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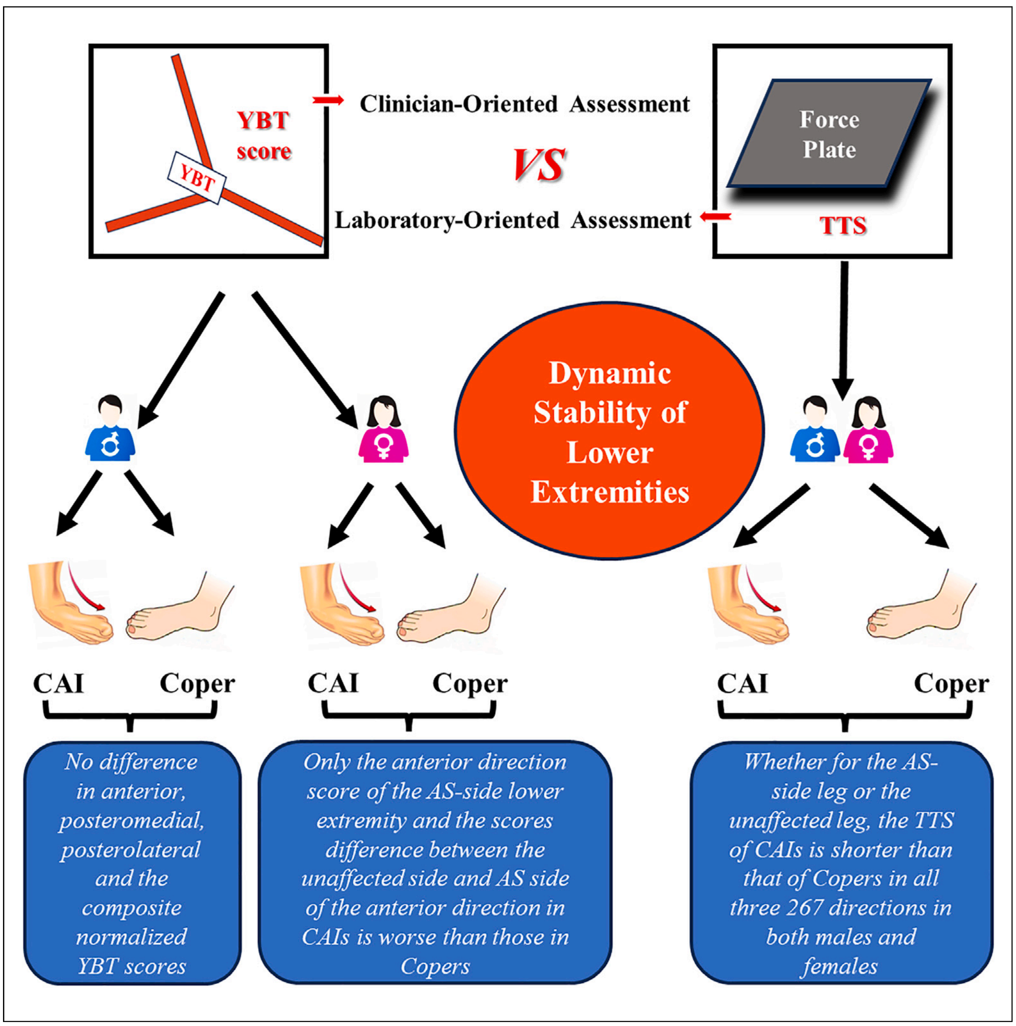

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Highlights

Opposite results occur when evaluating dynamic stability of CAIs using YBT and TTS

The female CAIs present the worse anterior-reach YBT compared with the female Copers

The TTS of CAIs is shorter than that of Copers

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Using clinician-oriented and laboratory-oriented assessments to study dynamic stability of individuals with chronic ankle instability

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SUMMARY

To compare the dynamic stability of lower extremities between Copers and individuals with chronic ankle instability (CAI) using clinician-oriented assessments (Y-balance test, YBT) and laboratory-oriented assessments (time to stabilization, TTS). 90 participants (Copers, 45; CAIs, 45) were recruited and measured by YBT and TTS to evaluate dynamic stability. The difference of dynamic stability between Copers and CAIs was examined using a two-factor MANOVA. Only for females in anterior direction, YBT scores for the AS side of Copers were significantly higher than that of CAIs. For males, the TTS of CAIs was significantly shorter than that of Copers in the anterior, lateral, and medial direction separately. For females, the TTS of CAIs is also significantly shorter than that of Copers in the anterior, lateral, and medial direction separately. There are opposite results when evaluating the dynamic stability difference between Copers and CAIs using YBT and TTS.

INTRODUCTION

Ankle sprain (AS), the most common injury of musculoskeletal disorders,[1,2] was suffered by approximately 1 in 10,000 people each day worldwide. AS also has extremely high recurrence rates, making many AS individuals become patients with chronic ankle instability (CAI).[1,2]

More than 40% of individuals with an AS history develop CAI, leading to a condition of additional AS or ongoing ankle weakness and pain.[3,4] For these patients, the repeated AS induced by CAI not only damages the physiological structure of the ankle joint[5,6] but also causes the dysfunction of neuromuscular control and proprioception around the ankle joint.[4,7–9] These constraints about the anatomic structure and sensorimotor function may directly change the movement strategies.[10,11] On the other hand, CAI can subsequently increase the risk of sequelae of sprained ankles and other chronic diseases (e.g., post-traumatic osteoarthritis of ankle joint)[1] and negatively affect the health-related quality of life by limiting their movement performance.[12]

A variety of researchers have applied single-leg hop test to measure the time to stabilization (TTS) to detect postural stability impairments of CAI.[13–16] Because it has been revealed that the movement of take-off and landing account for a large proportion in sports with a high incidence of AS,[17–19] this specific movement may be associated with the injury mechanism of AS. Although most studies have measured the TTS in the anterior direction of the single-leg hop test,[20,21] we believe that the movements of take-off and landing in different directions have corresponding scenes in daily life. Therefore, in this study, we detected the TTS in three directions (i.e., anterior, lateral, and medial) of the single-leg hop test or the adapted single-leg hop test. Considering that the movement of walking forward and downstairs is a possible scene of AS in daily life, we used the single-leg landing test (i.e., the adapted single-leg hop test) without jumping in the anterior direction instead of the traditional single-leg hop test.

The Y-Balance Test (YBT), as a reliable and valid dynamic stability test, can distinguish the dynamic postural control difference between legs with healthy and sprained ankles.[22,23] The YBT can assess several neuromuscular characteristics such as coordination, balance, flexibility, and strength of the lower extremity and it can comprehensively reflect the injury risk of lower extremities.[24–26] Therefore, we also used the YBT to compare the difference of dynamic stability between CAIs and Copers, who are the individuals with an initial AS history but do not report residual AS symptoms, repeated episodes of giving way, and neuromuscular control deficits.[27,28]

Although both TTS and YBT can evaluate the dynamic stability of lower extremities, they exactly have different orientations and concentrations for ankle instability. The TTS, as a laboratory-oriented assessment for ankle instability, concentrates more on stability after a dynamic movement, which represents stability when switching from a dynamic movement to a stable posture. While the YBT, as a clinician-oriented assessment for ankle instability, focuses more on stability during a dynamic movement, which represents stability control during a process of dynamic motion. As Gottlieb et al. have indicated that, although both mSEBT and jump-landing TTS aim to assess dynamic stability, their

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Table 1. The basic demographic characteristics of subjects (N = 85)

	Coper		CAI	
characteristic	Male (n = 17)	Female (n = 22)	Male (n = 23)	Female (n = 23)
Age, yrs	21.6 ± 2.6	21.8 ± 2.9	20.7 ± 1.5	22.1 ± 3.7
Height, cm	178.9 ± 6.3	162.4 ± 5.8	178.4 ± 5.9	162.5 ± 4.6
Body weight, kg	75.3 ± 9.4	59.2 ± 7.2	76.3 ± 11.7	60.2 ± 8.0
Active exercise per week, hrs	9.3 ± 4.7	4.7 ± 2.7	10.4 ± 4.3	5.2 ± 4.2
CAIT, score				
AS side	29.2 ± 0.9	28.6 ± 0.9	18.4 ± 3.8	17.2 ± 3.8
Unaffected side	29.6 ± 0.6	29.6 ± 0.7	27.6 ± 2.9	29.2 ± 1.2

outcomes are fundamentally different and they have suggested that different correlations of these two dynamic balance tests in people with and without CAI,[29] which can strongly support our opinion. It is necessary to investigate the difference of lower extremities between Copers and CAIs using the dynamic stability tests with different concentrations and orientations. Although numerous studies have compared the YBT or TTS between CAIs and Copers,[14,30–32] they have not simultaneously evaluated the potential difference of YBT and TTS (two different oriented dynamic stability tests) between CAIs and Copers. The objective of this study was to compare dynamic postural control of participants with CAI and Copers using the TTS of the single-leg landing test and the YBT. Exploring the difference of these two different dynamic stability tests in CAIs and Copers may provide further clinical rehabilitation ideas and training methods for transforming CAIs into Copers. For clinical cases, this will also provide a new perspective for evaluating the effectiveness of CAI rehabilitation prescription, that is, the rehabilitation effect can be evaluated under different dynamic stability using TTS and YBT. Considering that there are gender differences in muscle strength around the ankle joint (AJ)[33] and the range of motion of AJ,[34] which are the influential factors of dynamic stability of lower extremities,[35] we conduct the gender analysis in the results of YBT and TTS in this study.

Instead of CAIs, Copers do not report residual AS symptoms and extra AS events after an initial AS history.[27,28] Hence, we hypothesized that, in all three directions, the lower extremity dynamic stability of Copers was better than the individuals with CAI, whether through TTS or YBT.

RESULTS

The basic demographic characteristics of participants

The basic demographic characteristics of participants including age, height, body weight, active exercise per week, and CAIT score were summarized in Table 1. For the same gender, there was no significant difference in the demographic characteristics of participants between the Coper group and the CAI group.

The main effect and interaction effect of gender and AS-patient types on YBT scores

Table 2 shows that the two independent variables (gender and AS-patient type) have no interaction effect on YBT scores (F = 1.282, p = 0.257, Wilks'λ = 0.851, Partial $\eta 2$ = 0.149). The AS-patient type has a significant main effect on participants' YBT scores (F = 0.904, p = 0.034, Wilks'λ = 0.890, Partial $\eta 2$ = 0.110) and the gender has a significant main effect on participants' YBT scores (F = 4.006, p = 0.000, Wilks'λ = 0.646, Partial $\eta 2$ = 0.354). Specifically, Table 3 displays the means and standard deviations of the YBT normalized scores of the Coper and CAI groups. For the males, whether for the unaffected side or AS side of the lower extremity, there was no significant difference between Copers and CAI groups in anterior (P > 0.05), posteromedial (P > 0.05), posterolateral P > 0.05), and composite (P > 0.05) normalized YBT scores. For the females, only for the AS side of the lower extremity in anterior direction, the normalized YBT score of Copers (62.87 ± 1.37) was significantly higher than that of CAIs (58.87 ± 1.34, P < 0.05). For the males, there was no significant difference between Copers and CAIs in the difference between the unaffected side and AS side in anterior (P > 0.05), posteromedial (P > 0.05), posterolateral (P > 0.05), and composite (P > 0.05) normalized YBT scores. For the females, only for the anterior direction, the normalized YBT score difference between the unaffected side and AS side of CAIs (5.16 ± 1.46) was significantly higher than that of Copers (2.22 ± 1.50, P < 0.05).

The main effect and interaction effect of gender and AS-patient types on TTS

Table 4 shows that the two independent variables (gender and AS-individual type) have no interaction effect on TTS (F = 0.352, p = 0.705, Wilks'λ = 0.991, Partial $\eta 2$ = 0.009). The AS-patient type has a significant main effect on participants' TTS (F = 34.227, p = 0.000, Wilks'λ = 0.518, Partial $\eta 2$ = 0.482) and the gender has no significant main effect on participants' TTS (F = 1.104, p = 0.336, Wilks'λ = 0.973, Partial $\eta 2$ = 0.027). Specifically, Table 5 displays the means and standard deviations of the TTS in different directions for the unaffected-side and AS-side lower extremities in the Copers and CAIs. For the males, whether for the unaffected side or AS side, the TTS of CAIs is significantly shorter than that of Copers in the anterior (unaffected side: 1.01 ± 0.11 VS 1.84 ± 0.13, P < 0.01; AS side: 1.01 ± 0.11 VS 1.96 ± 0.13, p < 0.01), lateral (unaffected side: 1.08 ± 0.11 VS 1.95 ± 0.12, P < 0.01; AS side: 1.17 ± 0.11 VS 2.00 ± 0.13, P < 0.01), medial direction (unaffected

Table 2. The main effect and interaction effect of gender (male & female)and AS-patient types (CAI & Copers) on YBT scores

Dependent variable			Wilks' λ	*F*	*p* value	Partial $\eta 2$
Gender	Unaffected side	Anterior reach direction		4.795	0.031	0.055
		Posteromedial reach direction		1.178	0.281	0.014
		Posterolateral reach direction		3.777	0.055	0.044
		Composite scores		2.273	0.135	0.027
	AS side	Anterior reach direction		3.086	0.083	0.036
		Posteromedial reach direction		3.051	0.084	0.036
		Posterolateral reach direction		2.617	0.110	0.031
		Composite scores		2.885	0.093	0.034
	Difference between the unaffected side and AS side	Anterior reach direction		0.333	0.565	0.004
		Posteromedial reach direction		2.650	0.107	0.031
		Posterolateral reach direction		0.102	0.751	0.001
		Composite scores of three directions		0.785	0.378	0.009
			0.646	4.006	0.000	0.354
AS-patient type	Unaffected side	Anterior reach direction		3.094	0.031	0.102
		Posteromedial reach direction		2.750	0.048	0.091
		Posterolateral reach direction		4.535	0.005	0.142
		Composite scores		2.768	0.045	0.094
	AS side	Anterior reach direction		5.450	0.022	0.062
		Posteromedial reach direction		4.994	0.028	0.057
		Posterolateral reach direction		4.322	0.042	0.050
		Composite scores		5.759	0.019	0.066
	Difference between the unaffected side and AS side	Anterior reach direction		4.629	0.034	0.053
		Posteromedial reach direction		4.328	0.041	0.050
		Posterolateral reach direction		5.681	0.019	0.065
		Composite scores of three directions		4.359	0.040	0.050
			0.890	0.904	0.034	0.110
Gender*AS-patient type	Unaffected side	Anterior reach direction		0.375	0.542	0.005
		Posteromedial reach direction		0.341	0.561	0.004
		Posterolateral reach direction		1.225	0.272	0.015
		Composite scores		0.370	0.545	0.004
	AS side	Anterior reach direction		0.289	0.592	0.004
		Posteromedial reach direction		0.019	0.891	0.000
		Posterolateral reach direction		1.181	0.280	0.014
		Composite scores		0.181	0.672	0.002
	Difference between the unaffected side and AS side	Anterior reach direction		0.045	0.832	0.001
		Posteromedial reach direction		0.689	0.409	0.008
		Posterolateral reach direction		0.068	0.794	0.001
		Composite scores of three directions		0.049	0.825	0.001
			0.851	1.282	0.257	0.149

Table 3. The YBT normalized scores of CAI and Copers

		Male					Female				
		CAI	95%CI	Coper	95%CI	*p* value	CAI	95%CI	Coper	95%CI	*p* value
Unaffected side	Anterior reach direction	59.87 ± 1.31	[57.27,62.47]	60.43 ± 1.48	[57.50,63.37]	0.78	62.01 ± 1.31	[59.41,64.61]	64.24 ± 1.34	[61.58,66.90]	0.236
	Posteromedial reach direction	102.14 ± 2.33	[97.52,106.77]	106.18 ± 2.63	[100.95,111.41]	0.25	97.05 ± 2.33	[92.42,101.67]	98.30 ± 2.38	[93.53,102.99]	0.72
	Posterolateral reach direction	93.39 ± 2.53	[88.36,98.41]	99.23 ± 2.86	[93.55,104.91]	0.13	91.19 ± 2.53	[86.16,96.22]	91.22 ± 2.58	[86.08,96.36]	0.99
	Composite scores	85.13 ± 1.84	[81.48,88.79]	88.61 ± 2.08	[84.48,92.75]	0.21	83.42 ± 1.84	[79.76,87.07]	84.57 ± 1.88	[80.83,88.31]	0.66
AS side	Anterior reach direction	57.17 ± 1.34	[54.50,59.84]	59.67 ± 1.52	[56.66,62.69]	0.22	58.87 ± 1.34*	[56.20,61.54]	62.87 ± 1.37	[60.14,65.60]	0.04
	Posteromedial reach direction	101.39 ± 2.28	[96.86,105.92]	105.61 ± 2.57	[100.49,110.73]	0.22	93.71 ± 2.28	[89.18,98.24]	97.28 ± 2.33	[92.65,101.91]	0.28
	Posterolateral reach direction	92.47 ± 2.56	[87.38,97.56]	98.34 ± 2.89	[92.59,104.09]	0.13	91.06 ± 2.56	[85.97,96.14]	91.16 ± 2.61	[85.96,96.36]	0.98
	Composite scores	83.68 ± 1.86	[79.98,87.38]	87.87 ± 2.10	[83.69,92.06]	0.14	81.21 ± 1.86	[77.51,84.91]	83.77 ± 1.90	[79.99,87.55]	0.34
Difference between the unaffected side and AS side	Anterior reach direction	4.61 ± 1.46	[1.70,7.52]	1.02 ± 1.65	[-2.27,4.30]	0.11	5.16 ± 1.46*	[2.26,8.07]	2.22 ± 1.50	[-0.76,5.19]	0.02
	Posteromedial reach direction	0.56 ± 1.24	[-1.90,3.02]	−0.02 ± 1.40	[-2.80,2.77]	0.76	3.72 ± 1.24	[1.26,6.18]	1.01 ± 1.26	[-1.50,3.53]	0.13
	Posterolateral reach direction	1.00 ± 1.56	[-2.09,4.09]	0.31 ± 1.76	[-3.19,3.81]	0.77	0.06 ± 1.56	[-2.94,3.38]	0.22 ± 1.59	[-3.03,3.15]	0.94
	Composite scores of three directions	1.64 ± 0.99	[-0.32,3.60]	0.34 ± 1.12	[-1.88,2.56]	0.39	2.78 ± 0.99	[-0.81,4.74]	1.02 ± 1.01	[-0.99,3.03]	0.22

The *p* value indicates the significant difference between CAI and Coper in the same gender.

Table 4. The main effect and interaction effect of gender (male & female)and AS-patient types (CAI & Copers) on TTS

Dependent variable			Wilks'λ	F	p value	Partial η2
Gender	Unaffected side	Anterior direction		0.797	0.375	0.010
		Lateral direction		0.087	0.768	0.001
		Medial direction		0.253	0.617	0.003
	AS side	Anterior direction		0.842	0.362	0.010
		Lateral direction		0.069	0.245	0.622
		Medial direction		0.430	0.514	0.005
			0.973	1.104	0.336	0.027
AS-patient type	Unaffected side	Anterior direction		60.355	0.000	0.427
		Lateral direction		74.966	0.000	0.481
		Medial direction		66.801	0.000	0.452
	AS side	Anterior direction		68.558	0.000	0.458
		Lateral direction		60.430	0.000	0.427
		Medial direction		79.242	0.000	0.495
			0.518	37.227	0.000	0.482
Gender*AS-patient type	Unaffected side	Anterior direction		0.311	0.579	0.004
		Lateral direction		0.701	0.405	0.009
		Medial direction		0.080	0.778	0.001
	AS side	Anterior direction		0.020	0.888	0.000
		Lateral direction		0.445	0.507	0.005
		Medial direction		0.001	0.973	0.000
			0.991	0.352	0.705	0.009

side: 1.11 ± 0.11 VS 2.01 ± 0.13, $P < 0.01$; AS side: 1.11 ± 0.11 VS 2.11 ± 0.12, $P < 0.01$) separately. The same result occurs in females. Whether for the unaffected side or AS side in females, the TTS of CAIs is significantly shorter than that of Copers in the anterior (unaffected side: 0.84 ± 0.11 VS 1.80 ± 0.11, $P < 0.01$; AS side: 0.92 ± 0.11 VS 1.84 ± 0.11, $P < 0.01$), lateral (unaffected side: 1.01 ± 0.11 VS 2.08 ± 0.11, $P < 0.01$; AS side: 1.03 ± 0.11 VS 2.01 ± 0.11, $P < 0.01$), medial direction (unaffected side: 1.02 ± 0.11 VS 1.99 ± 0.11, $P < 0.01$; AS side: 1.04 ± 0.11 VS 2.03 ± 0.11, $P < 0.01$) separately.

DISCUSSION

This study evaluated the dynamic stability difference of lower extremities between AS Copers and adults with CAI using YBT (clinician-oriented assessment) and TTS (laboratory-oriented assessment). The findings demonstrated, for YBT in males, whether for the unaffected side or AS side of the lower extremity, there was no significant difference between Copers and CAI groups in anterior, posteromedial, posterolateral, and composite normalized YBT scores. For YBT in females, only the anterior direction score of the AS-side lower extremity and the scores difference between the unaffected side and AS side of the anterior direction in CAIs is worse than those in Copers. However, whether for the AS-side leg or the unaffected leg, the TTS of CAIs is shorter than that of Copers in all three directions in both males and females.

In terms of YBT, the MANOVA results that the main effect of AS-patient type (i.e., CAI and Coper) on YBT scores suggests that different AS-patient types may induce different dynamic stability. However, only in the anterior direction in females, the dynamic stability of the AS-side lower extremity of Copers was significantly better than that of CAIs. Several studies also have found that there is a significant difference in dynamic stability between CAIs and the healthy people in the anterior direction but not in other directions.[23,49] This may be because the YBT movement in the anterior direction is mainly affected by ankle dorsiflexion[50,51] and CAIs have smaller range of motion (ROM) of ankle dorsiflexion than Copers. Specifically, the anterior YBT relies more on squatting to reach a longer distance, whereas the posteromedial and posterolateral YBT can achieve longer distances through pelvic rotation and the ability to extend and abduct (adduct) the contralateral leg. On the other hand, the difference in anterior reach distance between CAIs and Copers may be due to individuals with CAI having lower ankle muscle activity and greater reliance on the gluteus maximus in stability and Copers using hip muscle strength for better performance. The findings of DeJong et al.'s study[27] may support our view. They have found that the activation of the gluteus maximus in the CAI group was higher than that in the control group when performing anterior YBT.

Our study has indicated that, for females, there is a significant difference in the anterior direction score of the AS-side lower extremity and the scores difference between the unaffected side and AS side of anterior direction between CAIs and Copers. We speculate that this may be

Table 5. The TTS of CAIs and Copers (unit: s)

		Anterior direction				Lateral direction				Medial direction			
		Unaffected side	95%CI	AS side	95%CI	Unaffected side	95%CI	AS side	95%CI	Unaffected side	95%CI	AS side	
Male	CAI	1.01 ± 0.11	[0.78,1.23]	1.01 ± 0.11	[0.79,1.22]	1.08 ± 0.11	[0.86,1.29]	1.17 + 0.11	[0.95,1.39]	1.11 ± 0.11	[0.90,1.33]	1.11 ± 0.11	[0.90,1.32]
	Coper	1.84 ± 0.13	[1.59,2.10]	1.96 ± 0.13	[1.71,2.21]	1.95 ± 0.12	[1.71,2.20]	2.00 ± 0.13	[1.73,2.25]	2.01 ± 0.13	[1.76,2.27]	2.11 ± 0.12	[1.86,2.35]
p value		0.000		0.000		0.000		0.000		0.000		0.000	
Female	CAI	0.84 ± 0.11	[0.62,1.06]	0.92 ± 0.11	[0.71,1.13]	1.01 ± 0.11	[0.80,1.23]	1.03 ± 0.11	[0.81,1.25]	1.02 ± 0.11	[0.81,1.24]	1.04 ± 0.11	[0.83,1.25]
	Coper	1.80 ± 0.11	[1.58,2.03]	1.84 ± 0.11	[1.62,2.06]	2.08 ± 0.11	[1.86,2.30]	2.01 ± 0.11	[1.78,2.23]	1.99 ± 0.11	[1.77,2.21]	2.03 ± 0.11	[1.81,2.24]
p value		0.000		0.000		0.000		0.000		0.000		0.000	

The *p* value indicates the significant difference between CAI and Coper in the same gender.

related to the difference in ankle dorsiflexion among males and females. It has been reported that males' ankle dorsiflexion ROM is significantly smaller than females.[52] Hence, for females, the ankle dorsiflexion ROM will decrease from a larger level to a smaller level after repeated AS, which may cause a significant difference in the anterior YBT score between CAIs and Copers. While for males, Copers' ankle dorsiflexion ROM is relatively small and has limited space to decrease after repeated AS (i.e., CAI). This may lead to a non-significant difference between CAIs and Copers. Unfortunately, we did not measure ankle dorsiflexion ROM of participants, so the exact reason for the gender difference in YBT can't be definitively explained in this study.

The MANOVA results that the main effect of AS-patient type (i.e., CAI and Coper) on TTS suggests that different AS-patient types may induce different dynamic stability. Quite interestingly, in both males and females, the time that CAIs reached stability after landing is shorter than Copers in all three directions. We believe that the possible reasons for this result of TTS are: (1) The change in CAIs' movement strategy. After landing on the ground, compared with Copers, CAIs will use more muscles around the proximal joint (e.g., hip and knee joint) to stabilize to compensate for the ankle instability[53]; while the Copers may only activate muscles around the ankle joint for stabilization. Therefore, CAIs reach stability faster than Copers. (2) The change in CAIs' subjective consciousness. Because CAIs have the experience of repeated AS, they may have a stronger consciousness of self-protection to prevent AS when performing jumping, which can make them adopt a movement strategy for rapid stabilization. Absolutely, further studies are needed to provide specific evidence for the change of protective strategies and joint stiffness when CAIs land from a high step to a stable plane.

This study used two well-recognized measurements (i.e., YBT and TTS) to evaluate the difference in dynamic stability between CAIs and Copers and these two methods lead to opposite results. This may be partly explained by the fact that YBT and TTS have different orientations in assessing the dynamic control function of ankles. The former mainly detects the ability of dynamic control of the supporting leg that standing on a stable plane when swinging the contralateral leg. To some extent, the swing range of the contralateral leg (i.e., the reached distance in three directions of YBT) can affect the score of the supporting leg. The latter is used to assess the ability to stabilize quickly from dynamic movement (e.g., jumping or walking downstairs) to static posture (e.g., standing on the floor).

Limitations of the study

There are several limitations in our study. Firstly, the health history is self-reported, which may cause recall bias. Secondly, we did not investigate participants' activity types and record the rehabilitation for ankle injuries. Thirdly, based on previous studies, the same height was chosen in our study for all participants' step heights in the TTS protocol, which may cause unequal task difficulty due to the differences in participants' height. We suggest that, in the future, researchers should standardize the step height based on the participant's body height to create a more equal task between participants with different heights. Fourthly, we did not collect kinematics and kinetic indices when doing these two protocols and this might lead to a limited explanation of our results. Lastly, participants in this study were recruited from Beijing Sports University and they were young and physically active, hence, our results may be not meaningful for other CAI populations.

Conclusions

This study demonstrates that there are opposite results when evaluating the dynamic stability difference of lower extremities between AS Copers and adults with CAI using YBT (clinician-oriented assessment) and TTS (laboratory-oriented assessment). This suggests that, for assessing the dynamic stability of lower extremities in CAIs comprehensively, both TTS (laboratory-oriented assessments) and YBT (clinician-oriented assessments) should be applied in clinical practice.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2024.108842.

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AUTHOR CONTRIBUTIONS

Conceptualization, X.H. and B.R.; Investigation, W.S., J.C., and B.R.; Formal analysis, X.H. and J.Q.; Writing-original draft, X.H., J.C., and W.S.; Writing-review & editing, B.R. and Q.G.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Software and algorithms		
SPSS 25.0	International Business Machines Corporation (IBM)	https://www.ibm.com/spss?mhsrc=ibmsearch_a&mhq=spss%20online
Python 3.8	Originator: Guido van Rossum	https://www.python.org/downloads/release/python-380
Other		
Y balance test	Functional Movement Systems	https://www.functionalmovement.com/store/23/y-balance_test_kit
Multicomponent Force Plate	Kistler Instrumente AG	https://www.kistler.com/INT/en/about-us/C00000001

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources and reagents should be directed to and will be fulfilled by the lead contact, Xiao Hou (houxiao0327@bsu.edu.cn).

Materials availability

This study did not generate new unique reagents.

Data and code availability

Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

A total of 90 participants with a history of unilateral ankle sprain identified as Copers (n=45) and individuals with CAI (n=45) were recruited from Beijing Sport University through the following inclusion and exclusion criteria of Coper and CAI (Table S1), which was endorsed by International Ankle Consortium and referred by several studies.[36–38] The sample size was determined as 64 (group 1 = 32, group 2 = 32) based on the power analysis with an assumption of a very large effect size (η-squared = 0.64), the alpha level at 0.05, the the number of response variables set as 18 (shown in Tables 1 and 2), and power at 0.95 for a two-factor MANOVA. The selection of a very large effect size was based on several studies[30,39–43] indicating a significant difference in stability between Copers and CAIs. Considering the drop-out of the participants and the invalid data, we determined the sample size as 90, and eventually, a total of 85 participants (Copers, n=39, age: 22.7 ± 2.6 years, male: n=18; CAI, n=46, age: 22.9 ± 3.8 years, male: n=23) finished the experiment.

The studies involving human participants were reviewed and approved by the ethics committee of Beijing Sport University (project number: 2020173H). All participants signed an informed consent approved by the Institutional Review Board of Beijing Sport University.

METHOD DETAILS

Study design

A blinding experiment design that testers and analyzers did not identify whether the participants were Copers or patients with CAI was used in this study. Each participant completed two dynamic stability test protocols. In order to reduce the carry-over effect, the sequence of test protocols was determined by a counterbalanced design that all participants were allocated into two groups, one group performed the YBT protocol first and then the TTS protocol, the other performed the TTS protocol first and then YBT protocol. Each participant drawed lots to decide whether to conduct the unaffected-side test or the AS-side test first. Each participant had a 10-min warm-up phase using dynamic stretching and bicycle ergometer before the test. The whole-body dynamic stretching took five minutes and the bicycle ergometer exercise with 60 r/min took five minutes.

Instrumentation

YBT

We used the YBT tool (Functional Movement Systems™, Danville, VA) to assess the dynamic stability of the tested leg when the opposite leg moved into three directions (i.e. anterior, posterolateral, and posteromedial).

Multicomponent force plate

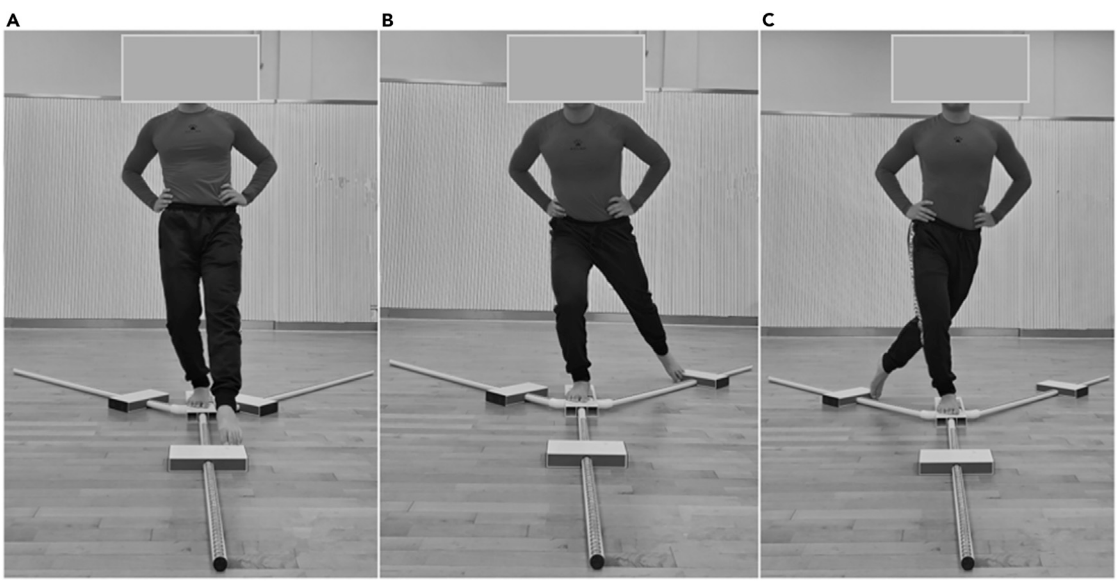
The TTS following a single-leg landing test was measured by the portable multi-component force plate (Kistler Instrumente AG, Type 9286A, Winterhur). The sampling frequency of the force plate was 1000 Hz and the field was 600 mm*400 mm.

Procedures

Before testing, participants signed an informed consent approved by Beijing Sport University. Simultaneously, they received a questionnaire of specific information about AS history, the Cumberland Ankle Instability Tool (CAIT), and active exercise to verify whether they met the inclusion criteria of this study. And then, all included participants were asked about age and measured height and body weight. After the investigation of basic information, participants were regarded as CAI or Coper based on the inclusion and exclusion criteria. Then, the allocation and experiment protocol were carried out.

YBT protocol

The YBT demonstrated high reliability over time and between raters[44] and could accurately measure dynamic neuromuscular control.[45] Each participant received the practice about YBT and their bilateral lower extremity lengths were measured. On a mat table with the participant supine, the participant's extremity length was measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial malleolus with a cloth tape measure.[45] The participants were required to stand barefoot on the tested lower extremity on the YBT stance plate with their midfoot toward the anterior direction and slowly push the reach indicator toward the tested direction with the contralateral lower extremity (see figure below).



The YBT movements in three directions

The YBT in (A) anterior, (B) posteromedial, and (C) posterolateral directions.

The order of the test leg and direction were randomized at each test session. Each direction of each side's lower extremity was tested three times and the maximum value was recorded as the final result of each direction. Shown as (1)(2)(3)(4), a larger normalized score in the certain direction means greater dynamic stability. In addition, the scores difference between the unaffected side and the AS side of each direction can be also calculated by the Equation 5.

The normalized scores of YBT were defined as

$$\textit{The anterior direction score} = \frac{\text{The maximum value of anterior direction}}{\text{The tested extremity length}} \times 100 \qquad \text{(Equation 1)}$$

$$\textit{The posteromedial direction score} = \frac{\text{The maximum value of posteriomedial direction}}{\text{The tested extremity length}} \times 100 \qquad \text{(Equation 2)}$$

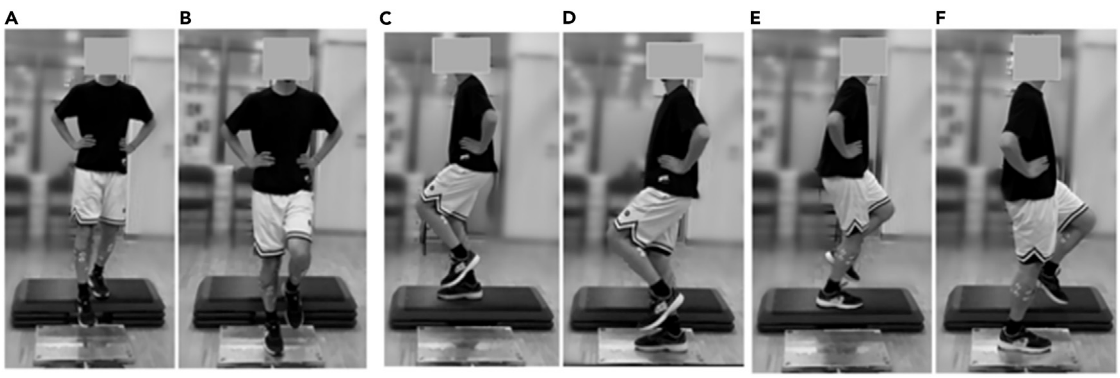
$$\textit{The posterolateral direction score} = \frac{\text{The maximum value of posteriolateral direction}}{\text{The tested extremity length}} \times 100 \quad \text{(Equation 3)}$$

$$\textit{The composite score} = \frac{\text{Anterior+Posteriomedial+Posteriolateral}}{3 \times \text{extremity length}} \times 100 \quad \text{(Equation 4)}$$

$$\textit{The scores difference between the unaffected side and the AS side of each direction}$$
$$= \frac{\text{The score of unaffected side} - \text{the score of AS side}}{(\text{The score of unaffected side+the score of AS side})/2} \quad \text{(Equation 5)}$$

TTS protocol

Participants were instructed to perform a single-leg landing test from a 20cm-high step, which was the common height of one stair in China, toward the center of a force plate in the anterior direction and a 16cm-high step[13] toward the center of a force plate in the medial and lateral directions separately. For the anterior direction (see figure below),



The movements of the single-leg landing/jumping test

The single-leg landing test (A) from a 20cm-high step toward the center of a force plate in the anterior direction (B) and standing on the tested lower limb to stabilization. The single-leg jumping test (C) from a 16cm-high step toward the center of a force plate in the medial direction (D) and standing on the tested lower limb to stabilization. The single-leg jumping test (E) from a 16cm-high step toward the center of a force plate in the lateral direction (F) and standing on the tested lower limb to stabilization.

each participant stood on the step in a unilateral-foot standing and bilateral-hand on hips posture. When the signal sounded, the participant's tested-side foot (i.e., the non-supporting foot on the step) landed on the center of the force plate, and kept stable for 15 seconds.[46] Considering the impact of vision on balance function, participants were asked to look forward during the entire testing process, without seeing their feet. For the medial (see figure below) or lateral (see figure below) direction, the participant stood with the tested-side leg on the step in a bilateral-hand on hips posture. When the signal sounded, the participant took off and jumped from the step toward the center of the force plate, which was located beside the step, and then landed on the tested single leg and stabilized for 15 seconds. Each participant completed 3 practice trials in each direction on each leg. Trials should be repeated if the participant performed a jumping after landing, touched down the force plate with the non-weight-bearing leg, hands left away from the waist[13] or the position of the participant's landing foot moved after the landing.

The Open-source software Python 3.8 was used to filter and calculate the original ground reaction force data, specifically using a second-order low-pass Butterworth filter with a cut-off frequency of 12Hz.[47] The TTS after landing was defined as the time for the vertical force component to reach and stay within 5% of the body weight.[48]

QUANTIFICATION AND STATISTICAL ANALYSIS

Data were presented as mean $\pm$ standard deviation (SD). Normality was checked using the Shapiro-Wilk test. Given that gender emerges as an independent variable and there are several dependent variables, the difference of dynamic stability between Copers and CAIs (i.e. the AS-patient type) was examined using a two-factor MANOVA. The Bonferroni analysis was used for the post hoc analysis.The significance was set at $\alpha < 0.05$. The 95% confidence interval (95%CI) for mean differences, Wilks'λ, F value, and Partial $\eta 2$ were reported. The statistical analysis was implemented by the SPSS software (Version 26, Chicago, IL).