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Different neuromuscular parameters are associated with knee abduction and hip adduction angles during functional tasks

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ABSTRACT

Knee abduction and hip adduction during functional tasks may indicate increased joint injury risk and discriminate between pathological and healthy people. Muscles' neuromuscular variables such as amplitude (EMG_{AMP}) and onset (EMG_{ONSET}) have been used to explain kinematics. The study aimed to evaluate the correlation between two EMG variables of seven trunk and lower limb muscles and 3D kinematics during two tasks. Eighteen physically-active women participated in the study. The following variables were obtained during single-leg squat and anterior step-down: (i) EMG_{AMP} and EMG_{ONSET} of fibularis longus (FL), tibialis anterior (TA), vastus medialis (VM), biceps femoris (BF), gluteus medius (GMED), ipsilateral (OB_IL) and contralateral (OB_CL) external obliques and (ii) knee abduction and hip adduction angular displacement (initial angle – angle at 60° of knee flexion). Spearman's correlation coefficient was calculated between kinematic and EMG variables. Greater knee abduction was correlated with delayed TA_{ONSET}, $GMED_{ONSET}$ and OB_IL_{ONSET} during step-down. Greater hip adduction was correlated with lower VM_{AMP}, BF_{AMP} and delayed VM_{ONSET} during step-down. Although task-specific, these results suggest that EMG_{ONSET} may influence knee abduction, while both EMG_{ONSET} and EMG_{AMP} may affect hip adduction. The identification of muscle activation patterns in relation to kinematics may help the development of injury prevention and rehabilitation programs.

1. Introduction

Kinematics of functional tasks may indicate increased injury risk and discriminate between pathological and healthy people (Nakagawa et al., 2012; Räisänen et al., 2018). In particular, increased knee valgus has been observed in people that went on to have a knee injury (Räisänen et al., 2018) and in people with patellofemoral pain (Nakagawa et al., 2012). Moreover, individuals with chronic conditions such as patellofemoral pain have also displayed increased hip adduction angles during single-leg squats (Nakagawa et al., 2012). Although these variables are considered relevant for injury risk estimation, the neuromuscular factors that are associated with specific motion patterns are insufficiently studied in the literature.

The relationship between knee and hip kinematics and forces generated by the muscles is complex. While frontal plane hip movement is largely controlled by muscles that primarily act on the joint (e.g., gluteus medius and tensor fascia latae), there are no muscles whose primary function is to move the knee in the frontal plane given that it is a bicondylar joint (Neumann, 2010). Despite that, knee abduction still occurs passively during functional tasks where the foot is in contact with the ground (Nakagawa et al., 2012). During these closed-chain tasks, the forces that generate this passive knee abduction are exerted by the ground reaction forces through the distal segments (foot and shank) and by the upper body mass through the proximal segments (trunk and hip) (Powers, 2010; Tiberio, 1987). Therefore, the association between frontal plane hip and knee angles and local (knee or hip), distal and proximal muscle activation can help us understand why these movements occur. In particular, we can hypothesize that the muscles that act as prime movers in frontal plane movement, such as the tibialis anterior and fibularis longus at the ankle, gluteus medius at the hip and external

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oblique at the trunk, could have a greater influence on frontal plane kinematics than those that primarily act on the other planes.

Single-leg squats and anterior step-downs are commonly used functional tasks due to their lower speed, greater safety and possibility of immediate visual feedback (Rabello et al., 2022), which are beneficial for the clinical evaluation of injuries such as patellofemoral pain, knee osteoarthritis and femoroacetabular impingement syndrome (Cabral et al., 2021; Malloy et al., 2021; Nakagawa et al., 2012). Other popular functional tasks are landing and cutting movements, which are more commonly used in the context of acute non-contact injuries such as the anterior cruciate ligament rupture (Hewett et al., 2005). Activation patterns of several muscles have been evaluated during the execution of these movements, albeit with a greater focus on the hip (Hollman et al., 2014; Nakagawa et al., 2012) and knee muscles (Hatfield et al., 2017; Mirzaie et al., 2019). Furthermore, different metrics of muscle activation have been evaluated, such as amplitudes (peak or mean) and onsets (Brindle et al., 2003; Neamatallah et al., 2020; Rodrigues et al., 2022c).

Because of its role in controlling movement, studies have sought to make inferences and hypothesis regarding joint kinematics (and consequently injury risk or mechanism) based on muscle activation results (Boudreau et al., 2009; Krause and Hollman, 2020; Mirzaie et al., 2019; Motealleh et al., 2015; Orozco-Chavez and Mendez-Rebolledo, 2018). However, the relationship between muscle activity and injury-related kinematics (such as knee abduction and hip adduction) has been investigated in few studies and only focused on activation amplitude and on the gluteal muscles (Hollman et al., 2014, 2009; Neamatallah et al., 2020). Concurrent evaluation of different variables and of muscles acting on different joints should provide a more comprehensive picture of the activation strategies employed. Therefore, this study aimed at identifying the association between knee and hip frontal plane kinematics during the single-leg squat and the anterior step-down with the activation amplitude and onset of muscles acting on the trunk, hip, knee, and ankle joints.

2. Materials and methods

2.1. Participants

Twenty-two participants were recruited for a larger study in our laboratory, whose results are presented elsewhere (Rabello et al., 2022). Among those, muscle activation data was successfully obtained from 18 physically active women, who performed all evaluations in a single day. Sample size was calculated on G*Power (version 3.1.9.6; University of Trier, Trier, Germany), adopting and Effect size $|\rho|$ of 0.5, α of 0.05 and Power (1-β) of 0.75 (Hollman et al., 2009). Participants were included if they performed physical activity two or more times a week, were between 18 and 40 years old, had no pain or discomfort on the evaluation day and had no history of lower limb or back surgery. All participants signed an informed consent form prior to taking part in the study, which was approved by the university's ethics committee. The participants were free to stop the experiment at any moment.

2.2. Tasks and instrumentation

Participants performed five repetitions of two tasks while kinematics and muscle activation were recorded for the dominant limb, which was determined with the question "which foot would you use to kick a ball?" (Fig. 1). For the single-leg squat, participants kept the contralateral knee

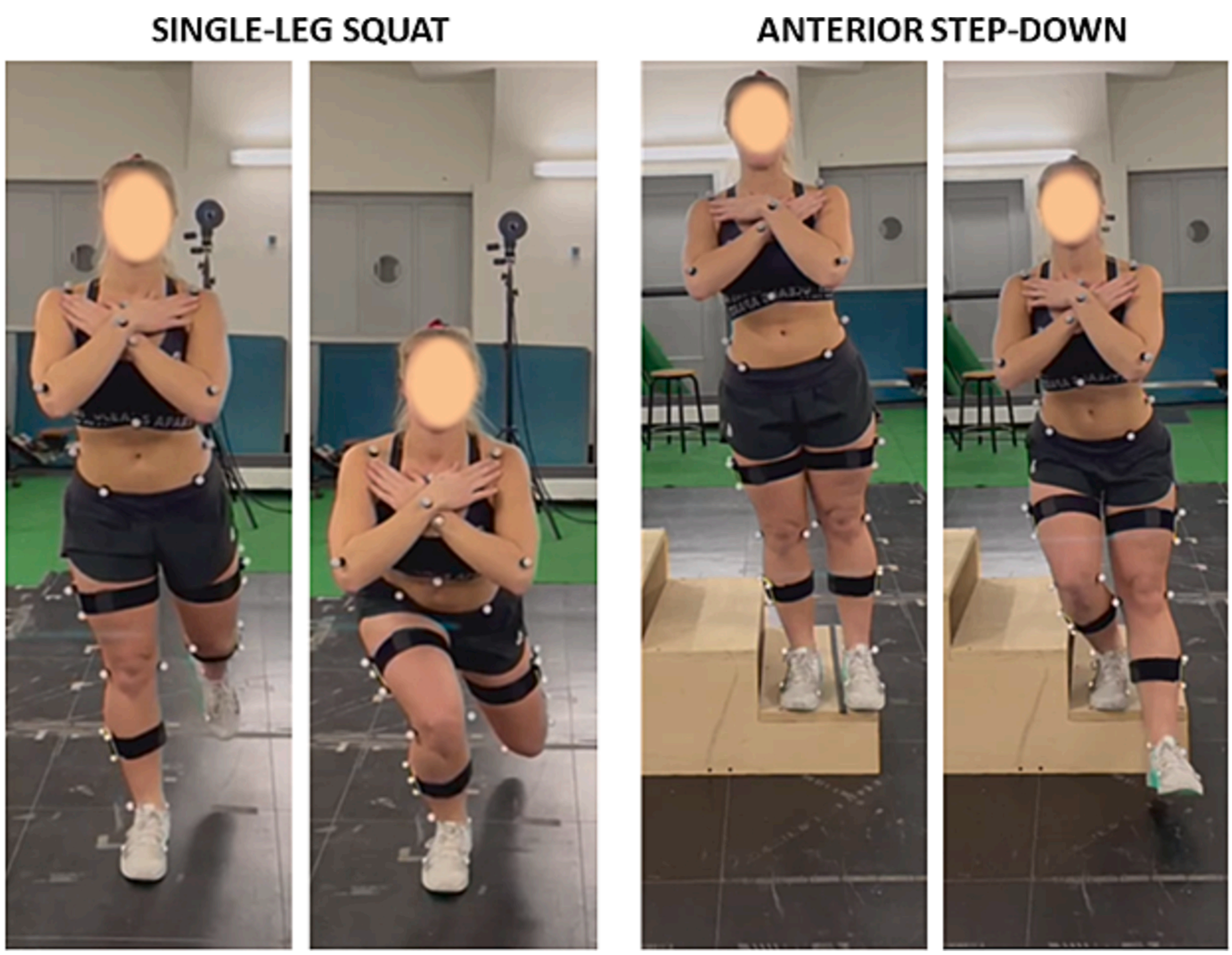

Fig. 1. Execution of the Single-Leg Squat and the Anterior Step-Down.

flexed at 90°, the thigh perpendicular to the ground and were instructed to squat until a comfortable depth before returning to the initial position. For the anterior step-down, participants were instructed to lightly touch the ground in front with their contralateral heel before returning to the initial position. This task was executed on a step with height between 15 and 17 cm according to the participants' height (i.e., 15 cm for participants shorter than 159 cm, 16 for those in between 160 and 175 cm and 17 cm for those taller than 175 cm). For all tasks, participants were instructed to keep their hands across their shoulders and movement speed was controlled using a metronome (three seconds eccentric and two seconds concentric). Prior to data collection, all participants performed as many trials as they required to familiarize themselves with the tasks and timing, resting as long as necessary to avoid fatigue effects.

Knee and hip kinematics were measured with a 9-camera 3D motion-capture system (60 Hz, BTS S.p.A, Garbagnate Milanese, Italy) using 38 passive retroreflective markers (Rabello et al., 2022). Muscle activation was estimated using surface electromyography (EMG) with 1020 Hz sampling rate, 16-bit resolution and differential amplifiers (bandwidth: 10–500 Hz) with common mode rejection ratio > 110 dB at 50–60 Hz and input impedance > 10 GΩ (FreeEMG, 300 BTS S.p.A, Garbagnate Milanese, Italy). Disk-shaped silver-silver chloride bipolar electrodes (diameter: 24 mm; interelectrode distance: 2 cm; Covidien, Dublin, Ireland) were positioned over the bellies of seven muscles and aligned with the fiber orientation: fibularis longus, tibialis anterior, vastus medialis, biceps femoris, gluteus medius, external obliques on the ipsilateral and contralateral sides. These muscles were selected because they represent primary movers in the frontal plane for the ankle, hip and trunk and the most important muscles acting on the knee joint. Skin preparation and electrode positioning were conducted according to the Surface ElectroMyoGraphy for the Non-invasive assessment of Muscles (SENIAM). Since they were unavailable on SENIAM, positioning on the oblique muscles followed previous literature (Rodrigues et al., 2022c). Maximum voluntary isometric contractions were conducted for the normalization of average EMG data after appropriate warm-up. Isometric trunk flexion was performed (in neutral trunk position) for the oblique muscles, hip abduction (in 10° of hip abduction and 0° of hip and knee flexion) for gluteus medius, knee flexion (in 30° knee flexion and 0° hip flexion) for biceps femoris, knee extension (in 90° of knee and hip flexion) for vastus medialis, ankle dorsiflexion (in neutral ankle position) for tibialis anterior and rearfoot eversion (in 0° of eversion) for fibularis longus (Fig. 2). Two trials were performed for each muscle with contractions lasting five seconds.

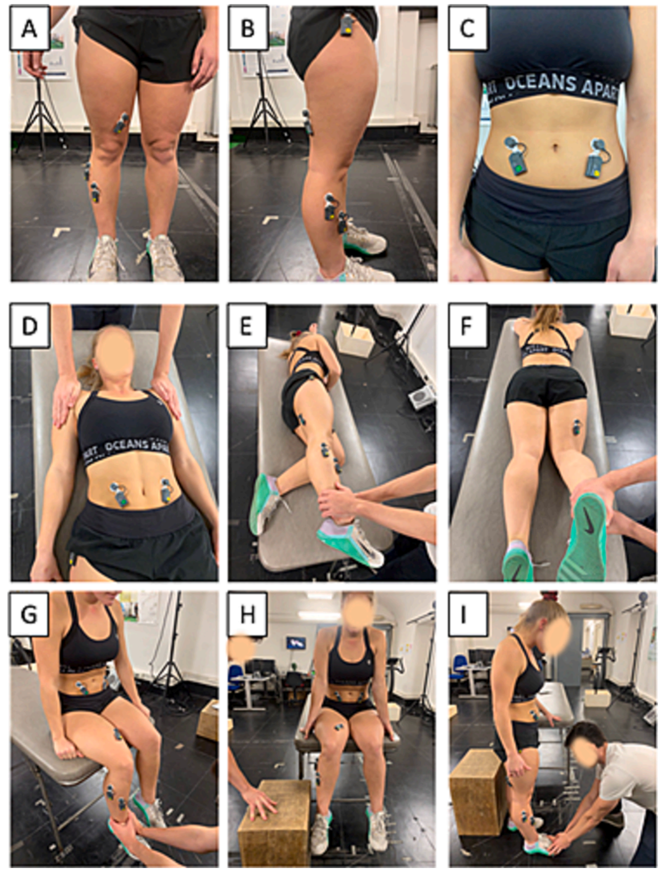

Fig. 2. Positioning of the seven EMG probes (A-C). Maximum voluntary isometric contractions against manual resistance for the external obliques (D), gluteus medius (E), biceps femoris (F), vastus medialis (G), fibularis longus (H) and tibialis anterior (I) muscles.

2.3. Data processing

2.3.1. Kinematics

Markers' 3D positions were reconstructed using SMARTTracker (BTS S.p.A, Garbagnate Milanese, Italy) and used to calculate knee and hip displacement angles in the frontal plane with Visual3D (C-Motion, Inc., Germantown, USA). For each participant, a model was created based on a 10-s static recording and applied to the movement trials. Three-dimensional knee and hip angles were calculated with a Cardan X-Y-Z rotation sequence. The eccentric phases of the two tasks were evaluated from the start of the movement (when knee flexion begins) until 60° of knee flexion. Movement start was considered the frame in which the knee flexion curve started to increase from the baseline (visual determination). Knee abduction and hip adduction angles for repetitions two to five were extracted during single-leg quiet standing (recorded prior to the task) and at the instant of 60° of knee flexion. The difference in angle between the two moments was calculated and adopted as the angular displacement. Trial one was discarded as it was considered a final practice trial. A standardized 60° angle was chosen for all tasks because they are performed with different knee flexion ranges and we sought to eliminate its influence on the frontal plane angles (Rabello et al., 2022).

2.3.2. Electromyography

In addition to the maximum voluntary isometric contractions, two common muscle activation metrics were obtained for each muscle using the raw EMG data and the start and end events: amplitude average (EMG_{AMP}) and onset (EMG_{ONSET}). The values for each metric for trials two to five were recorded and averaged. Data were processed and exported using Visual3D and analyzed using custom-written MATLAB code (Version 2021b; Mathworks Inc., Natwick, USA.).

For the analysis of EMG_{AMP}, data were rectified, high-pass filtered (20 Hz, Butterworth 4th order), smoothed (500 ms root mean square) and time-normalized to 101 samples. EMG_{AMP} was the average activation value from the start until 60° of knee flexion and expressed as the percentage of the EMG activation during the maximum voluntary isometric contractions. The EMG signal was not usable for 0–17% of the trials, resulting in the exclusion of 0–4 participants from the analysis due to lack of data, depending on the muscle. Using rectified and filtered data (not smoothed nor time-normalized), the EMG_{ONSET} of each muscle was defined as the moment in which the EMG signal amplitude signal rose above three standard deviations from the baseline (a 200 ms interval before the start of the movement) and was maintained for at least 25 ms following the start of knee flexion (i.e., start of the movement). The onset is expressed in milliseconds. Out of the 144 trials collected, the percentage of trials that did not present an onset and the consequent number of participants that did not have at least one onset recorded for each task were 45% and 1 (fibularis longus), 36% and 1 (tibialis anterior), 21% and 3 (vastus medialis), 36% and 5 (biceps femoris), 49% and 3 (gluteus medius), 40% and 3 (ipsilateral oblique) and 33% and 0 (contralateral oblique), respectively.

2.4. Statistical analysis

Fourteen EMG (7 muscles × 2 metrics) and two kinematic (knee abduction and hip adduction) variables were extracted for each of the two tasks. The Shapiro-Wilk test was conducted to verify data normality, finding that a large number of variables presented a non-normal distribution. Therefore, in order to find the association between the kinematic and EMG variables, the Spearman's correlation coefficient was calculated adopting 0.05 as the significance threshold. The correlation coefficients' magnitude were interpreted with Cohen's criterion: <0.1 = trivial, 0.1– 0.29 = small, 0.3–0.49 = moderate and > 0.5 = large.

3. Results

Fig. 3 shows the recorded values for the EMG variables of the seven muscles and the angular displacement in the frontal plane of knee and hip joints. Table 1 shows the correlations between each EMG and kinematic variables.

3.1. Knee abduction

During the single-leg squat, no significant correlations were found between knee abduction and any EMG variable. During the anterior step-down, greater EMG_{ONSET} delay of three muscles were significantly correlated with greater knee abduction. Tibialis anterior EMG_{ONSET}, gluteus medius EMG_{ONSET} and ipsilateral oblique EMG_{ONSET} all presented large correlations ($\rho > 0.596$).

3.2. Hip adduction

During the single-leg squat, no significant correlations were found between any EMG variables and hip adduction. During the anterior step-down, greater hip adduction was significantly correlated with lower EMG_{AMP} and delayed EMG_{ONSET}. Lower biceps femoris EMG_{AMP} and vastus medialis EMG_{AMP} presented a large and moderate correlation with greater hip adduction, respectively. A greater delay on vastus medialis EMG_{ONSET} presented a moderate correlation with greater hip adduction.

4. Discussion

Although muscle activation variables are commonly measured with the goal of understanding knee injury-related kinematic patterns, the relationships between these variables are still unclear. Depending on the measured variable and on the task, different muscles presented moderate or large correlations with either knee abduction or hip adduction, with varied p-values. Given that there are few similar correlation studies (Hollman et al., 2014, 2009; Neamatallah et al., 2020), in the next sections of the discussion our findings will also be compared to studies that investigated differences between people with patellofemoral pain and controls and between poor and good performers, as these studies compare activation between a group that displays larger frontal plane kinematics values.

Distinct EMG metrics are employed in the literature given that they actively measure different aspects of muscle activation. For studies using squats and step-downs, the amplitude of the EMG signal is the most frequently used metric, usually reported with its peak or, even more commonly, with its average (Hatfield et al., 2017; Rodrigues et al., 2022c). In our study, we found no association between knee abduction and average activation of any muscle in both tasks. These results agree with previous studies that found no differences in activation amplitude between controls and people that displayed medial knee displacement (Mauntel et al., 2013) or were bad performers (categorization that included excessive knee valgus) (Hollman et al., 2014). In addition, a recent *meta*-analysis (Rodrigues et al., 2022a) reported no differences in activation amplitude of the gluteus muscles in similar tasks between

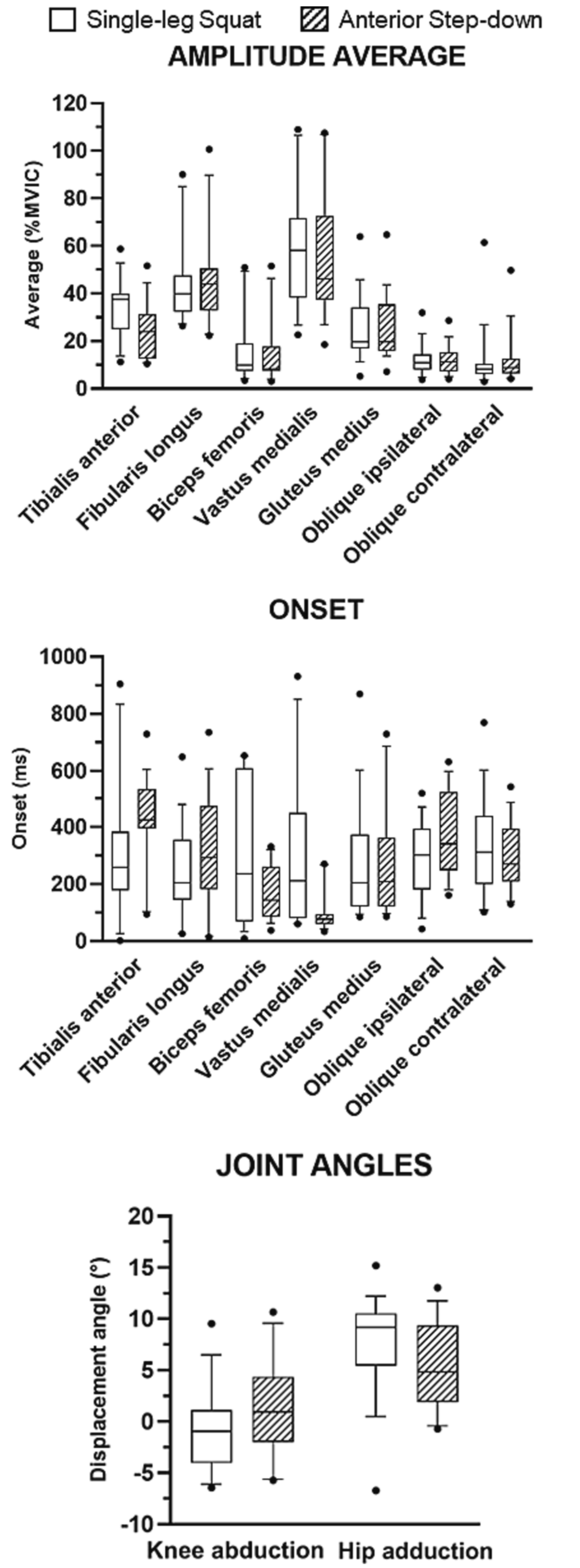

Fig. 3. EMG and kinematic variables. Boxplots show median, 10–90% range, maximum and minimal values.

Table 1
Spearman's ρ (p values) for the correlations between knee abduction, hip adduction and EMG variables.

Knee Abduction	**Single-leg squat**		**Anterior step-down**	
Muscle	Average	Onset	Average	Onset
Tibialis anterior	-0.182 (0.533)	-0.113 (0.667)	-0.275 (0.321)	**0.618 (0.011)**[b]
Fibularis longus	0.182 (0.516)	-0.176 (0.498)	-0.185 (0.492)	0.294 (0.269)
Biceps femoris	0.120 (0.646)	0.132 (0.668)	0.083 (0.751)	0.445 (0.064)
Vastus medialis	0.154 (0.554)	0.186 (0.508)	0.036 (0.887)	0.441 (0.067)
Gluteus medius	0.392 (0.119)	-0.432 (0.108)	0.401 (0.099)	**0.696 (0.004)**[b]
Oblique ipsilateral	0.146 (0.603)	-0.111 (0.694)	0.218 (0.435)	**0.596 (0.019)**[b]
Oblique contralateral	-0.098 (0.699)	0.013 (0.958)	-0.240 (0.336)	0.102 (0.687)
Hip adduction	**Single-leg squat**		**Anterior step-down**	
Muscle	Average	Onset	Average	Onset
Tibialis anterior	-0.459 (0.098)	-0.012 (0.963)	0.021 (0.940)	-0.159 (0.557)
Fibularis longus	-0.407 (0.132)	-0.267 (0.300)	-0.021 (0.940)	0.382 (0.144)
Biceps femoris	-0.265 (0.305)	0.297 (0.325)	**-0.667 (0.003)**[b]	0.245 (0.328)
Vastus medialis	-0.355 (0.162)	-0.421 (0.118)	**-0.490 (0.039)**[a]	**0.472 (0.048)**[a]
Gluteus medius	0.015 (0.955)	-0.239 (0.390)	-0.185 (0.463)	0.000 (1.00)
Oblique ipsilateral	-0.082 (0.771)	0.096 (0.732)	-0.129 (0.648)	-0.150 (0.594)
Oblique contralateral	-0.152 (0.548)	0.311 (0.210)	0.129 (0.610)	-0.020 (0.938)

Significant correlations are presented in bold. [a] = Moderate correlations; [b] = Large correlations, according to Cohen's criteria.

controls and people with patellofemoral pain, a pathology that has been previously associated with increased knee valgus (Nakagawa et al., 2012). Finally, three studies also reported no correlation between gluteus medius amplitude and knee valgus angles in women (Hollman et al., 2014, 2009; Neamatallah et al., 2020).

Meanwhile, decreased biceps femoris and vastus medialis amplitude were significantly correlated with higher hip adduction angles during the anterior step-down. Reduced activation of the two evaluated muscles that are primarily responsible for controlling knee sagittal movements may lead to decreased joint stability during the movement's descent phase by reducing joint control. This, in turn, could require increased hip adduction as a compensatory mechanism to maintain balance, explaining the relationship. These results were not replicated during the single-leg squat, likely due to the tasks' different characteristics (e.g., contralateral limb position) (Rabello et al., 2022). We did not find studies that evaluated these muscles in populations known for increased hip adduction during step-downs or the biceps femoris muscle during similar tasks. However, two studies evaluated the vastus medialis during the single-leg squat but did not present consistent results (Mirzaie et al., 2019; Rodrigues et al., 2022c). Mirzaie et al. (2019) found increased vastus medialis activation in healthy participants in comparison to patients with patellofemoral pain, while Rodrigues et al. (2022c) did not find any differences for the same population. Gluteus medius is the most commonly evaluated muscle in similar correlation studies. We did not find significant correlations with hip adduction, a result which is supported by Hollman et al. (2014, 2009) in two studies but oppose those found by Neamatallah et al. (2020), who reported a correlation between greater gluteus medius amplitude and greater hip adduction angles in healthy females.

The onset value gives information about the instant when the muscle "turns-on". Although there are some discrepancies regarding the determination of onset, (Morey-Klapsing et al., 2004) the metric has been considered relevant for patellofemoral pain (Alsaleh et al., 2021) and anterior cruciate ligament rupture patients (Theisen et al., 2016) in *meta*-analysis containing various tasks. We found that delayed onset times of tibialis anterior, gluteus medius and ipsilateral oblique were associated with higher knee abduction angles only during the anterior step-down. These findings suggest that earlier activation of muscles that act on the frontal plane of the distal (ankle) and proximal segments (hip and trunk) may be helpful in preventing excessive frontal plane knee motion. This could occur because these muscles can act by controlling the center of mass and the base of support from an earlier time and consequently require less compensation by the knee joint. Although tibialis anterior and ipsilateral oblique onset haven't been compared between people that specifically present greater knee abduction in similar tasks, our results for the gluteus medius are in line with Crossley et al.(2011), who found a delayed gluteus medius activation in poor performers during a step-down (originally called a single-leg squat in the study). However, a *meta*-analysis with patellofemoral pain patients did not find delayed activation of this muscle in similar tasks (Rodrigues et al., 2022a). Delayed vastus medialis activation was associated with increased hip adduction, possibly due to impairments in balance resulting from lower activation of this muscle that controls eccentric knee flexion at the very start of the movement. Greater instability at the knee joint could lead to excessive center of mass movement, which would require re-establishment of its position on top of the base of support that could be achieved by hip frontal plane movement. This result does not necessarily agree with previous patellofemoral pain studies that found no delayed vastus medialis onset in this group (Brindle et al., 2003; Earl et al., 2005), however, as our results indicate, this correlation is task-dependent and the aforementioned studies used stair-stepping or lateral step-down tasks.

Both the EMG and kinematic data presented substantial variability between participants; however, they are in line with what is found in the literature (Earl et al., 2005; Han et al., 2018; Hatfield et al., 2017; Mirzaie et al., 2019; Nakagawa et al., 2015; Orozco-Chavez and Mendez-Rebolledo, 2018). EMG_{AMP} is highly dependent on the normalization task (Burden, 2010), but similar studies have also found, for example, gluteus medius activation close to 20% (Han et al., 2018; Mirzaie et al., 2019), vastus medialis close to 50% (Hatfield et al., 2017) and external obliques close to 15% (Nakagawa et al., 2015) of MVIC in similar tasks. Our activity onset values are more difficult to compare with the current literature, as only few studies actually report their values and are limited to the vastus medialis, gluteus medius and biceps femoris (Earl et al., 2005; Han et al., 2018; Orozco-Chavez and Mendez-Rebolledo, 2018). Mean onset values ranged from 103 ms to 417 ms on average depending on the muscle and task involved and from 2 ms to 931 ms individually recorded values, which is in line with the literature that often presents very high standard deviation values (Earl et al., 2005; Han et al., 2018; Orozco-Chavez and Mendez-Rebolledo, 2018). Finally, our knee abduction and hip adduction values ranged from -6° to 11° and from -7° to 16°, respectively. Although higher values are proposed to increase the strain on the knee joint, there is no cut-off value that puts someone in greater risk of injury, making it difficult to determine if a certain activation amplitude or onset may suggest that someone is likely to get injured.

This study showed that some muscle activation variables from proximal, distal and local joints (i.e., hip, ankle and knee when referring to the knee joint) are associated with injury-related kinematic variables. However, for the correct usage and interpretation of EMG measurements in the context of injuries, it is important to take into account the limitations of each metric. Although EMG amplitude provides a quantitative measure of how active a muscle is (typically in relation to a maximal contraction), it does not represent the amount of torque that is being generated given that torque is also dependent on muscle architecture and joint angles (Hug et al., 2015). For this reason, lower and higher amplitudes can be interpreted as lack of neural drive leading to lower torque generation or as increased neural drive due to a compensatory strategy for reduced torque production capacity, respectively (Rodrigues et al., 2022a). Activation onset is also influenced by the criteria adopted to consider a muscle to be activated (e.g., 2, 3 or 5 standard deviations above a resting activation) (Rodrigues et al., 2022a) and can often not be identified in some trials (from 21% to 49% of trials in this study). It would be good practice for future studies to report the percentage of trials where the onset was actually present. Another common barrier is the muscle crosstalk that can influence the results, as the activity is registered under skin electrodes that are not exclusively targeting the muscle of interest (Konrad, 2005). Finally, both EMG and kinematic data provide high-frequency signals (typically above 500 Hz and 60 Hz, respectively), which are often reduced to a single number to represent it, losing possibly important data in the process (Pataky, 2010). Nonetheless, EMG remains essential for providing insights into how the neuromuscular system controls kinematics. Therefore, within the context of their limitations, specific variables can help in understanding the presence of injury-related patterns in certain populations and contribute to the development of evaluation tools and rehabilitation and prevention protocols. For example, adopting earlier activation of distal and proximal muscles may lead to reduced knee abduction angles and greater and earlier activation of the knee extensors as well as greater activation of the knee flexors may lead to reduced hip adduction angles due to improved stability.

In this study, we evaluated two commonly used muscle activation variables in muscles acting on distal, proximal, and local joints to the knee and hip. Along with the use of two different functional tasks, the multi-joint consideration is a strength of the study. There are some limitations that must be mentioned: (i) due to its sensitive position, we did not evaluate the gluteus maximus muscle, which has been proposed to influence knee valgus (Hollman et al., 2014, 2009). (ii) due to the limited number of available probes, we had to choose only seven out of the several muscles that act on the ankle, knee, hip and trunk. We decided to evaluate one prime mover of each joints' frontal plane movement plus the biceps femoris and the vastus medialis, which are two of the most important muscles that act on the knee joint. Other muscles acting on the other planes and different frontal plane prime movers might have displayed different associations; (iii) because of equipment limitations, MVICs were performed against manual resistance. Although similar techniques are used in the literature it is possible that participants did not achieve their maximal activation due to the instability of the resistance (Chamorro et al., 2017; Lyons et al., 2017). (iv) despite careful preparation and probe positioning, some trials from a few subjects were not correctly recorded and had to be excluded (v) we only evaluated women given that these tasks are frequently used in the context of patellofemoral pain and anterior cruciate ligament injuries, both of which affect women at a higher rate (Boling et al., 2010; Stanley et al., 2016). Therefore, care should be taken when applying our findings to different populations; (vi) because we sought to verify the relationship between kinematics with muscles that cross different joints, in two different metrics and in two different tasks, we ran a large number of correlations. Multiple comparisons might elevate the risk of type I error, particularly with reduced sample sizes, however, we chose not to adjust the significance level in order to avoid type II error. Another reason for not making this adjustment is that similar studies with multiple correlations also chose not to do so (Hollman et al., 2009; Neamatallah et al., 2020), thus, our choice was also made in order to facilitate comparisons. However, as there is a risk for type I error, we encourage the readers to consider the sample size, ρ and p-values when observing our data. Finally, there are other EMG metrics that can be used to describe muscle activity that were not evaluated in this study: activation duration was not possible to calculate due to the difficulty in identifying an offset (i.e., when the muscle turns-off) in a high number of trials due to the characteristics of the chosen tasks (Rodrigues et al., 2022a) and metrics in the frequency domain, such as median frequency and spectral analysis, were not evaluated due to issues regarding their validity and interpretation (Beaulieu et al., 2008; Enoka, 2008; Farina et al., 2004), although it has also been used in studies with similar tasks (Leporace et al., 2011; Rodrigues et al., 2022b).

5. Conclusion

We found that earlier onset of tibialis anterior, gluteus medius and ipsilateral external oblique were correlated with reduced knee abduction angles and that increased vastus medialis and biceps femoris activation amplitude and earlier vastus medialis onset correlated with increased hip adduction angles during the anterior step-down. The same results were not replicated during a single-leg squat, indicating a task-dependency effect. These findings provide insights into the relationship between muscle activation metrics and kinematics during functional task, allowing for the development of evidence-based hypothesis and inferences regarding injury-related outcomes, ultimately being helpful in establishing evaluation tools and rehabilitation and prevention programs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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