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A single session of hip abductors resistance exercise until failure changes shank muscle activation during landing tasks

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HIGHLIGHTS
- Greater degree of supination of the foot was observed in single-leg landing
- Higher activation of tibialis anterior was observed in double-leg landing
- Higher activation of peroneus longus was observed in single-leg landing
- Hip abductors exercise until failure reduces peroneus longus activation on landings.

ABBREVIATIONS

MVICs	Maximal voluntary isometric contractions
PL	Peroneus longus
RMS	Root mean square
TA	Tibialis anterior

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BACKGROUND: Weakness in the hip abductors can lead to lower limb misalignment and an elevated risk of injury. This can result in compensatory mechanisms at the ankle to maintain stability.
AIM: To verify the effects of a single session of hip abductors resistance exercise until failure on the foot pronation and EMG amplitude of shank muscles (peroneus longus - PL; tibialis anterior - TA) during landing tasks.
METHOD: Seventeen participants completed single-leg and double-leg landings both before and after a single session of hip abductors resistance exercise until failure. The exercise consisted of four sets of 10 repetitions maximum, with a 2-minute rest interval between each set. Measurements of PL and TA EMG amplitude and degree of foot pronation were performed during landings.
RESULTS: We observed a greater degree of supination of the foot during single-leg compared to double-leg landing ($p=0.006$), without effect of exercise. Regarding TA EMG amplitude, there was no exercise effect ($p=0.951$), with a higher amplitude observed in double-leg compared to single-leg landing ($p=0.001$). EMG amplitude of PL was higher during single-leg compared to double-leg landing ($p=0.003$) and the exercise significantly reduced its activation in both tasks ($p=0.032$).
CONCLUSION: Single-leg and double-leg landings exhibited variations in mechanics and activation patterns of the distal muscles. Following a single session of hip abductors resistance exercise until failure, there was a reduction in PL activation during landing tasks. This suggests that there were neuromuscular compensations occurring distally due to alterations in the hip abductor muscles.

KEYWORDS: Hip abductors | EMG | Ankle | Kinematics | Landing

INTRODUCTION

The gluteal muscles are a group of three muscles that are responsible for the stability and mobility of the lower limbs. They are anatomically divided into the gluteus maximus, gluteus medius, and gluteus minimus [1]. The gluteus medius muscle is a key player in pelvic stability and femoral movement control [2]. The gluteus medius is the primary hip abductor, accounting for 60% of the cross-sectional area of the abductor group. The gluteus minimus accounts for 20% of the cross-sectional area, and the tensor fascia latae accounts for 11% [3].

The hip abductors play a vital role in maintaining postural stability [4-6]. Weakness in the hip abductors has been identified as a significant factor associated with lower limb injuries, including femoroacetabular impingement [7], patellofemoral pain [8], anterior cruciate ligament rupture [9], low back pain [10], and ankle sprains people [11]. The muscles of the ankle and hip joints work together to control posture and balance in a variety of movements, especially those involving anteroposterior and mediolateral instabilities. This synergy is essential for maintaining stability [12].

Strong hip muscles are essential for maintaining ideal foot positioning during the heel strike phase [13]. Alterations or delays in muscle responses of joints can lead to kinematic changes, which can increase the risk of injury [14]. The muscles of the proximal and distal joints must work in harmony and have the coordination to maintain balance. The hip abductors play a vital role in stabilizing the trunk and pelvis, and preventing knee valgus during single-leg tasks [4]. The peroneus longus stabilizes the forefoot when the heel lifts off the support surface, while the tibialis anterior resists foot pronation [15].

Previous studies have investigated whether inducing weakness in the hip abductor muscles would lead to alterations in the ankle muscles, as this could result in a loss of postural stability [16, 17]. In line with this, Lee et al. [17] found that weakness in the hip abductors induced by an exercise protocol in healthy subjects led to postural misalignment and early activation of the peroneus muscles during unilateral landing. This demonstrated a compensatory effect to maintain foot stability and minimize the tendency for ankle inversion [17]. However, it is important to investigate whether such compensation also occurs in bilateral tasks, and whether these tasks elicit different activation responses in the distal muscles of the lower limb. This could aid in comprehending the involvement of distal muscles in upholding stability. Consequently, it may also shed light on the potential lower limb injuries arising from these compensatory mechanisms.

Therefore, the present study aimed to examine the effects of a single session of hip abductors resistance exercise until failure on foot kinematics and shank muscle activation during landing tasks in healthy subjects. We hypothesized that exercise session until failure would modify the EMG responses of distal muscles, mainly during single-leg tasks due to the increased stability demands.

METHODS

Participants

A total of 17 participants (9 females and 8 males) with no history of lower limb injury and a minimum of 3 months of strength training experience participated in the study after promotion on social media, at gyms, and on the university campus (age: 28.41 ± 6.05 years; body mass: 71.91 ± 12.88 kg; height: 1.69 ± 0.08 m; BMI = 24.91 ± 2.60 kg/m²; body fat percentage: 22.57 ± 0.04%). All participants trained with a minimum frequency of twice a week and were not engaged in any other high-volume training modality. On average, our participants had 6.11 ± 4.24 years of strength training experience. All participants provided informed consent before the study, and the study protocol was approved by the university's research ethics committee (approval number 76759817.7.0000.5668).

Experimental Design

Participants visited the laboratory on two separate days, with at least seven days between visits. On the first day, participants completed the Informed Consent Form, underwent body composition assessment, and performed a 10-repetition maximum test for hip abduction exercise in the side-lying position. This exercise was selected based on a previous study conducted in the laboratory, which demonstrated higher activation of the hip abductor muscles during this exercise [18].

On the second day, participants underwent the following assessments: (i) maximal voluntary isometric contraction of ankle dorsiflexors and evertors; (ii) kinematics and EMG parameters of the ankle muscles (peroneus longus - PL and tibialis anterior - TA) during single-leg or double-leg landing tasks (randomly determined); (iii) hip abductor strength exercise until exhaustion. Landing tasks were repeated after completing the exercise for comparison purposes.

Determination of exercise load

On the first day, the load for the side-lying hip abduction exercise was determined using the 10-repetition maximum test. Prior to the test, each participant performed a warm-up for the target muscles, consisting of 15 hip abduction repetitions in the side-lying position with a submaximal load. Participants were also familiarized with the controlled movement speed set at 60 beats per minute, guided by a metronome. The load was determined through trial and error, with three attempts performed and a five-minute interval between each attempt to minimize the effects of fatigue on the results [18]. In cases where the load could not be determined within the three attempts, the assessment was rescheduled for a future session.

Maximal Voluntary Isometric Contraction

On the second day, maximal voluntary isometric contractions (MVICs) were performed. The position for collecting the MVICs were chosen to maximize the muscle activation of both muscles. For the ankle evertors, participants were seated with their hip and knee extended and the dominant ankle in a neutral position. Participants were instructed to exert maximum force in ankle eversion against an external resistance. For the dorsiflexor muscles, individuals performed the movement while standing with the ankle in a neutral position. They were instructed to exert maximum force in ankle dorsiflexion against an external resistance [16].

Kinematic analysis during the landing tasks

Non-reflective colored adhesive markers were placed at four points [distal to proximal]: (i) 20 mm above the ground in the central region of the calcaneus; (ii) 50 mm above the ground in the central region of the calcaneus; (iii) at the Achilles tendon region in line with the lateral malleolus; and (iv) 150 mm above point C, in the center of the leg [19]. These markers were used to facilitate kinematic analysis during the execution of the landings. The participants stood on a standardized marking on the floor, with their feet parallel and positioned shoulder-width apart. They were instructed to maintain a bipedal stance initially, and an image was captured in this position to assess the degree of foot pronation at rest with bilateral support.

Subsequently, participants ascended a platform measuring 40 cm in height. In the case of the single-leg landing task, participants were directed to establish a stance on one leg, ensuring a vertical trunk position, while the opposite leg remained flexed at the knee. As for the double-leg landing task, participants maintained a stance with both legs offering support. Upon the researcher's instruction, participants performed forward jumps followed by landings. These landings were carried out with either single-leg support (using the dominant leg) or dual-leg support, a sequence that had been randomized beforehand. The objective was to accomplish the action comfortably, minimizing any balance disruptions while adhering to a designated floor marking. Following a period of familiarization and once participants felt prepared for official task execution, each task involved consecutively performing three landings [20].

In the frontal plane, a digital camera (Nikon CoolPix S203) with a sampling rate of 30Hz was located at the calcaneus level, positioned one meter distant from the participants. For the sagittal plane, recording was accomplished through a notebook's webcam (Sony Vaio CORE i3/ Model PCG-71911X), synchronized with the EMG signals originating from the Miotool 400 electromyograph (Miotec - Equipamentos Biomédicos, Porto Alegre, RS, Brazil) [16, 20]. The video recorded in the sagittal plane played a crucial role in pinpointing the EMG signal analysis. Both cameras were configured to consistently record videos throughout the entire test execution. The video recorded from the frontal plane was transferred to a computer to subsequent kinematic analysis, achieved through the utilization of Kinovea software (Kinovea Organization, France). For the analysis of kinematic parameters, the average derived from the three valid attempts was employed [16].

The measurement of subtalar joint pronation/supination involved calculating the angle disparity between the tibiocalcaneal segments, spanning from the initial stance in bipedal support to the final position during the either double and single-leg landing tasks. This final position was ascertained commencing from 230 ms following the limb's initial ground contact, as outlined by previous research[20]. The precise point of initial contact was recognized as the frame capturing the instance when the foot made contact with the ground. In this frame, a stopwatch was visible on the Kinovea interface and initiated timing. The frame corresponding to the 230 ms mark determined the measurement point (Figure 1).

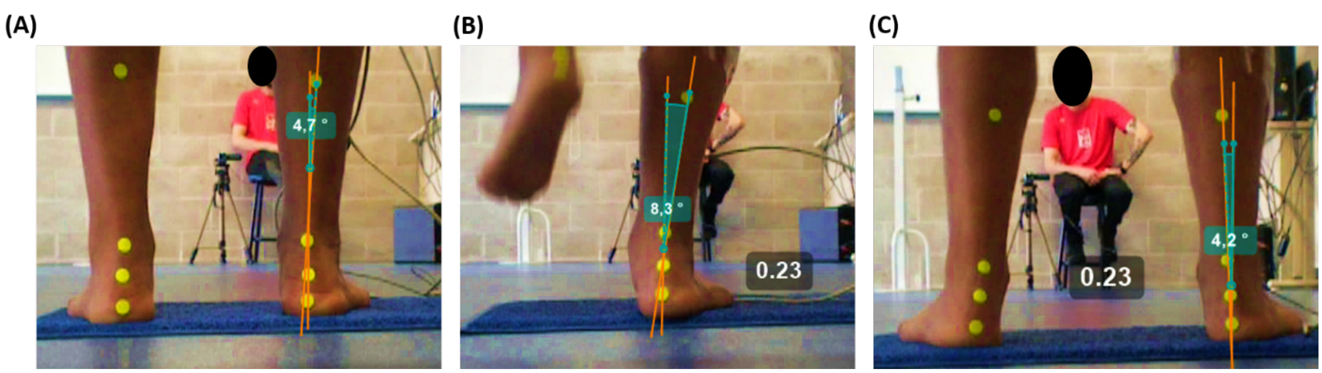

Figure 1. Measurements of foot pronation degree through kinematics during landing. Initial position in standing, with bilateral support (A), during single-leg landing (B), and double-leg landing (C).

EMG data acquisition

For the acquisition of the EMG signals, a Miotool 400 electromyograph (Miotec - Biomedical Equipment, Porto Alegre, RS, Brazil) was used, with a sampling rate of 2000 Hz per channel. The EMG signals from the PL and TA muscles were measured using pre-amplified surface electrodes with a bipolar configuration (Mini MediTrace 100, Kendall Medtrace), during all isometric contractions and during the performance of the landing tasks.

Prior to electrode placement, the process of reducing the skin's electrical impedance was conducted in accordance with the Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines [21]. For the PL muscle, the electrode pair was situated at a position equidistant (1/4) between the head of the fibula and the lateral malleolus. Regarding the TA muscle, the electrode pair was positioned at a location one-third (1/3) along the distance from the tip of the fibula to the medial malleolus. The reference electrode was affixed to the tibia. The electromyograph captured and recorded the signals using Miotec Suite software (Miotec - Biomedical Equipment, Porto Alegre, RS, Brazil)

EMG data analysis

The EMG data underwent analysis using Miotec Suite version 1.0 software (Miotec Biomedical Equipment, Porto Alegre, RS, Brazil), which included applying a band-pass filter (5th order Butterworth; with cut-off frequencies set at 20-500Hz) to the signals. These signals were subsequently subjected to smoothing, and the root mean square (RMS) value was derived using a moving window of 160 ms. Throughout the MVICs, the electromyograph-recorded signal served as the reference for identifying a 3-second window. This window aligned with the point of peak signal amplitude and stability. The MVIC displaying the most substantial activation amplitude was designated as the peak activation for the assessed muscles. These recorded values served as benchmarks to normalize the signals observed during the landing tasks, represented as percentages of the maximum. During the landing procedures, the RMS value was computed within the 230 ms after the initial foot-ground contact. This was determined through visual examination using synchronized imagery alongside the EMG data collection software, as detailed in our prior research [20].

Hip abductor resistance exercise until failure

Following the execution of the landing task, participants engaged in an exercise regimen encompassing 4 sets of side-lying hip abduction exercises, with each set targeting a maximum of 10 repetitions until concentric failure was reached. The exercise was executed at a cadence of 60 bpm, while a 2-minute pause was observed between successive sets. This particular protocol has been previously validated as capable of inducing muscle fatigue [16]. Right after concluding the exercise session, participants proceeded to perform the landing tasks to enable a comparative analysis.

Statistical Analysis

The Shapiro-Wilk test was used to assess the normality of the data. Descriptive statistics (means and standard deviations) were obtained. A factorial ANOVA was employed to compare the EMG amplitude of the PL and TA muscles and the degree of foot pronation during the landing in both tasks (single-leg and double-leg) and time (pre- and post-fatigue). A Bonferroni post-hoc test was conducted to identify the differences in case of a significant interaction. All analyses were performed using SPSS 20.0 software, with a significance level set at 0.05.

RESULTS

Regarding the kinematics, we did not observe an effect of the time (p=0.153) or a time-task interaction (p=0.163). However, a significant effect of the task was observed (p=0.006), indicating a higher degree of foot supination during single-leg landing than double-leg landing (Figure 2).

Regarding the EMG amplitude of the PL muscle, we identified significant effects of the task (p=0.003) and time (p=0.032), although no interaction between task and time was observed (p=0.523). Specifically, the PL muscle exhibited greater activation during single-leg landings, whereas lower activation was observed after the exercise session in both tasks. In relation to the EMG amplitude of the TA muscle, no significant effect of time was observed (p=0.951), nor did we detect an interaction between task and time (p=0.654). Nevertheless, the TA muscle displayed greater EMG amplitude during double-leg landings compared to single-leg landings (p=0.001) (Table 1).

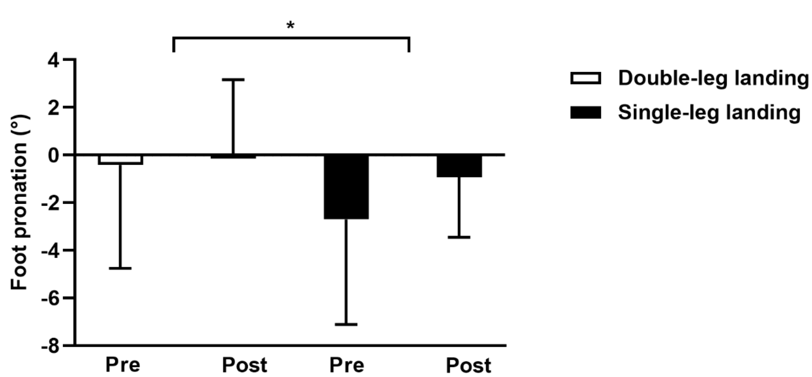

Figure 2. Degree of foot pronation in each task and time. Negative values indicate a higher degree of foot supination. *different between tasks.

Table 1. EMG amplitude of shank muscles during landing tasks

	Double-leg landing		Single-leg landing	
	Pre	**Post**	**Pre**	**Post**
PL (%CIVM)	99.28 ± 60.42	80.49 ± 39.45#	137.57 ± 68.90*	127.97 ± 66.20*#
TA (%CIVM)	63.91 ± 26.04	65.08 ± 28.72	48.86 ± 21.51*	47.94 ± 23.91*

Legend: PL = peroneus longus; TA = tibialis anterior; %MVIC = percentage of maximum voluntary isometric contraction; * different activation from double-leg landing; # lower activation than pre-exercise condition**.**

DISCUSSION

The aim of this study was to investigate the effect of a session of hip abductor resistance exercise until failure on foot kinematics and EMG amplitude of muscles involved in lateral (PL) and medial (TA) foot stabilization during different landing tasks. The results demonstrated that: (i) exercise until failure did not cause any changes in kinematics and TA EMG amplitude during both tasks; (ii) there was a significant reduction in PL EMG amplitude in both tasks after the hip abductor exercise until failure; (iii) single-leg landing resulted in a higher degree of foot supination compared to double-leg landing; (iv) PL EMG amplitude was higher in single-leg landing, and (v) TA EMG amplitude was higher in double-leg landing.

The diminished strength of the hip abductors, specifically the gluteus medius, is linked to increased levels of hip medial rotation and adduction during weight-bearing activities [22, 23]. These movements have the potential to trigger adjustments in the lower extremities and thereby compromise overall stability. Nonetheless, it's crucial to emphasize that individuals exhibiting higher dynamic knee valgus may demonstrate an excessive foot pronation [8, 24]. Alterations in the strength levels and activation parameters of the peroneus muscles have been recognized as a potential risk factor for lateral foot inversion [25], along with modifications in the reaction time of the tibialis anterior muscle during tasks which creating an ankle inversion mechanism [26]. Hence, the activation of these muscles plays a pivotal role in upholding stability, as they actively engage when the foot establishes contact with the ground during locomotion activities [17, 27].

Based on our results, a single session of hip abductors resistance exercise until failure reduced the PL EMG amplitude during both landings, which aligns with our hypothesis. The PL is a crucial muscle for preventing ankle inversion [28]. Following the landing subsequent to the hip abductor fatigue protocol, individuals might incline their trunk towards the supporting limb, causing a lateral shift in the center of mass and increasing the demand on the PL muscle to stabilize the ankle and sustain balance [17]. However, our study recorded a decrease in PL EMG amplitude following the exercise. It's plausible that the exercise utilized might not have exerted sufficient potency to markedly diminish hip abductor strength during landing. Consequently, we speculate that exercise create a warm-up effect [29] on the hip muscles could have potentially enhanced the stabilization role of the hip abductors. This could have led to a reduced tendency for lateral center of mass displacement and consequently required less activation of the PL for ankle stabilization during landing. Future studies need to confirm this speculation.

Our study demonstrated that single-leg landing resulted in a higher degree of supination and PL EMG amplitude, while double-leg landing led to greater TA EMG amplitude. During single-leg landing, the center of mass exhibits a more pronounced lateral displacement, which generates greater tendencies for lateralization, leading to increased foot supination and PL activation [30], as observed in our results. This activation is essential as it acts as a crucial stabilizer, aimed at diminishing the tendency for ankle inversion [28]. Conversely, in the case of double-leg landing, there exists an augmented predisposition for ankle eversion upon initial contact. This could elucidate the higher TA EMG amplitude in the double-leg landing, a stabilizing muscle positioned medially that contributes to ankle inversion [31].

We demonstrated that performing a single session of hip abductors resistance exercise until failure reduced the role of lateral ankle stabilizer muscles during landings. Therefore, future studies should investigate the role of proximal muscle strength exercise protocols on ankle and foot mechanics during other tasks, such as running. There are some important limitations in our study: (i) the use of 2D kinematic measurements does not allow us to assess changes that may occur in the transverse plane, such as tibial rotation, which has been found in previous studies [32]; (ii) the cameras had a low sampling frequency, especially for a fast task like landing, which may have introduced a degree of imprecision in the determination of events; (iii) furthermore, we chose to only monitor the TA and PL muscles, while the soleus muscle plays an important role in foot stabilization and knee load reduction [33]; (iv) another consideration is that we did not impose restrictions on the participants' foot strike patterns. This choice introduces greater variability within the sample concerning pronation levels, which in turn complicates the task of identifying significant differences.

CONCLUSION

Performing a single session of hip abductors resistance exercise until failure did not lead to changes in foot kinematics, but it did result in a reduction in peroneus longus EMG amplitude in both landing tasks. These findings suggest a connection between the loading of hip muscles and subsequent neuromuscular compensations in more distal regions during double-leg and single-leg landing tasks.

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