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original research

Effects of 2 Ankle Fatigue Models on the Duration of Postural Stability Dysfunction

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Context: Muscle fatigue is generally categorized in 2 ways: that caused by peripheral weakness (peripheral fatigue) and that caused by a progressive failure of voluntary neural drive (central fatigue). Numerous variables have been studied in conjunction with fatigue protocols, including postural stability, maximum voluntary contraction force, and reaction time. When torque recordings fall below 50% of a maximum voluntary contraction, the muscle is described as fatigued, but whether this value is a good indicator of fatigue has not been studied.

Objective: To compare the effects of 2 ankle musculature fatigue protocols (30% and 50%) on the duration of postural stability dysfunction.

Design: To assess differences between the 30% and 50% fatigue protocols, we calculated a 1 between-groups factor (subjects) and 2 within-groups factors (fatigue, test) analysis of variance.

Setting: E.J. Nutter Athletic Training Facility.

Patients or Other Participants: Twenty subjects (10 men, 10 women; age = 21.15 ± 2.23 years; height = 172.97 ± 9.86 cm; mass = 70.62 ± 14.60 kg) volunteered for this study. Subjects had no history of lower extremity injury, vestibular or balance disorders, functional ankle instability, or head injury in the past 6 months.

Intervention(s): On separate days, subjects performed isokinetic fatiguing contractions of the plantar flexors and dorsiflexors in a 30% protocol (70% decrease in strength) and a 50% protocol (50% decrease in strength).

Main Outcome Measure(s): Baseline and postfatigue postural stability scores were determined before and after the isokinetic fatiguing contractions. Plantar-flexion peak-torque measurements were obtained for the 2 fatiguing protocols. Three prefatigue and 12 postfatigue postural stability trials were recorded. Velocities for testing were 60°/s for plantar flexion and 120°/s for dorsiflexion.

Results: Sway velocity was significantly greater when the ankle was fatigued to 30% (1.56°/s) than in the 50% condition (1.36°/s). For the 30% protocol, sway was significantly impaired when the pretest condition (1.19°/s) was compared with posttest trial 1 (2.34°/s), trial 2 (2.37°/s), and trial 3 (1.71°/s). For the 50% protocol, sway was significantly impaired when the pretest condition (1.27°/s) was compared with posttest trial 1 (2.02°/s).

Conclusions: The 30% fatigue protocol resulted in significantly longer impairment of postural stability than the 50% protocol. Because the 30% protocol resulted in a greater effect but was relatively short-lived (approximately 75 to 90 s), it is more useful for research purposes.

Key Words: equilibrium, sway velocity, peripheral fatigue, isokinetic activity, balance

Several definitions of muscle fatigue have been used throughout the literature. Muscle fatigue has been defined by Miller et al[1] as the reduction in maximal force-generating capability during exercise. Others have defined fatigue as any exercise-induced reduction in the maximal capacity to generate force or power output.[2] Another definition, proposed by Mannion and Dolan,[3] suggested that fatigue is the inability to generate the maximal force that can be produced by the muscle in its fresh state. Regardless of the definition, the process and effects of fatigue continue to be investigated, because they are not completely understood.

Current literature focuses on 2 widely accepted classes of fatigue: that caused by peripheral weakness (peripheral fatigue) and that caused by a progressive failure of voluntary neural drive (central fatigue).[2] Peripheral fatigue is the classification that most often comes to mind, because it is the more local fatigue that affects 1 muscle or muscle group. Peripheral factors in fatigue primarily include metabolic inhibition of the contractile process and excitation-contraction coupling failure.[1,4–6] Central fatigue can be described as more of a psychological aspect of fatigue, in that it may originate from a lack of drive or motivation.[7] Hollge et al[7] described central fatigue as one of the most important limiting factors of sustained exercise in sports. The origin of fatigue (central or peripheral) is critical to the understanding of fatigue.

Numerous variables, including postural stability, maximum voluntary contraction force, and reaction time, have been studied in conjunction with fatigue protocols to help understand how fatigue affects the body and the ability of the body to function or perform. Postural control is both functional and performance based. Postural control or balance is defined as a function requiring the coordinated activation of joint, muscle, visual, and vestibular receptors to maintain the body's center of mass.[8] Sensory input from several sources, including the skin, joint capsule, ligaments, and muscle spindles, contributes to the maintenance of postural control. If the muscle spindle plays a significant role in this maintenance of stability, there should be a deficit in postural control after muscular fatigue. For this reason, several researchers have focused on the effects of fatigue on postural control.[8,9]

Methods used in the assessment and quantification of fatigue are varied in the literature.[3,10–12] Protocols that have been used to induce muscular fatigue in numerous studies are not heavily supported by the literature. For example, determination of force output as an indicator of fatigue is often arbitrarily set at a point equal to 50% of maximum.[8,9,13] Specifically, when torque recordings fall below 50% of a maximum voluntary contraction, the muscle is said to be fatigued. However, this percentage is not supported in the literature and has not been compared with other values to determine whether 50% is a good indicator of the point of muscular fatigue. The comparison of a 50% fatigue protocol with another fatigue protocol (30%) serves as the focus of the current research study. Our purpose was to compare the effects of 2 ankle musculature fatigue protocols on the duration of postural stability dysfunction and to determine whether 50% is a good indicator of the point of muscular fatigue.

METHODS

Subjects

Twenty healthy subjects (10 men, 10 women; mean age = 21.15 ± 2.23 years, mean height = 172.97 ± 9.86 cm, mass = 70.62 ± 14.60 kg) volunteered to participate in this study. Volunteers who denied a history of recent lower extremity injury, vestibular or balance disorders, functional ankle instability, and history of head injury in the past 6 months were eligible. The study was approved by the University of Kentucky Medical Institutional Review Board, and each subject reviewed and signed an informed consent before participating. An a priori power analysis (mean differences were estimated from Johnston et al[9]) with an effect size of 0.80 revealed that 13 to 14 subjects were needed to achieve a power of .70.

Instrumentation

We used the Kin-Com 125E PLUS isokinetic dynamometer (Chattanooga Corp, Hixson, TN) in the collection of plantar-flexion peak-torque data and during each of the fatigue protocols. All testing was completed in the E.J. Nutter Athletic Training Facility.

Postural stability was assessed using the long force plate of the NeuroCom SMART Balance Master (NeuroCom, Clackamas, OR), and data were collected at 100 Hz. The long force plate assesses postural stability by measuring sway velocity. Sway velocity is the ratio of the distance traveled by the center of gravity to the time of the trial (°/s).[14] With time held constant (10 seconds), an increase in the distance swayed signifies a higher sway velocity value. The validity and reliability of force-platform measures for stance stability were previously reported.[15,16] Intraclass correlation coefficients revealed high test-retest reliability for measures of sway (intraclass correlation coefficients > .90).[16]

Testing Protocol

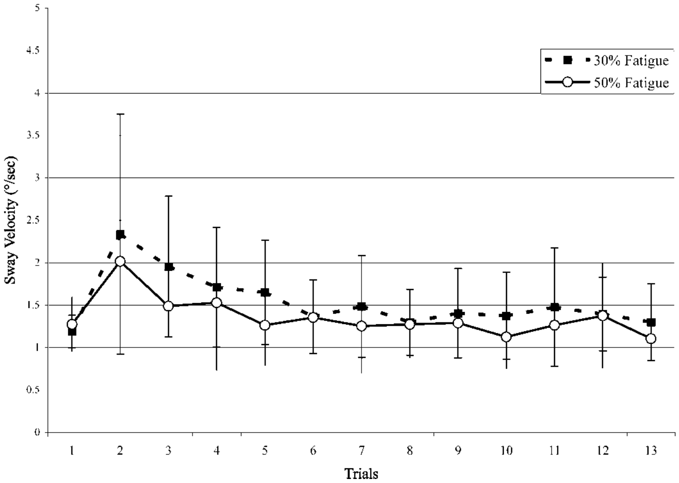
All subjects reported for testing on 2 separate days, with at least 5 days separating the sessions. On each day of testing, baseline plantar-flexor peak-torque values and baseline sway-velocity values were recorded. After plantar-flexion peak torque was recorded, subjects were assigned to 1 of 2 fatigue protocols (30% or 50%). Assignment of fatigue protocols was counterbalanced to control for a learning effect. After each subject completed the assigned fatigue protocol, we assessed postfatigue sway-velocity scores with the NeuroCom SMART Balance Master.

Assessment of Peak Muscular Force and Fatigue on the Kin-Com Dynamometer

Subjects were positioned lying prone on the dynamometer. The left foot was secured into the plantar-flexion/dorsiflexion attachment with an ankle and toe strap. A strap was also applied over the subject's midsection to keep him or her flat against the Kin-Com. Subjects completed 3 warm-up repetitions through a 30° range of motion (5° of dorsiflexion to 25° of plantar flexion). Three maximum repetitions were then completed, with the highest concentric plantar-flexion peak-torque value recorded as the maximum voluntary contraction (MVC). A rest period of 30 seconds was given between MVC trials, and 1 minute of rest was allowed before the fatigue protocol. Once MVC was established, subjects completed concentric/concentric, plantar-flexion/dorsiflexion contractions at 60 and 120°/s, respectively. Repetitions were continued until peak-torque values declined below the value for the assigned protocol (30% or 50% of the maximum value). For clarification, the 30% protocol is equal to a 70% decrease in strength, and the 50% protocol is equal to a 50% decrease in strength; ie, strength values were less than 30% and 50%, respectively, of maximum strength for 3 consecutive trials. Subjects were removed from the Kin-Com and repositioned on the long force plate for reevaluation of postural stability.

Balance Testing on the NeuroCom SMART Balance Master

Subjects were positioned in a unilateral stance on the dominant-stance leg. The medial malleolus and lateral aspect of the fifth metatarsal were aligned and standardized to a grid on the long force plate. All postural stability testing was done barefoot and with eyes closed. Each subject performed 1 practice and 2 test trials lasting 10 seconds each. The postural sway baseline score was calculated from the mean of pretest trial 2 and pretest trial 3. After the fatigue protocol, we again assessed balance. The time from the completion of the fatigue protocol until the initiation of the balance assessment was less than or equal to 15 seconds. The postfatigue balance assessment consisted of performing a series of 12 10-second balance trials with the eyes closed, for a total of 4 minutes. Testing was continued for 4 minutes to allow direct comparison between the 2 fatigue protocols. Pilot testing revealed that postural sway scores would return to baseline within this 4-minute period. The 12 trials were necessary to determine exactly when values returned to baseline over the 4-minute period. A 10-second rest period was provided between trials.



Representation of postural sway during postfatigue trials.

Statistical Analysis

The design of this study was a pretest-posttest group design. Sway velocity was the dependent variable. The independent variables were intervention (30% or 50% fatigue) and the test (pretest or posttest). The postural sway baseline score was calculated from the mean of pretest trials 2 and 3. We performed a 1 between-groups factor (subjects) and 2 within-groups factors (fatigue, test) repeated-measures analysis of variance to assess differences between the 30% and 50% fatigue protocols. A Tukey post hoc procedure was used to determine significant mean comparisons. A probability level of $\leq$.05 was considered significant.

RESULTS

A significant main effect was noted for fatigue ($F_{1,19} = 4.385$, $P < .05$). Sway velocity was significantly greater in the 30% condition (1.56°/s) versus the 50% condition (1.35°/s). A significant main effect was also seen for trial ($F_{12,228} = 7.294$, $P < .01$). For the 30% protocol, sway was significantly impaired when the pretest condition (1.19°/s) was compared with posttest trial 1 (2.34°/s), trial 2 (2.37°/s), and trial 3 (1.71°/s). For the 50% protocol, sway was significantly impaired when the pretest condition (1.27°/s) was compared with posttest trial 1 (2.02°/s). Postural sway was significantly impaired for approximately 75 seconds after completion of the 30% condition and for approximately 35 seconds after the 50% condition. Postural sway values for the 30% and 50% conditions are presented for the 12 posttest trials in the Figure 1 The mean number of completed plantar-flexion and dorsiflexion muscle contractions for the 30% and 50% protocols were 75.85 and 50.1 repetitions, respectively.

DISCUSSION

Sway velocity values for the 30% condition were significantly higher than sway velocity values for the 50% condition. Although no researchers have compared 2 fatigue protocols, the effect of fatigue on postural stability has been addressed. Johnston et al[9] found a significant decrease in subjects' ability to balance on an unstable platform after an isokinetic fatigue protocol ($P < 0.001$). Similar results were found by Lundin et al.[17] After fatigue of the plantar flexors and dorsiflexors, anterior-posterior sway amplitude (P=0.065) and medial-lateral sway amplitude both increased ($P < 0.05$).[17] Because postural sway increases after fatiguing exercise, we might assume that the greater the percentage of fatigue, the greater the anticipated increase in sway. Our results confirm that fatiguing a subject to 50% of maximum resulted in increased postural sway velocity, but this effect was less than that seen in the 30% fatigue protocol.

The duration of postural stability disturbance was different between the 30% and 50% fatigue conditions. In the 30% condition, sway was significantly impaired when posttest trials 1, 2, and 3 were compared with pretest values. The duration of significant sway impairment for the 30% condition was approximately 75 seconds. In the 50% condition, sway was impaired only for the first posttest trial when compared with the pretest value. The duration of significant sway impairment for the 50% condition was approximately 35 seconds. These results vary somewhat from those in the literature on recovery and time course of fatigue. In 1997, Nardone et al[11] reported that fatigue effects appeared immediately postexercise but had short duration and were nonexistent within 15 minutes postexercise. In a similar report,[18] they demonstrated that sway increased most in the initial few minutes with respect to pre-exercise values and then plateaued. All sway variables had returned to control values between 10 and 15 minutes postexercise.[18] Our results may differ from those of the aforementioned researchers, who reported longer-lasting fatigue effects for several reasons. In our protocol, we fatigued the ankle plantar flexors and dorsiflexors, which contribute to the maintenance of postural sway by controlling anterior-posterior sway. Because the larger ankle musculature were fatigued, it is possible that subjects began using other muscles to compensate. We did not fatigue the medial-lateral stabilizers of the ankle, which may have assumed a more dominant role in maintaining postural stability when the anterior-posterior stabilizers were fatigued. The plantar flexors and dorsiflexors are the largest of the ankle musculature, so one might expect these muscles would have the most pronounced effect on postural stability. In addition, subjects may have changed their balance strategies. Instead of relying primarily on the ankle musculature, other, more proximal muscles may have been recruited. Corrective action of the proximal joints (knee and hip) is increased when a subject balances using a single limb on a foam versus firm surface.[19] The fatigued subjects may have relied more on the proximal joints for stability because of the compromised feedback and recruitment of the plantar flexors and dorsiflexors. The long force plate we used for assessment of postural stability did not collect shear forces, so we were unable to determine whether a hip or ankle strategy was being used, and this is one of the limitations of our study. Another explanation for a quick return of postural stability values to baseline lies in the nature of the protocol. The MVC trials and the fatigue protocol require maximum effort. Therefore, it is inherently difficult to know if all subjects gave their maximal efforts during all of the testing. By the nature of the protocol, we did not stop testing until subjects' peak torques fell below the specified percentage 3 consecutive times. The primary investigator (K.M.R.) attempted to verbally motivate each subject, thus decreasing the potential for motivation to be a factor. All of these are plausible explanations for the quick return of postural sway values to baseline.

Several investigators who have used 50% as their indicator of fatigue have shown a rapid recovery rate and short-lived fatigue effects. Sahlin and Ren[20] examined contraction capacity during recovery from a fatiguing contraction. Their results were in contrast to those of Nardone et al.[18] Subjects held sustained isometric contractions at 66% of MVC until force declined to less than 50%. Force was rapidly restored: at 15 seconds postfatigue, force was 80% of MVC, and after 2 minutes, force values had returned to baseline.[20] These short-lived effects of fatigue appear to be similar to those we found, especially those in the 50% condition. Carson et al,[21] examining the effects of prolonged activity on vertical jump performance, also found short-lived effects of fatigue. After 15 seconds of rest (postfatigue), subjects were able to jump 75% to 80% of their maximum jump heights. At 40 and 60 seconds after fatigue, subjects were able to jump 85% and 85% to 90% of their maximum jump heights, respectively.[21] Both protocols targeted the lower extremity and used 50% as their fatigue indicator. Because the effects of fatigue were short lived, it would be interesting to determine if longer-lasting effects would result from performing the same protocols with a lower percentage as the fatigue indicator.

As stated previously, researchers have not examined or compared the use of 2 or more indicators of fatigue on postural stability. In this study, the 50% fatigue condition was compared with a greater level of fatigue (30%) based on pilot studies conducted by the primary investigator. At the 30% threshold, subjects were able to complete the fatigue protocol while also demonstrating the effects of muscular fatigue. When lower threshold percentages were pilot tested, some subjects experienced muscle cramping and were not able to complete the protocol to the targeted threshold percentage. Pilot testing revealed that subjects completing the protocol to the 30% threshold had the longest-lasting disturbances in postural stability compared with percentages between the 30% and 50% threshold levels. For these reasons, the 30% fatigue condition was used for comparison with the 50% fatigue condition. Comparison of other levels of fatigue is an area that should be further examined, through methods including, but not limited to, muscular force production.

Studies of the process of recovery from fatigue have had varied results, particularly because researchers have used different methods and fatigue protocols as well as different variables to measure fatigue effects. Many of these authors used a more general aerobic exercise protocol to induce fatigue that is more central in nature.[9,11,18] Others attempted to fatigue a specific muscle or muscle group, resulting in a more localized, peripheral fatigue.[17,20–23] Our fatigue protocol targeted only the ankle plantar flexors and dorsiflexors, making it more peripheral in nature. As stated previously, this may have accounted for the rapid return of postural sway values to baseline. The differences in fatigue protocol and the type of fatigue should be considered when attempting to compare fatigue effects and the recovery process.

CONCLUSIONS

Fatigue research often has as the indicator of fatigue a value arbitrarily defined to be 50% or less of maximum output.[8,9,13,20,21,23] However, this percentage is not validated in the literature. If a 50% fatigue condition has short-lived effects on a performance variable, it may not be the best indicator of fatigue for research purposes, especially those evaluating fatigue interventions. Our purpose was to determine if the effects of a 30% fatigue condition were any greater or longer lasting than those of a 50% fatigue condition. Our results confirm that if postural sway increases as a result of fatigue, then a greater amount of fatigue causes longer-lasting postural stability disturbances. This allows a greater window for research purposes related to fatigue interventions. Clinically, one should appreciate the time window necessary for complete recovery from muscular fatigue, generally between 2 and 3 minutes. During this time period, postural stability is compromised and may result in an athlete being more susceptible to injury.

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COMMENTARY

Mark Hoffman, PhD, ATC

Editor's Note: Mark Hoffman, PhD, ATC, is Undergraduate Athletic Training Program Director and Sports Medicine Laboratory Director at Oregon State University and a member of the *JAT* Editorial Board.

The authors of this article studied an experimental protocol used to fatigue muscles of the leg. They induced fatigue to 2 levels and measured the effects of the fatigue on postural control. I appreciate the opportunity to comment on this article. My comments are directed toward 3 aspects of the article: (1) the theoretic but thus far still controversial prolonged effects of fatigue on muscle spindle activity of postural muscles in the human, (2) the debatable contribution of the study's conclusions to the literature base and their potential to affect clinical and research practices, and (3) the inconsistency between the introduction and the conclusion as they relate to the purpose of the study.

Early in the paper, the authors stated that muscle fatigue affects muscle spindle activity—specifically, ''If the muscle spindle plays a significant role in the maintenance of stability, there should be a deficit in postural control after muscle fatigue.'' Although there is support for alterations of muscle spindle activity during sustained contractions and after a fatigue protocol, this statement is somewhat theoretic. Muscle spindle activity has been evaluated indirectly and directly in both human and animal models.[1,2] Macefield et al[1] studied muscle spindle activity in humans during sustained contractions and found that spindle activity decreased over time during sustained contractions. Additionally, Pedersen et al[2] studied muscle spindle ensembles in the cat during and after a fatigue protocol and reported that they do, in fact, decrease after fatigue in the gastrocnemius. Even though muscle spindle activity may have been affected by the fatigue protocol used in this article, it is quite possible that the induced effect on the muscle spindle may not have been the mechanism responsible for the observed changes in postural control. For example, the effects on postural control seen in this study may have been related solely to a decreased capacity of the muscles of the leg to generate force after being fatigued.

Additionally, I would like to comment on the authors' use of a reference for the effects of fatigue on the muscle spindle. They referenced a statement based on comments by Johnston et al,[3] who wrote, ''We cannot state definitively that fatigue affects proprioception. However, it seems plausible that some form of muscle spindle desensitization or perhaps ligament relaxation and Golgi tendon desensitization occurs with excessive fatigue. This may lead to decreased efferent muscle response and poorer ability to maintain balance.''

Thus, the authors may have inadvertently misled the reader as to what is and is not known concerning muscle spindle activity and fatigue in postural muscles.

The authors stated that the use of the 50% fatigue protocol ''is not supported in the literature and has not been compared to other values to determine whether 50% is a good indicator of the point of muscular fatigue.'' Based on this comment, I would expect the next step in addressing this problem to have been a validation of the 50% protocol or validation of any isokinetic protocol used to induce muscular fatigue. Clearly, there is a need to validate fatigue protocols that are based on a functional outcome (percentage decline in force output) to a ''gold standard'' measure of fatigue. The utility of comparing a protocol that has not been validated or ''accepted in the literature'' to another protocol that uses the same approach but at a greater level of fatigue remains unclear.

The authors provided the following statement of purpose in the introduction section of the article: ''Our purpose was to compare the effects of 2 ankle musculature fatigue protocols on the duration of postural stability dysfunction and to determine whether 50% is a good indicator of the point of muscular fatigue.'' It is unclear how the authors planned to determine whether 50% fatigue was a ''good'' measure of fatigue in the absence of a ''gold standard'' measurement of muscle fatigue. Furthermore, it appears intuitive that if 50% fatigue has a detrimental effect on postural control, a greater level of fatigue would have at least an equal and most likely a greater effect on postural dysfunction. Additionally, in the Conclusions section, the authors stated their purpose was ''to determine if the effects of a 30% fatigue condition were any greater or longer lasting than those of a 50% fatigue condition.'' It appears that the stated purpose in the Conclusions section more accurately describes the focus of the study.

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AUTHORS' RESPONSE

We thank Dr. Hoffman for his commentary on our article and appreciate the opportunity to respond.

In response to the reviewer's first point regarding the effect of muscle fatigue on muscle spindle activity, we agree that the postural stability disturbances found in our study are likely the effect of several mechanisms that we were not able to specifically define with our equipment. As pointed out by the reviewer, there is evidence in the literature that muscle spindle activity is decreased after various fatigue protocols.[1–3] Whether or not the fatigue protocol we used had the same effect on the muscle spindle cannot be definitively determined with our methods and laboratory equipment. However, certainly there was no attempt on our parts to mislead the reader as to the contribution of muscle spindle activity to the postural stability disturbances we describe in the results. These statements were included only to help the reader understand one of the several mechanisms by which muscle fatigue causes postural stability dysfunction. Clearly, the effect of muscle fatigue on muscle spindle activity is an area that deserves attention in further research efforts. Several hypotheses have been suggested as a reason for increases in postural sway. The sensitivity of the muscle spindle is impaired by prolonged exercise in animals[2,3]; sense of position and movement is altered, and sensitivity to muscle vibration is decreased after fatigue.[3–5] Also, as Dr. Hoffman stated, the cause of the increase in postural sway may be an inability to maintain contractile force. This explanation has been supported by several authors[5,6] and challenged by others.[7,8] Although we do not suggest that the decrease in muscle spindle activity was the underlying physiologic cause, it is a viable alternative. More than likely, several linked physiologic mechanisms are impaired after fatigue.

We compared 2 indicators of fatigue and the duration of the postural stability disturbances they caused; we were not attempting to validate a specific isokinetic protocol for the induction of muscular fatigue. There is no ''gold standard'' measure of functional fatigue; however, it is accepted in the literature and at our scientific symposiums that 50% is a viable indicator of ''fatigue.'' Fatigue is often assessed with isokinetic[9–11] or isometric fatiguing contractions,[12,13] and/or more functional testing protocols,[14] using 50% as the indicator of fatigue. To our knowledge, no percentages have been ''accepted in the literature,'' thereby proving the need for comparisons, which was, in fact, the aim of our research. Our findings demonstrated that the 50% indicator resulted in postural stability disturbances but that these disturbances were not as long-lasting as those disturbances produced by the 30% indicator. This finding would appear obvious (more fatigue results in less potential to generate and maintain force), but to our knowledge, no comparison of different percentages of fatigue on postural stability has been reported. Therefore, our findings are unique and document the amount of time that postural stability is altered, which is particularly important for the scientific study of postural stability. For instance, providing the greatest window of time when the effect of fatigue is present may be warranted. We anticipate that our results will be more useful in future research regarding levels of fatigue and fatigue interventions and not as relevant in the clinical setting. Again, we thank you for the opportunity and found the process to be intellectually stimulating.

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