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Does Alteration of Balance Control After Ankle Muscle Fatigue in National Judo Athletes Depend on Postural Task Difficulty?

Amine Ghram [1, 2, *], Pablo B Costa [3], Louis-Solal Giboin [4], Sirine Abidi [5], Sameh Ghroubi [6], Mohamed Habib Elleuch [6] and Abdelmoneem Yahia [6]

[1] Department of Exercise Physiology, Faculty of Physical Education and Sports Sciences, University of Tehran, Tehran, Iran
[2] Healthy Living for Pandemic Event Protection (Hl - Pivot) Network, Chicago, IL, USA
[3] Department of Kinesiology, California State University, Fullerton, California, USA
[4] Sensorimotor Performance Lab, Department of Sport Science, University of Konstanz, Konstanz, Germany
[5] Research Laboratory Education, Motricity, Sport and Health (LR19JS01), High Institute of Sport and Physical Education of Sfax, University of Sfax, Sfax, Tunisia
[6] Department of Physical and Rehabilitation Medicine, Habib Bourguiba Hospital, Sfax, Tunisia

[*] *Corresponding author*: Department of Exercise Physiology, Faculty of Physical Education and Sports Sciences, University of Tehran, Tehran, Iran. Email: ghram.amine@hotmail.fr

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Abstract

Background: The purpose of the present study was to assess the impacts of plantar-flexors and dorsi-flexors fatigue following isokinetic contractions on postural control in nine young healthy national level judo athletes.

Methods: Participants were required to stand still on a force plate with opened and closed eyes in feet together (FT) and single leg (SL) stance before (PRE) and after (POST) an isokinetic fatigue protocol. Mediolateral sway (ML sway), anteroposterior sway (AP sway), and velocity sway were calculated and used to assess the postural control.

Results: Velocity sway POST was significantly ($P < 0.001$) higher than PRE in FT stance and SL stance. Velocity sway POST was significantly higher in the SL stance than the FT stance ($P = 0.01$). During eyes closed, a significant interaction postural task by fatigue for all parameters was found. All parameters increased significantly after fatigue compared to PRE. After fatigue, ML sway, AP sway, and velocity sway were significantly higher for the SL stance than the FT stance.

Conclusions: Ankle muscle fatigue led to reduced postural stability during different stances in young healthy judo athletes. This effect was more accentuated when vision was removed and the base of support was reduced. Alteration of postural control depended on the difficulty of the postural stance.

Keywords: Lower Limb, Muscle Fatigue, Balance, Judo, Posture

1. Background

Balance control plays an important role in sports related to postural control and may yield to a successful performance (1). Elite athletes use balance training to improve balance (2) and prevent lower extremity injuries (3). Moreover, poor balance in athletes is considered as a predictor of increased lower extremity injury risk (4). Plantar flexors (PFs) and dorsiflexors (DFs) muscles play a significant role for the maintenance of balance control during bipedal and unipedal balanced conditions (5, 6). Several studies geared towards the effects of ankle muscle fatigue on balance control (7-11). However, the results are contradictory. This inconsistence may be related to methodological differences through studies (7).

Indeed, postural control is altered when the degree of difficulty rises by varying the base of support (7, 12, 13), reducing the input from sensory system (14), or diminishing the neuromuscular system's efficiency with fatigue (15-18). These different variables can interact differently and explain the variations of performance.

Judo is a sport in which balance and coordination must be at the highest level, despite occurrence of large amount of neuromuscular fatigue that can impair postural control (19). A judoka needs to handle the center of the mass of the adversary relative to the base of their support and their adversary land on their backs with speed gathered in the fall as a consequence (20).

Balance disruptions due to falls and throws can lead to ankle injuries (21). Injury risk is higher in elite judokas (49 - 88%) during competition compared with training (22).

The safety of practitioners is of the highest priority and injuries can occur due to muscle fatigue which due to the high participation rate in a combat sport (23). Therefore, research on judo muscle fatigue in regard to postural control is essential in identifying risk factors.

Interestingly judokas, who compete at high level, uses the visual information more than lower level judokas to maintain their stability (24). Moreover, professional athletes predominantly utilize specific sensory information in regulating posture in relation with the requirements of each discipline (25, 26) and vision may be essential in posturokinetic activities as the competition level increases (24). Thus, it appears necessary to analyze the postural performance of judo athletes in situations where ankle muscles are fatigued and with or without visual information support.

In practice, judo athletes perform several throwing techniques performed efficiently in a variety of circumstances (27). Tokui-waza is a favorite technique performed by judokas on two or one leg support to induce an imbalance of an opponent (27). Thus, observing the effect of muscle fatigue specifically on bipodal or monopodal stance in judois relevant.

2. Objectives

Therefore, the purpose of the present study was to evaluate the effects of PFs and DFs muscle fatigue on postural control during bipedal or monopodal stance tasks with or without visual support in judo athletes. Based on previous study (7), we hypothesized that ankle muscle fatigue would alter the postural sway and this would be associated with task difficulty such as absence of visual information and change of base of support.

3. Methods

3.1. Participants

Nine national male judo athletes with right lower limb dominance (20.4 ± 2.83 years, 73 ± 9.05 kg, 180 cm ± 5 cm, weekly training: 10 - 14 hours, judo experience at least 10 years, level of competency: 1st and 3rd dan black belt) agreed to participate in this study. All participants d had competed in national tournaments. None had stopped training for more than three weeks during the six months before the study due to injury or other reasons. Literature shows that most injuries occur on the dominant side (28).

Exclusion criteria were neurological or musculoskeletal problems, history of falls, or ankle injury, in the past year that could affect their ability to perform the experiment. Participants wore nonrestrictive athletic clothing at the time of testing. Participants avoided strenuous activity 48 hours prior to the data collection session. Written informed consent was obtained from all participants. The study was approved by Research Ethics Committee of University of Sfax and conducted according to the Institutional Review Board and the Declaration of Helsinki.

3.2. Body Composition

Data identifying body composition were recorded under the same conditions in the morning and with participants not using any medication. Body height was measured using a digi¬tal stadiometer and body mass was measured using a digital scale (Seca Instruments Ltd., Germany). Body height was measured within 0.1 cm and body mass was measured within 0.1 kg. Body mass index (BMI) was calculated by diving body mass (kg) by height squared (m^2).

3.3. Postural Task

Postural data were collected using a static stabilometric platform (Satel; 480 × 480 × 65 mm; Satel, Blagnac, France) composed of a steel plate supported by three tri-axial transducers at a sampling rate of 40 Hz (29). This device has three strain gauges and records the displacement of the participant's foot pressure while standing on the platform. Static stance on the force platform consisted on changing the base of support. Participants were required to stand still on a force plate with their arms on their sides in two different stances with both visual conditions (7): Feet together (FT) stance with eyes opened (EO) and eyes closed (EC); single leg (SL) stance with EO and EC.

During the FT task, participants were asked to stand feet 30° apart (inter-malleolar distance of 5 cm). The participant was asked to stand still, with arms hanging by his side and knees straight. During the SL task, participants were required to stand on their dominant leg determined by the preferred kicking leg. They were instructed to sway as little as possible. The other leg was held in a position of neutral hip extension and 90° of knee flexion. For the two tasks, participants were instructed to stand upright and look straight ahead at a point approximately two meters away at eye level. According to the French Posturology Association normative standards, each trial lasted 51.2 sec (29) for FT task and 30 sec (8) for SL tasks. The rest time between each condition (FT-EO, FT-EC, SL-EO, and SL-EC) was set at10 seconds. All conditions were performed before and after the fatigue protocol. The task order was randomized between judo athletes. These conditions were new to the judo athletes as they did not correspond to the usual balance situation found in the specific practice of judo.

Four postural parameters were calculated in this study to assess balance performance: "Medio-lateral sway (ML sway)" represented the center of pressure (CoP) sway in ML direction (mm), "antero-posterior sway (AP sway)" represented the CoP sway in antero-posterior (AP) direction (mm), and "velocity sway (mm/s)" represented by the total CoP displacement divided by time. An increase in static balance scores indicates impairment in the balance of the individual.

3.4. Ankle Fatigue Muscle Protocol

Immediately following the postural tasks and not exceeding 40 sec, participants performed the fatigue protocol using an isokinetic dynamometer (Cybex Norm II; Medimex). In order to determine the initial peak torque (IPT) values, two sets of concentric/concentric ankle plantar/dorsiflexion movements were performed at 60°/s throughout a 90° range of motion during the concentric contraction (29). The first set was a familiarization task and consisted of three submaximal and three maximal contractions. In the second set, three trials of maximal effort were performed with no rest between repetitions. The highest peak torque of three repetitions was recorded as IPT (30).

Regarding the isokinetic ankle test, the participant laid on a supine position with the hip and knee straight. Velcro straps secured the chest, pelvis, thigh, and foot. An anti-slip mat was placed under the back to prevent the participant sliding on the bench, and a towel was folded under the straight knee to minimize uncomfortable hyperextension. The arms were kept crossed over the chest. The axis of rotation just distal to the lateral malleolus was aligned with the rotational axis of the lever arm on dynamometer. The range of motion of the ankle joint was set at 10° dorsiflexion and 40° plantar flexion. The 90° position of the ankle joint was regarded as the neutral 0° position.

After a 2- to 3-min rest, the fatigue protocol was started, during which participants performed maximal continuous concentric/concentric plantar/dorsiflexion movements at 60°/s. The test was performed with the dominant limb, defined as the preferred leg to kick a ball. The choosing of the dominant leg is explained by the possible etiological factor in predicting an injury because the joints of the non-dominant limb were thought to be more unstable during maneuver in judo as in cutting, stopping, and jump landing. Fatigue was deemed to have occurred when the torque output in both directions decreased below 50% of IPT for three consecutive movements (8, 17, 31). Verbal encouragement was given throughout all tests and fatigue protocols. After completing the fatigue protocols, participants left the dynamometer and conducted a postural stability task with a delay of no more than 20 s. All data obtained to examine the change of postural control ability before and after muscle fatigue were described by mean and standard deviation to identify their patterns.

3.5. Statistics Analysis

Data were assessed for normality and homogeneity of variance using the Shapiro-Wilk and Levene tests, respectively. Mean and standard deviation (SD) values were calculated for each dependent variable. A three-way within participant ANOVA (2 fatigue × 2 postural task × 2 vision) was used to assess potential differences between fatigue (PRE vs. POST), postural task (FT vs. SL), and vision (EO vs. EC) on the dependent variables: ML sway, AP sway, and velocity sway. Bonferronni post-hoc analysis was performed if necessary. All statistical tests were processed using STATISTICA Software (version 8.0; StatSoft, France). For all statistical tests, the significance level was set at 0.05.

4. Results

4.1. ML Sway

There was no three-way interaction (fatigue × vision × postural task) and no two-way interactions for fatigue × postural task or vision × postural task ($P > 0.05$). However, there was a significant interaction for fatigue × vision ($P < 0.001$) (Table 1). ML sway increased in both EO and EC conditions for the FT and SL stances ($P < 0.001$) with greater increases in the EC than that in the EO. As expected, there was a main effect of postural task indicating ML sway was higher for the SL than the FT stance ($P < 0.01$) (Figure 1).

4.2. AP Sway

There was no three-way interaction (fatigue × vision × postural task) and no two-way interaction for vision × postural task ($P > 0.05$). However, there were significant interactions for fatigue × vision ($P < 0.001$) and fatigue × postural task ($P = 0.02$) (Table 1). AP sway increased in both EO and EC conditions for the FT and SL stances ($P < 0.001$) with greater increases in the EC than that in the EO. In addition, AP sway increased in both FT and SL stances for the EO and EC conditions ($P < 0.05$) with greater increases in the SL than that in the FT stance (Figure 2).

4.3. Velocity Sway

There was no three-way interaction (fatigue × vision × postural task) and no two-way interaction for vision × postural task ($P > 0.05$). However, there was a significant interaction for fatigue × vision and fatigue × postural task ($P < 0.001$) (Table 1). Velocity sway increased in both EO and EC condition at FT and SL stance ($P < 0.001$) with greater

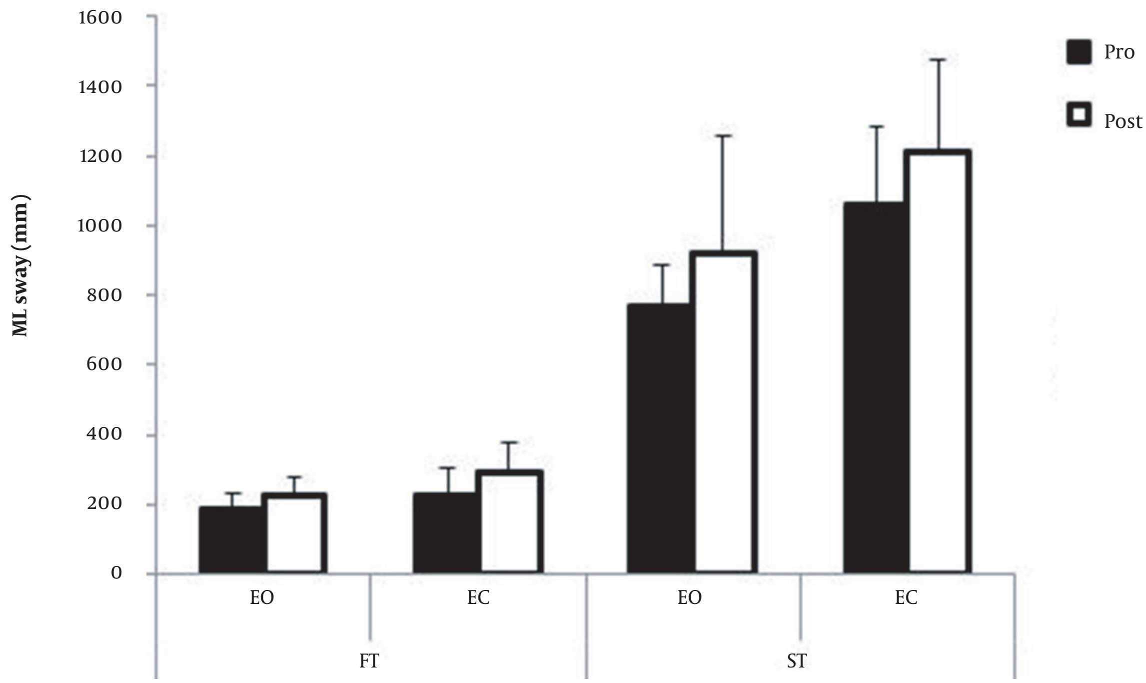

Figure 1. Mean values and standard deviation (SD) of ML sway in the two conditions of pre (pre-fatigue) and post (post-fatigue) under two postural task (FT, feet together vs. SL, single leg) with eyes open (EO) or eyes closed (EC).

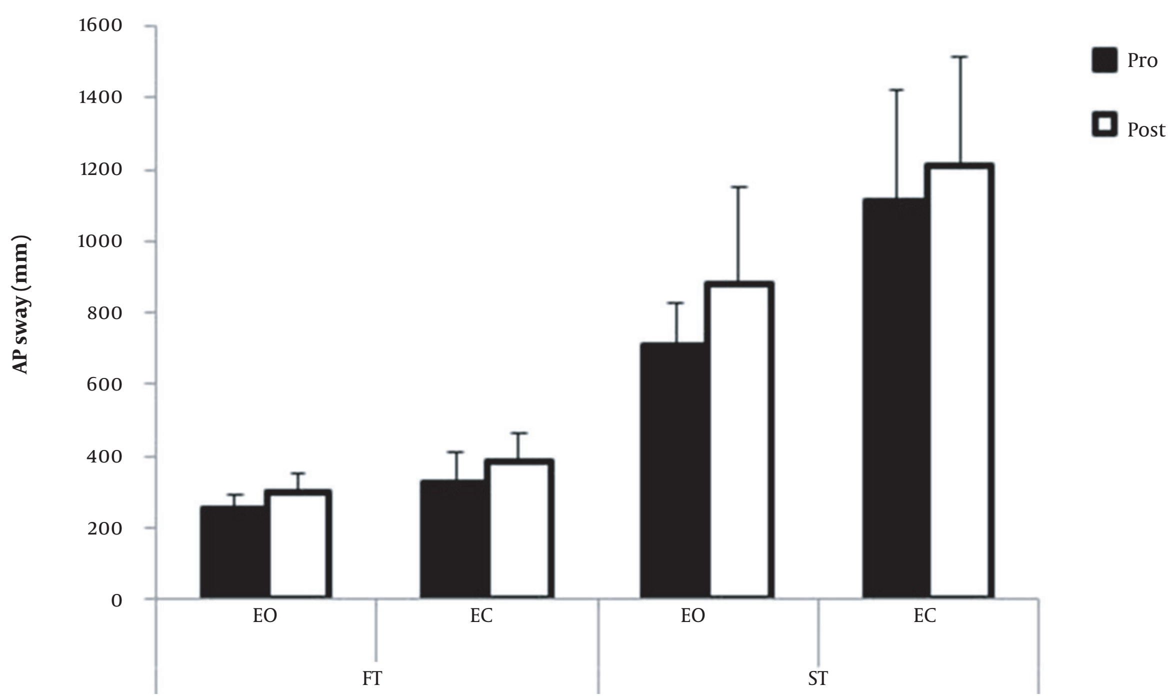

Figure 2. Mean values and standard deviation (SD) of AP sway in the two conditions of pre (pre-fatigue) and post (post-fatigue) under two postural task (FT, feet together vs. SL, single leg) with eyes open (EO) or eyes closed (EC).

Table 1. Results of the Three-Way ANOVA (Fatigue × Vision × Postural Task) for the Three Postural Variables: F Ratio and P Values by Variable Independent [a]

Effects	ML Sway		AP Sway		Velocity Swat	
	F Ratio	P-Value	F Ratio	P-Value	F Ratio	P-Value
Fatigue	76.86	< 0.001	62.12	< 0.001	176.65	< 0.001
Vision	81.08	< 0.001	75.92	< 0.001	74.65	< 0.001
Postural task	18.66	0.002	34.07	< 0.001	40.86	< 0.001
Fatigue × vision	53.24	< 0.001	47.74	< 0.001	41.25	< 0.001
Fatigue × postural task	NS		7.51	0.02	30.41	< 0.001
Vision × postural task	NS		NS		NS	
Fatigue × vision × postural task	NS		NS		NS	

Abbreviations: ML sway, mediolateral sway; AP sway, anteroposterior sway.
[a] NS: non-significant ($P > 0.05$).

increases in the EC than that in the EO. In addition, velocity sway increased in both FT and SL stances for the EO and EC conditions ($P < 0.001$) with greater increases in the SL than that in the FT stance (Figure 3).

5. Discussion

The present study investigated the effects of fatigue of the PFs and DFs muscles on postural task performance characteristics in judo athletes. The findings of the present study showed postural sway increased after ankle muscle fatigue. Furthermore, the postural sway with EC was more altered by fatigue and was greater during SL stance than FT stance for AP sway and velocity sway. To our knowledge, this study is the first description of a disturbance of different postural control task after isokinetic ankle muscle fatigue in judo athletes.

5.1. Effect of Fatigue

Our results showed that isokinetic ankle muscle fatigue induced a perturbation in postural sway under different task difficulty. Previous studies examined the effects of ankle muscle fatigue on postural control (7-11). However, the use of different methods to induce the fatigability of ankle muscle and the variety of balance control protocol were probably at the origin of the inconsistent results across studies. It was reported that fatiguing of PFs and DFs simultaneously was related with greater alteration in postural stability than when the PFs or DFs were fatigued separately in healthy adults (8). Although the ankle strategy is predominantly utilized during quiet standing, the use of the hip strategy augments with the task difficulty (32). We presume that here, the SL and FT stance were controlled by a combination of ankle and hip strategy. Thus, the impairment of ankle proprioception could have been compensated by an increased reliance on the hip strategy (32).

Interestingly, our results differ from previous studies. In our study, we used unilateral dynamic isokinetic contraction to induce fatigue in both PF and DF, which resulted in significant impairment of postural control in both ML and AP directions, and in a higher impairment the more difficult the task. This differ from Bisson et al. who have shown that fatiguing isometric or isokinetic contractions of PF lead to postural impairments only in the AP direction (33), and different from Bisson et al. who have shown that isometric fatiguing contraction of PF had no differential effect on postural tasks of different difficulty (7). The one muscle fatigue group can lead to changes different than those caused by the simultaneous fatigue of the same muscle group and its antagonist muscles, because of differential effects on variables affecting postural control, such as joint stiffness (34) or weighting of proprioceptive information (35). Besides, the more muscle fatigue, the more proprioception impairment associated with fatigue could be important and consequently lead to a greater decrease in postural control (8). Thirdly, the higher the muscle fatigue and the higher proportion of motor units (MU) required to be activated to produce the same force/power. Also, the higher the muscle fatigue, the higher variability in MU activity (36). All these effects induce a higher production of noise in the central nervous system (CNS) and in the muscle, leading to a more random motor command and possibly a more impaired balance performance.

5.2. Effect of Vision

The present study revealed that postural sway was significantly higher during EC condition than EO condition. Our results confirm the importance of visual information for postural control, particularly during

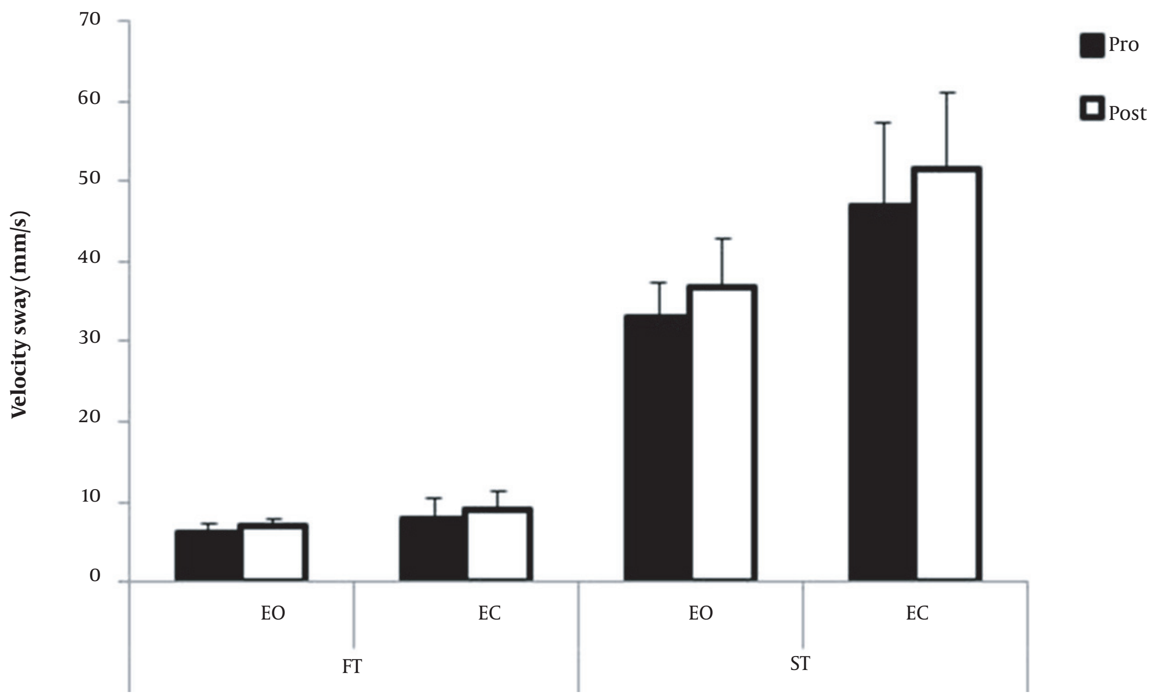

Figure 3. Mean values and standard deviation (SD) of velocity sway in the two conditions of pre (pre-fatigue) and post (post-fatigue) under two postural task (FT, feet together vs. SL, single leg) with eyes open (EO) or eyes closed (EC).

difficult tasks (7). Our results are in line with studies that have shown increases in CoP sway when standing with eyes closed (37-39), during tandem stance (39), during SL stance (37), or during FT stance (38). Riemann et al. revealed a rise increase in sway from the FT task to the SL task (13).

Further, the data of the present study showed a significant interaction between vision and fatigue for all parameters. The present results are in agreement with previous studies that examined the effects of ankle fatigue on the FT task with EO or EC (7, 16, 40, 41). These results emphasize the importance of vision to maintain postural control in fatigued conditions. We speculate that with the impairment of proprioception due to fatigue, the postural control system relies more on the visual system.

In addition, the postural task in the present study was executed when the visual information was absent which indicated that the vision can mitigate the destabilizing the effect of muscle fatigue which induced by PFs and DFs muscles on bipedal and unipedal postural control. Also, closing the eyes leads to avoid visual information which interfere with the induction of postural behaviours and can allow assessing the accurate effect of unilateral ankle muscles fatigue on the control of bipedal and unipedal leg stance.

The present findings suggest that PFs and DFs muscle fatigue impaired the effectiveness of the postural control system and increased the amount of postural regulatory activity required when the postural support surface information was altered by standing on bipedal stance to a greater extent than when it was unipedal stance.

5.3. Limitation

The main limitation of the present study is that we used unilateral fatiguing contractions only while comparing balance performance between unipedal and bipedal stance. Therefore, the interaction between fatigue or vision and the task difficulty (i.e. bipedal vs. unipedal stance) found in the present study could be a methodological bias. Experiments with fatiguing contractions on both sides in both PF and DF should be done to conclude on this topic.

Further, isokinetic dynamometer was used for the induction of fatigue instead of more ecological fatiguing task (e.g. test performed pre and post training or even competition). However, this was not possible, as we could not use the stabilometric platform outside the research laboratory. Another limitation comes from the small sample size. It must be noted that the sample comprised exclusively young, male judokas participants to avoid possible differences caused by sex, and other types of sport. Finally, because postural performance is most probably specific to the task trained (42), future research should involve the investigation of more ecological, dynamic and/or functional tasks.

5.4. Conclusions

Maximal, short-duration fatiguing exercise involving plantar and dorsiflexion at an angular velocity of 60°/s resulted in impairment of postural control in AP and ML directions as well as an increase in postural sway. Moreover, these impairments were accentuated with eyes closed when compared with eyes open. It also seemed that the effect of fatigue on balance performance was dependent to the intrinsic difficulty of the balance task. Collectively, these findings underscore the importance of stability performance by taking into account specific muscle fatigue. If a judo athlete does not have adequate balance, he or she cannot perform at their highest level. Practically, the benefits of an adequate balance may provide an enhanced sense of control to the judo athletes. In addition, judo athletes have to improve their stability under different difficulty, and should possibly be aware of the importance of visual information when performing under highly fatiguing conditions. Sports researchers, athletic trainers, physiotherapists, and physicians should be aware of these effects when determining an appropriate exercise protocol for unipedal and bipedal postural control after injury and could benefit from a known relationship between postural performances and ankle muscle fatigue as a consequence of training throughout a sports season.

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Footnotes

Authors' Contribution: A. G., A. Y.: study concept, and design. A. G., P. B. C. : drafting of the manuscript. A. G., L.G. : statistical analysis. S. A., S. G.: performed parts of the statistical analysis and helped to draft the manuscript, and revised the manuscript. L. G.: collected the clinical data and interpreted them. L. G., A. Y.: revised the manuscript. M. H. E.: administrative, technical, and material support, and study supervision. All authors read and approved the final manuscript.

Conflict of Interests: The authors declare that they have no conflicts of interest concerning this article.

Data Reproducibility: The data presented in this study are openly available in one of the repositories or will be available on request from the corresponding author by this journal representative at any time during submission or after publication. Otherwise, all consequences of possible withdrawal or future retraction will be with the corresponding author.

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