

Acute responses to local tibialis anterior fatigue: Effects on dynamic balance and muscle mechanical properties

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Abstract

Background: Local muscle fatigue can influence the neural functional mechanisms and intrinsic mechanical properties of the muscle. Considering the importance of the tibialis anterior (TA) muscle during walking and upright standing positions, the primary aim of this study is to understand how induced local muscle fatigue affects both dynamic balance and changes in muscle mechanical properties.

Methods: Thirty healthy participants (mean age: 21.83 ± 1.41 years) were included in the study. Muscle mechanical properties of the dominant TA were assessed using MyotonPro, and dynamic balance was evaluated bilaterally with the Modified Star Excursion Balance Test (mSEBT) before and after the fatigue protocol. The fatigue protocol was applied bilaterally to ankle dorsiflexor muscle muscles and consisted of repeated 30-s isometric dorsiflexion contractions followed by 15-s rest intervals, continued until participants reported a Borg Rating of Perceived Exertion score of 7 or higher.

Result: Following the fatigue protocol, a significant improvement was observed in left mSEBT and right mSEBT scores ($p < 0.05$), except in the anterior direction, where no significant change was detected. Regarding muscle mechanical properties, stiffness decreased, but this change was not statistically significant ($p = 0.06$), whereas relaxation time and creep significantly increased ($p < 0.05$).

Conclusion: Localized ankle dorsiflexor muscle fatigue acutely altered both dynamic balance and muscle mechanical properties. The apparent improvement in mSEBT scores likely reflects short-term neuromuscular compensation rather than genuine performance enhancement. Decreased stiffness and increased relaxation indicate transient adaptations in the muscle's passive behavior.

Keywords

muscle fatigue, balance, postural control, muscle mechanical properties

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Introduction

Local muscle fatigue describes a transient reduction in muscle performance resulting from repetitive or sustained activity of a specific muscle or muscle group, ultimately impairing its ability to generate adequate force or power output.¹ The fatigue process induces several physiological changes within the neuromuscular system, such as decrease in motor unit firing frequency, insufficient oxygen and nutrient delivery, and disruptions in electrochemical transmission.² These physiological alterations may lead to changes in proprioception and peripheral perception, resulting in inaccurate processing of sensory information and possible modifications in body schema.³ Consequently, such disturbances can impair neuromuscular control and

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reduce the efficiency of muscle contractions, directly compromising postural stability.³

During locomotion, the tibialis anterior (TA) muscle is predominantly active in the early stance phase, particularly within the first quarter after heel contact, where it assists in controlling foot placement and shock absorption.⁴ Beyond its role in gait, the TA also contributes significantly to postural stability during standing.⁵ Anatomically, it originates from the lateral surface of the tibia and inserts into the medial cuneiform and the base of the first metatarsal, enabling dorsiflexion and inversion.⁶ In addition, TA plays a crucial role in maintaining upright posture, balance, and walking.^{7,8} Local fatigue in this muscle may therefore lead to impairments in dynamic postural stability, altered lower-limb kinematics and reductions in overall functional performance.^{9–12} As a consequence of these fatigue-related changes, the neuromuscular system may recruit various compensatory mechanisms to mitigate their adverse effects and help maintain functional performance during the acute phase of fatigue.^{13,14}

Muscle fatigue not only influences neural and functional mechanisms but also affects the intrinsic mechanical properties of the muscle, including its tone, stiffness, and elasticity. Previous research has shown that muscle fatigue can decrease muscle tone and stiffness while increasing elasticity in several muscle groups.¹⁵ Furthermore, studies have demonstrated that locally induced muscle fatigue in specific muscle groups can also lead to alterations in mechanical properties.^{16,17} In recent years, handheld devices such as MyotonPRO have been widely adopted for their validity, reliability, and sensitivity in quantifying passive muscle mechanical properties. This method provides a non-invasive and objective assessment of muscle tone, stiffness, and elasticity, offering a valuable complement to traditional neurophysiological and functional measurements.^{17,18} Evaluating these mechanical changes following localized fatigue, in addition to the accompanying neural and functional effects, may therefore serve as a valuable approach for monitoring fatigue progression, assessing injury risk, and informing rehabilitation strategies.

Although previous studies have investigated the effects of localized muscle fatigue on postural control, proprioception, muscle activation, and functional performance, the relationship between fatigue-related changes in dynamic balance and the mechanical properties of the fatigued muscle remains less explored. In particular, the combined assessment of dynamic balance performance and passive muscle mechanical properties may provide complementary information regarding the acute neuromechanical responses to localized fatigue. To our knowledge, no previous study has simultaneously examined dynamic balance performance using the modified Star Excursion Balance Test (mSEBT) and passive mechanical properties of the tibialis anterior using MyotonPRO following localized fatigue. By simultaneously examining these functional and mechanical outcomes, this study sought to provide a more

comprehensive understanding of the acute neuromechanical responses associated with localized muscle fatigue. We hypothesized that acute ankle dorsiflexor muscle fatigue would lead to deterioration in dynamic balance performance accompanied by alterations in the mechanical characteristics of the TA muscle.

Methods

This study was conducted as a single-center, pretest–posttest comparative, and cross-sectional design. Ethical approval was obtained from the Non-Interventional Clinical Research Ethics Committee of Istanbul Beykent University (approval number: E-45778635-050.99-196509). All procedures were carried out in accordance with the ethical principles of the Declaration of Helsinki. Participant recruitment took place between 15.07.2025 and 31.09.2025. Prior to participation, all volunteers provided written informed consent. Following the consent process, participants completed a demographic and clinical information questionnaire and subsequently took part in all measurement procedures.

Participants

The study included 30 healthy participants (19F, 11 M) aged 18–25 years, who were confirmed to have low or moderate physical activity levels according to the International Physical Activity Questionnaire Short Form (IPAQ-SF).¹⁹ The IPAQ-SF was used to characterize participants' habitual physical activity levels and to ensure that participants had comparable low-to-moderate physical activity profiles, thereby minimizing potential differences in habitual activity that could influence fatigue and balance responses. Since the present study employed a pretest–posttest design, the power analysis was conducted based on a paired-samples t-test. As a reference for the expected effect size, a previous study that examined changes in postural sway following localized muscle fatigue was used.²⁰ Based on their reported results for total sway during single-leg stance, the calculated effect size (Cohen's *d*) was 1.19. However, to adopt a more conservative approach and reduce potential overestimation, a large effect size (Cohen's *d*=0.8) was assumed for the current analysis. The alpha (α) level was set at 0.05, and to minimize the probability of Type II error, the target statistical power ($1-\beta$) was set at 0.95. According to these parameters, the G*Power analysis (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany)²¹ indicated that a minimum of 23 participants was required to achieve the desired statistical power. To account for potential dropouts, eight additional participants were recruited, resulting in a final sample of 30 participants completing the study. Leg dominance was identified based on the preferred leg used to kick a ball, as determined by the ball-kick test.²² Participants were required to have no history of neurological or orthopedic disorders, no lower-limb injury or surgery, and

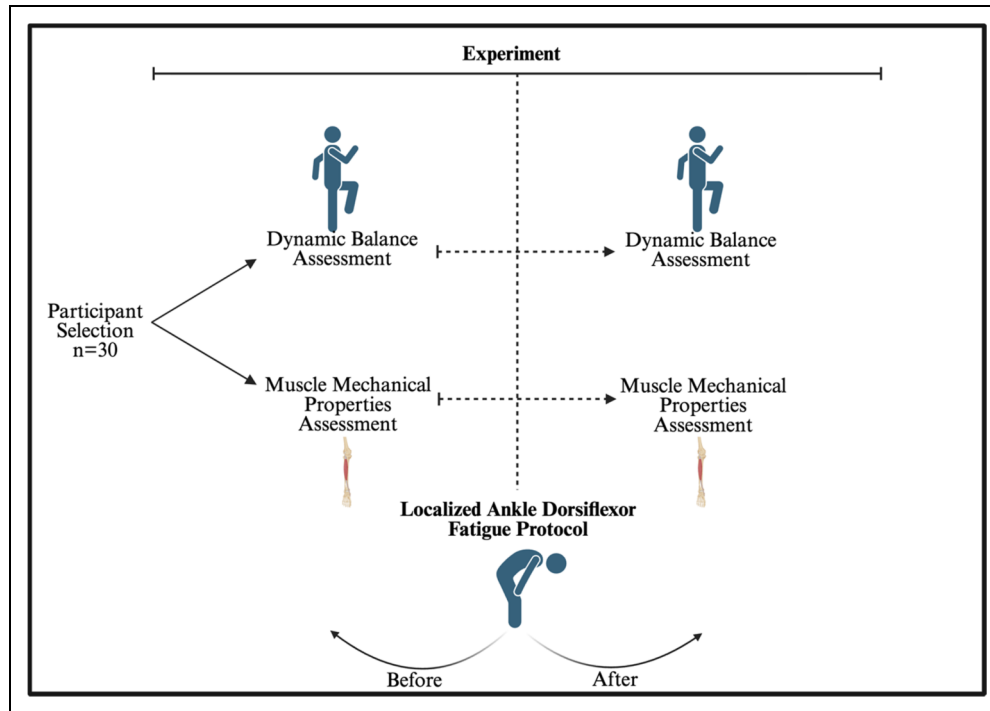


Figure 1. Flow of the experimental protocol.

to comply with the pre-assessment preparation criteria: refraining from strenuous exercise or manual therapy within the past 48 h, avoiding caffeine or alcohol intake within the past 24 h, and ensuring adequate sleep the night before the measurements. All participants provided written informed consent prior to participation.

Individuals were excluded if they had a history of lower-limb injury or surgery within the past six months, recurrent ankle sprains, or if they were professional athletes or regularly engaged in high-intensity exercise. Participants with vestibular disorders, peripheral or diabetic neuropathy, rheumatologic diseases, significant orthopedic deformities, or neurological conditions were also excluded. Additionally, those presenting with acute pain, infection, or systemic illness; using medications that could affect muscle tone or balance within the previous 72 h; consuming high amounts of caffeine (≥ 200 mg) or alcohol within the past 24 h; being pregnant; unable to comply with the study protocol; or providing incomplete data were not included in the analysis.

Procedures

A schematic representation of the experimental procedure, showing the sequence of assessments and the local fatigue protocol, is presented in Figure 1.

Fatigue protocol

To induce fatigue in the ankle dorsiflexor muscles, participants were positioned prone on a treatment table. The pelvis

and trunk were stabilized against the treatment table to minimize unwanted movement and sliding during the contractions. Resistance was provided by the fixed surface of the treatment table against which participants pushed their feet during bilateral isometric dorsiflexion (Figure 2). The protocol consisted of 30-s isometric contractions followed by 15 s of rest, repeated cyclically.¹¹ Because the protocol was not based on a predetermined percentage of maximal voluntary contraction, contraction intensity was operationally defined as maximal voluntary effort sustained during each repetition, and the protocol was continued until participants reported a Borg Rating of Perceived Exertion score of 7 or higher. Standardized verbal instructions were provided to ensure participants performed each 30-s contraction with maximal voluntary effort. Additionally, the protocol was stopped in cases of pain, cramping, impaired movement control, or presyncope symptoms. The duration and rhythm of the contractions were standardized using a metronome, and the researcher provided verbal cues to indicate the start and end of each contraction and rest period to ensure consistency across participants. The total duration (minutes) of the fatigue protocol was recorded for each participant. Thus, while the duration and rhythm of each contraction-rest cycle were standardized across participants, the total number of cycles and overall protocol duration varied according to the predefined termination criterion. To minimize compensatory movements, toe extension and ankle inversion/eversion were visually monitored, and verbal feedback was provided as necessary. Immediately

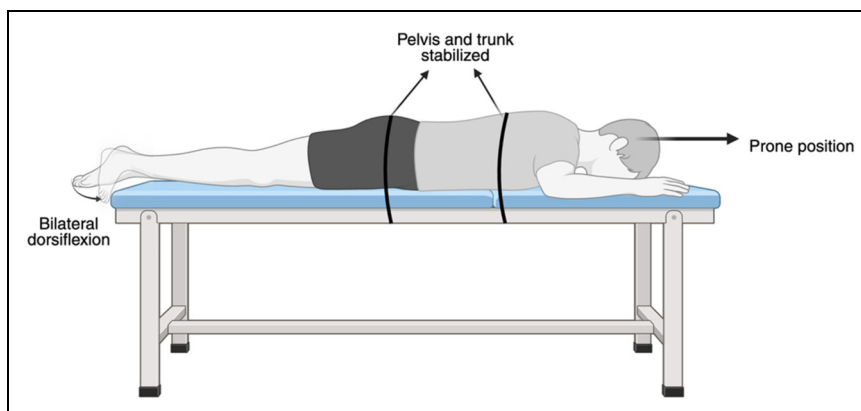


Figure 2. Experimental setup for the ankle dorsiflexor fatigue protocol.

after completion of the fatigue protocol, post-fatigue myotonometric assessment was initiated without any delayed rest interval. Since the myotonometric measurements were taken only from the dominant leg and required 10 s on average, dynamic balance testing followed immediately, with no rest given between assessments.

Mechanical properties assessment

The mechanical properties of the TA muscle were assessed using the MyotonPRO device (Myoton AS, Tallinn, Estonia). This device quantifies the muscle's passive mechanical response by recording the damped oscillations produced in the tissue following a brief, low force mechanical impulse.²³ From these oscillations, the device calculates several parameters: muscle tone (F), dynamic stiffness (S), logarithmic decrement (D), relaxation time (R), and creep (C). These parameters provide a reliable and noninvasive quantification of the passive mechanical profile of the muscle.²⁴

Measurements were obtained at two time points, before and immediately after the fatigue protocol, at the same anatomical site for consistency. The most prominent contractile region of the dominant TA was identified by palpation, and its location was marked on the skin to ensure reproducibility across sessions.^{18,24} During each measurement, the probe was positioned perpendicular (90°) to the skin surface while the muscle was in a relaxed state. Using the multiscan mode, a minimum of five valid repetitions were collected, and the mean of these repetitions was used for statistical analysis. The mechanical properties measurements were obtained from the dominant tibialis anterior to provide a standardized assessment of the fatigued muscle while minimizing the duration of post-fatigue measurements

Dynamic balance assessment

Dynamic balance was assessed using the mSEBT on both legs.²⁵ Participants stood barefoot on one leg with their

hands placed on the hips, keeping the stance foot fixed on the testing surface, and were instructed to reach as far as possible with the contralateral leg in the anterior, postero-medial, and posterolateral directions. Prior to the measurements, each participant performed four to six practice trials in each direction to familiarize themselves with the test. Following the familiarization, three valid trials were recorded for each direction. Reach distances were normalized to limb length and expressed as percentages (% of limb length).

A trial was considered invalid and repeated if the heel lifted from the ground, the stance foot moved, the hands left the hips, or the reaching leg dragged along the line. The order of reaching directions was counterbalanced to minimize potential learning and fatigue effects. Participants rested for 10 to 15 s between trials and 30 to 60 s between directions. Following the post-fatigue MyotonPRO assessment, the mSEBT was initiated immediately without an additional rest interval, with the dominant limb tested first, followed by the non-dominant limb. All balance assessments were performed in the same sequence before and immediately after the fatigue protocol.²⁵ The mSEBT was performed bilaterally to assess dynamic balance performance of both lower limbs, as the test evaluates reach performance for each limb across multiple directions.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Prior to the analyses, the normality of data distribution was examined using the Shapiro–Wilk test. For variables with a normal distribution, paired samples t test was used to compare pre and post fatigue values. For variables that did not follow a normal distribution, the Wilcoxon signed rank test, the nonparametric equivalent, was applied. To assess the clinical relevance of the statistically significant findings, effect sizes were calculated. For parameters

Table 1. Descriptive characteristics of the participants.

Variable	Mean $\pm$ SD, n (%)
Age	21.83 $\pm$ 1.41
Gender	
Female	19 (63.3%)
Male	11 (36.7%)
Leg Dominancy	
Right	27 (90%)
Left	3 (10%)
Height (cm)	170.46 $\pm$ 7.61
Weight (kg)	66.93 $\pm$ 13.85
BMI (kg/m ²)	22.92 $\pm$ 4.03
IPAQ Score (MET-min/week)	2489.56 $\pm$ 1558.34
IPAQ Category	
Low	12
Moderate	18

BMI: Body Mass Index; IPAQ: International Physical Activity Questionnaire.

following a normal distribution and analyzed using the paired samples t-test, Cohen's *d* was computed. For non-normally distributed parameters analyzed with the Wilcoxon signed-rank test, the effect size was reported as a correlation coefficient (*r*). The *r* value was calculated using the formula $r = Z / \sqrt{N}$, where *Z* is the test statistic and *N* represents the number of observations. This approach provides a valid and up-to-date estimation method for interpreting non-parametric test results, as recommended in recent methodological literature.²⁶ Effect size interpretation followed conventional thresholds: for Cohen's *d*, 0.20 was considered small, 0.50 medium, and 0.80 large; for *r*, 0.10 was considered small, 0.30 medium, and 0.50 large. A *p* value < 0.05 was considered statistically significant for all analyses.

Result

Participant characteristics and fatigue protocol duration

The demographic and physical characteristics of the 30 participants are summarized in Table 1. The mean age of the participants was 21.83 $\pm$ 1.41 years, the mean height was 170.46 $\pm$ 7.61 cm, and the mean body mass index (BMI) was 22.92 $\pm$ 4.03 kg/m². The majority of the participants were female (*n* = 19, 63.3%), and most participants were right-side dominant (*n* = 27, 90%). Regarding physical activity, 12 participants were classified as low and 18 as moderate according to the IPAQ-SF. Across all participants, the bilateral dorsiflexor fatigue protocol lasted 5.47 $\pm$ 0.41 min on average.

Changes in dynamic balance performance after fatigue

On the left side, significant increases were observed in the posteromedial (*p* < 0.001, *d* = 0.72), posterolateral (*p* <

0.05, *d* = 0.5), and composite scores (*p* < 0.001, *d* = 0.73) after fatigue. On the right side, the posteromedial direction demonstrated a significant increase according to the Wilcoxon signed rank test (*p* = 0.001, *r* = 0.59). Significant post-fatigue increases were also found in the posterolateral (*p* < 0.001, *d* = 0.84) and composite scores (*p* < 0.001, *d* = 0.74) (Table 2).

Changes in muscle mechanical properties

Following the fatigue protocol, the mechanical properties of the dominant tibialis anterior muscle showed a significant increase in relaxation time (*p* = 0.02, *d* = 0.43), and a similar significant increase was observed in creep values (*p* = 0.02, *d* = 0.44). Both changes indicated moderate effect sizes. Muscle stiffness approached the threshold of significance (*p* = 0.06, *r* = 0.34) but did not reach statistical significance (Table 2).

Discussion

This study investigated the acute effects of an isometric fatigue protocol applied to the ankle dorsiflexor muscles on dynamic balance performance and TA muscle mechanical properties in healthy young adults. To the best of our knowledge, this is the first study to simultaneously evaluate both balance performance and mechanical muscle properties following localized fatigue of the ankle dorsiflexors. Considering that the TA is highly active during the stance phase and several components of locomotion, examining its acute fatigue-related changes from both a functional perspective (postural control) and a mechanical perspective provides a more comprehensive understanding of the fundamental effects of local muscle fatigue.

General muscle fatigue, such as that induced by activities like cycling, triathlon, or running, involves the activation of multiple muscle groups and is known to reduce neuromuscular efficiency by disrupting proprioceptive and exteroceptive feedback or their integration.^{12,27,28} In contrast, during localized muscle fatigue, the neuromuscular system, through mechanisms such as reflex pathways, motor unit activation, and the gamma loop, attempts to maintain postural control and keep the system functionally active in the acute phase.^{1,3,29,30} Our findings may be consistent with an acute compensatory response that helps preserve postural control after localized dorsiflexor fatigue.^{3,31} These compensatory responses could enhance apparent balance control, representing a short-lived adaptation rather than a true improvement in postural performance. This physiological explanation may help interpret our balance findings, which did not fully align with the commonly reported post-fatigue decline in dynamic stability.

Indeed, recent study has shown that lower limb muscle fatigue commonly impairs proprioception.³² However, the significant post-fatigue increase observed in our study

Table 2. Changes in balance performance and muscle mechanical properties before and after fatigue.

Variables	Before Mean $\pm$ SD, n (%)	After Mean $\pm$ SD, n (%)	Test statistic (t or Z)	p value	Effect size (d or r)
<i>Dynamic Balance Test</i>					
L-mSEBT Anterior (%)	94.19 $\pm$ 14.22	93.65 $\pm$ 14.17	$t^a(29) = 0.302$	0.764	d = 0.06
L-mSEBT Posteromedial (%)	108.50 $\pm$ 19.73	116.75 $\pm$ 16.47	$t^a(29) = -3.938$	0.000	d = 0.72
L-mSEBT Posterolateral (%)	96.73 $\pm$ 15.87	102.99 $\pm$ 16.79	$t^a(29) = -2.739$	0.010	d = 0.50
L-mSEBT Composite (%)	99.81 $\pm$ 11.81	105.36 $\pm$ 13.62	$t^a(29) = -3.980$	0.000	d = 0.73
R-mSEBT Anterior (%)	95.99 $\pm$ 12.52	95.61 $\pm$ 12.06	$t^a(29) = 0.294$	0.771	d = 0.05
R-mSEBT Posteromedial (%)	110.75 $\pm$ 19.22	118.32 $\pm$ 15.18	$Z^b = -3.211$	0.001	r = 0.59
R-mSEBT Posterolateral (%)	97.53 $\pm$ 18.15	105.02 $\pm$ 17.19	$t^a(29) = -4.586$	0.000	d = 0.84
R-mSEBT Composite (%)	101.42 $\pm$ 12.71	106.32 $\pm$ 12.05	$t^a(29) = -4.075$	0.000	d = 0.74
<i>Muscle Mechanical Properties</i>					
Tone – F (Hz)	18.30 $\pm$ 3.68	17.61 $\pm$ 3.63	$t^a(29) = 1.404$	0.171	d = 0.26
Stiffness – S (N/m)	472.9 $\pm$ 169.11	393.36 $\pm$ 98.01	$Z^b = -1.882$	0.06	r = 0.34
Logarithmic decrement – D	1.06 $\pm$ 0.17	1.04 $\pm$ 0.18	$t^a(29) = 0.479$	0.636	d = 0.09
Relaxation – R	12.98 $\pm$ 3.38	14.60 $\pm$ 2.68	$t^a(29) = -2.374$	0.024	d = 0.43
Creep – C	0.81 $\pm$ 0.08	0.91 $\pm$ 0.04	$t^a(29) = -2.405$	0.023	d = 0.44

L-mSEBT: Left Modified Star Excursion Balance Test; R-mSEBT: Right Modified Star Excursion Balance Test. %: Reach distance normalized to limb length. F: Frequency (Hz); S: (N/m); D: Decrement; R: Relaxation Time (ms); C: Creep (ratio). t^a : Paired Samples t-Test; Z^b : Wilcoxon Signed Rank Test. $p < 0.05$ was considered statistically significant, and statistically significant differences are indicated in bold.

appears consistent with evidence suggesting that the motor control system exhibits an acute adaptive capacity following localized fatigue. Some studies have also reported either unchanged or even improved post-fatigue balance performance.^{33,34} Such findings have been proposed to reflect changes in motor coordination that may help maintain movement stability.³⁵ At the central level, previous research has demonstrated that muscle fatigue enhances corticomuscular coherence in the beta frequency band, indicating a stronger coupling between the sensorimotor cortex and the fatigued muscle.³⁶ This finding has been interpreted as indicating that central nervous system may increase its contribution to motor output to preserve steadiness and control despite peripheral fatigue. Previous studies have suggested that proximal control strategies involving the hip and trunk may contribute to postural stabilization when distal muscles are fatigued.^{37–39} One possible explanation is that differences in hip and trunk may contribute to reach performance in the mSEBT.⁴⁰ In the present study, the significant increases observed in the posterior and posterolateral directions may reflect such a proximal compensation strategy. While anterior reaching is primarily dependent on ankle control, reaching in the posterior directions relies more on hip and trunk mobility.³⁷ Therefore, as the fatigued ankle muscles become less effective in their stabilizing role, the findings may be compatible with a shift toward a hip-dominant strategy, although this was not directly evaluated in the present study. This direction-specific mechanism may also help explain why no significant difference was observed in the anterior direction. Previous work suggests that SEBT performance is direction-dependent, with anterior and posterior reach directions relying on partly different neuromuscular and postural control demands.⁴¹ Therefore, the acute effects of

dorsiflexor fatigue may not be expressed uniformly across directions, potentially reflecting differences in the neuromuscular and postural demands of each reach directions. These findings highlight the importance of considering that changes in reach distance may reflect compensatory movement strategies rather than true improvements in dynamic balance. Future studies incorporating EMG and kinematic analyses are needed to verify the underlying mechanisms.

While these adaptive neuromuscular and postural responses may help maintain balance acutely, fatigue also alters the intrinsic mechanical behavior of the muscle, reflecting both structural and viscoelastic adaptations. In previous *in vivo* and *in vitro* studies examining isotonic or eccentric fatigue, an increase in muscle stiffness has generally been observed immediately after exercise.^{42–44} This increase is thought to result from mechanical loading during muscle lengthening, leading to microstructural damage, sarcomere disorganization, connective tissue fluid accumulation, and edema formation. However, Rotllan et al., 2024 reported a decrease in stiffness values of the Vastus Lateralis, Vastus Medialis, Lateral Gastrocnemius, and Medial Gastrocnemius muscles following repeated cycling competitions.¹⁵ Although this finding contradicts most of the existing literature, it may be explained by sample size limitations or accumulated fatigue effects under real-world conditions. In the present study, stiffness decreased, but this change was not statistically significant, while relaxation time and creep significantly increased. This pattern likely indicates mechanical relaxation rather than a structural tightening of the tissue. It is also worth noting that most previous studies were conducted on biarticular muscles such as the vastus lateralis, gastrocnemius or hamstrings, which experience greater

mechanical strain during movement.^{42–44} In contrast, the TA is a monoarticular muscle primarily responsible for fine motor control and balance. Therefore, the reduction in tone and stiffness observed in our study may reflect reflexive muscle relaxation and metabolic fatigue effects, rather than mechanical microdamage typically associated with isotonic or eccentric protocols. In contrast, no significant changes were observed in muscle tone or logarithmic decrement. Since logarithmic decrement is considered an indirect indicator of muscle elasticity, this finding may suggest that the acute fatigue protocol did not substantially alter the elastic recovery capacity of the tissue. Similarly, the absence of a significant change in muscle tone may indicate that short-term dorsiflexor fatigue affected viscoelastic and passive resistance properties more than baseline oscillatory tension. Together, these findings support the idea that the mechanical response to acute fatigue was selective rather than uniform across all muscle mechanical properties.

Collectively, these findings suggest that the changes observed in tibialis anterior mechanical properties and dynamic balance performance should be interpreted as related but not directly equivalent responses to the same fatigue stimulus. While muscle mechanical properties reflect local alterations in passive mechanical behavior, mSEBT performance reflects a broader functional output shaped by neuromuscular coordination and compensatory postural strategies. Therefore, the present results may indicate that acute dorsiflexor fatigue induced local mechanical changes while simultaneously prompting functional adaptations that helped preserve or even enhance direction-specific balance performance.

This study has several methodological limitations. One major limitation is that the isometric fatigue protocol used in this research may not fully replicate the fatigue experienced during dynamic sporting activities, as isometric and isotonic protocols elicit distinct physiological responses.⁴⁵ In addition, fatigue was determined based on perceived exertion during voluntary maximal isometric contractions, without objective confirmation using measures such as force reduction assessed by a dynamometer or electromyographic indicators. Consequently, inter-individual differences in perceived exertion may have resulted in variability in the actual physiological level of fatigue achieved across participants. Although the borg rating of perceived exertion is a widely accepted and practical method for monitoring exercise intensity, subjective fatigue perception does not necessarily reflect the same degree of neuromuscular fatigue in every individual. Therefore, this variability may have influenced the magnitude of the observed changes in both dynamic balance and muscle mechanical properties. Future studies should combine subjective ratings with objective physiological measures to ensure a more standardized quantification of fatigue.

In conclusion this study demonstrated that localized fatigue of the ankle dorsiflexor muscles acutely alters both dynamic balance performance and muscle mechanical properties.

While postural stability appeared to improve immediately after fatigue, this effect may represent a short-term neuromuscular compensation rather than a genuine enhancement in balance performance. At the mechanical level, fatigue induced a tendency toward decreased stiffness and increased relaxation and creep, indicating a temporary loss of muscle tension and passive integrity. These findings suggest that, despite the apparent maintenance of functional balance, the muscle's ability to resist external loading and maintain fine motor control may be transiently compromised following fatigue. From a functional perspective, these findings highlight the potential for functional balance tests such as the mSEBT to mask underlying changes in muscle mechanical properties following fatigue. Future studies should further explore the temporal persistence and clinical relevance of these compensatory and mechanical responses in both athletic and rehabilitation populations.

Abbreviations

TA	Tibialis Anterior
mSEBT	Modified Star Excursion Balance Test
IPAQ-SF	International Physical Activity Questionnaire Short Form

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Ethical approval and informed consent statement

Ethical approval was obtained from the Istanbul Beykent University Non-Interventional Clinical Research Ethics Committee (Approval No: E-45778635-050.99-196509). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data sharing statement

All relevant data are provided within the manuscript and its Supporting Information files. The dataset has been fully anonymized in accordance with ethical and institutional guidelines to ensure that no identifying information of participants is disclosed.

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