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Research article

Effect of different ankle braces on lower extremity kinematics and kinetics following special-induced fatigue for volleyball players with functional ankle instability

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A R T I C L E I N F O

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A B S T R A C T

Background: The aim of this study is to examine the effects of different ankle braces on functional ankle instability (FAI) participants following special-induced fatigue, which will provide advice for preventing ankle sprains in volleyball game.

Methods: A total of 18 male collegiate volleyball players with FAI were recruited. The kinematics and kinetics data were acquired from the participants during single-leg drop landing using the infrared motion capture system (Mars2H, Nokov, China) and the force platform (Bertec, USA). A 2 × 2 within subjects design ANOVA was adopted to analyze the data.

Results: Whether fatigue or not, soft and semi-rigid brace reduced the ankle inversion ($P = 0.025$). Moreover, soft brace reduced the sagittal range of motion (ROM) of the ankle joint before fatigue ($P = 0.05$). In addition, the semi-rigid brace shortened the time to stability in the medial and lateral directions ($P = 0.039$) as well as the vertical directions ($P < 0.001$). The semi-rigid brace reduced the ground reaction force post-fatigue ($P = 0.001$).

Conclusion: Soft ankle brace reduced the sagittal range of motion pre-fatigue. Since volleyball requires athletes to jumping and landing repeatedly, and the ankle sagittal ROM was an important cushion during landings. Thus, soft ankle brace might result in overuse injury for lower extremity. However, the semi-rigid ankle brace increased the dynamic stability in the medial and vertical directions, and reduced the ankle inversion angle and forward ground reaction force post-fatigue. This ensured that the volleyball player's ankle was in a neutral position during landing, reducing the risk of excessive inversion caused by contact with the opposing player during spike and block.

1. Introduction

Functional Ankle Instability (FAI) is a functional deficiency disease that presents with a tendency to "giving way" during sports. It is mainly caused by incorrect movement patterns resulting in multiple ankle sprains which gradually develop. Recently, FAI is commonly seen in volleyball players [1]. An epidemiological study suggested that up to 20% of volleyball players developed into FAI since the sport involves repeated jumping and high ground reaction forces (GRF) on the joints over time [2]. All relevant studies revealed that balance control deficit and lack of designated muscle activation sequence during landing movement exist in an individual with FAI leading to degraded functional performance, which could lead to a serious decline in volleyball performance [3]. FAI might also be

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associated with ankle arthritis, which might end a volleyball career prematurely once it develops [4]. Furthermore, FAI significantly increased the risk of recurrent ankle sprain, with a high incidence rate of 40–50% [1], which also could lead to reduce movement confidence due to the fear of re-injury [5].

Based on this evidence, rare studies have aimed to understand the underlying mechanisms contributing to recurrent injury. Notably, ankle sprains in FAI patients often occurred in landing [6], especially in single-leg landing (85%) [7]. Existing research has further highlighted that FAI patients often exhibited a smaller sagittal range of motion (ROM) [8] and greater ankle inversion [7]. This landing strategy has been prone to cause recurrent ankle sprain, accounting for nearly 85% of all injuries across all sports disciplines and levels of competition [9]. Furthermore, an increase in GRF, time to stability (TTS), and a decrease in time to peak GRF (TTP) have been observed in athletes with FAI [10,11]. There was some evidence that the above motion patterns of FAI might cause imbalance and excessive load rate of their ankle, which also increased the risk of recurrent ankle sprain [11].

An epidemiological study found that up to 71% of ankle injuries occurred in the middle and late stages of the game [12], which might explain that fatigue also was a risk factor to cause recurrent ankle sprain of FAI. Fatigue has been found to decrease in ankle sagittal ROM and increase in frontal TTS during landing [13]. In addition, a number of researchers have observed that fatigue increases the vertical GRF of FAI patients to three to six times their individual body weight when they perform jump-landing [1]. The above changes would further increase the risk of ankle sprains [8]. Additionally, sports fatigue is common in volleyball training and competition [14]. This may be the reason for the high rate of recurrent sprain in volleyball players with FAI.

Accordingly, considerable studies have investigated the effectiveness of protective equipment in preventing ankle sprains in FAI patients. Ankle bracing was the most common method of preventing ankle sprains currently and could reduce the rate of repetitive sprains in volleyball players with FAI [15]. Compared with no ankle brace, Lace-up ankle brace could reduce the incidence of ankle sprains of basketball athletes from 1.41 to 0.47 injuries per 1000 AEs [16]. Semi-rigid ankle brace reduced the incidence of ankle sprains in volleyball players from 0.98 to 0.07 per 1000 AEs [15]. Notably, the kinematic and kinetic mechanisms of the two types of ankle brace may be different. Existing research has suggested that a semi-rigid ankle brace successfully lowers the risk of ankle sprain by restricting ankle inversion, while a lace-up ankle brace has been related to decreased vertical GRF and increased ankle sagittal ROM [17]. However, existing research has only investigated the prevention mechanism of ankle brace at the non-fatigue state. Besides, research of the effects of ankle bracing on kinematics and kinetics after fatigue is still rare, and the results remain unclear, thus hindering the understanding of the protective effect of ankle brace in true match situation.

The purpose of this study is to determine the effect of ankle braces on the kinematics and kinetics of FAI before and after volleyball special-induced fatigue. The hypothesis was that (1) Fatigue and ankle braces affect the motion strategy of the ankle in sagittal and frontal planes. (2) Since fatigue mainly reduces the frontal dynamic stability of the ankle (TTS), and previous studies have pointed out that semi-rigid ankle braces mainly provide support for the ankle frontal plane. Therefore, we hypothesized that wearing a semi-rigid ankle brace increases the dynamic stability and reduces the medial and lateral forces of the ankle joint at fatigue state.

2. Methods

2.1. Participants

The participants recruited in this study were male collegiate volleyball players with FAI. FAI patients were required to meet the inclusion criteria in Table 1 [18]. A priori power analysis was conducted using G*Power 3.1.9.2 [19] to identify the appropriate sample size for a 2 × 3 (fatigue × brace condition) repeated measures ANOVA. It was determined that 17 participated would be needed to achieve 80% power at a statistical significance criterion of 0.05, with a large effect size (Cohen's $f = 0.4$). Additional participants (6 person) were collected in case of potential failure to complete the tasks. Finally, a total of 23 FAI patients were recruited in accordance with the inclusion criteria. However, three of them had a history of lower limb injury three months before the experiment. Two people were excluded since they had the Beighton score less than 4. Consequently, 18 participants were included. Information of them was shown in Table 2. The studies involving human participants were reviewed and approved by the Science and Ethics Committee of

Table 1
FAI inclusion criteria.

Inclusion criteria	Exclusion criteria
1 Initial ankle sprain for over 12 months ago, and the sprain resulted in either at least three days of immobilization or non-weight bearing or the use of a protective device. 2. Recurrent ankle sprain (at least two sprains in the same ankle), giving way (more than twice in the recent six months), or feeling of instability in the previously injured ankle during activities of daily living. 3. Negative anterior drawer test and talar tilt test. 4. Cumberland ankle instability tool (CAIT) score lower than 24.	1. Participants had Godin Leisure Time Physical Activity score lower than 10. 2. Fracture requiring realignment or musculoskeletal surgery in either lower extremity. 3. Acute trauma in either lower extremity in the previous 3 months, or time since the last sprain of less than 3 months. 4. Positive talar tilt test or anterior drawer test findings. 5. Osteoarthritis in either lower extremity, head trauma, inner ear disease, muscular dystrophy, or other conditions that could affect normal gait. 6. General joint hypermobility (Beighton and Horan score equal to or higher than 4).

Taiyuan University of Technology, China. The participants provided their written informed consent to participate in this study.

2.2. Procedures

2.2.1. Experiment preparation

The participants wore the test shoes and shorts uniformly provided by the experimenters. Firstly, the maximal vertical jump height (Vert_{max}) of the respective participant was assessed. A total of 29 reflective markers were placed in accordance with Helen Hayes marker-set. The locations of the reflective marker points were reference to a previous study [20]. The respective locations were the top of the head, anterior head point, posterior head point, left/right acromion, left/right lateral epicondyle of the humerus, midpoint of the line connecting the left/right ulnar styloid process with the radial styloid process, right scapular point, left/right anterior superior iliac spine, midpoint of the spinous processes of the 4th and 5th lumbar vertebrae, left/right anterior thigh, left/right lateral femoral condyle, left/right medial femoral condyle, left/right tibial trochanter, left/right external fibular ankle, left/right internal tibial ankle, left/right midpoint of the second and third metatarsals, and left/right foot. In this study, two types of ankle braces were selected, i.e., semi-rigid ankle brace and soft ankle brace. Semi-rigid ankle brace (active T2, Cramer, USA) was defined as using semi-rigid material to support both sides of the ankle joint (Fig. 1-a). Soft ankle brace (195, McDavid, USA) was defined as a type of ankle brace that wraps the ankle joint with an elastic material (Fig. 1-b) [21,22]. The infrared light spot motion capture system (Mars2H, Nokov, China) was used to obtain the marker point motion data at a collection frequency of 200 Hz. The three-dimensional force platform (Bertec, USA) was used to connect the infrared lens through the synchronous acquisition card to collect the GRF data synchronously. The sampling frequency was 1000 Hz.

2.2.2. Testing protocol

First, all participants had performed 10-min warm-up activities before test, which comprised of full-body dynamic stretching, directional running, vertical take-off, and stop-jumping. Subsequently, the experimenters demonstrated the testing maneuver of this study, i.e., single-leg landing. Participants could practice this maneuver, and the experimenters provided oral feedback throughout the independent practice. In the formal experiment, the participants wore semi-rigid and soft ankle braces to complete single-leg landing. A random number generator was adopted to determine the sequence of two ankle braces to avoid bias.

In the single-leg landing test, the participants placed their hands on the hip joints to reduce the effect of the swing arm. The involved leg supported the whole body, and the toes were pointed forward. When participants heard the start signal, they fell from the platform with a height of 35 cm without vertical initial velocity while maintaining upright for 5 s after landing to calculate TTS (Fig. 2). Participants were necessary to completing three successful trials in the respective situation for analysis.

2.3. Fatigue protocol

Compared with the non-specific fatigue protocol, the specific fatigue protocol used in this study can simulate the fatigue caused by volleyball specific actions, such as block, stride, and jump, and its results are more relevant to the actual sports. The fatigue protocol consisted of 3 stations, which were **volleyball specific agility test**, **lunge digging**, and **continuous blocking jumping**. Among them, the **volleyball-specific agility test** consisted of forward sprint, diagonal backward step, and lateral slide step in the order shown in Fig. 3-a. **Lunge digging** was defined as the participants' legs alternately striding forward and retracting to the starting point, such that the knee of striding leg close to 90° and the straight trunk were required. The respective leg strode forward five times at a frequency of 0.5 Hz. The distance of lunges between the starting and ending points equaled to the subject's lower limb length (the length from the trochanter to the ankle inner side). The experimenters taped the starting point and the end point of lunges on the floor and controlled the participant's movement rate by metronome. This maneuver was mainly adopted to simulate volleyball players and adjust their body positions to complete digging by striding during game and training (Fig. 3-b). During **continuous blocking jumping**, participants was required to complete 10 consecutive jumping with blocking action. Before take-off, the participants were asked to prepare for the jump with both arms bent on both sides of the body. After take-off, both arms were quickly extended straight upwards, with five fingers spread out in front, and ensured that both hands touched the mark on the wall. The marker height equaled to the standing touch height plus 50% of the previously measured Vert_{max} (Fig. 3-c).

The fatigue protocol was explained and demonstrated to participants prior to the first test. Afterwards, participants were asked to practice the fatigue protocol once and a baseline time was established. Fatigue was determined if the single cycle time was 50% longer than the baseline test time, while the heart rate was greater than 85% of the maximum heart rate and the rating of perceived exertion (RPE) was more than 17. After reaching the fatigue state, the subjects were immediately transferred to the test area and wore semi-rigid ankle braces and soft ankle braces to complete the single-leg landing. The movement requirements were consistent with those in the pre-fatigue test.

Table 2
The demographics of participants (mean ± SD).

Age (year)	Height (cm)	Mass (kg)	Training experience (year)	CAIT score	Beighton score
19.9 ± 1.6	182.2 ± 6.6	70.8 ± 8.3	6.7 ± 1.6	18.6 ± 2.6	7.4 ± 1.4

CAIT： Cumberland ankle instability tool， CAIT.

a semi-rigid ankle brace b lace-up ankle brace

Fig. 1. Total type of ankle brace in this study.

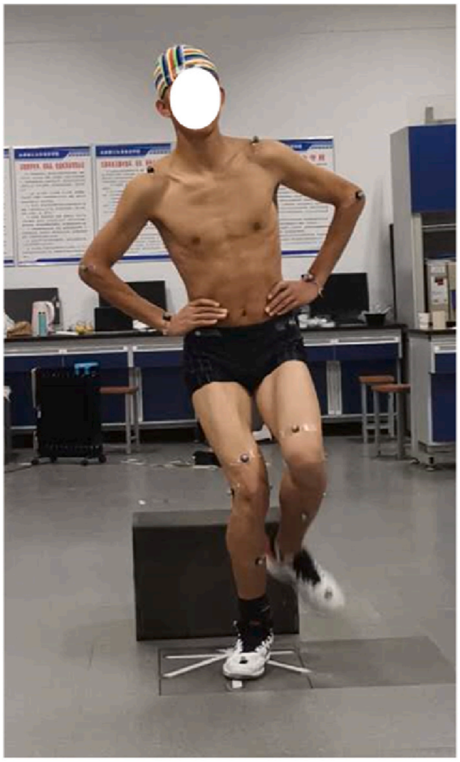

Fig. 2. Testing maneuvers.

2.4. Data processing

The Marker motion coordinates and ground reaction force data were processed using Cortex-64 2.6.2 (Motion Analysis Inc, USA) software. 3D coordinates of all landmarks are smoothed by second-order Butterworth low-pass filter (cut-off frequency 13 Hz). A multi-rigid body model of the human joint was established based on the reflective marker points. Ankle joint centers were determined as the midpoint between the medial and lateral malleoli, with the x-axis as the medial-lateral axis (flexion-extension), the z-axis as the anterior-posterior axis (abduction-adduction), and the z-axis as the distal-proximal/longitudinal axis (internal-external rotation). Joint motions were then quantified using Euler's equations, with a rotational sequence of $Z\,Y'\,X''$. ROM was obtained by the maximum value of joint motion minus the minimum value. The kinetic data were low-pass filtered by 50 Hz (MS3D7.0, Motion Soft, Inc, USA). Subsequently, the GRF data was normalized as the multiple of body mass (N). TTP was calculated from the time of initial contact (IC) to the peak GRF. The sequential estimation method was used to calculate the time to stabilization (TTS) during landing. The algorithm was performed by calculating the cumulative average of all ground reaction force data points during single-leg landing, adding one data point in turn. Next, the cumulative average value was compared with the overall ground reaction force average value. The participants were considered to have reached a stable state if the cumulative mean reached within ±0.25 SDs of the overall mean, and

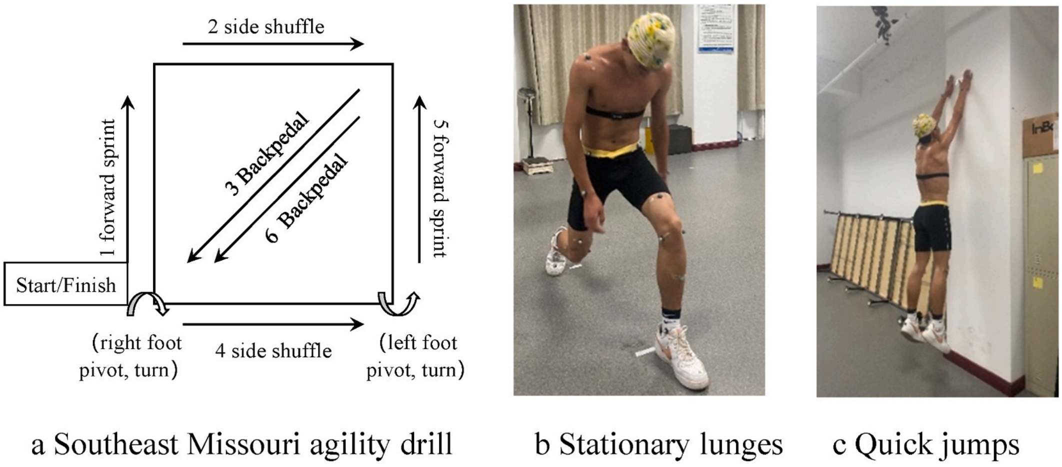

Fig. 3. Fatigue protocol.

the time of cumulative mean reached within ±0.25 SDs of the overall mean was TTS. The movement cycle was defined as from IC to maximum ankle dorsiflexion angle during landing.

2.5. Statistical analysis

First, the main effects of all dependent variables were determined using Two-way repeated-measures ANOVA (fatigue × brace condition). Based on the assumption that there was a significant interaction between factors, Post hoc pairwise comparisons and one-way ANOVA (LSD procedure) were conducted to verify where there were differences. The level of significant difference was $P < 0.05$. All statistical analyses were completed in SPSS 22.0.

3. Results

3.1. Fatigue induced

Volleyball players spent 15.6 ± 8.5 min to complete the fatigue protocol for this study. The baseline test time was 46.2 ± 12.1 s, and the final time was 74.9 ± 12.3 s. The average heart rate before fatigue was 122.1 ± 9.2 times/min, the average heart rate during fatigue induction was 157.3 ± 8.3 times/min, the highest heart rate was 188.0 ± 10.8 times/min (Fig. 4). Furthermore, The RPE reached 17.9 ± 0.9 after fatigue.

As can be seen above, participants took 50% longer to complete a single cycle than the baseline test time, while the heart rate was greater than 85% of the maximum heart rate and the rating of perceived exertion (RPE) was more than 17. Therefore, the subjects were considered to have reached fatigue state after the fatigue protocol of this study.

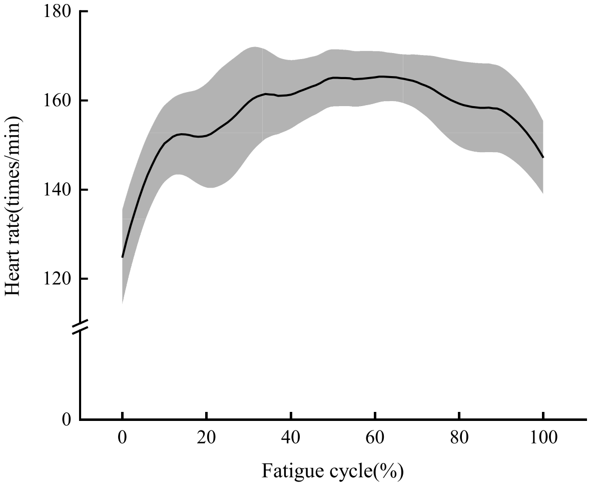

Fig. 4. The change of heart rate for fatigue protocols.

3.2. Ankle inversion angle

The participants showed a 26.9% higher peak ankle inversion angle compared with pre-fatigue ($P = 0.049$). Moreover, the semi-rigid achieved a lower IC ankle inversion angle before fatigue (93.9% vs. 51.6%, $P = 0.026$), as well as a lower peak ankle inversion angle (84.2% vs. 44.8%, $P = 0.025$). The result indicated that the semi-rigid ankle brace displayed a longer limitation time than the lace-up ankle brace (100% vs. 82%, Fig. 5, Table 3).

3.3. Ankle sagittal ROM

Significant interactive effects were found for ankle sagittal ROM ($F_{[2,114]} = 3.539$, $P = 0.032$). The result of the post hoc *t*-test indicated that lace-up ankle brace displayed lower ankle sagittal ROM before fatigue ($P = 0.05$, Fig. 6).

3.4. GRF, TTP, and TTS

The participants demonstrated higher TTS in the internal-external direction (pre-fatigue = 3.4s ± 0.3s, post-fatigue = 3.6s ± 0.3s, $P = 0.014$) and higher TTS in the vertical direction (pre-fatigue = 3.6s ± 0.3s, post-fatigue = 3.9s ± 0.3s, $P = 0.011$). The semi-rigid ankle brace reduced the anterior-posterior GRF by 52.4% ($P = 0.001$) after fatigue. Regardless of fatigue, semi-rigid ankle brace decreased the TTS in the internal-external directions (10.7% pre-fatigue and 11.3% post-fatigue, $P = 0.039$) and the vertical direction (8.6% pre-fatigue and 14.0% post-fatigue, $P < 0.001$, Fig. 7).

4. Discussion

Existing research had only investigated the prevention mechanism of ankle brace at the non-fatigue state. Changes in ankle kinesthesia and muscle strength due to fatigue were likely to alter the protective mechanism of the ankle brace. Therefore, this study aims to determine the effect of ankle brace on the 3D kinematics and kinetics in FAI patients before and after fatigue. The results of this study supported the hypothesis, i.e., (1) Fatigue and ankle braces affect the motion strategy of the ankle in sagittal and frontal planes. (2) Wearing a semi-rigid ankle brace increases the dynamic stability and reduces the medial and lateral forces of the ankle joint at fatigue state.

4.1. Comparison of different ankle braces

The primary mechanism of ankle sprains was excessive ankle inversion, which was consistent with previous studies. Dubin et al. [23] had suggested that ankle inversion up to 30°–45° can cause ankle lateral ligament injury. Moreover, some studies had suggested that greater ankle inversion increased the displacement of the talus. The stresses increased in the lateral and medial parts of the intercondylar line of the lateral malleolus, the lower fibula, and the talus wound [12]. Frequent ankle sprains might damage the lateral ankle ligaments [12]. Therefore, the overall goal of an ankle brace employed in athletics was to reduce ankle inversion. The result of this study indicated that the ankle inversion angle was significantly reduced under the semi-rigid and lace-up ankle brace conditions. We also observed that the ankle inversion angle was significantly lower in the semi-rigid ankle brace compared with lace-up ankle

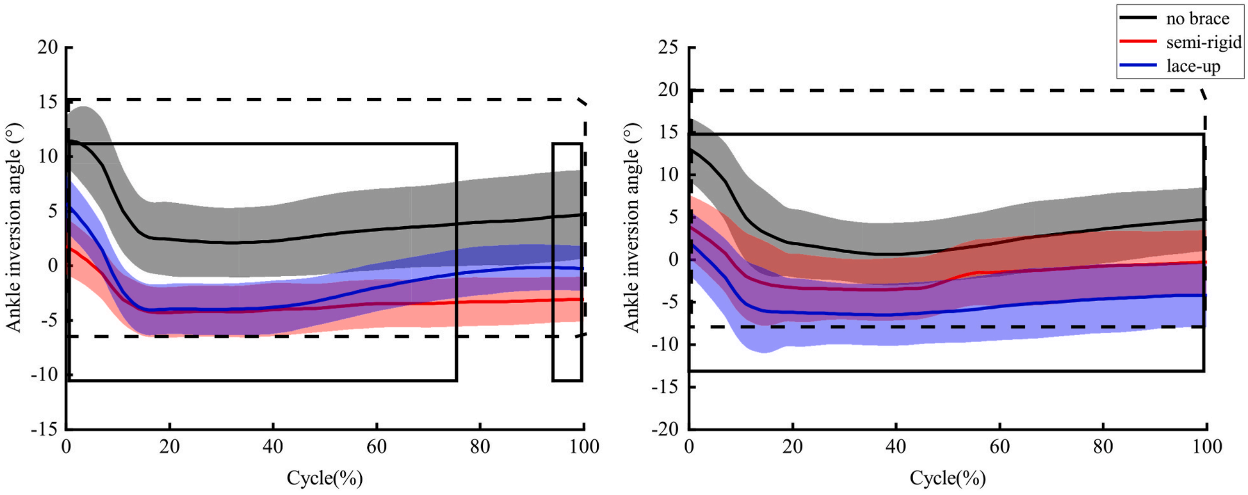

Fig. 5. Influence trend of ankle brace on ankle joint biomechanics before and after fatigue. The figure from left to right showed the results before and after fatigue. The virtual frame depicted that the effect of the semi-rigid ankle brace was significant, and the real frame showed that the effect of the lace-up ankle brace was significant (P < 0.05).

Table 3
The effect of different ankle braces on the ankle inversion angle before and after fatigue.

	Pre-fatigue			Post-fatigue		
	No brace	Semi-rigid	Lace-up	No brace	Semi-rigid	Lace-up
IC ankle inversion angle (°)	10.7 ± 5.8	0.7 ± 5.3[a,c]	5.2 ± 7.3[b]	11.8 ± 6.9	4.0 ± 6.5[a]	1.0 ± 7.8[b]
Peak ankle inversion angle (°)	12.5 ± 6.7*	2.0 ± 5.6[a,c]	6.9 ± 7.0[b]	15.8 ± 8.9	5.8 ± 8.6[a]	3.5 ± 6.9[b]

*indicates significant difference between before and after fatigue.

[a] indicates significant difference between a semi-rigid ankle brace and no brace ($P < 0.05$).

[b] indicates a significant difference between a lace-up ankle brace and no brace ($P < 0.05$).

[c] indicates a significant difference between a semi-rigid ankle brace and a lace-up ankle brace ($P < 0.05$).

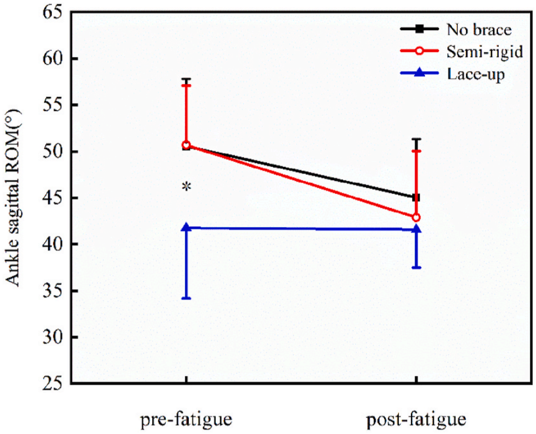

Fig. 6. Influence of ankle brace on ankle sagittal ROM before and after fatigue.

brace (initial contact: 10.1° vs. 5.5°, peak ankle dorsiflexion: 10.5° vs. 5.6°). The differences might be correlated with the different materials of ankle braces. To be specific, the semi-rigid ankle was primarily supported by the EVA plastic splint, whereas the lace-up ankle brace was pulled by nylon materials [21]. It was noteworthy that the former had strong supporting strength for the ankle joint, such that it exhibited a greater ability to limit ankle inversion. Moreover, a semi-rigid ankle brace had a longer limitation time than a lace-up ankle brace (100% vs. 82%). It was speculated that the above result might be correlated with the different mechanisms to limit inversion between semi-rigid and lace-up ankle braces. In general, the semi-rigid ankle brace mainly provided mechanical support (external torque) for the ankle joint, while the lace-up ankle brace reduced the ankle inversion angle by promoting the activation of the peroneus longus. The peroneus longus muscle was a primary dynamic defense mechanism against the inversion moments (internal torque) [24]. It was rather remarkable that the ankle would undergo plantar flexion to dorsiflexion in the latter phase of the landing, and the peroneus longus was passively elongated. Existing research had suggested that muscle strength decreased considerably when it was stretched [25], such that the lace-up ankle had no ability to limit ankle inversion at the later phase of the landing.

In addition, smaller sagittal ROM of the ankle joint was also a risk factor for ankle sprain. This was because the function of the sagittal motion was to energy dissipation in the landing task [26]. Accordingly, the restriction of the ankle motion might hamper the ability of the ankle joint to attenuate GRF. As a result, the load and stress around the ankle joint increased significantly, which increased the risk of ankle sprain. Moreover, the bi-joint muscles of the ankle joint might continuously upload the impact force to the knee joint, and the extensor of the knee joint would be activated to complete energy dissipation. The musculature of the trunk might also need to be used till the person's mass has stabilized [26]. However, the increase in energy absorption of proximal joints might lead to a greater risk of injury, especially soft tissue injury [27]. Ankle sagittal ROM was considerably reduced by 17.4% with the application of the lace-up ankle brace, which was consistent with previous studies. Smith et al. [28] aimed to explain this result from the perspective of muscle activation. They suggested that a lace-up ankle brace inhibited the activation of the gastrocnemius, which was the main plantar flexor of the ankle. From the perspective of injury prevention, the reduction in ankle sagittal ROM would damage the absorb ability of ankle and increase the risk of lower extremity injuries [6]. It therefore was suggested that athletes should pay attention to the knee injury when wearing lace-up ankle braces. Furthermore, strength training could be conducted to prevent knee joint injury caused by compensatory strategy if necessary.

Excessive GRF might increase the load and stress of the lateral ligament of ankle joint, such that it was also considered a risk factor for ankle sprain. It was important to note that the semi-rigid ankle joint reduced the GRF in the anterior-posterior directions by 52.4% after fatigue. Numerous people considered that the reason for this was that semi-rigid ankle brace improved the afferent feedback of skin receptors and increased the ankle proprioception of FAI patients [29]. This mechanism made patients adjusted the ankle position to absorb the GRF better, thus facilitating the prevention of ankle sprains for FAI patients [30].

Functional ankle instability amplified the decreased degree of dynamic postural stability caused by fatigue due to inadequate

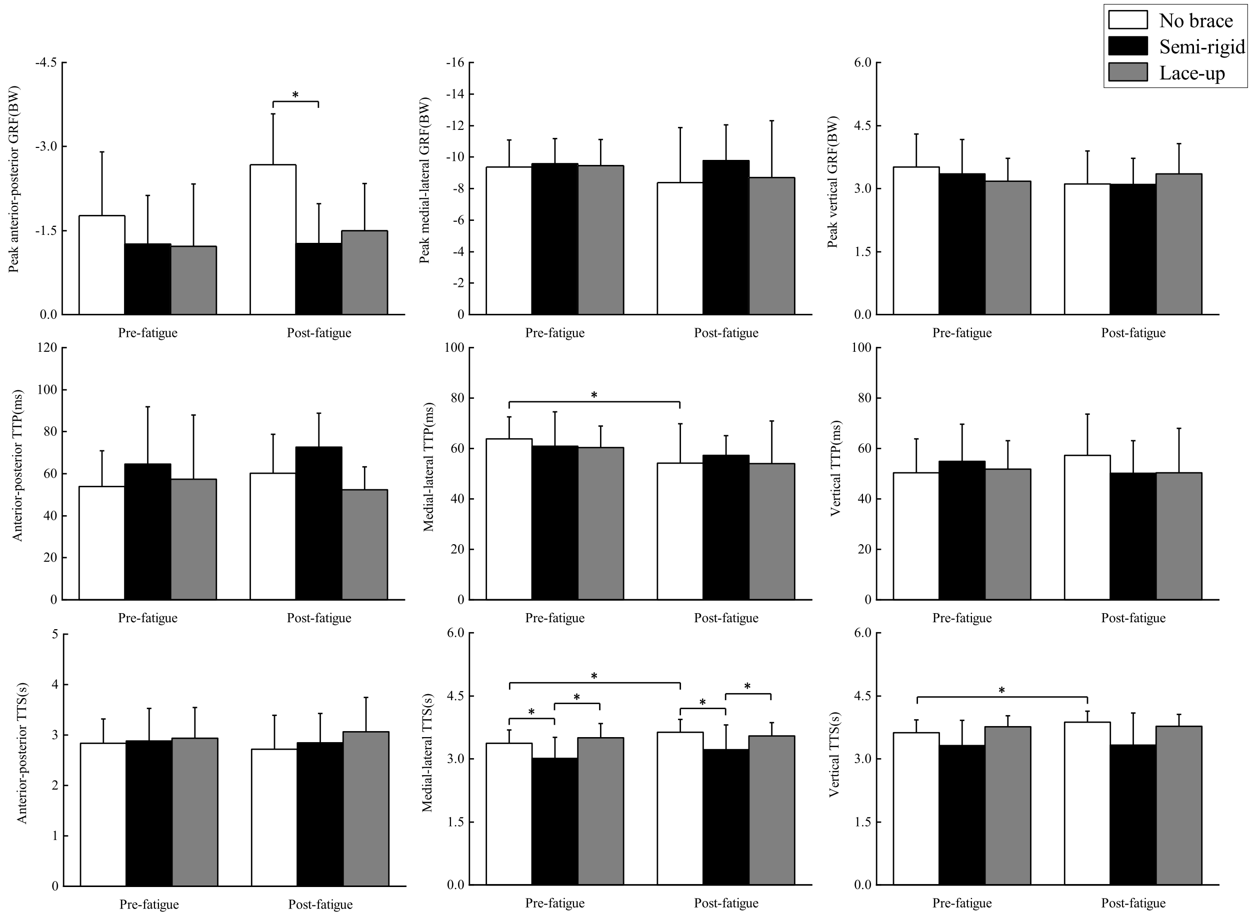

Fig. 7. Effect of ankle brace on GRF, TTP and TTS before and after fatigue.

muscle control and impaired proprioception, which might increase the risk of repetitive ankle sprains. TTS was an important indicator to assess dynamic postural stability during single-leg landing. In general, longer TTS indicated poorer dynamic postural control [31]. In this study, a semi-rigid ankle brace reduced the TTS in the medial directions (10.7%–11.3%), while a lace-up ankle brace did not affect TTS. Notably, the semi-rigid ankle brace was made from EVA plastic plates and hinges. For its design, the frontal ROM of the ankle was significantly reduced by semi-rigid materials, such that it increased the dynamic stability in the medial-lateral directions [31]. Another possible reason was that the semi-rigid ankle brace had a wider coverage area than the lace-up ankle brace, such that it would produce a stronger stimulation on the peripheral receptors of the ankle, thus increasing the stability [32].

4.2. Limitation

This study also had the following research limitations. A volleyball special fatigue protocol was adopted in this study. However, it was a short-term fatigue protocol. It was known that a volleyball game usually lasts more than 1 h. Thus, it is suggested that the effect of ankle brace after long-term fatigue can be considered in future studies. In addition, we must acknowledge that there were many different types of ankle brace, such as rigid, compression ankle brace etc, and only the two most used types were included in this study. A comprehensive evaluation of all types of ankle brace would be carried out in the future. Finally, the study was a cross-sectional survey, and it was impossible to infer the causal-and-effect relationship.

5. Conclusion

Soft ankle brace reduced the ankle inversion of volleyball players with FAI. This ensured that the volleyball player's ankle was in a neutral position during landing, reducing the risk of excessive inversion caused by contact with the opposing player during spike and block. It was worth nothing that the soft ankle brace limited the sagittal range of motion pre-fatigue. Since volleyball requires athletes to jumping and landing repeatedly, and the ankle sagittal ROM was an important cushion during landings. Thus, soft ankle brace might result in overuse injury for lower extremity. Moreover, the semi-rigid ankle brace increased the dynamic stability in the medial and vertical directions, and semi-rigid ankle brace reduced the forward ground reaction force post-fatigue. The above results reveal that the protection mechanism of the semi-rigid ankle brace should be more comprehensive. This study suggests that the semi-rigid ankle brace is more effective in lowering the risk of secondary sprains for volleyball players with FAI.

Ethical approval

All research was approved by the university's institutional review board, the approval code was TYUT-202304010. All subjects read and signed an informed consent document prior to participation and agreed to publish their images with the article.

Ethical statement

The research performed in this investigation was approved by the university's institutional review board, the approval code was TYUT-202304010. All subjects read and signed an informed consent document prior to participation.

Author contribution statement

Zeyi Zhang: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Meizhen Zhang: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

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