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Lower Limb Muscle Activation Adaptation During Single and Dual Walking Tasks in Healthy Young Adults

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ABSTRACT

Background: Falls due to altered balance is a worldwide health concern. Previous investigations have delved into the effect of dual-tasking balance and gait (kinematic alteration) because of the increased attentional loads demanded from the brain. In addition, impaired neuromuscular patterns could additionally contribute to gait alterations and increased fall risk. This study aims to identify the muscle activation pattern of lower limb musculature during single and dual tasks in healthy young adults.

Methods: Thirty-four participants (9 males and 25 females, mean age of 24.88 ± 5.13) completed two 7-meter level ground walk trials under singular then dual tasks. We implemented an amplitude analysis filter to normalize EMG amplitude data to obtain a percentage of the amplitude (0-100%) and timing amplitude.

Results: The ANOVA analysis revealed no considerable distinction in muscle activity amplitude among dual and single cognitive tasks ($p \geq 0.05$). When assessing the activation pattern while walking on an even surface, Gluteus maximus (GMAX) and gastrocnemius (GA) exhibited similar timing patterns associated with gluteus medius ($p = 0.01$) and tibialis anterior ($p = 0.001$). GMAX showed greater average amplitude contrasted to most of the research musculature.

Conclusion: Our investigation identified similarities in lower extremity muscle activity patterns among single and dual tasks in healthy young adults. This study ushers in recognizing distinct muscle activation patterns among lower extremity musculature. Clinicians should consider activation of lower limb extensor musculature during gait training, prioritizing GMAX, GA, and Gluteus Medius weakness contributing to impaired gait mechanics to minimize gait imbalances regarding muscle activity.

Keywords: Dual Cognitive, Neuromuscular Activation, Gait and Dual Tasks, Lower Limb Amplitude, Neuromuscular Coordination, Even Walkway Amplitude Adaptations.

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INTRODUCTION

According to the World Health Organization (WHO), falls are a severe health problem. Falls can be fatal, accounting for one of the top two risk factors associated with death worldwide. Furthermore, fall risk increases with age, with the most substantial fall percentages among adults aged 60 years and older [14].

One of the primary reasons people withstand falls is the inability to hold the center of gravity (CoG) within the base of support (BoS) area while walking or standing. In humans, the CoG is broader than the BoS in standing, demanding the utilization of several postural control mechanisms to preserve equilibrium [10]. Postural mechanisms are required in static and dynamic balance and comprise the ankle, hip, and stepping strategies. The mechanism chosen depends on the degree of perturbation, with the ankle strategy being adequate for lower-amplitude perturbations and the stepping strategy being sufficient for higher-amplitude perturbations. Each balance strategy recruits specific muscle groups to perform synergistically and maintain equilibrium. Falls occur when an individual fails to adapt to a perturbation promptly [13].

Another reason for falls and injuries is a failure to accommodate a perturbation because of impairments in the visual, somatosensory, or vestibular system, which comprise the balance system. Deficits in any of the three systems can result in postural instability and increase the risk of falls. Theories such as dynamic system theory (DST) attempt to explain the interplay between these sensory networks. DST shows that the three balance networks must synchronize sensory information to retain stability, particularly when the balance is extensively challenged [13] by a perturbation. When a good interplay of the various balance systems occurs, individuals can prevent falls while navigating different surfaces, using sensory modification or reweighting. However, sensory reweighting fails when one or more balance systems are impaired, requiring the body to rely on the remaining sensory information attempting to preserve balance [13].

The challenge is that these adjustments on the balance system or postural strategies are unnoticeable for some time, producing difficulties in determining gait or balance impairments and avoiding falls. Nevertheless, it is more often than not that falls and injuries shocked those experiencing the variations mentioned above. One approach to single out these impairments is by challenging the subject to achieve dual tasks in standing. Dual tasks are the individual's ability to operate two or more cognitive and motor activities concurrently while maintaining an upright posture. For example, balancing on one foot while reciting the alphabet involves dual tasking.

Similarly, with ambulation, dual tasking requires increased cognition requirements, resulting in the need for greater attention, balance, and executive function compared to singular tasks [7]. Leland et al. discovered that when patients walked at self-selected speeds and were asked to recall five-set number sequences, gait speeds decreased with a reduction in attention spans (2017). Consequently, investigations have revealed that reduced gait speeds can be correlated with an enhanced risk for falls [6].

We can observe normal human gait in two phases: the stance phase and the swing phase [8]. Each gait phase corresponds to target muscle activations at the hip, knee, and ankle [12]. In clinical settings, muscle activation during the gait cycle can be assessed non-invasively using surface electromyography (sEMG). Surface EMG electrodes directly contact the skin overlying muscles desired for data retrieval [1]. As reported in the article by Agostini et al., probes are frequently situated over agonist and antagonistic muscle pairings at multiple joints to interpret the desired pairs' co-contraction relationship further. This study analyzed the agonist and antagonistic relationship between the tibialis anterior and gastrocnemius and gluteus maximus and gluteus medius.

Considering the above, this study attempted to answer the following questions: 1) Does dual cognitive tasks influence the muscle's amplitude and time percentage while walking on an even surface walkway in healthy young adults. 2) Does Gmax and GA display patterns similar to those of TA and Glut Med during forwarding propulsion? 3) Are there muscles that exhibit higher activation than others while walking on an even surface walkway?

METHODS

Participants: Thirty-four participants (9 males and 25 females) among 24.88 ± 5.13 years old signed the approved informed consent (protocol # FY2020-32) were recruited from Texas Woman's University (TWU) and the surrounding community to participate in this research study.

Related to the inclusion criteria, we recruited subjects that met the following requirements: 1) Between the ages of 21-40 years old, 2) Both genders, 3) Ability to ambulate without an assistive device, 4) No back or lower extremity injury in the previous six months and 5) No medications that can cause drowsiness or sleepiness 24 hours prior data collection.

PROCEDURES

Data collection was performed at TWU T. Boone Pickens Institute of Health Sciences, located in Dallas, Texas. Prior data were collected, all subjects signed the informed consent, had a member of the research team explaining the purpose of the study, their role, and were asked questions to confirm their understanding of the following events. Subsequently, the participants were equipped with electromyography surface electrodes.

A team member gathered demographic data and vitals, such as blood pressure, pulse, and O2 saturation. Subjects who wore glasses or contacts were identified and wore their devices during testing. The total time commitment was 40 min per subject for the screening and gait protocols.

EMG Placement: Data were collected via electromyography surface electrode system (EMG) surface electrode system (Delsys, Inc. Boston, MA) and MobilityLab: APDM's MobilityLabTM (APDM Inc., http://apdm.com). The EMG activity of the gluteus maximus (GMAX), gluteus medius (GMED), tibialis anterior (TA), and gastrocnemius (GA) muscles were collected at 1,000 Hz with the electrodes placed according to the recommendations of Sacco & Kasman. In addition, electrodes were placed on the lateral muscle bellies of the TA and GA muscles. The muscle amplitude or activity and the maximal and minimal activation time were calculated using EMG analysis software for each task and all muscles.

Participants were requested to determine their dominant leg. When needed, areas of the selected dominant leg were shaved with a non-electric razor to place and ensure the EMG electrodes. An EMG surface electrode was located on the dominant side/leg over the GMAX, GMED, TA, and GA. Partakers wore EMG surface electrodes for the entirety of testing.

EMG-Maximal Voluntary Isometric Contraction: Before the gait protocol, each subject was inquired to perform a maximal contraction (MC) test for each leg muscle using the EMG electrode system. The GMAX, GMED, TA, and GA muscles were tested for MC while the participants stood in a single-leg stance on their dominant leg, utilizing a chair for support. When prompted, participants extended their dominant hips with a straight knee to achieve the GMAX MC and repeated the procedure in abduction to get the GMED MC. The TA MC was achieved by raising their toes in the air while maintaining their heel on the ground, and the participants acquired the GA MC by lifting their heels off the floor onto their toes. We recorded each of the positions for 10 s as they produced the MC force.

Gait Assessment: The data collection area for the gait protocol included a 7-meter even surface walkway made by a green line for the starting portion and a large orange cone at the opposite end. For all tasks, we instructed participants to start behind the green line, start walking after hearing the tone, walk at a self-selected speed, reach the cone, turn around the cone, continue walking until hearing the second tone. We adopted the tone sound both as feedback for the participants to start and end the tasks, and it also notifies the completion of the 7-meter gait protocol. We designed the gait protocol as follows:

I. Single tasks (2 trials): Participants were guided, to begin with, their toes behind a green line and, after the beep, started walking on an even surface at an individually selected comfortable pace. Next, participants were instructed to walk around the cone and turn to the starting point (green line) upon reaching the cone. After the second tone, participants were notified that the tests were over. The second walking trial was enacted identical to the first.

II. Dual Cognitive Tasks (2 two trials): All the participants completed two more walking sessions, this occasion with the cognitive component of counting backward from 100 by threes. These tasks were achieved in the same directions and measurements as the original walking tests.

Data Analysis: In considering the EMG data, an amplitude analysis filter was applied to normalize the amplitude data on EMG works analysis software generating the amplitude percentage (0-100%). An Excel spreadsheet was obtained with the normalized amplitude data with the associated time for each muscle and task. Then, the time data was further modified and normalized to a percentage. The purpose of standardizing the amplitude and time data was to compare the results among tasks.

For each muscle on all tasks, the maximal and minimal % amplitude were identified with their respective time %. In addition, the average amplitude for each muscle was also calculated. This database was created and recorded in a spreadsheet and imported into SPSS version 25 as the statistical program for further analysis. An ANOVA analysis was used for all comparisons of the variables of interest.

The data points of interest were the minimum, maximal, and average for each muscle's amplitude in percentage. Additionally, the time in the gait cycle of maximal and minimal activation occurred. Therefore, a P-value of 0.05 or less was considered significant in this study.

In the current study, we performed two different comparisons. First, we compared amplitudes and timing for single and dual tasks to understand the cognitive input impact. Second, we compared amplitudes and timing among the various muscles to identify muscle patterns while walking on an even surface.

RESULTS

Table 1 illustrates the demographic information of the participants. The participants had average systolic blood pressure (BP) of 118.82 ± 15.75 (mmHg), diastolic BP of 76.27 ± 9.09 (mmHg), resting heart rate of 69.82 +/- 11.58 (bpm), and resting oxygen saturation of 97.97 +/- 2.23. Partakers had an average height of 65.85 ± 3.27 (in.), weight of 145.39 +/- 23.86 (lbs), and body mass index of 23.46 +/- 2.87 (kg/m^2). Of the participants, 29 were right-leg-dominant, while five were left-leg dominant. Six of the participants wore glasses or contacts during testing (Table 1).

Table 1: Demographic data of all participants

Characteristics	Participant Data
Age	24.88 +/- 5.13
Gender	Male= 9 Female = 25
Height (in)	65.85 +/- 3.27
Weight (lb)	145.39 +/- 23.86
BMI (kg/m^2)	23.46 +/- 2.87
Heart Rate (bpm)	69.82 +/- 11.58
Systolic BP (mmHg)	118.82 +/- 15.75
Diastolic BP (mmHg)	76.27 +/- 9.09
Sat O2 (%)	97.97 +/- 2.23
Leg Dominance	R = 29 L = 5
Glasses	Glasses = 6 No glasses = 28

Table 2a and b exhibited no significant differences in the amplitude of any muscle activity between single and dual tasking (Tables 2a and 2b).

Table 2a: Comparisons of EMG AMPLITUDE for GMAX and GMED among tasks. Results of repeated measure ANOVA were performed comparing single and dual. Significance level set at p≤0.01.

Glut Max	Single Tasks Means and SD	Dual Tasks Means and SD	P-value
MAX % TIME	48.29 +/- 17.35	49.71 +/- 23.90	0.94
MAX AMP	75.87 +/- 36.19	76.08 +/- 34.84	0.98
MIN % TIME	40.85 +/-34.87	53.03 +/-35.30	0.19
MIN AMP	44.78 +/- 16.34	43.98 +/- 14.99	0.84
AVG AMP	64.08 +/- 23.95	63.21 +/- 21.51	0.89
Glut Med	Means and SD	Means and SD	P-Value
MAX % TIME	53.82 +/- 19.75	54.61 +/- 21.57	0.97
MAX AMP	63.91 +/- 25.02	58.05 +/- 24.12	0.08
MIN % TIME	33.08 +/- 37.48	44.38 +/- 33.09	0.20
MIN AMP	25.45 +/- 13.69	25.34 +/- 15.30	0.70
AVG AMP	36.68 +/- 17.32	77.19 +/- 118.13	0.21
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

Table 2b: Comparisons of EMG AMPLITUDEfor TA and GA among tasks. Results of repeated measure ANOVA were performed comparing single and dual. Significance level set at p≤0.01.

Tibialis Anterior	Single Tasks Means and SD	Dual Tasks Means and SD	P-value
MAX % TIME	40.03 +/- 24.59	39.40 +/- 18.57	0.92
MAX AMP	58.75 +/- 34.27	51.32 +/- 26.89	0.37
MIN % TIME	21.97 +/- 31.95	18.72 +/- 30.88	0.70
MIN AMP	7.26 +/- 5.82	6.75 +/- 5.61	0.74
AVG AMP	17.22 +/- 8.51	16.01 +/- 8.85	0.60
Gastrocnemius	Means and SD	Means and SD	P-Value
MAX % TIME	41.18 +/- 21.59	44.07 +/- 21.29	0.62
MAX AMP	96.96 +/- 41.32	81.65 +/- 46.50	0.20
MIN % TIME	36.13 +/- 28.90	51.02 +/- 20.99	0.05
MIN AMP	11.34 +/- 9.67	11.02 +/- 9.24	0.90
AVG AMP	33.75 +/- 38.38	27.22 +/- 34.08	0.50
^WP=Walk and Push, RP=Run and Push, S.D.=Standard Deviation			

In contrast, Table 3 depicts multiple significant findings during the comparison of when in the gait cycle each muscle was activated both maximally and minimally and the amplitude of each muscle's activity during this time. Significant differences were seen in the following muscles: 1) maximum amplitude (MAX AMP) of the GMAX compared to the GMED (p-value = 0.01) and TA (p-value = 0.001), 2) minimum amplitude (MIN AMP) of the GMAX compared to the GMED, GA, and TA (p = 0.001); 3) MIN AMP of the GMED compared to the GA and TA (p-values = 0.001), 4) average amplitude (AVG AMP) of the GMAX compared to the TA (p-value = 0.01), and 5) AVG AMP of the GMED compared to the TA (p-value = 0.001).

Table 3: Comparison of Timing of Maximal Muscle Activation Between Muscles During Gait Activity. Results of repeated measure ANOVA performed comparing muscles. Significance level set at p≤0.01.

MAX % TIME	Means and SD	Means and SD	P-Value
	GMAX: 48.29 +/- 17.35	GMED: 53.82 +/- 19.75 GA: 41.18 +/- 21.59 TA: 38.8 +/- 24.59	0.63 0.11 0.06
	GMED: 53.82 +/- 19.75	GA: 41.18 +/- 21.59 TA: 38.8 +/- 24.59	0.05 0.05
	GA: 41.18 +/- 21.59	TA: 38.8 +/- 24.59	0.75
MAX AMP	**Means and SD**	**Means and SD**	**P-Value**
	GMAX: 75.87 +/- 36.19	GMED: 63.91 +/- 25.02 GA: 96.96 +/- 41.32 TA: 58.75 +/- 34.27	0.01 0.46 0.001
	GMED: 63.91 +/- 25.02	GA: 96.96 +/- 41.32 TA: 58.75 +/- 34.27	0.05 0.75
	GA: 96.96 +/- 41.32	TA: 58.75 +/- 34.27	0.05
MIN % TIME	**Means and SD**	**Means and SD**	**P-Value**
	GMAX: 40.85 +/-34.87	GMED: 33.08 +/- 37.48 GA: 36.13 +/- 28.90 TA: 21.97 +/- 31.95	0.71 0.55 0.05
	GMED: 33.08 +/- 37.48	GA: 36.13 +/- 28.90 TA: 21.97 +/- 31.95	0.82 0.06
	GA: 36.13 +/- 28.90	TA: 21.97 +/- 31.95	0.81
MIN AMP Means and SD Means and SD P-Value			
	GMAX: 44+/- 16.34	GMED: 25.45 +/- 13.69 GA: 11.34 +/- 9.67 TA: 7.26 +/- 5.82	0.001 0.001 0.001
	GMED: 25.45 +/- 13.69	GA: 11.34 +/- 9.67 TA: 7.26 +/- 5.82	0.001 0.001
	GA: 11.34 +/- 9.67	TA: 7.26 +/- 5.82	0.14
AVG AMP	**Means and SD**	**Means and SD**	**P-Value**
	GMAX: 64.08 +/- 23.95	GMED: 68.7 +/- 23.9 GA: 33.75 +/- 38.38 TA: 17.22 +/- 8.51	0.76 0.05 0.01
	GMED: 68.7 +/- 23.9	GA: 33.75 +/- 38.38 TA: 17.22 +/- 8.51	0.05 0.001
	GA: 33.75 +/- 38.38	TA: 17.22 +/- 8.51	0.25

^TA=Tibialis Anterior Muscle
^GA=Gastrocnemius Muscle
^GMAX=Gluteus Maximus Muscles
^GMED=Gluteus Medius Muscles
^P=P-Value
^S.D.=Standard Deviation
^P-Value>.05 is not significant
*P-Value<.05 is significant
S.D.=Standard Deviation

DISCUSSION

This study intended to determine if dual cognitive tasks influence muscle amplitude and time percentage of the amplitude while walking on an even surface in healthy young adults. In addition, we tried to understand the amplitude recruitment patterns of various muscles while walking on an even surface. To our knowledge, limited studies have been published comparing single and dual cognitive tasks' influence and patterns on muscle amplitude and time percentage during ambulation on even surfaces. Previously, we established three questions related to single and dual tasks in combination with lower limb muscle activities.

First, do dual cognitive tasks influence the muscle's amplitude and time percentage of the amplitude while walking on an even surface walkway in healthy young adults? This study discovered that single and dual cognitive tasks exhibit similarities in time and amplitude. Therefore, dual tasks in young, healthy adults do not require changes in amplitude or timing of amplitude to adapt to the environment, similar to singular tasks. Regarding time percentage during singular tasks, the majority of the muscles studied activated at a similar rate maximally and minimally; hence, muscle recruitment during gait occurred simultaneously in the studied muscles during singular tasks. This evidence implies that dual-tasking does not change the amplitude of muscle contractions for GMAX, GMED, GA, and TA during gait in healthy young subjects due to the similarities seen in the muscles' amplitude and timing. With no differences observed in muscle amplitude under dual-tasking conditions in gait, the assumption can be made that dual-tasking does not require alterations in muscle activity to overcome larger cognitive efforts for young healthy adults performing dual-tasks.

In contrast to our findings, Fraser et al. (2007) conducted a study on younger and older adults to discern the effects of balance and age on muscle activation via surface electromyography (sEMG) while walking under divided attention, otherwise known as dual-tasking. The dual tasks for this study included researchers auditorily presenting words to subjects, followed by a prompt for subjects to identify if said words represented a living thing with a yes or no answer. Participants in this study performed walking tasks at a comfortable self-selected walking speed, similar to our participants. At the same time, muscle activity was measured in the vastus medialis oblique, vastus lateralis, medial hamstring, lateral hamstring, medial GA, lateral GA, TA, and peroneus longus muscles. The study design allowed for sEMG data collection, obtaining the mean amplitude data from each muscle from heel strike to toe-off based on each subject's maximum voluntary contraction (MVIC), providing a percentage of the maximum MVIC per muscle. Researchers defined the effects of dual-tasking as dual-task costs (DTCs) calculated by computing the difference between singular task performance and dual-tasking performance with regard to muscle activity. The results portrayed the following: both populations proved to have a facilitation effect on muscle activity with dual-tasking for level ground gait, and both groups had decreased muscle activity during the stance phase of gait, yet not during preparatory phases, defined as a brief phase before heel strike. Investigators also found that a higher cognitive control was needed when participants set a self-paced moderate walking speed; however, attentional involvement oscillated throughout phases of gait, with the stance phase showing the most sensitivity to larger attentional loads [5].

Although Fraser and colleagues' work details some findings in direct opposition to ours, these results show promising future directions for our findings. The Fraser study found facilitation effects during dual-tasking for younger and older adults, leading one to inquire whether our cognitive efforts had been at an increased difficulty could increase muscle activity have occurred during gait (2007). Furthermore, our participants chose a self-selected walking speed not defined as low, moderate, or high intensity, leaving the question of whether our set walking speeds were at a high enough intensity to show a difference in muscle activity related to cognitive demand increase with walking speed intensity increase.

Finally, as previously mentioned, our proposed rationale for increased GMAX activity during the minimal activation period was partly due to the stance phase of gait requiring a higher muscle activity demand than the swing phase. We propose that because the stance phases during gait require larger muscle activity demands, they are possibly more susceptible to being affected by larger attentional loads placed on them by dual-tasking. These results may not have been seen during our analysis because of the decreased cognitive demand placed on the system during swing phases of gait, creating a balancing effect on gait as a whole.

We conclude that the cognitive task was adequate to understand its impact on muscle activation; however, the even surface walkway was not challenging enough for this cohort. Nevertheless, information on these tasks and surfaces could establish baseline data and a precedent when comparing groups with different pathologies and cognitive statuses. Future studies should explore the differences in lower extremity muscle activation while ambulating on various surfaces and performing dual tasks.

Second, do Gmax and GA exhibit patterns similar to TA and Glut Med during forwarding propulsion? Yes, concerning maximum and minimum amplitudes or activation, both the extensor muscles of GMAX and GA were activated similarly and more than TA and GMED in singular tasks. This finding exhibits evidence that the extensor or posterior musculature of the hip is more active and more frequently active than the flexor or anterior musculature of the hip of the lower extremity during gait with singular tasks. However, there were differences in minimal amplitude or activation in the GMAX compared to GMED, GA, and TA, but GMAX had a greater amplitude than the other three muscles. The significance of GMAX activation more frequently than GMED, GA, and TA leads to the interpretation that larger global muscles like GMAX activate more during minimal muscle activation phases of gait with singular tasks.

In a prior study by Majlesi et al. (2017), gait in healthy young subjects and deaf subjects was studied to compare the TA's muscle activation, gastrocnemius medialis, and vastus lateralis. Researchers have found that healthy subjects have minimal TA activation because most of the stance phase of gait is controlled by eccentric muscle activation of the GA [9]. These results exemplify a similarity to our finding of greater posterior musculature recruitment during max, min, and average amplitudes. Reasonably, this could be accounted for by the stance phases of gait consuming roughly 60% of the gait cycle, while swing phases consume 40% (RLA, 2001).

Furthermore, our minimal activation period containing heightened GMAX activity could be partly due to GMAX having a more substantial contribution during the stance phase of gait. According to Rancho Los Amigos (2001), the stance phase of gait necessitates a greater need for hip stabilization than stabilization at the knee and ankle (2001). Hip stabilization in the medial-lateral plane is achieved initially via GMED activation, then through midstance (MSt) to terminal stance (TSt) via ground reaction forces (GRF) created by forces exerted by the ground onto the body passing through joint lines (Barela et al., 2014).

Conversely, throughout the stance phase, hip extension is controlled by GMAX activity. As the lower extremity moves throughout the stance phase, the major hip extensors fire to achieve hip extension and forward progression (RLA, 2001). Likewise, findings by Arnold et al. were identified by analyzing muscular contributions at the hip and knee throughout gait. Researchers found that GMAX has the most significant potential to accelerate the hip and knee into extension along with adductor magnus, hamstrings, vastus lateralis, and vastus medialis during the single-limb stance of gait [2]. These results corroborate our findings as well as Majlesi et al. (2017). To further elaborate on the relationship of the extensor or posterior musculature during stance phases, RLA states GA activity peaks during stance to prevent lower leg collapse as the body progresses over a singular limb, further explaining our observed similarities in GA and GMAX activity during maximal and minimal activation periods (RLA, 2001).

Finally, are there muscles that show greater activation than others while walking on an even surface walkway? Yes, evaluating the average activation or amplitude of the muscles examined established GMAX to have a similar average amplitude to GMED, yet greater than GA and TA, which were activated with the same force or amplitude. Accordingly, we expected that larger global muscles such as GMAX and GMED would activate more on average than smaller localized muscles such as the GA and TA. This discovery can be associated with the earlier discussed position of the stance phase of gait requiring notable hip extension and stabilization (RLA, 2001). Muscle activity from GMAX accomplishes hip extension throughout the stance phase. At the same time, GMED is a primary stabilizer in the frontal plane along the medial-lateral axis [3]. We observed a reduced average of muscle activity in the GA and TA because of a lesser demand to control the knee and ankle joints through muscle activation otherwise controlled via GRF through joint lines [3].

Based on our findings, we propose focusing on activating lower extremity extensor musculature during general weakness resulting in impairments in gait mechanics. Thus, a priority should be placed on GMAX, GA, and GMED to minimize gait imbalances regarding muscle activity. Additionally, we urged physiotherapists to direct their attention toward the stance phase of gait and focus on the implications that the extensor musculature can play during this phase, as delineated in this investigation.

CONCLUSION

The purpose of this research was to determine the muscle activation pattern of lower limb musculature during single and dual tasks in apparently healthy young adults. Our study identified similarities in lower limb muscle patterns between single and dual tasks. However, our outcomes illustrate the unique muscle activation patterns during walking on an even surface walkway.

The findings of this study can help guide clinicians with the design and implementation of gait training programs. Previous research has established that dual tasking increases attentional loads, leading to competition among cerebral areas to control movement, resulting in one cerebral area's dominance over the other [4]. This dominance was believed to manifest in altered gait patterns and decreased balance during dual-tasking. Our investigation has shown this to be inaccurate regarding muscle activity during gait in healthy young adults. Healthcare professionals will now be able to better utilize dual-tasking during gait by understanding its effect on muscle activity.

The current work discussed limiting factors that the authors intend to explore as possible future research endeavors. Although we can correlate our findings with separate phases of gait, a limitation to our study involves the failure to examine muscle activity at each subphase of gait. Our design did not include specific phases of gait because our observation of the impact of phases on the results did not occur until data collection began. As mentioned above, the participants in our study were allowed to choose a self-selected walking speed at a comfortable pace, but the intensity level does not constrain us. It is possible that the self-selected pace chosen by our participants was too low of intensity when combined with dual-tasking to show a significant change in muscle activity under dual-tasking conditions, as seen in the works by Fraser et al. (2007). Closely related, our results could have been constrained by the decreased difficulty for our dual-task (counting backward from 100 by threes). Another plausible explanation could be that a learning effect of our dual-task occurred with repeated walking trials.

Future studies should consider investigating further into muscle activation of the studied muscles in the subdivided phases of gait to understand better the contributions of muscle activity during stance and swing phases. Second, the intensity of the cognitive tasks as it applies to dual-tasking can be explored in the future with consideration of gait speed and surface type. Third, future research should delve into dual tasking and gait-related to cognitively impaired individuals, such as cognitive decline seen in older adults as part of the natural aging process. On one final note, our study found no changes in muscle activity with the introduction of dual-tasking during gait; therefore, future research should explore the impact of different types of surfaces (ramp, stairs, treadmill) on muscle activation during dual-cognitive tasks.

Declaration

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Ethics approval:

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Authors' contributions: All authors contributed to the study conception and design.

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