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The Relationship between the Ability to Cope with Unexpected Perturbations and Mechanical and Functional Ankle Instability

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Abstract: We aimed to examine the associations between ankle instability, identified by mechanical and functional assessments, and an individual's ability to cope unexpected perturbations. Sixty students were assessed for *five* different mechanical/functional ankle instability assessments: the Cumberland Ankle Instability Tool (CAIT), history of previous ankle sprains, the Ankle Instability Instrument (AII) questionnaires, proprioception ability, and mechanical instability. The point where participants lost postural balance due to an unexpected perturbation was recorded when participants were standing on BalanceTutor-Treadmill® with eyes open-SO, eyes closed-SC, tandem-dominant-leg forward-TD, tandem non-dominant-leg forward-TND, single-leg same side-SLSS, single-leg opposite side-SLOS and walking. Significant correlations were found between: CAIT and perturbation in the TND-position; AII scores and perturbations in TD and TND positions; ankle sprains and perturbations in SC, ND, and NTD positions; and proprioception ability and perturbations in SO, SC, TD, TND, and walking ($p < 0.05$). No correlations were found between mechanical assessments and perturbations. Survival-analyses showed significant differences in coping with perturbations between individuals identified with CAI in 4/5 mechanical/functional assessments compared to those with no-CAI in 4/5 assessments ($p < 0.05$). Functional ankle instability and proprioception ability were associated with the ability to cope with unexpected perturbations when starting from different standing/walking positions. Individuals with 'stable' ankles in most mechanical/functional assessments had better ability to cope perturbations than those with 'unstable' ankles.

Keywords: ankle stability; functional assessment; mechanical assessment; proprioception

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1. Introduction

Lateral ankle sprain is one of the most common musculoskeletal injuries among individuals who participate in sports and recreational physical activities [1–4]. After an ankle sprain occurs, the damage caused to the ankle joint, the connective tissue, and the surrounding muscles and peripheral nerves mainly reduce the ability of the person's lower extremities to perform movements correctly [5,6]. Recent systematic reviews showed that the most common factors related to ankle sprains include factors such as BMI, ankle plantar and dorsiflexion strength, hip strength, single leg landing performance and previous ankle injuries, along with other psychosocial, predisposing, intrinsic and extrinsic factors [7–9]. Following initial sprains, a high proportion of individuals develop recurrent injuries, associated symptoms, and persistent ankle dysfunction, referred to as chronic ankle instability (CAI) [1,10]. People with CAI suffer from a combination of ligamentous laxity and reduced sensorimotor control [10,11], and report mechanical and/or functional instability of the ankle joint [12].

The literature definitions and research inclusion criteria for people with CAI have demonstrated a wide range of reported characteristics [13], as well as mechanical and functional clinical signs and symptoms [10,14]. A common complaint by individuals with CAI following an ankle injury is that they experience episodes when the ankle feels unstable or is at risk of giving way when performing functional activities. Determining the incidence of these episodes through a self-reported ankle instability questionnaire is necessary. The Cumberland Ankle Instability Tool (CAIT) questionnaire [15] and the Ankle Instability Instrument questionnaire (AII) [16] are recommended by the International Ankle Consortium for self-report about the frequency and circumstances of these instability episodes [10].

Being able to appropriately respond to unexpected perturbations is critical for maintaining balance and preventing falls while walking [17]. Response times to unexpected perturbations among healthy individuals are between 70–180 ms post-perturbation [18]. This response attempts to maintain the centre of gravity within the base of support, or through change-in-support responses such as taking a step forward to intersect the line of gravity and increase the base of support [19]. A review of the literature finds that postural reactions following unexpected perturbations correlate strongly to perturbation intensity, direction, and timing with regards to body orientation [19]. Responses may also differ between different standing positions and walking speeds at the time of the perturbation [20,21]. Such differences may be attributed to different levels of neuromuscular control or overloading, as well as to differences in weight distribution and dissimilar muscle activation patterns occurring in differing conditions of perturbation [22,23]. In individuals with CAI, changes in the motor control system following damage to the mechanoreceptors could interfere with postural balance, reducing functionality of proprioception-related abilities and the individual's ability to rapidly and accurately respond to the unexpected perturbations [16,24].

The aim of this study was to determine whether there is an association between the different mechanical and functional assessments and the ability of individuals to cope with unexpected perturbations when undertaking a range of different standing/walking positions. The study also examined the association between different mechanical and functional ankle instability assessments at the ankle. For this study, we hypothesized a positive correlation between the different mechanical and functional ankle instability assessments; and, that individuals with mechanical and functional ankle instability will have reduced ability to respond to unexpected perturbations in all the different standing/walking positions.

2. Methods

2.1. Participants

Prior to recruiting participants, we calculated the required sample size with G*Power version 3.1. We assumed that 30% of participants would have chronic ankle instability [25] and that we would conduct an analysis of variance (ANOVA) with repeated measures, set $\alpha = 0.05$, with power of $1 - \beta = 0.90$, and could expect an effect size of 0.25. This calculation suggested an estimated required sample size of 54 participants.

Prior to commencing the study, institutional ethics committee approval was granted by XXX. After providing written informed consent, 60 healthy physical education students (31 females) participated in the study. The participants were from the same training college and were recruited through emails and posts on social media for physical education students at the college. Their average age was 24.6 ± 2.7 years.

2.2. Procedure

Following the endorsed standard inclusion criteria for CAI as described by the International Ankle Consortium [12], mechanical instability for participants was assessed through manual testing using predefined criteria for instability [26]. The clinical assessments used in this study were the Talar Tilt Test (TTT) and the Anterior Drawer Test (ADT) [27].

The participants completed the following three questionnaires: (1) CAIT questionnaire [28]; (2) Previous Ankle Sprain Questionnaire; (3) AII Questionnaire [16]. The participants then underwent anthropometric measurements and a range of physical assessments using the following tools: (1) BalanceTutor Treadmill (MediTouch, Israel) [29]; (2) Active

Movement Extent Discrimination Assessment (AMEDA) device [30]; and (3) two clinical CAI assessment tests, the TTT and ADT [27]. The assessments were conducted by certified physical therapists. The three questionnaires and the AMEDA tool served as functional assessments, while the two CAI assessment tools served as mechanical assessment tools. Each individual was defined as either CAI or non-CAI for each of these five functional and mechanical assessment tools separately, excluding the BalanceTutor. All participants were tested using their weight-bearing as dominant leg.

2.3. Instruments

Anthropometric measurements: Each participant's anthropometric features (weight, height, leg length) were recorded and BMI was calculated.

CAIT Questionnaire: This questionnaire was developed for subjectively assessing functional ankle instability and has been proven to be reliable and valid. The CAIT consists of nine items with multiple choice options, making the tool simple to complete and precise. A discrete score is given for the left and right ankles, with a maximum score of 30. The lower the score, the lower the ankle function A score of $\leq$25 on the CAIT questionnaire indicates self-reported ankle instability [15].

Ankle Sprain Questionnaire: This questionnaire includes five yes/no questions, examining the participant's ankle injury history. The questions include the following questions: Did your first ankle sprain happened more than a year ago? (yes/no); Did your last ankle sprain happened more than 3 months ago? (yes/no); Did your previous ankle sprain/s prevented you from doing physical activity for at least one day? (yes/no); Did you have an inflammation or swelling around your ankle after the sprain? (yes/no); Did you sprained your ankle at least twice? (yes/no).

AII Questionnaire: The third and final questionnaire included nine yes/no questions assessing ankle instability [16]. Positive answers for at least five questions, including a positive answer for the first question, indicated ankle instability.

BalanceTutor Treadmill: This apparatus is an innovative perturbation treadmill that enables postural control and balance training. The participant is protected by a harness on a treadmill platform that moves in medial/lateral planes enabling simulation of both slipping and tripping while undertaking standing or walking tasks. The system allows the incorporation of varying degrees of task difficulty level (up to 20 possible levels, depending on the participants' abilities). Sensors that are integrated into the BalanceTutor Treadmill enable a range of controlled perturbations – both expected and unexpected [29]. The participants' reactive postural control was tested in seven different conditions: (1) standing on both legs with their eyes open (SO); (2) standing on both legs with their eyes closed (SC); (3) standing tandem with the dominant leg placed forward (TD); (4) standing tandem with the non-dominant leg placed forward (TND); (5) standing on one leg with perturbation to the lateral side (SLSS), whereby the participants alternate the standing leg at each level; (6) standing on one leg with perturbation to the medial side (SLOS), the participant alternates the standing leg; and (7) walking (3 km/h). The tests are presented in Figure 1A–D.

All participants started in either condition 1 or 2 (randomized), followed by either condition 3 or 4 (also randomized). Finally, the participants performed conditions 5, 6, and 7. In each condition, perturbations were presented every 12–20 s, with an associated increased acceleration speed and in an unexpected direction (right/left), except for the SLSS and SLOS positions. "Loss of postural balance" was defined as the level of perturbation at which the original location of the foot in the standing conditions was altered, stepping beyond the treadmill's lateral borders, any change to hand position (except during walking), or crossing over the legs while walking. The velocity of the platform's movement increased with every perturbation in the SO, SC, TD, TND, and walking positions, and with every second perturbation in the SLSS and SLOS positions.

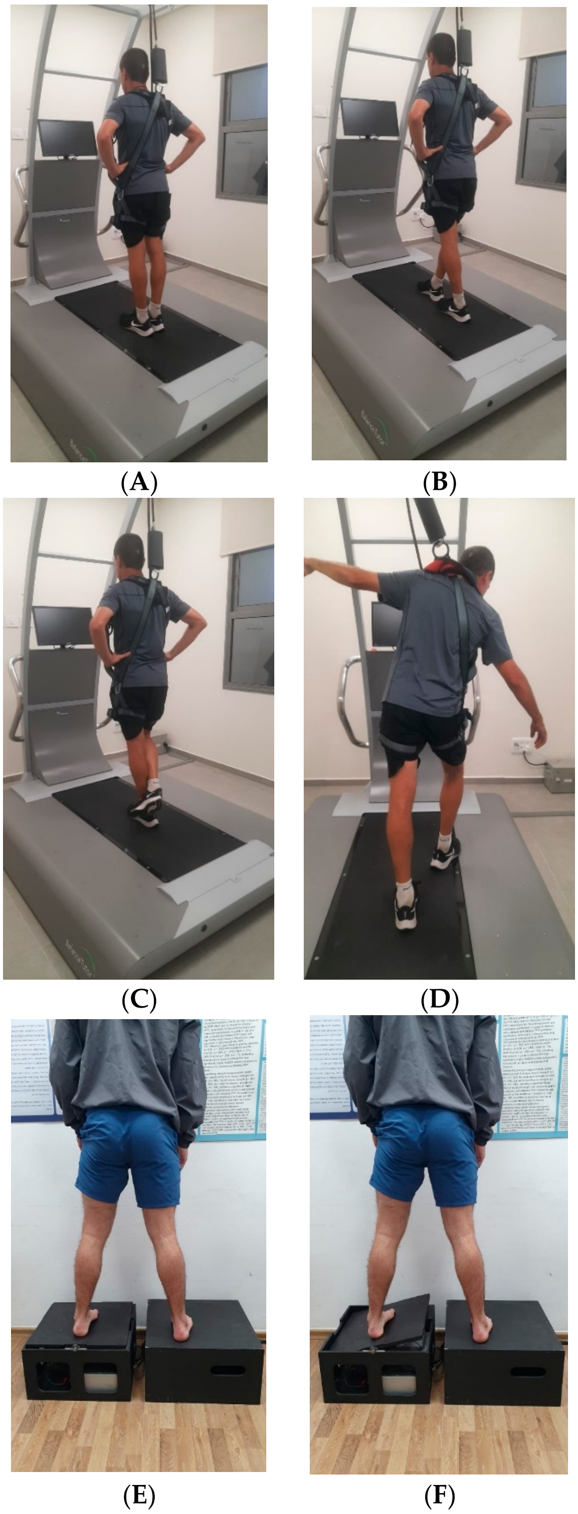


Figure 1. Different starting position on BalanceTutor device (**A**–**D**); and, assessing the extent of the inversion angle on the AMEDA device (**E**,**F**): (**A**) eyes open position and eyes closed position; (**B**) tandem-dominant leg forward position and tandem non-dominant leg forward position; (**C**) single leg same side position and single leg opposite side position; (**D**) "Loss of postural control"; (**E**) horizontal position on the AMEDA; and (**F**) position 5 on the AMEDA.

AMEDA Device: This device evaluates ankle proprioception ability by measuring ankle inversion movement discrimination. The participants stand on a platform on which one foot can be inverted from the horizontal starting position to a predetermined set of stop positions. In this study, inversion limits were set at five possible angles, from 10.5° to 14.5°, with 1° difference between each angle, and numbered from 1 to 5, respectively. Following familiarization with each of the five movement extents, the participants were randomly presented with a sequence of 50 stops and asked to identify which of the five angles had been set each time they inverted to the limit. Sensory acuity was calculated as the participants' ability to discriminate between adjacent angles (1–2, 2–3, 3–4, 4–5), using the area under the curve (AUC) of the receiver operating characteristic (ROC) curve as the discriminating score for each pair of angles. The final score was comprised of the mean AUC of the AUCs for all four pairs of angles [30] (Figure 1E,F).

CAI mechanical assessments: In this study, the TTT and the ADT were applied, as they have been shown to have high specificity, as when positive, they are useful in ruling in an ankle ligament injury. To perform the TTT test, the clinician stabilizes the participant's distal leg while their knee is in a flexed, relaxed position, and moves the talus and calcaneus into inversion. When the ankle is at a 20° plantar flexion, the anterior talofibular ligament (ATFL) is tested; when the ankle is at a 0–10° of dorsiflexion, the calcaneofibular ligament (CFL) is tested [27]. The ADT test was designed to assess the integrity of the anterior talo-fibular ligament. A score of II or III indicated ankle instability as follows: I = stable joint; II = partially unstable; and III = completely unstable [31] (Figure 2).

Figure 2. Anterior Drawer Test (**A**: hand position **B**: drawing the talus and calcaneus anteriorly) and Medial Talar Tilt Test (**A**: hand position **B**: talar tilt action).

2.4. Statistical Analysis

Descriptive means and standard deviations are presented for the anthropometric variables; *t*-test and chi-square tests were used to compare between genders. As the perturbation variables were characterized by the level at which the participants "lost" their postural control, these were analyzed as nonparametric variables, and Spearman correlations were calculated. Moreover, as all ankle instability assessments were normally distributed, Pearson correlations were performed for associations between the different assessments. Following the assessments, the participants were divided into two categories for each assessment: with and without ankle instability, respectively (CAIT: ≤25, >25; AII: ≥5, <5; clinical assessment (TTT and ADT): I vs. II, III; ankle sprain questionnaire: =5, ≤4). The participants were divided into three groups: (1) 'Stable Group' with no-CAI in four out of five mechanical/functional assessments; (2) 'Unstable Group' with CAI in in four out of five mechanical/functional assessments; and (3) 'Intermediate instability group' with CAI/no-CAI in less than four out of five in the mechanical/ functional assessments. The 'stable' and the 'unstable' groups were compared using the survival method (Kaplan-Meier); with the median lifetime and standard errors presented.

3. Results

Age and Anthropometric parameters: No significant age differences was found between genders (F = 25.3 ± 3.9, M = 26.9 ± 6.1). The weight and height of the male participants were significantly higher than those of the female participants ($p < 0.05$), but no significant differences were seen between the BMI of the two gender groups (weight: F = 60.1 ± 9.3, M = 76.7 ± 13.6; height: F = 164.2 ± 6.7, M = 179.3 ± 7.0; BMI: F = 22.3 ± 2.6, M = 23.7 ± 3.2). No gender differences were found in the TTT and ADT clinical assessments.

Table 1 presents Pearson correlations in between the different mechanical or functional ankle instability assessments and the scores for the dominant and non-dominant leg. *Age* was positively correlated with the ability to cope in the SO position (r = 0.36, $p < 0.01$); *weight* was negatively correlated with the ability to cope with perturbation in SLOS and walking (r = −0.34, $p < 0.01$ and r = −0.3, $p < 0.05$, respectively); and *height* was negatively correlated with perturbation coping in SO, SLOS, and walking (r = −0.31, $p < 0.05$; r = −0.36, $p = 0.02$ and r = −0.36, $p = 0.02$, respectively). BMI was not significantly correlated with the ability to cope with perturbations.

Table 1. Correlations (Pearson's r values) between the different mechanical and functional ankle instability assessments for the dominant (D) and non-dominant legs (ND).

	CAIT D	CAITN D	Ankle Sprains	AII D	AII ND	Clinical ass. D	Clinical ass. ND	AMEDA D
CAIT D	-							
CAIT ND	0.762 *	-						
Ankle sprains	−0.626 *	−0.710 *	-					
AII D	−0.833 *	−0.555 *	0.670 *	-				
AII ND	−0.434 *	−0.733 *	0.662 *	0.378 *	-			
Clinical ass. D	−0.497 *	−0.386 *	0.283 *	0.563 *	0.383 *	-		
Clinical ass. ND	−0.379 *	−0.560 *	0.363 *	0.281 *	0.420 *	0.452 *	-	
AUC D	0.453 *	0.273 *	−0.418 *	−0.434 *	−0.215	−0.199	−0.086	-
AUC ND	0.211	0.196	−0.762 *	0.153	−0.285 *	−0.138	−0.183	0.646 *

* Significant correlations ($p < 0.05$); D = dominant leg; ND = non-dominant leg; CAIT = Cumberland Ankle Instability Tool; AII- Ankle Instability Instrument questionnaire; Clinical ass. = Clinical assessment; AUC = AMEDA results; Ankle sprains = previous ankle sprains questionnaire.

Looking at the correlations between the different mechanical and functional ankle instability assessments and the ability to cope perturbations in different starting positions, significant correlations were found between CAIT scores for both the dominant and non-dominant legs and perturbation in the TND position (r = 0.296, p = 0.02 and r = 0.325, p = 0.01, respectively). Correlations were also found between the AII questionnaire data regarding the dominant leg and the TD / TND positions (r = −0.283, p = 0.03 and r = −0.365, p < 0.01, respectively), and between the AII questionnaire data regarding the non-dominant leg and the TND position (r = −0.324, p < 0.01). Furthermore, significant correlations were found between AUC scores in both legs and the SO position (r = 0.349, p < 0.01 and r = 0.447, p < 0.01, respectively), SC (r = 0.364, p < 0.01 and r = 0.413, p < 0.01, respectively), TD (r = 0.346, p < 0.01 and r = 0.308, p = 0.02, respectively), TND (r = 0.280, p = 0.03 and r = 0.329, p = 0.01, respectively), and walking positions (r = 0.418, p = 0.02 and r = 0.439, p < 0.01, respectively). Finally, correlations were observed between data regarding previous ankle sprains and the SC, TD, and TND positions (r = −0.333, p < 0.01; r = −0.285, p < 0.03 and r = −0.367, p < 0.01, respectively).

When examining correlations between participants' *mechanical/functional ankle instability* (yes/no by categories) and their ability to cope with perturbations, our findings indicated a significantly lower ability to cope with unexpected perturbations among individuals with low CAIT scores (≤25) in both legs compared to participants with high CAIT(>25) scores in the TD position (p < 0.01 and p < 0.01, respectively) and in the TND position (p < 0.01 and p = 0.01, respectively). This same pattern was found for those with high AII questionnaire scores (<5) compared with low scores (≥5) in coping with perturbations in the SO (p < 0.01 and p < 0.01, respectively), SC (p = 0.04 and p < 0.03, respectively), TD (p < 0.01 and p < 0.01, respectively), TND (p < 0.01 and p < 0.02, respectively) and walking positions (p < 0.04 and p = 0.04, respectively). Finally, this pattern was also seen among participants with low scores on the ankle sprains history questionnaire (≤4) compared to those with high score (=5) and coping with perturbations in the SO (p = 0.03), SC (p < 0.01), TD (p < 0.02), TND (p < 0.01); and walking positions (p < 0.01), as seen in Table 2.

Table 2. Median (IQR) for those with and without ankle instability in each starting position.

		SO	SC	TD	TND	SLSS	SLOS	Walk
CAIT D	≤25	15 (3)	12 (6)	6 (3) *	6 (3) *	6 (4)	6 (0)	12 (3)
	>25	15 (6)	12 (6)	9 (3) *	9 (3) *	6 (6)	6 (2)	12 (3)
CAIT ND	≤25	15 (6)	12 (8)	6 (3) *	6 (3) *	6 (6)	6 (0)	12 (3)
	>25	15 (6)	12 (6)	9 (3) *	9 (2) *	9 (4)	6 (1)	14 (3)
AII D	≥5	14 (3) *	12 (6) *	6 (3) *	6 (6) *	6 (6)	6 (0)	12 (3) *
	<5	15 (6) *	14 (6) *	9 (3) *	9 (3) *	6 (4)	6 (0)	15 (6) *
AII ND	≥5	12 (3) *	9 (6)*	6 (0) *	6 (6) *	6 (7)	6 (2)	9 (6) *
	<5	15 (6) *	12 (6) *	9 (3) *	9 (3) *	6 (4)	6 (0)	12 (3) *
Clinical ass. D	≥2	15 (6)	12 (6)	8 (3)	9 (3)	6 (6)	6 (1)	12 (3)
	<2	15 (5)	15 (6)	9 (3)	9 (3)	6 (4)	6 (0)	15 (9)
Clinical ass. ND	≥2	15 (3)	12 (6)	6 (3)	9 (3)	6 (6)	6 (0)	12 (3)
	<2	15 (6)	15 (9)	9 (3)	9 (3)	6 (4)	6 (0)	12 (3)
Ankle sprains	=5	12 (6) *	9 (6) *	6 (3) *	6 (3) *	4 (6)	6 (0)	12 (6) *
	≤4	15 (6) *	15 (6) *	9 (3) *	9 (3) *	6 (4)	6 (0)	15 (6) *

* Significant difference between the two categories (p < 0.05). D = dominant leg; ND = non-dominant leg; CAIT = Cumberland Ankle Instability Tool; AII- Ankle Instability Instrument questionnaire; Clinical ass. = Clinical assessment; AUC = AMEDA results; Ankle sprains = previous ankle sprains questionnaire; SO = eyes open position; SC = eyes closed position; TD = tandem-dominant leg forward position; TND = tandem non-dominant leg forward position; SLSS = single leg same side position; SLOS = single leg opposite side position; walk = walking.

The number and percentage of individuals with CAI (1) and with no-CAI (0) in the different mechanical/functional assessments is shown in Table 3. The ability to cope with perturbations in individuals with "stable" and "unstable" ankles was determined. Survival analyses showed significant differences between participants with no CAI in at least four of the five mechanical and functional assessments ("stable" group) and those with CAI in at least four of the five mechanical and functional assessments ("unstable" group) in the SO, SC, TD and TND positions ($p < 0.05$, $p < 0.04$, $p < 0.02$ and $p < 0.01$, respectively), Table 4 and in Figure 3.

Finally, only the participants' AII questionnaire scores significantly differentiated between participants with unilateral, bilateral, and no ankle instability in their ability to cope with increased level of unexpected perturbations.

Table 3. Number and percentage of individuals with CAI (1) and with no-CAI (0) in the different mechanical/functional assessments.

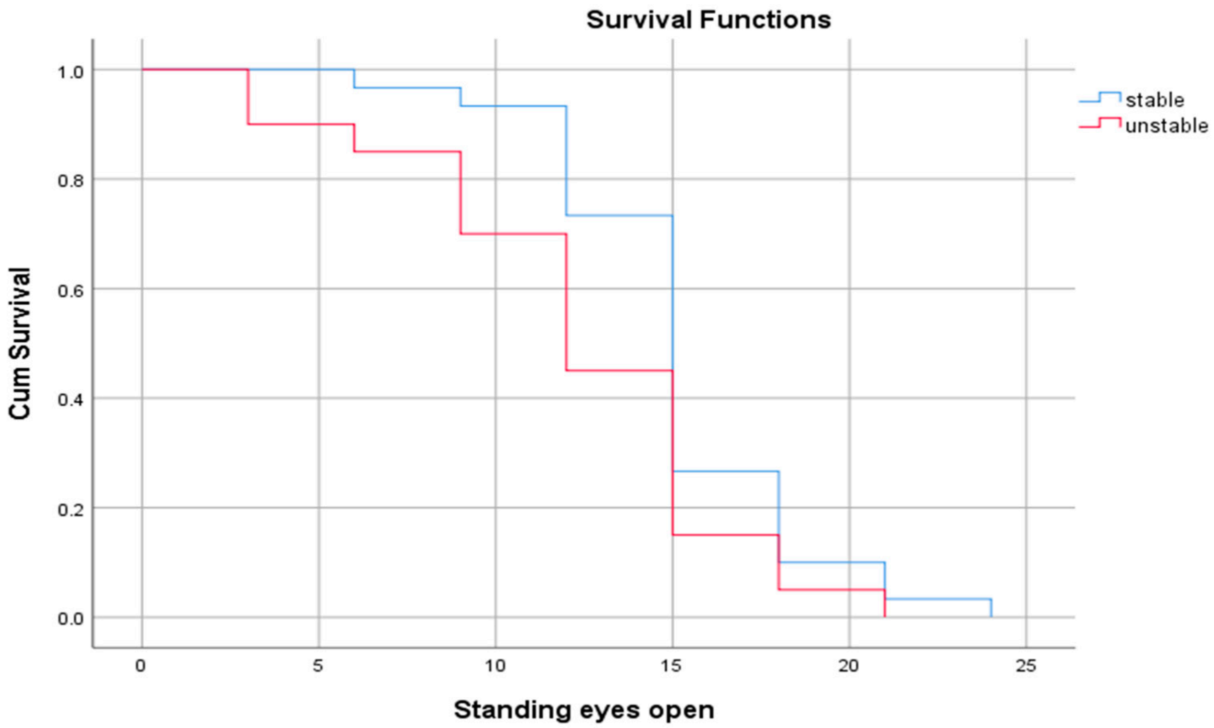
	Ankle Sprains ($0 \leq 4$; $1 = 5$)	**ALL ($0 < 5$; $1 \geq 5$)**	**Clinical ass. ($0 < 2$; $1 \geq 2$)**	**CAIT ($0 > 25$; $1 \leq 25$)**	**AUC (0 = Low. Tertile 1 = Upp. Tertile)**	**n (%)**
No-CAI in ≥4/5 assessments ("Stable" group)	0	0	0	0	0	13 (22.0)
	0	0	0	0	1	8 (13.6)
	0	0	0	1	0	1 (1.7)
	0	0	1	0	0	7 (11.9)
	1	0	0	0	0	1 (1.7)
CAI/no-CAI in <4 assessments	0	0	1	1	0	4 (6.8)
	0	0	1	1	1	1 (1.7)
	1	0	0	0	1	1 (1.7)
	1	0	0	1	0	1 (1.7)
	1	0	0	1	1	1 (1.7)
	1	0	1	1	0	1 (1.7)
CAI in ≥4/5 assessments ("Unstable" group)	1	0	1	1	1	2 (3.4)
	1	1	1	1	0	6 (10.2)
	1	1	1	1	1	12 (20.3)

CAIT = Cumberland Ankle Instability Tool; AII- Ankle Instability Instrument questionnaire; Clinical ass. = Clinical assment; AUC = AMEDA results; Ankle sprains= previous ankle sprains questionnaire.

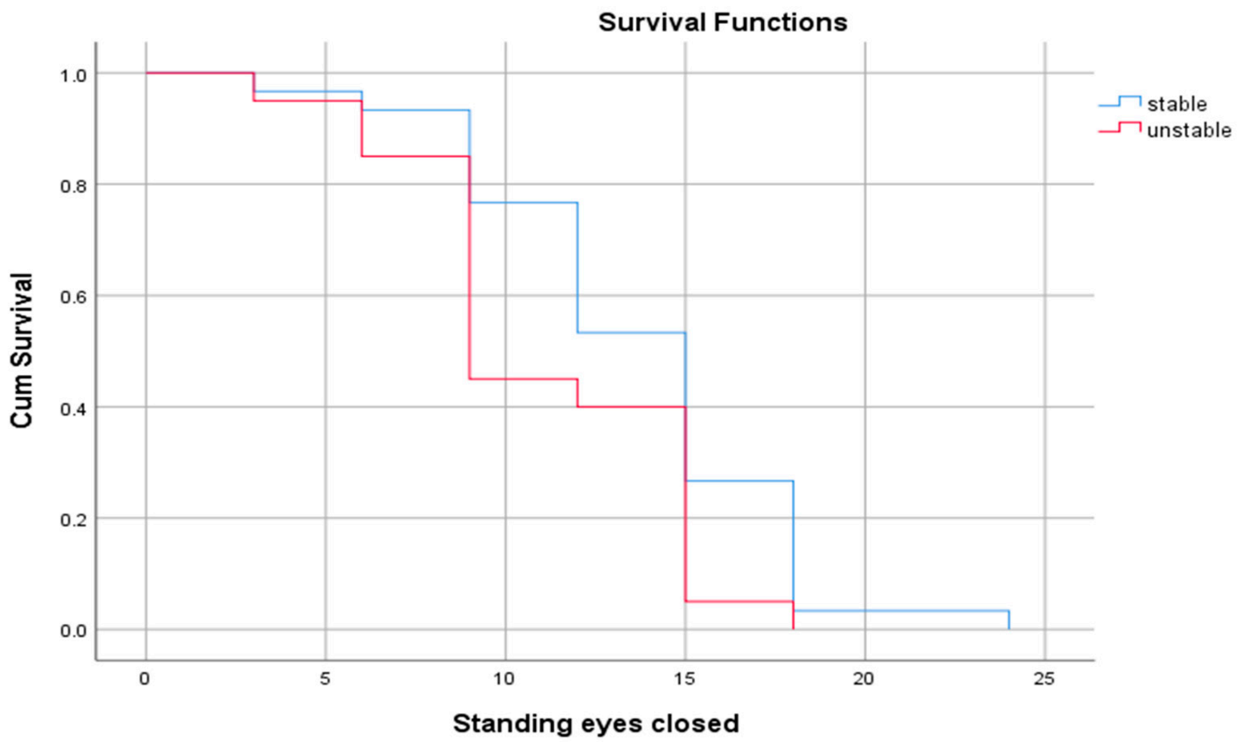
Table 4. Median ± SE for the level of losing postural balance in individuals in the "stable" and the "unstable" groups.

	SO	**SC**	**TD**	**TND**	**SLSS**	**SLOS**	**Walk**
(A) "stable" group	15 (0.55)	12 (0.96)	9 (0.31)	9 (0.23)	6 (0.65)	6 (0.22)	15 (0.70)
(B) "unstable" group	15 (0.98)	9 (1.43)	6 (0.57)	6 (0.68)	4 (1.19)	6 (0.8)	12 (1.18)

SO = eyes open position; SC = eyes closed position; TD = tandem-dominant leg forward position; TND = tandem non-dominant leg forward position; SLSS = single leg same side position; SLOS = single leg opposite side position; walk = walking.

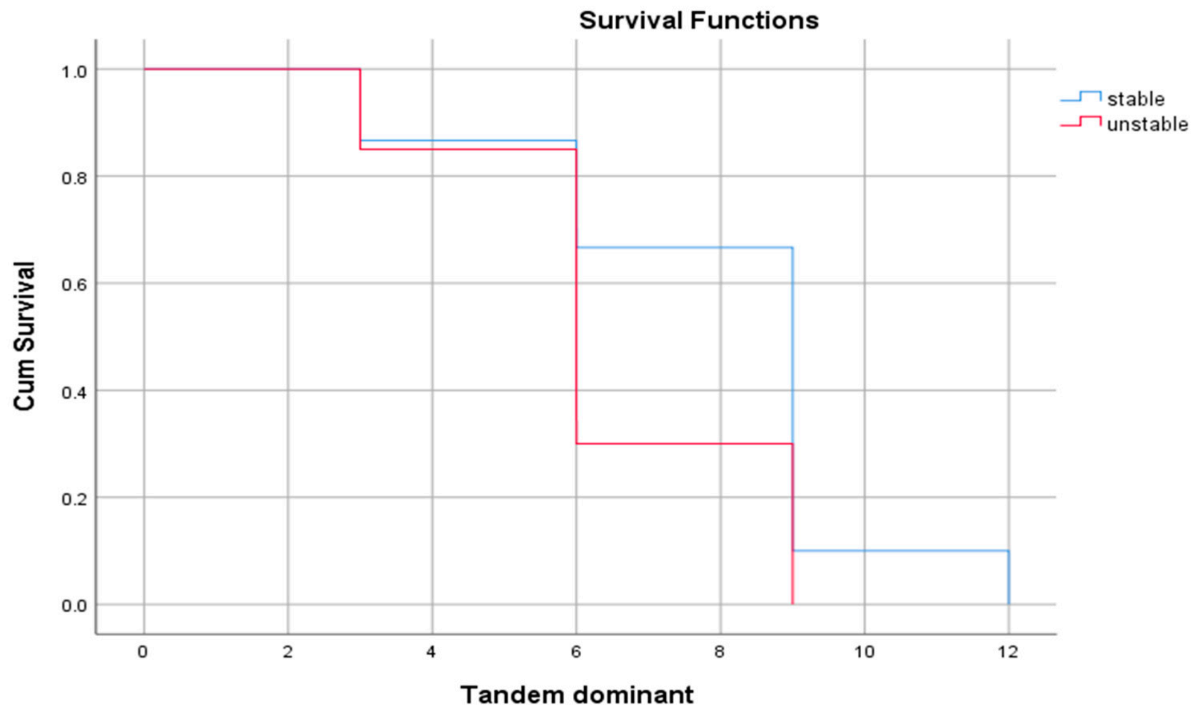


(**A**)



(**B**)

Figure 3. *Cont*.



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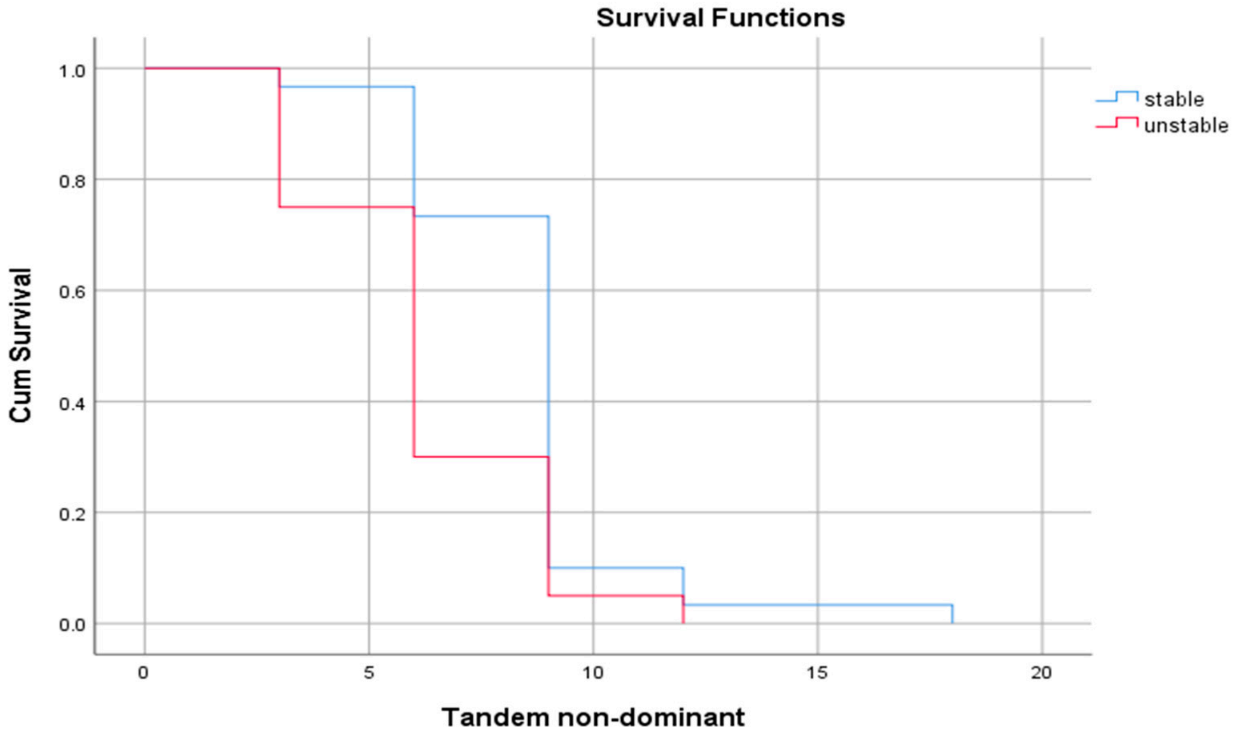

(**D**)

Figure 3. Survival curve for the level of losing postural balance in: (**A**) standing eyes open position (**B**) standing eyes closed position; (**C**) tandem-dominant leg forward; and (**D**) tandem non-dominant leg forward position] in individuals in the "stable" and "unstable" groups. Cum = cumulative.

4. Discussion

The aim of this study was to examine the association between ankle instability and an individual's ability to cope with unexpected perturbations. The findings of this study indicate several correlations between the various mechanical and functional assessments. However, differences in the ability to cope with unexpected perturbations were apparent when participants were assessed depending on their method of CAI identification or evaluation. Similar to the current results, Donahue et al. [32] reported accuracy of predictions of ankle stability as non-homogenous, and inconsistent identification statuses when combining the CAIT and AII questionnaires.

Significant associations have been previously reported between CAI-related deficits that were identified through a range of mechanical and functional assessments [33]. Unlike the current study, Hiller et al. [34] reported a low degree of correlation between mechanical and functional instability. Whereas Hirai et al. [35] found no relationship between the severity of functional ankle instability and mechanical ankle instability, suggesting that different factors are associated with these two instabilities. In the current study, the approach to identifying CAI through combining several mechanical and functional assessments stemmed from the wide discrepancies appearing in the literature in the inclusion criteria and definitions of CAI, which has been suggested to lead to non-homogenous groupings and inconsistent identification of individuals with CAI [13]. The participants' different coping abilities for the range of perturbations presented supports the concept that not all cases of CAI stem from the same mechanism, and not all cases of CAI present with the same functional or mechanical impairments [11]. Moreover, our findings indicate that implementing only one single measure for assessing CAI does not adequately identify individuals as meeting the minimally accepted criteria for being considered as suffering from CAI [32].

In the current study, individuals who were identified with CAI based on functional assessments were found to have a reduced ability to cope with unexpected perturbations compared with those with without CAI. These findings are consistent with the literature, where previous studies of balance and recovery from perturbation were shown to be impaired in individuals with CAI [34,36]. These differences are suggested to be as a result of factors such as functional limitations, including abnormal muscle activation, longer stabilization time, impaired kinematic and kinetic parameters [10,25].

Where healthy individuals may increase the intensity level of their responses appropriately in response to increased intensity levels of perturbation [19], individuals with CAI suffer from a reduced ability to respond appropriately, often relying on different postural strategies to restore balance and cope with perturbations [37]. Individuals with CAI tend to use one single strategy, with little ability to adjust or change their response across different perturbation conditions [11,38]. This limited ability to develop appropriate responses that effectively address external perturbations reduces the ability of these individuals to cope with perturbations compared to their healthy counterparts [39].

The finding of significant correlations in the current study between reduced proprioception ability (assessed by the AMEDA device) and a reduced ability to cope with unexpected perturbation in most conditions for the CAI group is in accordance with previous studies [16,40]. Individuals with CAI tend to use different proprioception strategies for weighting the sensory inputs that control their balance following perturbations when compared to individuals without CAI [21,41,42]. This may stem from the disruption caused to the sensory organs in ligamentous structure, muscles, tendons, and nerves around the ankle joint following repeated ankle sprains [41,43]. Alghadir et al. [43] showed deficits in ankle proprioception in patients with chronic ankle sprains; and both Hertel et al. [10] and Witchalls et al. [44] noted that insufficient proprioception ability reduced the ability to cope with unexpected perturbations. However, a systematic review by Hiller et al. [45] (which didn't include an evaluation of AMEDA assessment) reported no differences in inversion joint position sense in response to perturbation in individuals with recurrent ankle sprains, suggesting that further studies are needed to address the question in individuals with CAI.

In the current study, those who were identified with CAI by clinical mechanical assessment showed no reduced ability to cope with perturbations compared with those with no CAI. Doherty et al. [25] have previously suggested that CAI is an encompassing term used to classify an individual who presents with both mechanical and functional instability of the ankle joint following an initial lateral ankle sprain injury. In addition, positive correlations were found in the current study between the functional and clinical/mechanical assessments. This result might be attributable to an alternative explanation, whereby a component of CAI is *functional instability*, which may or may not occur in conjunction with *mechanical instability* or with *recurring sprains* [34]. In other words, these three components can coexist in several combinations [34], with individual sometimes being assessed as having CAI in only one or two of these. When TTT and ADT assessments are positive, they indicate an ankle ligament injury. On the other hand, when these assessment are negative, this does not necessarily rule out CAI [14,27], Although the clinical assessments in this study correlated with the functional assessments, the ability of the clinical assessment per se to differentiate between those with and without CAI based on their observed responses to unexpected perturbations is limited.

The ability of individuals with CAI in the current study to cope with unexpected perturbation was subject to the different standing/walking positions in which the perturbation occurred. To the best of our knowledge, previous studies have not compared individuals' responses to unexpected perturbations when perturbations have occurred in different standing/walking positions. However, previous authors have indicated that the direction, displacement, and velocity of perturbations may influence the kinematic responses and the different postural strategies used [46]. Furthermore, Rosenblum et al. [47] reported different muscle activation patterns in response to different directions/types of unexpected perturbations, and Picot and colleagues [21] suggest that when perturbations were presented on different type of surfaces, different strategies and muscle activations occur in response. In the current study, single-leg perturbations to the lateral (SLOS) or to the medial (SLSS) sides were not correlated with any functional or mechanical instability, nor were differentiations seen between individuals with and without CAI in their responses to perturbations. Similar to our result, Sousa et al. [48] described a reduced ability to adjust to a unilateral perturbation in individuals with functional ankle instability—possibly due to a fear of falling even when standing on both legs. It might be suggested that the lack of correlation between SLOS and SLSS positions with any functional or mechanical instability may be due to a ceiling effect—the two single leg tests were too difficult to achieve high scores for perturbation survival, regardless of yes/no CAI.

Finally, the tandem position was found to be the main standing posture that differentiated between those with 'unstable' ankles (i.e., individuals who exhibited CAI in at least four of the five mechanical and functional assessments) and those with 'stable' ankles (i.e., individuals who exhibited no CAI in at least four of the five mechanical and functional assessments) when responding to perturbations. The tandem position is an asymmetrical position with a wider A-P and narrower M-L base of support, making this posture harder to cope with following perturbations compared to the other double stance standing/walking positions [18,19,29]. It has been previously indicated that, following active movements starting in an asymmetric initial foot position, different patterns of onset of stabilizing muscles and different balance control strategies are used when compared with symmetric initial foot positions [22]. Furthermore, turning into the asymmetrical posture further increases the Center of Pressure (COP) velocity compared to symmetrical positions [23]. The tandem positions, being relatively novel and challenging postures for the participants, may challenge the sensory efforts required from those with CAI compared to those with no CAI, thereby enabling the response to this posture to be used to discriminate between the two groups in response to perturbations. Opposed to the SLOS and SLSS positions, it might be that the bilateral stance positions (SO, SC) were too easy positions to discriminate between those with and without CAI (Floor effect). The tandem stance achieves the mixture of difficulty (not too hard, like the SLSS or SLOS, and not too easy like the SC and SO) to challenge those with CAI; yet those with healthy ankles can still perform.

4.1. Limitations and Future Studies

No kinematic or kinetic parameters being collected in this study and the exact time of perturbation in the cycle while participants were walking was not controlled, which should be addressed in future research. Moreover, previous physical condition (such as ankle joint mobility/muscle tone for the muscles surrounding the ankle joint and generalized joint hypermobility) was not considered for our healthy physical education students. However, having a random presentation of the perturbation mimics the reality of sudden unexpected events that challenge balance even in athletic populations.

Future studies could also benefit from further assessing parameters that can distribute between genders such as generalized joint hypermobility; and, the effect of perturbation type, magnitude, and direction on the extent and the degree of retention of single leg and double leg responses (in symmetrical and asymmetrical positions) in both healthy and injured populations [17].

4.2. Clinical Implications

Based on the results of the current study, it can be recommended that researchers and clinicians employ a number of functional assessments when determining ankle stability status [32]. As perturbation-based exercise interventions can challenge postural-control strategies and improve reactive motor control [20] these might provide a promising strategy for improving sensorimotor control and perceived function for patients with CAI [18,49]. A systematic review by Caldemeyer and colleagues [50] highlighted the importance and effectiveness of neuromuscular training programs incorporating strength, balance, plyometric, and agility training for reducing the risk of ankle sprains in female athletes [50]. Furthermore, proprioceptive training programs consisted of classic proprioceptive exercises, interactive proprioceptive exercises and training at different intensity, duration and volume, were found to be effective to reduce the occurrence of ankle sprains and for repair of ankle external compartment, restored proprioceptive and postural control in healthy and in post-operated CAI populations [51,52].

Finally, performing tasks while standing on a single leg and in an initial asymmetric foot position (conditions that replicate daily life activities) should be encouraged and incorporated into sporting exercises and rehabilitation interventions [22].

5. Conclusions

As expected, individuals with low CAIT scores had a lower ability to cope perturbations in TD and in TND positions compared to those with high CAIT scores. The same pattern was found between those with high AII questionnaire scores compared to those with low AII scores in the SO, SC, TD, TND, and walking positions; and, between participants with low scores on the ankle sprains history questionnaire compared to those with high score on that questionnaire in SO, SC, TD, TND, and walking positions. However, no differences were found between individuals with positive and with negative mechanical assessments in their ability to cope perturbations in all positions tested. Furthermore, participants with no-CAI in at least four of the five mechanical and functional assessments had better ability to cope perturbations in the SO, SC, TD and TND positions compared with those with CAI in at least four of the five mechanical and functional assessments. As such, several functional and mechanical assessments for CAI should be conducted rather than relying on one single measure when assessing individuals for their CAI status. Finally, it is important to assess different postures, i.e., standing/walking positions (e.g., single vs. double stance; asymmetrical vs. symmetrical positions) and their impact on the individuals' ability to cope with unexpected perturbations.

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