Postural stability and lower leg muscle activity during a diagonal single-leg landing differs in male collegiate soccer players with and without functional ankle instability

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Abstract The purpose of this study was to investigate postural stability and lower leg muscular activity in male collegiate soccer players with functional ankle instability (FAI), during a diagonal landing. Twenty-two male collegiate soccer players were divided into an FAI group (n = 11) and healthy control group (n = 11). Muscle reaction times for sudden ankle inversion were measured to evaluate neuromuscular control in the peroneus longus (PL), peroneus brevis (PB), tibialis anterior (TA), gastrocnemius lateral head (GL), and gastrocnemius medial head (GM). Time to anteroposterior stabilization (TTSAP), time to mediolateral stabilization (TTSML), and activity of these muscles during a diagonal single-leg landing was measured. Reaction times in the peroneus muscles were delayed in the FAI group, compared to the control group (PL: *P < 0.01, PB: *P = 0.02). TTSML was increased in the FAI group, compared to the control group (P = 0.02). Muscular activity of PL, PB, and TA were reduced in the FAI group, compared to controls, during a diagonal single-leg landing (PL: *P < 0.05, from 87 ms pre-initial contact [pre-IC] to 108 ms post-initial contact [post-IC], PB: *P < 0.05, from 180 ms pre-IC to 123 ms post-IC, TA: *P < 0.05, from 65 ms to 203 ms post-IC). Male collegiate soccer players with FAI had increased TTSML and reduced muscle activity in PL, PB, and TA during diagonal single-leg landing. It is important for clinicians to assess the postural stability and function of the lower leg muscle activity, during rehabilitation after ankle sprains.

Keywords : functional ankle instability, time to stabilization, diagonal landing, muscle activity, collegiate soccer player

Introduction

Ankle sprain is one of the most common injuries acquired in collegiate sports9). This is especially true in soccer, where the repetitive kicking motion, constant change of direction, and frequent landing, leaves the ankle joint particularly susceptible to injury. Ankle sprains account for approximately 23% of total injuries acquired in collegiate soccer9). The lateral ligaments of the ankle, such as the anterior talofibular and calcaneofibular, are susceptible to injury and account for over 70% of all ankle ligament sprains9). Additionally, after acute ankle sprain, 17.5% of players with ankle injuries missed more than 6 weeks of training9). Furthermore, ankle sprains are known to be an injury type with one of the highest risks of recurrence in soccer9).

Functional ankle instability (FAI) often develops because of ankle sprain. One of the major problems of FAI is the residual symptoms, such as the sensation of “giving way,” chronic pain, and feelings of instability in the ankle9). It has reported that a patient with FAI may have functional deficits, such as delayed peroneus reaction time9), postural control deficit9), and positional sensing error at the ankle joint9). Additionally, previous studies suggested that patients with FAI have reduced peroneus longus activity10,11), and increased inversion of the ankle joint during a landing11-13). The inverted ankle joint may result in a recurrent ankle sprain.

Functional deficit of the peroneus muscles, whose major action is eversion of the ankle, is considered the reason why individuals with FAI could not maintain proper ankle position during landing. The peroneus muscles are the best protector against ankle inversion during foot strike40), and are important in stabilizing the ankle against lateral perturbation. However, Konradsen et al.13) reported that muscle reaction time was too slow to protect the ankle in case of sudden inversion occurring at the time of initial contact. Therefore, pre-activation of the peroneus muscle...
during landing may be more important for preventing an ankle inversion sprain due to an inverted ankle position. Resultant tissue trauma from an ankle sprain could decrease the amplitude of sensory traffic (from capsuloligamentous and musculotendinous mechanoreceptors in the maintenance of joint sensation) at low levels of force. Unfortunately, the decrease in afferent traffic persisted in FAI individuals \(^{16,17}\). Palmieri-Smith et al. \(^{18}\) suggested that one of the plausible mechanisms leading to reduced peroneus muscle activity was the altered afferent traffic influencing the γ loop system. Consequently, measurement of peroneus muscle activity during single-leg landing is important for evaluation of FAI individuals.

Time to stabilization (TTS), the time required for an individual to return to single-leg stability after landing, has been used to evaluate dynamic postural stability. The landing test was considered an effective evaluation method for soccer players with FAI, as one of the most common causes of non-contact ankle sprain in soccer is landing \(^3\). Previous studies reported that individuals with an unstable ankle had higher TTS than that observed in individuals with stable ankles, when performing a forward landing \(^{19}\) and lateral landing \(^{20}\). On the contrary, during a diagonal landing, no significant difference in TTS was observed between individuals with and without FAI \(^{15}\). The study investigated the fatigue effects for sensorimotor control in FAI individuals recruited from various sports, such as basketball and soccer. However, Matsuda et al. \(^22\) reported that balance ability to a stable one-legged stance in soccer players was higher than that in the basketball players. The difference in balance ability may influence the result of this study. The lateral and rotational load on the ankle joint during a diagonal landing was considered significantly higher than that of a forward and lateral landing. To our knowledge, measurement of TTS using a diagonal landing has not been fully investigated. Thus, it is not yet clear if soccer players with FAI have an increased TTS during a diagonal landing.

Non-contact ankle sprains were associated with incorrect foot positioning at landing in soccer players \(^{23}\). In addition, some situations in soccer require not only a forward and lateral landing, but also a diagonal landing. Therefore, a diagonal landing test should be conducted to evaluate soccer players with FAI. The purpose of this study was to more clearly characterize postural stability and muscle activity in collegiate soccer players with FAI, using the diagonal single-leg landing stabilization test. We hypothesized that TTS would increase and muscle activity in peroneus muscles would decrease during diagonal single-leg landing in male collegiate soccer players with FAI.

**Materials and Methods**

**Participants**

Twenty-two male collegiate soccer players (age: 18.9 ± 0.9 years; height: 169.6 ± 5.7 cm, body mass: 63.3 ± 5.9 kg, body fat: 11.3 ± 2.2 %), who had trained six or more times per week, were recruited for our study from our university soccer club, part of the Division 1 Japan University Football Association. The players were classified into those with FAI (FAI group, n = 11), and those with no history of ankle sprain (control group, n = 11). The inclusion criteria for the FAI group included the following: (a) history of at least two significant ankle sprains, occurring at least twelve months prior to study enrollment, that resulted in at least one interrupted day of desired physical activity, and (b) history of the previously injured ankle joint “giving way,” and/or recurrent sprain, and/or “feelings of instability.” The “feelings of instability” was defined using a Japanese version of the Cumberland Ankle Instability Tool (CAIT-J) score of less than or equal to 25 points \(^{24}\). The inclusion criteria for the control group included; no history of ankle sprain and a CAIT-J score of 30 points. The exclusion criteria were as follows: (a) history of surgery on musculoskeletal structures, and/or fracture, requiring realignment of either lower limb; (b) acute injury to the musculoskeletal structures of another lower extremity joint, in the previous three months, which impacted joint integrity and function, resulting in at least one day of interrupted desired physical activity; and (c) daily performance of balance training. This final criterion is based on the International Ankle Consortium \(^{25}\). Performance of balance training was included in the exclusion criteria as soccer players with FAI improved their postural stability after ankle disk training \(^{26}\). For individuals who qualified for the FAI group, the injured ankle with the lowest CAIT-J score was designated for testing. In cases when both ankles had the same score, participants were asked to select the ankle that they used more frequently when both ankles had the same score, participants were asked to select the ankle that they used more frequently for single-leg landing in soccer training. All participants were informed of the purpose of this study and provided written informed consent. The study was approved by the Research Ethics Committee at the University of Tsukuba Graduate School of Comprehensive Human Sciences [No. 27-155].

**Experimental procedure**

Surface electromyography (sEMG) electrodes (SX230-1000, inter-electrode distance 2 cm, Biometrics, UK) were attached parallel to the peroneus longus (PL), peroneus brevis (PB), tibialis anterior (TA), gastrocnemius lateralis (GL), and gastrocnemius medialis (GM), muscle fiber direction. Proper electrode placement was verified by observing the sEMG signal on a computer monitor during ankle eversion, dorsiflexion, and plantar flexion. A ground electrode was placed on the ulnar styloid process. Muscle reaction time was recorded during a sudden ankle inversion test. Subsequently, a 3 second (s) maximum voluntary isometric contraction (MVC) was recorded for each muscle, and repeated in triplicate. MVC for the PL and PB muscles were measured with the participant in an
elongated sitting position, performing eversion associated to plantar flexion against manual resistance. The TA muscle was assessed also in an elongated sitting position, with the participant performing dorsiflexion associated with inversion against manual resistance. The GL and GM muscles were assessed with the participant in a standing position, performing plantar flexion comparable to a “calf raise,” while pressing the shoulder from above. Lastly, ground reaction forces (GRFs) and muscle activity were recorded during a diagonal single-leg drop landing stabilization test.

Sudden ankle inversion test
The sudden ankle inversion test was performed using a custom-built trap door. The device tilted to 25° and stimulated an inversion of the ankle. The participants were asked to look straight ahead and assume a relaxed standing position on the trap door, with their second toe and calcaneal tuberosity in line, whilst maintaining an even distribution of weight between both legs. The examiner triggered the trap door from behind the participants, to prevent them from predicting the time, and side at which the trap door was triggered. Each trial was randomly performed on either side, and repeated to ensure three trials on the test side.

Diagonal single-leg drop landing stabilization test
The participants were instructed to perform a single-leg landing stabilization test. They stood barefoot on one leg on a 30 cm high box, which was positioned 5 cm posterior to the force plate. They then hopped down diagonally (45° anterolateral), landing on the same leg on the center of the force plate. They then stabilized as quickly as possible after landing, and balanced for 20 seconds with hands on their hips. The participants performed a few trial runs to feel comfortable with the task. Three successful landings were recorded. A landing was considered unsuccessful if a participant displaced their standing leg, touched the floor with their contralateral leg, or disengaged their hands from their hips.

Data collection and processing
Surface electromyography data
Muscle activities were recorded using sEMG for PL, PB, TA, GL, and GM muscles. The sEMG signals were converted from A/D at a sampling signal of 1,000 Hz, amplified with a 1,000-fold gain, and bandpass filtered at 20 Hz (low) and 400 Hz (high). These signals were analyzed using the TRIAS data importing and analysis system (Biometrics, UK).

For calculation of muscle reaction time, the starting point of the trap door tilt was recorded as a digital signal. The sEMG signals were rectified and filtered with a low-pass at 25 Hz, based on a previous study. The muscle reaction time was defined as the time starting the trap door tilt, to the time when the activity passed the threshold of at least three standard deviations (SDs) from the average of the signal at a relaxed standing position. The mean of three test-side trials was calculated for statistical analysis.

During a single-leg landing test, the sEMG recording was synchronized with the GRFs obtained by the force plate. The initial contact (IC) was identified as the time when the vertical GRF was first above 10 N. The period from 300 milliseconds (ms) pre-IC to 300 ms post-IC was analyzed. The sEMG signals during the MVC were filtered by a low-pass Butterworth filter with a cutoff frequency of 5 Hz after full-wave rectification. The mean of major activity for an interval of 1 s during each muscle’s MVC was calculated and averaged as the filtered MVC. For assessment of the muscle activity using a linear envelope, each sEMG signal from 300 ms pre-IC to 300 ms post-IC was also filtered by a low-pass Butterworth filter with a cutoff frequency of 5 Hz after full-wave rectification, and then normalized to the filtered MVC of each muscle (%MVC). sEMG signals from three successful drop landings were averaged for statistical analysis.

Ground reaction forces
The ground reaction forces (GRFs) were recorded using a force plate (type 9286B, Kistler Instrument Corp., Winterthur, Switzerland), and converted from A/D at a sampling signal of 200 Hz. For calculation of TTS, the anteroposterior and mediolateral components of the GRFs were filtered using a second-order recursive low-pass Butterworth digital filter, with an estimated optimum cutoff frequency of 12.53 Hz. These were separately analyzed from peak GRFs to 20 seconds later using the TRIAS data analysis system (Biometrics, UK). The last 10 seconds of GRF components in the control group, which were divided by the body weight of each participant (N), were averaged for calculating an overall mean range of variation variables (SRV). Three SDs of the overall mean range of variation variables were calculated and added to the variation variables to create a normalized range-of-variation variable. The normalized range-of-variation variables in the anteroposterior and mediolateral directions were 0.0046 and 0.0054, respectively. For calculation of the normalized reference variable for each participant, the normalized range-of-variation variables were multiplied by the body weight of each participant (N). We fit an unbound third-order polynomial to each of the rectified components of the GRFs in the anteroposterior and mediolateral directions. Time to anteroposterior stabilization (TTSAP) and mediolateral stabilization (TTSML) for each component of the GRFs was the time taken for the unbound third-order polynomial to be lower than the normalized reference variable. The average value of TTS for each participant was calculated using three tests for statistical analysis. These calculations were repeated for each participant.
**Statistical analysis**

All statistical analysis was conducted using SPSS Statistics (version 21; IBM Corporation Armonk, NY, USA). Between-group differences were determined using independent t-tests. The CAIT-J scores were not normally distributed; therefore, they were evaluated using a Mann-Whitney U test. Effect size (ES) and mean differences (MD), with a 95% confidence interval (95% CI), were calculated to determine a clinically relevant difference. ES was based on the report of Cohen’s d as small (0.2), medium (0.5), or large (0.8). The significance level was set a priori at \( P < 0.05 \).

**Results**

**Participant demographics**

Participant demographics are described in Table 1. No significant differences were founded between the FAI and control groups in terms of age (years), height (cm), body mass (kg), and body fat (%). There was a significant difference between the FAI and control groups in the CAIT-J score (\( P < 0.01 \)).

**Sudden ankle inversion test**

Muscle reaction times are shown in Table 2. The reaction times were significantly longer in the FAI group, in PL and PB muscles, when compared with the control group (PL: \( P = 0.001 \), ES = 1.74, MD = 11.60 ms [95% CI: 5.65 to 17.55], PB: \( P = 0.011 \), ES = 1.20, MD = 14.03 ms [95% CI: 3.60 to 24.46]). There were no significant differences between the groups when assessing the TA, LG, and MG muscles.

**Diagonal single-leg drop landing stabilization test TTS values**

TTSAP and TTSML results are shown in Table 3. There was no significant difference between the groups in TTSAP (\( P = 0.35 \), ES = 0.39, MD = 0.07 s [95% CI: −0.08 to 0.21]).

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**Table 1. Participant Demographics**

|                       | FAI group \((n = 11)\) | Control group \((n = 11)\) | \( P \) values |
|-----------------------|-------------------------|----------------------------|----------------|
| Age (years)           | 18.3 ± 0.5              | 18.9 ± 1.0                 | 0.08           |
| Height (cm)           | 167.6 ± 5.2             | 171.6 ± 5.6                | 0.10           |
| Body mass (kg)        | 61.9 ± 5.4              | 64.7 ± 6.3                 | 0.28           |
| Body fat (%)          | 10.9 ± 2.2              | 11.7 ± 1.5                 | 0.37           |
| CAIT-J (score)        | 21.1 ± 3.1              | 30.0 ± 0.0                 | < 0.01\(^a\)   |

Note. Values are means ± SD.

Abbreviation: CAIT-J, Cumberland Ankle Instability Tool Japanese version.

\(^a\): Significant differences is observed in CAIT-J between FAI and control groups \(( P < 0.05 \))

**Table 2. Muscle reaction times (ms)**

| Muscles | FAI group \((n = 11)\) | Control group \((n = 11)\) | \( t \) values | \( P \) values | ES | MD | 95% CI Lower | 95% CI Upper |
|---------|-------------------------|-----------------------------|----------------|---------------|----|----|--------------|--------------|
| PL      | 82.03 ± 6.01            | 71.07 ± 7.38                | 4.06           | < 0.01\(^a\) | 1.74| 11.60| 5.65         | 17.55        |
| PB      | 81.79 ± 9.96            | 70.10 ± 11.33               | 2.80           | 0.01\(^a\)   | 1.20| 14.03| 3.60         | 24.46        |
| TA      | 75.67 ± 5.87            | 72.53 ± 9.26                | 1.22           | 0.24          | 0.52| 4.06 | −2.86        | 10.98        |
| GL      | 88.42 ± 8.14            | 90.63 ± 14.02               | 0.08           | 0.93          | 0.04| 0.45 | −10.81       | 11.72        |
| GM      | 100.52 ± 18.54          | 103.53 ± 22.07              | −0.27          | 0.78          | 0.12| −2.36| −20.00       | 15.28        |

Note. Values are means ± SD.

Abbreviation: PL, peroneus longus. PB, peroneus brevis. TA, tibialis anterior. GL, gastrocnemius lateral head. GM, gastrocnemius medial head.

\(^a\): Significant differences is observed in PL and PB muscles between FAI and control groups \(( P < 0.05 \))
to 0.21]). TTSML was significantly longer in the FAI group, compared to the control group ($P = 0.012$, $ES = 1.08$, $MD = 0.41s [95\% CI: 0.10 to 0.72]$).

**Muscle activity**

Muscle activities are shown in Fig. 1. The FAI group had significantly reduced activity in the PL muscle during the period from 75 ms pre-IC to 60 ms post-IC ($P < 0.05$, $ES \geq 0.80$). In addition, the FAI group had significantly reduced activity in the PB muscle during the period from 151 ms pre-IC to 116 ms post-IC ($P < 0.05$, $ES \geq 0.80$). Furthermore, the FAI group had significantly reduced activity in the TA muscle during the period from 69 ms to 203 ms post-IC ($P < 0.05$, $ES \geq 0.80$). There were no significant differences between the groups when assessing the GL and GM muscles during all time periods (GL: $P \geq 0.35$, $ES \leq 0.41$, GM: $P \geq 0.38$, $ES \leq 0.39$).

**Discussion**

To examine the characteristics of postural stability and muscle activity in male collegiate soccer players with FAI, we conducted the diagonal single-leg drop landing stabilization test, and compared FAI and a control group. Although there was no significant difference in TTSAP between the groups, the FAI group showed an increased stabilization time in TTSML. Additionally, the FAI group had significantly reduced activity in the PB muscle during the period from post-IC, and exhibited a delayed muscle reaction time in the peroneus muscles.

**Muscle reaction time**

The results of the sudden ankle inversion test showed that muscle reaction times in PL and PB muscles, presented significant differences between the FAI and control groups. Similar results were reported by other studies. $t$-tests were performed to compare the reaction times of the groups. The FAI group had significantly reduced muscle activity in these muscles.

**Time to stabilization**

The results of the diagonal single-leg drop-landing test indicated that only TTSML was increased in the FAI group, when compared to the control group. This suggests that individuals with FAI have a postural stability deficit in the lateral direction. The previous studies also support a postural stability deficit for the lateral direction, even when the conducted test was a forward landing. The lateral ligaments of the ankle, such as the anterior talofibular and calcaneofibular, restrict ankle inversion, which is susceptible to damage by an ankle sprain. Failure of joint restriction by the ligaments may result in an increased TTSML in the FAI group. Additionally, an impaired organ of proprioception is also considered one of the causes for postural stability deficit. Some mechanoreceptors have been identified in the lateral ligaments of the human ankle. Damage to the mechanoreceptor decreases afferent nerve activities, and subsequently affects muscle activity for stabilizing ankle perturbation. These functional deficits may attribute to a longer TTSML in the FAI group.

A meta-analysis indicates that individuals with an unstable ankle have balance impairments. Nevertheless, there is no consensus about postural deficit in the individuals with FAI. While findings from several cross-sectional studies have highlighted the postural deficits during landing tasks in those with an unstable ankle, $t$-tests have reported no significant difference in postural stability between individuals with and those without FAI. The contradictory results may arise because of variation in the balance ability, which is different among various sports and improved by balance disk training. The present study was only targeted at male collegiate soccer players with FAI. Further studies are needed to investigate the postural stability and muscle activity in female collegiate soccer players with FAI.

**Table 3. Time to stabilization (s)**

|              | FAI group ($n = 11$) | Control group ($n = 11$) | $t$ values | $P$ values | ES | MD | 95% CI |
|--------------|----------------------|--------------------------|------------|------------|----|----|--------|
| TTSAP        | 4.37 ± 0.20          | 4.31 ± 0.12              | 0.96       | 0.35       | 0.39 | 0.07 | -0.08  | 0.21 |
| TTSML        | 4.63 ± 0.35          | 4.22 ± 0.35              | 2.77       | 0.01*      | 1.08 | 0.41 | 0.10   | 0.72 |

*Note. Values are mean ± SD.*

Abbreviation: TTSAP, time to anteroposterior stabilization. TTSML, time to stabilization.

*a: Significant differences is observed in TTSML between FAI and control groups ($P < 0.05$)
Fig. 1  Mean linear electromyogram envelopes of functional ankle instability and control groups during 300 ms of pre- and post-IC. The gray-boxed area represents the area of statistical significance ($P < 0.05$). Values are mean ± SE.
players who do not perform balance training daily, and demonstrated the probability of postural stability deficits in FAI individuals. However, the findings from this study are insufficient to conclude whether individuals with FAI have postural stability deficits; sample bias may have been incurred because of the small number of participants (22) who were recruited from one university soccer team. Therefore, a study with adequate power calculations and a long-term follow-up study would be required to determine the presence of postural stability deficits in individuals with FAI.

Muscle activity

Muscle activity measurements during the diagonal single-leg drop-landing test showed that PL, PB, and TA muscle activity were reduced in the FAI group, when compared to the control group. This decreased muscle activity would contribute to impaired postural stability. In particular, reduced peroneus muscle activity during the period of pre- and post-IC, would result in increased TTSML in the FAI group. Delahunt et al. reported reduced activity of the PL muscle in FAI subjects observed over a period of 200 ms pre-IC, in a single-leg forward landing. Similarly, Suda et al. reported that PL muscle activity was significantly reduced in FAI subjects during pre-IC in a sideward lateral cutting maneuver. Adequate muscle activity in peroneus muscles may be required to stabilize the ankle position during pre-IC. However, individuals with FAI are not able to adequately activate peroneus muscles.

The peroneus muscles are an important stabilizer for lateral perturbation at the ankle joint during a landing, especially when the foot is not in contact with the ground. If there is a decline in peroneus muscle activity, resulting in an inverted ankle position at landing, the incidence of a recurrent ankle sprain and a feeling of “giving way” may be increased, even if the peroneus muscle reacts normally. Previous studies have demonstrated that the time-to-peak inversion angle of the ankle sprain was approximately 80 ms to 200 ms post-IC. Konradsen et al. suggested that protecting the ankle against sudden inversion was difficult after the foot is in contact with the ground, due to the ankle eversion against a sudden inversion stimulus occurring later than 176 ms. Therefore, to prevent ankle inversion sprain, pre-activation, rather than muscle reaction time, is important at landing. Delahunt et al. reported that the reduction in PL muscle activity was accompanied by an inverted position of the ankle joint during pre-IC. The present study implied that both PL and PB muscle dysfunction may increase inversion of the ankle joint in individuals with FAI. To the best of our knowledge, this is the first report regarding the inadequacy of PB muscle activity during diagonal landing. The reduction in PB muscle activity was observed from 176 ms pre-IC, earlier than was observed in PL muscle activity, implying that PB muscle activity is important in stabilization of the ankle joint during the early phase of landing.

In the present study, the FAI group had a reduction in TA muscle activity during the period post-IC. Reduced TA muscle activity in FAI individuals was also observed in volleyball players during a sideward lateral cutting. These results suggest that individuals with FAI may not be able to accurately activate the TA muscle during landing. Previous studies suggested that individuals with an unstable ankle joint exhibit a large flexion angle of the hip and knee during a cross-cutting movement. Inaccurate activity on the TA muscles, whose major action is dorsiflexion of the foot, may affect the hip and knee movements on the sagittal plane during the cutting movement.

It is probable that TTSML and muscle reaction time are increased for individuals with FAI, compared to individuals with stable ankles, among male collegiate soccer players. Reduced activity in the PL, PB, and TA muscles may cause FAI individuals to have reduced postural stability during a diagonal single-leg landing. Therefore, it is important for clinicians to assess the postural stability and muscle activity during rehabilitation after ankle sprains.

Limitations

In the present study, we did not evaluate mechanical ankle instability, which is objectively measured by stress test or stress radiography. The influence of mechanical ankle instability on the study outcome was not clear as individuals with mechanical ankle instability may have been mixed in with the FAI group. Moreover, lower limb joint motion was not measured. It was not clear whether reduced muscle activity influences lower limb joint motion during landing. In future research, it is necessary to categorize the FAI individuals who have mechanical ankle instability and include the simultaneous evaluation of joint motion and muscle activity.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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