle Instability

Projecto elaborado com vista à obtenção do grau de Mestre em Fisioterapia, na Especialidade de Músculo-Esquelética

Orientador: Mestre com título de Especialista José Manuel Fernandes Esteves, Professor Adjunto da Escola Superior de Saúde do Alcoitão, Fisioterapeuta
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Abstract

Introduction: Lateral ankle sprain (LAS) is one of the most common musculoskeletal injuries and it is estimated that up to 40% of acute ankle sprains can end up developing Chronic Ankle Instability (CAI). Literature shows that individuals with CAI have a higher probability of having both static and dynamic postural control deficits. Although, there is a lack of consistency in the studies detecting postural control deficits in subjects with CAI. **Objectives:** Compare individuals with and without CAI in static and dynamic postural control using the Y Balance Test (YBT) and posturography measures in the Leg Stance Test (LST). Additionally, check if there is a correlation between the reach distance on the YBT and the LST results. **Design:** Cross-sectional comparative observational study and correlation study. **Methods:** This study had a total of 42 participants, 19 in the CAI group and 23 in the healthy group. Selection criteria were based on the International Ankle Consortium position statement for CAI sample studies. To allocate the participants to each group we used the Identification of Functional Ankle Instability (IdFAI) where a cut-off of 11 points was used. All participants performed the YBT and the LST. The reached distance on the YBT and the posturographic variables while performing the LST were compared between subjects with and without CAI. Additionally, we searched for a correlation between the YBT reach distance and the results of the CoP displacement measures on the LST. **Results:** No significant differences ($p>0,05$) were found between groups in any reach distance of the YBT and there were also no significant differences ($p>0,05$) in LST posturographic measures. When examining the correlation between reach distance in the YBT with the CoP measures from the LST, it was found a very weak to weak correlation (Spearman's Rho $< \pm 0,40$) between the variables studied. **Conclusions:** The results indicate that there is no significant difference between individuals with and without CAI in dynamic and static postural control using YBT and LST, respectively. Additionally, there is no strong correlation between the results of the YBT and LST in both groups. This results interpretation should be done carefully due to our modest sample. Our study showed that YBT and LST are not the best tests to use when assessing individuals with CAI or, at least, they should not be used exclusively.

Keywords: Lateral ankle sprain, Chronic ankle instability, YBT, LST, Static postural control, Dynamic postural control.

Resumo

Introdução: A entorse lateral do tornozelo é uma das lesões musculo-esqueléticas mais comuns e é estimado que até 40% das entorses agudas do tornozelo possam acabar por desenvolver Instabilidade Crónica do Tornozelo (ICT). A literatura mostra que individuos com ICT têm uma maior probabilidade de apresentar défices de controlo motor tanto estático como dinâmico. Apesar disso, existe falta de consistência nos estudos focados em detetar défices de controlo postural em sujeitos com ICT. **Objetivos:** Comparar indivíduos com e sem ICT no controlo postural estático e dinâmico utilizando o *Y Balance Test* (YBT) e medidas posturográficas no *Leg Stance Test* (LST). Adicionalmente, verificar se existe uma correlação entre a distância alcançada no YBT e os resultados obtidos no LST. **Desenho:** Estudo transversal observacional comparativo e correlacional. **Metodologia:** Este estudo teve um total de 42 participantes, 19 no grupo CAI e 23 no grupo saudável (Healthy group). Os critérios de seleção foram baseados na declaração de príncipio do *International Ankle Consortium* para estudos com amostras com ICT. De modo a alocar os participantes a cada grupo usámos o Identification of Functional Ankle Instability (IdFAI) onde foi usado um *cut-off* de 11 pontos. Todos os participantes realizaram o YBT e o LST. A distância alcançada no YBT e as variáveis posturográficas avaliadas durante a execução do LST foram comparadas entre os sujeitos com e sem ICT. Adicionalmente, averiguámos se existia uma correlação entre a distância alcançada no YBT e os resultados do deslocamento do centro de pressão (CP) no LST. **Resultados:** Não foram encontradas diferenças significativas ($p>0,05$) entre grupos em nenhuma das direções do YBT e, igualmente, não foram encontradas diferenças significativas ($p>0,05$) nas medidas posturográficas no LST. Quando examinada a correlaçao entre a distância alcançada no YBT com as medidas do CP do LST, foi encontrada uma correlação muito fraca a fraca (rho de Spearman $< \pm 0,40$) entre as variáveis estudadas. **Conclusão:** Os resultados indicam que não existe uma diferença significativa entre indivíduos com e sem ICT no controlo postural dinâmico e estático, utilizando o YBT e o LST, respetivamente. Adicionalmente, não existe uma correlação forte entre os resultados do YBT e do LST em ambos os grupos. A interpretação destes resultados deve ser feita com precaução devido à nossa modesta amostra. O nosso estudo mostrou que o YBT e o LST não são os melhores testes a usar na avaliação de sujeitos com ICT ou, pelo menos, não devem ser utilizados de forma exclusiva.

Palavras-chave: Entorse Lateral da Tibiotársica, Instabilidade Crónica do Tornozelo, YBT, LST, Controlo postural estático, Controlo postural dinâmico.

Introduction

Lateral ankle sprain (LAS) is one of the most common injuries in the orthopedic field both in active and non-active people (Hertel & Corbett, 2019). It is estimated that about 40% of acute ankle sprain individuals will develop chronic ankle instability (CAI), this can be due to failure of functional rehabilitation after acute sprain (Miklovic, Donovan, Protzuk, Kang & Feger, 2018). The lack of a good rehabilitation process in individuals with LAS can have consequences on physical activity levels and, the evidence that acute and recurrent ankle joint trauma can lead to the development of post-traumatic ankle osteoarthritis is growing (Gribble et al., 2014). In the economic field, it represents a significant load on the health care system (Rosen, Needle & Ko, 2019).

CAI has been described in the literature for a long time and has suffered changes since the presentation of the first comprehensive theory of ankle instability in 1965 by Freeman. Freeman concluded with his study that the pathological process responsible for functional ankle instability was, at that time, unknown but persistent mechanical varus instability of the talus was a possible cause, as well as adhesion formation after a first injury. Lately, this concept evolved into a more biopsychosocial definition and can be characterized by recurrent episodes or perceptions of the ankle "giving away"; repetitive episodes of ankle sprains that persist for more than 1 year after the first acute ankle sprain; ongoing symptoms such as weakness, pain, reduced range of motion; diminished self-reported function (Hertel & Corbett, 2019). These signs and symptoms can be caused by different components. In 2019, Hertel and Corbett proposed an updated model of CAI, they organized the causes and findings in CAI subjects and LAS in 8 components, being: primary tissue injury – in articles studying the mechanism of injury of the LAS it appears that both excessive inversion and internal rotation of the rearfoot on the tibia is the most common mechanism and that the anterior talofibular ligament (ATFL) is usually the first to be injured in a LAS, followed by the calcaneofibular ligament (CFL) in most severe injuries; pathomechanical impairments – pathologic laxity, arthrokinematics restrictions, osteokinematic restrictions, secondary tissue injury, tissue adaptations; sensory-perceptual impairments – diminished somatosensation, perceived instability, pain, kinesiophobia, impaired self-reported function, diminished health-related quality of life; motor-behavioral impairments – altered reflexes, neuromuscular inhibition, muscle weakness, balance deficits, altered movement patterns, reduced physical activity; personal factors – physical attributes, medical history, psychological profile can influence the response of the body when

injured and during the recovery; environmental factors – such as societal expectations, social support, access to health care.

Although a lot of the components, as mentioned above, can influence an individual with CAI, for this study, we will be focusing on the motor-behavioral impairments and more specifically balance deficits and poor postural control.

Postural control is present in everyday living and is necessary to perform many activities. Our central nervous system regulates sensory information brought by other systems in the body aiming to produce adequate motor output to maintain a controlled and balanced posture. The existent literature on this topic suggests that individuals with CAI present deficits in postural control. Both static and dynamic impairments have been found in CAI individuals when compared to a healthy population or when compared to the opposite healthy limb (Simpson *et al.*, 2019). There are a lot of instruments that assess both dynamic and static stability, from free-of-cost ones to more complex ones. The literature appears to show impaired static and dynamic stability in CAI individuals.

Dynamic stability tests like the Star Excursion Balance Test (SEBT) or the Y Balance Test (YBT) which is a reduced version of the SEBT (Coughlan, Fullam, Delahunt, Gissane & Caulfielf, 2012), have been used in both clinical and research context, they can measure postural dynamic stability which is closer to the daily living activities than the postural static stability assessments. The literature appears to show a reduction in reach distance in the YBT when subjects with CAI are compared with healthy subjects (Doherty et al., 2016a, 2016b; Hoch, Staton, Medina McKeon, Mattacola, & McKeon, 2012; McCann et al., 2017; cited by Simpson et al., 2019). These poor results can be due to sensorimotor impairments associated with CAI or any of the components mentioned above such as pain, kinesiophobia or neuromuscular impairments. These given impairments people experience can change their ability to perform activities of daily living and it has been studied that up to 72% of these people are unable to maintain their previous physical activity levels and 6% couldn't participate in any occupational activity (Al Adal, Pourkazemi, Mackey, & Hiller, 2019).

Static postural control is assessed when the subject stands still in an upright posture. This can be assessed qualitatively through observation or quantitatively, using methods that can measure the oscillation of the body or a variable associated with that oscillation, such as posturography. The most common used posturographic measure is the Center of Pressure (CoP), which can be defined by the application point of the resultant vertical forces acting on the support surface. In the research field, the most common instrument to measure the CoP is the force plate. Regarding the CoP there are a lot of variables that can be analyzed in order to

have a perspective of how the body behaves in a static upright position and that are highly used in research: total oscillation displacement, displacement amplitude, mean velocity, among others (Duarte & Freitas, 2010). In static stability, CAI individuals show postural control deficits when compared to healthy controls (Arnold, De la Motte, Linens & Ross, 2009; Munn, Sulliva &, Schneiders, 2010 cited by McKeon, Stein, Ingersoll & Hertel, 2012).

There are several references showing that individuals with CAI have postural control deficits when compared with healthy individuals, using both static and dynamic postural control measures (Simpson *et al.*, 2019; Doherty et al., 2016a, 2016b; Hoch, Staton, Medina McKeon, Mattacola, & McKeon, 2012; McCann et al., 2017; Arnold et al., 2009; Munn et al., 2010; McKeon et al., 2012). Recent studies examined Center of Pressure (CoP) excursions (the most common method of assessing postural control) during SEBT in healthy and CAI (Jaber et al., 2018) populations and contributed to the understanding that sensorimotor and mechanical impairments contribute to poor dynamic stability. Because there was a lack of consistency in detecting postural control deficits, the authors suggest more research on this topic.

This study aimed to compare individuals with CAI and healthy subjects in dynamic postural control, using the YBT and static postural control, using posturography measures in the leg stance test (LST) [CoP total excursion, amplitude, confidence circle (CC) area and mean sway velocity]. Additionally, we wanted to analyze if there was a relationship between the reach distance on the YBT and the results obtained with the LST. The goal was to see if there was a correlation between the reach distance obtained in any of the directions of the YBT and the results of the LST on both groups, CAI and the healthy group.

Methodology

Study Type

This study is a cross-sectional comparative observational study. We measured and compared the results in the YBT and posturographic data between individuals with CAI and healthy individuals. Our aim with this study was to identify if there is a difference between individuals with and without CAI in reach distance (YBT) and total excursion, amplitude, CC area and oscillation velocity of the CoP displacement.

Additionally, it is also a correlation study since we studied the correlation between the reach distance on the YBT and the posturographic results on the LST.

Participants

This study was approved by the Ethics Committee of *Escola Superior de Saúde do Alcoitão* (code nº12-2021).

Before the participation of any individual in the study, we explained the purposes of the study and asked the participants to sign an informed consent form where there was information about the study, procedures as well as rights according to the Helsinki Declaration from the World Medical Association. Also on this consent form, there was information about the confidentiality, privacy and anonymity of the participants.

The participants in this study are active volunteers, young adults between the ages of 18 and 34. It is a convenience sample since the participants are mostly students from a High Education institution, for operational ease reasons. There are two different groups in our study, one group with self-reported CAI (CAI group) and the second group with healthy subjects (Healthy group).

An a priori power analysis was conducted using G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Germany, version 3.1.9.6) to calculate the necessary sample size (Erdfelder, Faul & Buchner, 1996). The sample size was estimated using a moderate effect size of 0,5, level of significance α=0,05 and power of 0,80. This results in a total of 42 participants, 21 in each group but we were only able to recruit 19 subjects for the CAI group while the Healthy group had 23 subjects.

Based on the International Ankle Consortium position statement about the selection criteria for patients with CAI (Gribble et al., 2014), the inclusion criteria for the CAI group were: 1) a history of at least one significant lateral ankle sprain; 2) that initial ankle sprain must have occurred at least 12 months before the study; 3) at least one ankle sprain was associated with inflammatory symptoms and the loss of function of more than a day; 4) the most recent ankle sprain must have occurred at least 3 months before the study; 5) a history of the previously injured ankle "giving away" and/or recurrent sprain and/or "feelings of instability". "Feelings of instability" were assessed using a self-reported questionnaire that was filled by the participants. According to the International Ankle Consortium (Gribble et al., 2014), self reported ankle instability should be confirmed using a validated questionnaire with its associated cut-off score. The Identification of Functional Ankle Instability (IdFAI) questionnaire was used. Is it a questionnaire that was already translated and validated for the Portuguese population by members of the Escola Superior de Saúde do Alcoitão community. This is an ankle instability self-reported questionnaire that is currently recommended by the

International Ankle Consortium, to enroll in the study as an element of the CAI group, the participant must have a score of >11 in the IdFAI (Gribble et al., 2014).

Exclusion criteria for this study were: 1) a history of previous surgeries to the musculoskeletal structures in the lower extremities; 2) a history of a fracture in the lower limbs requiring realignment; 3) acute injury to the musculoskeletal structures on the lower extremities in the previous 3 months, which impacted joint integrity and function and resulted in a loss of function for at least one day (Gribble et al., 2014); 4) presence of any pain or complain in the lower extremities on the collecting data day. The healthy group must have scored lower than 11 in the IdFAI questionnaire and, same as the CAI group, were excluded if presented with any of the exclusion criteria for the CAI group.

We ended up with a sample of 42 subjects, with an average age of 22,31 years. In the two groups together, we had a total of 27 female participants and 15 male participants.

In the CAI group, the average age was 21,63 where 14 subjects were female and 5 male. In the Healthy group, we had an average of 22,87 years old with 13 females and 10 males. More information on the participants is presented in table 1.

Table 1: Anthropometric and socio-demographic characterization of the sample: Levene's Test for equality of variances

Variables	Total N=42	CAI Group N=19	Healthy Group N=23	P Value
Age Mean (years) (Min-Max)	22,31 (18-34)	21,63 (18-27)	22,87 (18-34)	0,044
Sex Total (N) (Female/Male)	42 (27/15)	14/5	13/10	
Weight Mean (Kg) (Min-Max)	67,304 (47,100-99,300)	66,695 (52,200-99,200)	67,81 (47,100-99,300)	0,422
Height Mean (m) (Min-Max)	1,68 (1,53-1,85)	1,708 (1,62-1,85)	1,66 (1,53-1,82)	0,344
BMI Mean (Kg/m^2) (Min-Max)	23,71 (19,48-37,19)	22,80 (19,53-32,21)	24,46 (19,48-37,19)	0,640
Number of LAS Mean (N) (Min-Max)	1,08 (0-5)	3,5 (0-10)	0,4 (0-3)	0,003
IdFAI Score Mean (N) (Min-Max)	9,81 (0-26)	17,05 (12-26)	3,80 (0-11)	0,337
Physical Activity (N) (yes/no)	27/15	14/5	13/10	

Min: Minimum; Max: Maximum; BMI: Body Max Index; LAS: Lateral Ankle Sprain IdFAI: Identification of Functional Ankle Instability

Variables

For this study, the independent variable was the population studied, with and without CAI.

The dependent variables, used to collect the data for the study were: the reached distance (anterior, posterolateral and posteromedial directions) in the YBT, normalized to the leg length (percentage); total, anterior-posterior (AP) and medial-lateral (ML) excursion of CoP; anterior-

posterior (AP) and medial-lateral (ML) amplitude of CoP excursion; confidence circle (CC) area of CoP excursion; total, anterior-posterior (AP) and medial-lateral (ML) mean sway velocity.

Instruments

Anthropometric and socio-demographic Data Questionnaire

The anthropometric and socio-demographic data questionnaire intends to classify and organize the population of this study. This way it was possible to analyze the subjects of the study on topics like sex, age, height, weight and body mass index (BMI) and to better understand the outcomes that resulted from the static and dynamic assessment. The interviewer asked the questions to participants and fulfilled the questionnaire. Besides the demographic characterization questions, there were asked questions related to physical activity (if the participants are physically active, how often they practice and what activity). There were also asked questions to determine if the participants could be included in the study, if they matched the inclusion criteria or if they did not and had to be excluded from the study.

Identification of Functional Ankle Instability (IdFAI)

The IdFAI is a self-reported questionnaire designed to detect if individuals meet the minimum criteria to be included in a functional ankle instability population. This questionnaire is based on two previous instruments: the Cumberland Ankle Instability Tool (CAIT) and the Ankle Instability Instrument (AII), all three currently recommended by the International Ankle Consortium (Gribble et al., 2014). This is a 10 questions instrument grouped into 3 factors: 1) focus on the history of ankle instability; 2) focus on information related to the initial ankle sprain and 3) collect information about the feeling of instability during activities of daily living.

Studies focusing on the reliability of this instrument demonstrated overall excellent test-retest reliability (ICC=0,92) and also excellent reliability in the 3 factors (factor 1: ICC=0,81; factor 2: ICC=0,94; factor 3: ICC=0,83) (Donahue, Simon, & Docherty, 2013). In another study, the IdFAI also demonstrated overall excellent test-retest reliability (ICC=0,959). These results indicate that this instrument is a valuable tool in both clinical and research settings (Gurav, Ganu, & Panhale, 2014).

The IdFAI was validated for the Portuguese population showing to be a highly reliable and valid self-reported questionnaire to assess ankle instability in the Portuguese population (Ribeiro, E. 2020).

Y Balance Test

The YBT is a postural dynamic balance test largely used in studies related to the ankle and, most specifically, in papers on the CAI population. It is a simple test used to measure dynamic balance. It came from a modified version of the SEBT which evaluated dynamic balance in 8 different directions. YBT was reduced to 3 directions: anterior, posteromedial, and posterolateral (Coughlan et al., 2012).

Studies investigating this test found that it is a reliable test for measuring single-limb stance excursion distances while testing dynamic balance. Good to excellent interrater reliability [Intraclass Correlation Coefficient (ICC)=0,99 to 1 with 95% Confidence Intervals (CI) ranging from 0,92 to 1] and intrarater reliability (ICC of 0,85-9,91 with 95% CI ranging from 0,62 to 0,96 (Plisky et al., 2009); another study found a interrater reliability with ICC equal 0,85 to 0,93 (95% CI, 0,75 – 0,96) and test-retest reliability with ICC 0,80 to 0.85 (95% CI, 0,68 – 0,91) (Shaffer et al., 2013).

The individual performing the test stood barefoot on one leg with hands placed on the hips (Hébert-Losier, 2017), setting the midfoot at the center of the Y platform while the other lower limb reached in the 3 different directions as far as possible while balanced. The person performed 3 trials in each direction, and the distance in centimeters was collected. An average of the 3 measures was done and the value was normalized for the limb length by dividing the reach distance by limb length and then multiplying by 100 to account for the leg length influence on the test. The limb length was measured from the anterior superior iliac spine to the medial malleoli with the participant in the supine position.

Posturography

For the study of posturographic variables, we used the Bertec force plate (Bertec Corporation, Columbus, Ohio, United States) with its data acquisition software Digital Acquire ™. This force plate simultaneously measures three force components (Fx, Fy and Fz, where Fx is the anteroposterior direction, Fy medial-lateral direction and Fz vertical direction) and three-moment components about x, y and z axes for a total of six outputs that are used to compute the Center of Pressure (CoP) (BERTEC Corporation, 2012).

CoP is the point where the pressure of the body over the soles of the feet would be if it was only concentrated in one spot (Ruhe, Fejer & Walker, 2011). We can have different variables to measure the CoP displacement like the ones we used: total excursion, which refers to the total length of the CoP path whereas the anterior-posterior (AP) excursion refers to the total length of the CoP path in the AP direction, same as medial-lateral (ML) direction (Prieto,

Myklebust, Hoffmann, Lovett & Myklebust, 1996); amplitude (or range) is the maximal distance over two points of the stabilogram which is equivalent to the distance between the minimum and the maximum positions of the signal and is examined in anterior-posterior (AP) and medial-lateral (ML) direction (Quijoux et al., 2021); confidence circle (CC) area is the 95% confidence circle area, which is the area of a circle with a radius equal to the one sided 95% confidence limit of the result distance, being the area of the stabilogram with a circle that includes 95% of the distances from the mean CoP (assuming that the distances are normally distributed) (Prieto et al., 1996); mean sway velocity that can be defined as the sum of the distances between consecutive points, divided by the duration of the recording, this variable is considered as one of the most reliable of the CoP (Quijoux et al., 2021) and can be analyzed in total, anterior-posterior (AP) or medial-lateral (ML) directions.

Procedures

Description of Procedures

Participants were asked to fill and sign the Informed Consent. The data collection started with the application of the anthropometric and socio-demographic data questionnaire by the interviewer. The participants were then asked to fill out the IdFAI questionnaire.

After the answer to several questions of the questionnaire and after fulfilling the IdFAI, we measured and weighed the participants. To acknowledge the dominant side, we performed two tests of dominancy: the step test which consisted of asking the individual to stay behind a step looking forward and then we asked the subject to go over the step, the limb the participant started the movement with was the dominant limb. We performed a second leg dominance test which consisted of asking the individual to focus a point on the wall and we pushed the individual to the front and, the leg that moved was considered the dominant limb. When the lower limb didn't match in both tests, the individual was considered ambidextrous.

For each participant, we measured the leg length. We asked the individual to lay supine over a table, with a measuring tape starting on the ipsilateral anterior superior iliac spine and down to the medial malleoli (Hébert-Losier, 2017), and both lower limbs were measured.

After measuring the leg length, which was used to normalize the reach distance, we asked the subject to stand barefoot over the YBT. The subject was asked to put the midfoot over the center of the YBT and to stand on the tested leg. We instructed the subject to place both hands on the hips and try to reach with the other leg as far as possible in the three different directions always balanced and without lifting the heel off the platform. As training and before actually collecting data, the subject performed three practice trials in each direction.

Following the explanation and practice of the YBT in the three different directions, we instructed the participants about the second test to be performed, the Leg Stance Test, where the subject had to place the tested foot over the center of the force plate, hands placed on the hips and looking to a target that was placed on the wall in front. Each participant was instructed to lift the non-tested foot off the platform and maintain the position for 30 seconds while the results were being recorded by the Bertec data acquisition software.

After all the explanations of the procedures and after making sure the participants didn't have any doubts, we started recording the results. The order of performing the tests (3 directions on the YBT with each lower limb and LST with each limb) was randomly assigned to each participant. In total, each participant performed 3 trials in the three directions of the YBT with each lower limb and 3 trials on each lower limb on the LST. The participant had thirty seconds of rest time between each repetition in the same direction and sixty seconds of rest time when changing to another direction or test.

Data Processing

For the reach distance of the YBT, the examiner measured, in centimeters, the distance between the beginning of the foot and the maximal reach distance touched by the toes of the participant in every 3 trials. An average of the 3 measurements was calculated and then the value was normalized to the leg length by dividing the average reach distance by leg length and then multiplying by 100. A percentage of leg length was used for analysis in both lower limbs.

The force plate data were collected with 1000Hz sample rate. The raw data was filtered using a 50Hz low-pass filter, 7th Butterworth and they were processed after the assessment with a specific MATLAB routine (version R2020b, Mathworks, Inc., Natick, Massachusetts, USA) according to the results collected from the trials for each participant in the LST.

After processing the data acquired from the force plate, an Excel database was filled with the results. For the LST, we did an average of the results obtained with the 3 trials for each lower limb and with each variable. In the end, we gathered an average of the 3 trials of the total excursion for the right lower limb and the left lower limb; we did the same for the amplitude variable (average of 3 trials for each limb in AP and ML components), CC area, mean oscillation velocity, AP and ML oscillation velocity.

Statistical Analysis

For the statistical analysis of this project, it was used the IBM SPSS Statistics 28.0.0.0.

Descriptive statistics were used to analyze our sample characteristics together with the results from both YBT and CoP measures. We used central tendency measures such as median for the reach distance obtained with the YBT and CoP measures. And for measures of dispersion, we used variance, minimum and maximum.

For the statistical inference, we first compared the chronic unstable ankle of the CAI group with the dominant side of the Healthy group and then we compared again the unstable ankle of the CAI group with the Healthy group non-dominant side.

To know which tests to use to compare our two groups, we started by analyzing the normality of the sample using Shapiro-Wilk test. Since some variables did not match the normality principle (<0.05) we used non-parametric tests. Mann-Whitney *U* was used since it is used to compare whether there is a difference in the dependent variable for two independent groups (Huang & Zhang, 2020), which in this study are CAI and Healthy groups.

Additionally, for the analysis of the correlation between the variables used, we used Spearman correlation test, which is a nonparametric measure of rank correlation, it assesses the relationship between two variables and how well it can be described (Eden, Li & Shepherd, 2021).

Results

In this section, the results of the comparison between CAI group and Healthy group are presented. We compared the CAI side with the dominant side of the Healthy group in reach distance of the YBT and posturographic measures during the LST and also the CAI side with the non-dominant side of the Healthy group, also in both YBT and LST.

In the first comparison (CAI side vs Healthy group dominant side), we did not find any significant differences between groups in any reach distance (anterior p=0,640; posterolateral p=0,426; posteromedial p=0,215) of the YBT. Looking at the Cop measures, there were also no significant differences in the leg stance mean total excursion (p=0,133), anteroposterior excursion (p=0,261, mediolateral excursion (p=0,056); anteroposterior amplitude (p=0,752), mediolateral amplitude (p=0,261); CC area (p=0,570); mean oscillation velocity (p=0,133), anteroposterior oscillation velocity (p=0,261) and mediolateral oscillation velocity (p=0,056). Results are shown in table 2.

Table 2: Comparison with Mann-Whitney *U* test - CAI Group vs Healthy Group-Dominant Side

Variables	CAI Group				Healthy Group Dominant Side				P Value
	Median	Variance	Min	Max	Median	Variance	Min	Max	
YBT Ant (%)	65,34	59,98	51,43	82,77	67,71	25,37	56,85	78,39	0,640
YBT PL (%)	82,89	102,44	56,52	97,41	83,92	85,60	64,06	95,97	0,426
YBT PM (%)	82,01	99,57	56,16	100,53	86,95	51,36	69,05	98,95	0,215
LST Total Excursion (m)	1,08	0,11	0,77	2,08	1,23	0,17	0,89	2,41	0,133
LST Total Excursion AP (m)	0,68	0,10	0,49	1,74	0,77	0,09	0,55	1,61	0,261
LST Total Excursion ML (m)	0,69	0,02	0,49	1,00	0,80	0,05	0,59	1,45	0,056
LST Amplitude AP (m)	0,04	0,00	0,03	0,10	0,05	0,00	0,03	0,08	0,752
LST Amplitude ML (m)	0,03	0,00	0,02	0,04	0,03	0,00	0,03	0,05	0,261
LST CC Area (m^2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,570
LST Total Oscillation Velocity (m/s)	0,22	0,00	0,15	0,42	0,25	0,01	0,18	0,48	0,133
LST AP Oscillation Velocity (m/s)	0,14	0,00	0,10	0,35	0,15	0,00	0,11	0,32	0,261
LST ML Oscillation Velocity (m/s)	0,14	0,00	0,10	0,20	0,16	0,00	0,12	0,29	0,056

YBT: Y Balance Test; Ant: Anterior; PL: Posterolateral; PM: Posteromedial; LST: Leg Stance Test; AP: Anteroposterior; CC: Confidence Circle; ML: Mediolateral; Min: Minimum; Max: Maximum

When comparing the CAI side with the non-dominant side of the healthy group, the results were similar, with no significant differences: YBT reach distances (anterior p=0,230; posterolateral p=0,536; posteromedial p=0,318). Leg Stance mean total excursion (p=0,139), anteroposterior excursion (p=0,103), mediolateral excursion (p=0,146); anteroposterior amplitude (p=0,810), mediolateral amplitude (p=0,771); CC area (p=0,640); mean oscillation velocity (p=0,139), anteroposterior oscillation velocity (p=0,103) and mediolateral oscillation velocity (p=0,146). Results can be analyzed in table 3.

Table 3: Comparison with Mann-Whitney *U* test - CAI Group vs Healthy Group- non-dominant Side

Variables	CAI Group				Healthy Group non-dominant Side				P Value
	Median	Variance	Min	Max	Median	Variance	Min	Max	
YBT Ant (%)	65,34	59,98	51,43	82,77	67,45	23,80	60,49	77,06	0,230
YBT PL (%)	82,89	102,44	56,52	97,41	81,51	50,05	64,97	92,63	0,536
YBT PM (%)	82,01	99,57	56,16	100,53	82,77	62,60	73,25	99,61	0,318
LST Total Excursion (m)	1,08	0,11	0,77	2,08	1,21	0,17	0,87	2,87	0,139
LST Total Excursion AP (m)	0,69	0,10	0,49	1,74	0,77	0,10	0,54	2,10	0,103
LST Total Excursion ML (m)	0,69	0,02	0,49	1,00	0,79	0,05	0,56	1,51	0,146
LST Amplitude AP (m)	0,04	0,00	0,03	0,10	0,05	0,00	0,03	0,11	0,810
LST Amplitude ML (m)	0,03	0,00	0,02	0,04	0,03	0,00	0,02	0,08	0,771
LST CC Area (m^2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,640
LST Total Oscillation Velocity (m/s)	0,22	0,01	0,15	0,42	0,24	0,01	0,17	0,57	0,139
LST AP Oscillation Velocity (m/s)	0,14	0,00	0,10	0,35	0,15	0,00	0,11	0,42	0,103
LST ML Oscillation Velocity (m/s)	0,14	0,00	0,10	0,20	0,16	0,00	0,11	0,30	0,146

YBT: Y Balance Test; Ant: Anterior; PL: Posterolateral; PM: Posteromedial; LST: Leg Stance Test; AP: Anteroposterior; CC: Confidence Circle; ML: Mediolateral; Min: Minimum; Max: Maximum

Additionally, we examined the correlation between reach distance in the YBT with the LST posturographic variables. The goal was to determine if there was a correlation between the distance the subject could reach and the different variables of the CoP such as total excursion, amplitude, CC area and mean oscillation velocity.

We found a very weak to weak correlation ($-0,394 \geq r_s \geq 0.087$) between the reached distance on the YBT and the CoP variables on the LST in the individuals studied, except for the correlation between AP amplitude of CoP excursion and the PL direction of the YBT, where the correlation was negatively moderate ($r_s=-0,493$), when comparing the CAI side with the dominant side of the Healthy group and also the CAI side with the non-dominant side of the Healthy group (table 4 and table 5, respectively).

Table 4: Correlation with Spearman's test - CAI Group vs Healthy Group-Dominant Side between YBT and LST - Spearman's Rho values (r_s)

	LST Total Excursion Mean	LST Total Excursion AP	LST Total Excursion ML	LST Amplitude AP	LST Amplitude ML	LST CC Area	LST Mean Oscillation Velocity	LST AP Oscillation Velocity	LST ML Oscillation Velocity
YBT Ant	-0,124	-0,136	-0,069	-0,141	-0,257	-0,135	-0,124	-0,136	-0,069
YBT PL	-0,287	-0,358	-0,100	-0,493	-0,169	-0,394	-0,287	-0,358	-0,100
YBT PM	-0,207	-0,284	-0,024	-0,333	-0,083	-0,283	-0,207	-0,284	-0,024

YBT: Y Balance Test; Ant: Anterior; PL: Posterolateral; PM: Posteromedial; LST: Leg Stance Test; AP: Anteroposterior; CC: Confidence Circle; ML: Mediolateral; Min: Minimum; Max: Maximum.

Table 5: Correlation with Spearman's test - CAI Group vs Healthy Group- non-dominant Side between YBT and LST- Spearman's Rho values (r_s)

	LST Total Excursion Mean	LST Total Excursion AP	LST Total Excursion ML	LST Amplitude AP	LST Amplitude ML	LST CC Area	LST Mean Oscillation Velocity	LST AP Oscillation Velocity	LST ML Oscillation Velocity
YBT Ant	-0,082	-0,090	-0,034	-0,068	-0,050	0,054	-0,082	-0,090	-0,034
YBT PL	-0,127	-0,211	0,065	-0,308	0,067	0,038	-0,127	-0,211	0,065
YBT PM	-0,182	-0,234	-0,046	-0,240	0,087	0,050	-0,182	-0,234	-0,046

YBT: Y Balance Test; Ant: Anterior; PL: Posterolateral; PM: Posteromedial; LST: Leg Stance Test; AP: Anteroposterior; CC: Confidence Circle; ML: Mediolateral; Min: Minimum; Max: Maximum

Discussion

The goal of this study was to compare and see if there were differences between subjects with chronic ankle instability and healthy individuals in a matter of dynamic postural control using the YBT and static postural control using posturographic measures of the CoP. Additionally, we wanted to see if there was a correlation between these two postural control properties, both dynamic and static, which means that we wanted to evaluate if there was a correlation between the reach distance obtained in the YBT with the posturographic data collected in each CAI and healthy group during the performance of the Leg Stance test.

According to the literature reviewed, both static and dynamic impairments can be found in CAI individuals when compared to a healthy population. These studies included several

variables including reach distances in dynamic balance tests (YBT or SEBT) and static balance assessments and almost all studies concluded that there was a lack of consistency in detecting postural control deficits and recommended more research on this topic (Simpson *et al*., 2019; Doherty et al., 2016a, 2016b; Hoch, Staton, Medina McKeon, Mattacola, & McKeon, 2012; McCann et al., 2017).

Differentiating between two groups, CAI group and healthy group, we found that there were no significant differences between the two groups in any of the variables studied. We didn't find a significant difference between groups in reach distance using the YBT. Concerning the posturographic variables, we didn't find significant differences in the leg stance test in variables such as total excursion, amplitude, CC area and oscillation velocity when comparing both groups.

The theoretical framework used to guide this study showed that individuals with CAI had poorer results in static and dynamic postural control when compared to healthy individuals with healthy ankles (Simpson et al., 2019). In 2019, Simpson et al referred to other studies that showed a reduction in reach distance, mainly in the anterior direction in individuals with CAI. This goes against the results we had in this study. This can be due to our sample being greatly composed of young and active participants, as the sample was mostly chosen from a High Education School.

On the second goal we had with this study, we focused on the correlation between reach distance on the YBT and posturographic CoP data collected during the performance of the LST. We wanted to know if there was a correlation between the reach distance in the 3 different directions of the YBT and the CoP posturography data in the LST. We found a very weak to weak correlation between these two tests in the total excursion, amplitude, CC area and oscillation velocity during the performance of the LST.

Since the project was performed with students from a specific and singular High Education School, we did not have access to a lot of subjects which made us have a modest sample of subjects to analyze. This is a limitation of the study because it reduces the power of the study and increases the margin of error (Hackshaw, 2008). As the sample was chosen from a High Education School, we had a very young population to study (mean age of 22 years old) where most of the participants were physically active (64%), this reduces our sample to a specific and reduced group of people and their physical preparation can play an important role on the results obtained. Would be interesting to approach a bigger and more heterogeneous sample.

Subjects on this study were allocated to two different groups, one group with CAI and the other a Healthy group. On the eligibility criteria for the groups, the difference between subjects to be allocated to one of the two groups was the score obtained in the IdFAI questionnaire therefore, some of the patients allocated to the Healthy group suffered ankle sprains in the past although they had a score bellow the cut-off value of 11 in the IdFAI. It could be interesting to have a complete healthy group, with subjects that never suffered a ankle sprain injury so we could compare CAI individuals with complete ankle healthy individuals. The fact that some of the individuals allocated to the Healthy group have already suffered ankle sprains althought they do not match CAI criteria, may explain the nonexistent significant differences between groups on the variables studied.

Another aspect that can be a limitation and can contribute to different results of the study is the fact that we don't have pre-injury data from the participants who were allocated to the CAI group. It is unknown whether the results preceded or occurred because of the injury that resulted in CAI. This way, we have no way to know if the results in this group have a correlation with the CAI or if it is the result of other components such as lower limb muscle strength, core strength, previous injuries to any other joint, etc. This made us think the tests we used to assess postural control, both YBT and LST are, biomechanically, very complex tests. While performing single-leg activities or tests a lot of components are being tested. With this study, our focus was on the ankle and how different could the results of someone who has CAI compared to a healthy ankle be. Nonetheless, a lot of other joints can play a role in the results of these tests. In a recent study, Nelson, Wilson and Becker (2021), studied the kinematic and kinetic predictors of Y Balance Test performance and the results went according to what other studies showed which was that kinematics of the ankle, knee, hip and torso were all important on predicting YBT reach distances. Therefore, the ankle joint can influence reach distance on this test but it is not the only joint responsible for the reach distances. It would, therefore, be important to find a more specific and exclusive ankle test that could assess individuals with CAI. In this note, since Chronic Ankle Instability is one of the consequences a person who suffered a first ankle sprain can present, it would be interesting to assess the ankle using tests that can reproduce the mechanism of injury suffered by these sujects. We could be looking at a test assessing the behavior of the ankle on landing after a jump, maybe this would be a more specific test to use on assessing the ankle in subjetcs with CAI.

Conclusion

No significant differences were found between those with CAI and healthy participants in reach distances on the YBT or the LST analyzing posturographic variables (total excursion, amplitude, CC area and oscillation velocity). Additionally, no strong correlation was found between the studied variables, we did not find a relationship between the reach distance in the YBT and the posturographic data collected during the performance of the LST.

Nonetheless, our modest sample makes generalization of the results unfeasible and their interpretation should be done carefully. The results found in this study encourage further investigation with a larger and more complex population to find specific tests that can focus on the ankle joint and that demonstrate significant differences between CAI and healthy ankles and individuals. Applying this to clinical practice, this shows us that, to assess patients with CAI, YBT and LST activities are not the best tests to use or, at least, they should not be used exclusively.

Bibliography

Ai, C., Huang, L., & Zhang, Z. (2020). A mann–whitney test of distributional effects in a multivalued treatment. Journal of Statistical Planning and Inference, 209, 85-100.

Al Adal, S., Pourkazemi, F., Mackey, M., & Hiller, C. E. (2019). The prevalence of pain in people with chronic ankle instability: A systematic review. *Journal of Athletic Training*, *54*(6), 662–670. https://doi.org/10.4085/1062-6050-531-17

Arnold, B. L., De La Motte, S., Linens, S., & Ross, S. E. (2009). Ankle instability is associated with balance impairments: a meta-analysis. *Med Sci Sports Exerc*, *41*(5), 1048-1062.

BERTEC Corporation. (2012). *Bertec Force Plates*. 13–13. Retrieved from https://static1.squarespace.com/static/5b3256317e3c3a8e8e029991/t/5bdb00ef032be4a79cba9bdf/1541079284413/Force+Plate+Manual.pdf

Coughlan, G. F., Fullam, K., Delahunt, E., Gissane, C., & Caulfield, B. M. (2012). A comparison between performance on selected directions of the star excursion balance test and the Y balance test. *Journal of athletic training*, *47*(4), 366-371.

Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., & Delahunt, E. (2016a). Dynamic balance deficits in individuals with chronic ankle instability compared to ankle sprain copers 1 year after a first-time lateral ankle sprain injury. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(4), 1086–1095. https://doi.org/10.1007/s00167-015-3744-z

Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., & Delahunt, E. (2016b). Single-leg drop landing movement strategies in participants with chronic ankle instability compared with lateral ankle sprain 'copers.' *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(4), 1049–1059. https://doi.org/10.1007/s00167-015-3852-9

Donahue, M., Simon, J., & Docherty, C. L. (2013). Reliability and Validity of a New Questionnaire Created to Establish the Presence of Functional Ankle Instability: The

IdFAI. *Athletic Training & Sports Health Care*, *5*(1), 38–43. https://doi.org/10.3928/19425864-20121212-02

Duarte, M., & Freitas, S. M. (2010). Revisão sobre posturografia baseada em plataforma de força para avaliação do equilíbrio. *Brazilian Journal of Physical Therapy*, *14*, 183-192.

Eden, S. K., Li, C., & Shepherd, B. E. (2021). Nonparametric estimation of Spearman's rank correlation with bivariate survival data. *Biometrics*.

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments, and Computers*, *28*(1), 1–11. https://doi.org/10.3758/BF03203630

Freeman, M. A. R. (1965). Instability of the foot after injuries to the lateral ligament of the ankle. *The Journal of bone and joint surgery. British volume*, *47*(4), 669-677.

Gribble, P. A., Delahunt, E., Bleakley, C., Caulfield, B., Docherty, C., Fourchet, F., … Wikstrom, E. (2014). Selection criteria for patients with chronic ankle instability in controlled research: A position statement of the International Ankle Consortium. *British Journal of Sports Medicine*, *48*(13), 1014–1018. https://doi.org/10.1136/bjsports-2013-093175

Gurav, R. S., Ganu, S. S., & Panhale, V. P. (2014). Reliability of the identifi cation of functional ankle instability (IdFAI) scale across different age groups in adults. *North American Journal of Medical Sciences*, *6*(10), 516–518. https://doi.org/10.4103/1947-2714.143283

Hackshaw, A. (2008). Small studies: Strengths and limitations. *European Respiratory Journal*, *32*(5), 1141–1143. https://doi.org/10.1183/09031936.00136408

Hébert-Losier, K. (2017). Clinical implications of hand position and lower limb length measurement method on Y-balance test scores and interpretations. *Journal of Athletic Training*, *52*(10), 910–917. https://doi.org/10.4085/1062-6050-52.8.02

Hertel, J., & Corbett, R. O. (2019). An updated model of chronic ankle instability. *Journal of athletic training*, *54*(6), 572-588.

Hoch, M. C., Staton, G. S., Medina McKeon, J. M., Mattacola, C. G., & McKeon, P. O. (2012). Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. Journal of Science and Medicine in Sport, 15(6), 574–579. https://doi.org/10.1016/j.jsams.2012.02.009

Jaber, H., Lohman, E., Daher, N., Bains, G., Nagaraj, A., Mayekar, P., … Alameri, M. (2018). Neuromuscular control of ankle and hip during performance of the star excursion balance test in subjects with and without chronic ankle instability. PLoS ONE, 13(8), 1–16. https://doi.org/10.1371/journal.pone.0201479

Keith, T. R., Condon, T. A., Phillips, A., McKeon, P. O., & King, D. L. (2016). Postural control strategies are dependent on reach direction in the Star Excursion Balance Test. International Journal of Athletic Therapy and Training, 21(6), 33-39.

McCann, R. S., Crossett, I. D., Terada, M., Kosik, K. B., Bolding, B. A., & Gribble, P. A. (2017). Hip strength and star excursion balance test deficits of patients with chronic ankle instability. *Journal of Science and Medicine in Sport*, *20*(11), 992–996. https://doi.org/10.1016/j.jsams.2017.05.005

McKeon, P. O., Stein, A. J., Ingersoll, C. D., & Hertel, J. (2012). Altered plantar-receptor stimulation impairs postural control in those with chronic ankle instability. *Journal of sport rehabilitation*, *21*(1), 1-6.

Miklovic, T. M., Donovan, L., Protzuk, O. A., Kang, M. S., & Feger, M. A. (2018). Acute lateral ankle sprain to chronic ankle instability: a pathway of dysfunction. *The Physician and sportsmedicine*, *46*(1), 116-122.

Munn, J., Sullivan, S. J., & Schneiders, A. G. (2010). Evidence of sensorimotor deficits in functional ankle instability: a systematic review with meta-analysis. *Journal of science and medicine in sport*, *13*(1), 2-12.

Nelson, S., Wilson, C. S., & Becker, J. (2021). Kinematic and kinetic predictors of Y-balance test performance. International journal of sports physical therapy, 16(2), 371.

Plisky, P. J., Gorman, P. P., Butler, R. J., Kiesel, K. B., Underwood, F. B., & Elkins, B. (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy : NAJSPT*, *4*(2), 92–99. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21509114%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC2953327

Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., & Myklebust, B. M. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Transactions on biomedical engineering, 43(9), 956-966.

Quijoux, F., Nicolaï, A., Chairi, I., Bargiotas, I., Ricard, D., Yelnik, A., ... & Audiffren, J. (2021). A review of center of pressure (COP) variables to quantify standing balance in elderly people: Algorithms and open-access code. Physiological Reports, 9(22), e15067.

Ribeiro, E. (2020). *Validation of psychometric characteristics validity and reliability of Portuguese version of Identification of Functional Ankle Instability (IdFAI)* (Doctoral dissertation).

Rosen, A. B., Needle, A. R., & Ko, J. (2019). Ability of functional performance tests to identify individuals with chronic ankle instability: a systematic review with meta-analysis. *Clinical Journal of Sport Medicine*, *29*(6), 509-522.

Ruhe, A., Fejer, R., & Walker, B. (2011). Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: a systematic review of the literature. European Spine Journal, 20(3), 358-368.

Shaffer, S. W., Teyhen, D. S., Lorenson, C. L., Warren, R. L., Koreerat, C. M., Straseske, C. A., & Childs, J. D. (2013). Y-Balance Test: A Reliability Study Involving Multiple Raters. *Military Medicine*, *178*(11), 1264–1270. https://doi.org/10.7205/milmed-d-13-00222

Simpson, J. D., Rendos, N. K., Stewart, E. M., Turner, A. J., Wilson, S. J., Macias, D.

M., … Knight, A. C. (2019). Bilateral spatiotemporal postural control impairments are present in participants with chronic ankle instability. *Physical Therapy in Sport*, *39*, 1–7. https://doi.org/10.1016/j.ptsp.2019.06.002