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RESEARCH ARTICLE

Adaptation of the Lower Extremity Neuromuscular Activation While Performing the Ross Submaximal Cardiovascular Test in Healthy Adults

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ABSTRACT

Background: **Submaximal exercise tests using treadmills are reliable predictors of cardiovascular and musculoskeletal performances in adults. Understanding neuromuscular lower extremity muscle activation during treadmill walking can help clinicians tailor rehabilitation and training programs for their condition.**

Subjects: **Ten healthy participants (22.6 ± 1.08 years of age) were recruited for this study.**

Method: **Participants were instructed to walk on a treadmill at a speed of 3.4 mph and 0% elevation for 3 min. The elevation increased every 3 min by 3% and 4% in women and men, respectively. Data on the muscle activation of the tibialis anterior (TA), gastrocnemius (GA), rectus femoris (QUADS), and semimembranosus (HS) were collected using surface electromyography.**

Results: **There were slight differences in the muscle activation between the muscle groups at various intervals. The results revealed that the tibialis anterior and semimembranosus took longer to activate and showed trends of more extended activation periods with an increase in inclination.**

Conclusion: **Analysis of electromyography (EMG) activity in healthy young adults during submaximal exercise testing on a treadmill revealed a delay in muscle activation and increased active time in the tibialis anterior and semimembranosus musculatures.**

Keywords: Lower Limb, Muscle Adaptation, Neuromuscular Activation, Ross Test.

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1. Introduction

Gait impairments can be found in orthopedic and neurological disorders (Pirker & Katzenschlager, 2017). Identifying abnormalities or deficits in muscle activation using electromyography (EMG) during gait can help professionals create a tailored exercise program to combat impairments secondary to these conditions. Oxygen consumption plays a crucial role in muscle activation, and implementing a treadmill program on even health-compromised individuals can positively affect their respiratory system (Ivey *et al*., 2015).

When analyzing the activation of various lower extremity (LE) muscles while walking on level ground, Moreira *et al*. (2021) found that EMG analysis of the tibialis anterior (TA), biceps femoris (BF), lateral gastrocnemius (GAL) and vastus lateralis (VL) showed minimal differences in muscle activation at varying speeds throughout the gait cycle. This minimal difference suggests that LE muscle activation remained relatively constant while walking on level ground, regardless of speed. However, the peak activity of each muscle differs throughout the gait cycle (Moreira *et al*., 2021). With even surface walking, Moreira *et al*. (2021) found that the TA and GAL were the most active muscles throughout the gait cycle. TA is more active at the beginning and end, and GAL is more active in the middle.

Additionally, Schmitz *et al*. (2009) compared LE muscle activation at various walking speeds between healthy young adults and older adults to determine whether age affects specific muscle activation during gait. During the mid-stance, older adults showed variation in the activation of the TA and soleus than young adults at all walking speeds. Additionally, diverse adaptability was identified in the VL and medial hamstrings during the loading response and mid-stance at the fastest walking speed in older adults. The above suggests an impaired adaptability pattern in increased coactivation across the ankle and knee joints (Schmitz *et al*., 2009).

Normally, humans can ambulate across various terrains with minimal cognitive effort. However, in the presence of disease or trauma, neuromuscular communication can be affected and cause deviations in gait patterns, making it difficult to adapt to changes in inclination or speed. Muscle synergies are believed to exist in the different muscles of the lower extremities. Similar muscle activation has been observed when adapting to varying speeds and inclinations on a treadmill. The most notable distinctions were found in the soleus, peroneals, gastrocnemius (lateral and medial), biceps femoris, vastus lateralis, and medialis musculature among five different speeds and inclinations (Gonzalez-Vargas *et al*., 2015). Similar synergistic activity patterns have been observed in various studies, indicating consistency across walking tasks (Saito *et al*., 2018). Saito *et al*. (2018) found that EMG analysis increased activation with speed and inclination, but no significant variations were found in activation patterns during a gait cycle.

Investigating muscle patterns in healthy subjects during submaximal exercise protocols allows a better understanding of muscle activation and how these patterns compare with lower-intensity training. For instance, Clos and Lepers (2020) examined submaximal eccentric and concentric activation during cycling, where they found less muscle activation in the rectus femoris, vastus lateralis, biceps femoris, and soleus during eccentric cycling and no difference in the concentric portion concerning muscle activation. Further, Clos and Lepers discovered that heart rate and muscle activation seemed to decline after each cyclic trial for concentric and eccentric training (Clos & Lepers, 2020). Additionally, during rowing (land and water), Bazzucchi *et al*. (2013) established that initially, there was more muscular activation in water due to the force needed to overcome the water resistance. However, the mean analysis of the values showed that on-land rowing required more activation throughout the race than underwater, specifically in the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, and tibialis anterior. Heart rate was significantly lower while performing underwater, while VO2 showed no significant difference but was still overall lower underwater (Bazzucchi *et al*., 2013). Finally, Rosario (2020) studied the lower limb neuromuscular pattern while pushing a sled and identified an inverted relationship during walking and pushing said sled. This above distinction promotes the idea that while pushing the sled, walking could develop and modify the environment, thus promoting muscle endurance and running strengthening.

Thus, based on the aforementioned, we ask ourselves, what are the lower-extremity neuromuscular adaptations when walking up an incline in healthy young adults? We postulate that to understand the mechanism and benefits of specific activities, it is necessary to study neuromuscular patterns of the involved musculature. Consequently, this study aimed to assess lower-extremity muscle activation during a submaximal exercise test at different inclinations.

2. Method

2.1. Participants

Participants were recruited by word-of-mouth from Texas Woman's University in Dallas, TX, USA. The inclusion criterion for this study was that the individual should be a healthy young adult 20–45 years of age. The exclusion criteria were as follows: 1) history of low back or leg injury within the last six months, 2) women who were pregnant or could potentially be pregnant, 3) presence or history of angina, 4) stage III hypertension (systolic blood pressure ≥180 mmHg, diastolic blood pressure ≥120 mmHg), 5) resting SBP of 160–179 mmHg and resting DBP of 100–179 mmHg, 6) presence or history of heart disease, 7) pain in the lower extremities, 8) uncontrolled asthma (lack of bronchodilator/inhaler), 9) recent surgery within the last six months, and 10) recent lower extremity injury within the last six months.

2.2. Procedure

The Institutional Review Board (IRB) approved this study (Protocol FY2020-32), and informed consent was obtained before screening and testing began. Demographic and baseline data were collected prior to data collection. Data were collected using a surface EMG system (Delsys Inc.

Boston, MA). EMG electrodes were placed on the tibialis anterior (TA), gastrocnemius-lateral head (GA), rectus femoris (QUADS), and semimembranosus (HAMS) muscles of the dominant leg. A perturbation was applied posteriorly to identify the dominant extremity. Similar to the study of Bowman and Rosario (2021), the dominant limb was determined as the leg utilized in the stepping strategy for balance recovery. The leg was shaved using an electric razor to improve the EMG electrode placement and reduce signal interference if needed.

Ross Test Protocol: Participants were instructed to begin walking on a treadmill at 3.4 mph and 0% elevation for 3 minutes. The elevation increased every 3 min by 3% and 4% in women and men, respectively. The submaximal heart rate was measured during the final 15 seconds of every minute using a pulse oximeter. The test was terminated if the participant 1) reached 75% of their maximum heart rate, 2) reported lightheadedness, 3) requested to stop, 4) experienced chest pain/angina, or 5) reported pain in the lower extremities. Upon termination of the test, the heart rate was measured, and the time completed was documented. A cool-down period of 2 min followed by a 5-minute observation was required before leaving the testing site.

2.3. *Measures*

The activation of the four lower extremity muscles was measured using surface electromyography at different inclination grades. EMG data analysis was performed on each muscle during the first 30 s of each interval to allow for any muscle adaptation that would occur with adjustment of the inclination. Data recorded from the analysis included the time before peak muscle activation, time at peak muscle activation, and time after peak muscle activation for the first peak at 30 seconds and the subsequent peak (second peak).

2.4. *Data Analysis*

This study collected EMG data for four lower extremity muscles at six different levels of inclination. However, owing to the small number of participants who completed the protocol (six intervals), only the first three intervals were compared. In this study, the duration of muscle activation was determined by identifying two data points: the difference between the time after and before the peak. The EMG data were analyzed using the SPSS Data Analysis 28 system for repeated measures ANOVA. Descriptive statistics and pairwise comparisons were conducted for variables of interest. This study achieved statistical significance with a p-value equal to or less than 0.05.

3. Results

Table I presents the participants' demographic information. The participants had an average systolic blood pressure (BP) of 117.6 ± 18.596 (mmHg), diastolic BP of 77.6 ± 8.396 (mmHg), resting heart rate of 77.30 ± 9.581 (bpm) and resting oxygen saturation of 98.6 ± 0.516 (SPO2). Participants had an average height of 1.633 ± 0.078 (m), weight of 71.227 ± 19.157 (kg), age of 22.6 ± 1.075 (years), and body mass index of 26.585 ± 6.540 (kg/m^2). Of the 10 participants, 9 were right-leg-dominant, and 2 were left-leg-dominant. The participants had an average test completion time of 8:43:06.00 ± 4:44:53.56 (mins: seconds), with an average stage termination of 3.4 ± 1.647 (1–6).

TABLE I: Demographic Data of All Participants

Characteristics	Participant data
Age (yrs)	22.6 ± 1.08
Gender	Male = 1
	Female = 9
Height (m)	1.63 ± 0.08
Weight (kg)	71.23 ± 19.16
BMI (kg/m^2)	26.59 ± 6.54
Heart rate (bpm)	77.30 ± 9.58
Systolic BP (mmHg)	117.60 ± 18.60
Diastolic BP (mmHg)	77.60 ± 8.40
Sat O2 (%)	98.60 ± 0.52
Leg dominance	Right: 8
	Left: 2
Stage at which the test was terminated (1–6)	3.40 ± 1.65
Time the test was completed (mins: seconds)	8:43:06 ± 4:44:53.56
Heart rate at termination of the test (bpm)	149.30 ± 2.54

Table II shows the results of a repeated-measures ANOVA, comparing TA and GA time to peak and the activation time (duration) at different intervals throughout the Ross Test. There were no significant differences between the time to peak and the activation time of the TA and GA muscles with changes in inclination. It was noted that TA took longer to activate but was active longer than GA (Figs. 1 and 2).

TABLE II: Comparison of TA Activation by Stages

Variable	Interval	TA Mean and SD	GA Mean and SD	P value
Time to peak	1 (0%)	0.302 +/– 0.341	0.209 +/– 0.278	0.510
	2 (3%)	0.330 +/– 0.350	0.219 +/– 0.336	0.522
	3 (6%)	0.396 +/– 0.432	0.140 +/– 0.236	0.306
Duration	1 (0%)	0.421 +/– 0.440	0.385 +/– 0.477	0.847
	2 (3%)	0.497 +/– 0.524	0.317 +/– 0.442	0.451
	3 (6%)	0.523 +/– 0.563	0.250 +/– 0.386	0.411

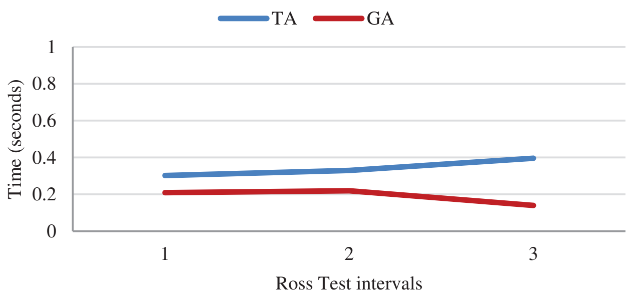

Fig. 1. Comparison of TA vs. GA time to peak by level of inclination.

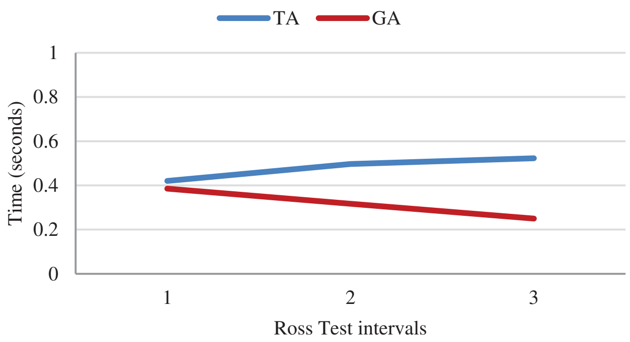

Fig. 2. Comparison of TA vs. GA duration by level of inclination.

Table III presents the results of a repeated-measures ANOVA, where the time to peak and duration of the QUADS and HS muscle activation were compared at different intervals throughout the Ross Test. While there were no significant differences in the time to peak and duration of activation between the QUADS and HS, it was noted that hamstrings took longer to activate and were active longer than the quads (Figs. 3 and 4).

TABLE III: Comparison of QUADS vs. HAMS

Variable	Stage	QUADS Mean and SD	HAMS Mean and SD	P value
Time to peak	1 (0%)	0.154 +/– 0.181	0.253 +/– 0.215	0.315
	2 (3%)	0.111 +/– 0.132	0.316 +/– 0.267	0.087
	3 (6%)	0.201 +/– 0.247	0.269 +/– 0.159	0.588
Duration	1 (0%)	0.316 +/– 0.375	0.590 +/– 0.480	0.186
	2 (3%)	0.396 +/– 0.498	0.717 +/– 0.449	0.103
	3 (6%)	0.353 +/– 0.404	0.782 +/– 0.357	0.082

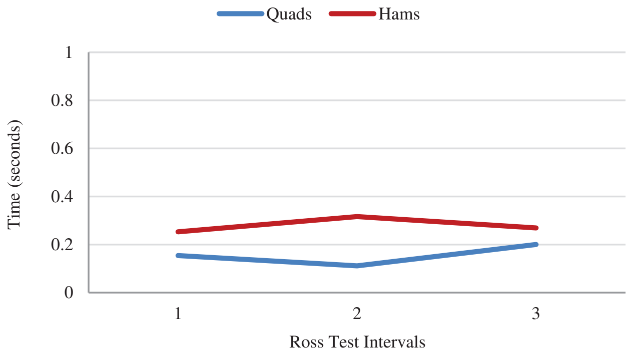

Fig. 3. Comparison of Quads vs. Hams time to peak by level of inclination.

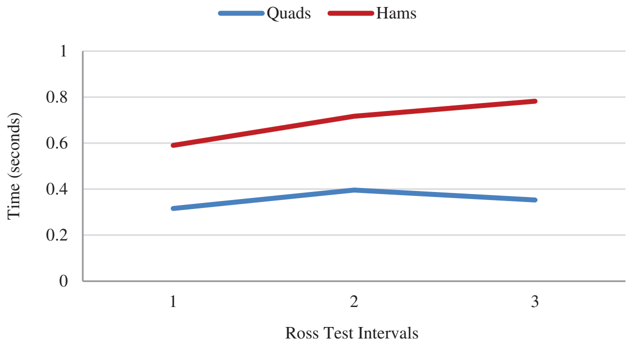

Fig. 4. Comparison of Quads vs. Hams duration by level of inclination.

4. Discussion

The prevailing question the current study was to answer was: What are the neuromuscular adjustments in lower extremities when walking up an incline in healthy young adults? The current study identified diverse trends related to lower limb musculature. TA and HS took longer to activate and were active longer than GA and QUADS.

As mentioned above, the first main discovery in this study was at the ankle joint, and how the tibialis anterior took longer to activate or turn on but was active longer than the gastrocnemius when performing the Ross Protocol. A systematic review by Magrath *et al.* (2022) described how the TA is more active at the beginning and end of the gait cycle to allow for toe clearance. In contrast, the GA showed increased activity during midstance and terminal stance to propel the body forward. Some researchers propose there is no definite activation pattern during normal gait in healthy adults, based on findings from Di Nardo *et al.* (2013), who indicated different activation intervals and activities throughout the phases of gait, which are usually not reported in healthy adults. In a different population, Acuña *et al.* (2022) revealed the effects of traumatic brain injury on muscle recruitment and that TA, and the medial head of the gastrocnemius revealed impaired muscle activation. Subsequently, it showed impairment in the dynamic gait index, with an average of 19 +/± 5.45%, correlating with an increased fall risk. We consider the TA was recruited further to ensure toe clearance from the treadmill surface as the incline increased (Rosario *et al.*, 2018, 2020). This prolonged activation can boost the endurance capabilities of said muscle. Future studies should repeat the Ross protocol pair with neuromuscular activation. However, pressure sensors should be used to identify the data points where the limb is in contact with the ground, such as a heel strike.

The second main finding in this examination was at the hip/knee joint, concerning the HA taking longer to activate but remaining active more than the QUADS. These results suggest the HA is taking the role of a hip stabilizer, concentric and eccentrically, as the inclination progresses. Similar to our statement, Franz and Kram demonstrated an increase in bicep femoris activation with grades steeper than 3 degrees. The biceps femoris functions as a knee flexor and a hip extensor. Bradford *et al.* (2016) further revealed an increase in bicep femoris activity with inclination, which equated to an increase in trunk flexion. Increased trunk flexion helps improve stability, but it requires the hip extensor group, which involves the bicep femoris, to produce a longer muscle contraction and recruit the hip extension needed to overcome trunk flexion. These increased inclinations will provoke shorter step lengths and, therefore, increased cadence. The increased cadence leads to an increased frequency of eccentric control by the bicep femoris at the knee, which we observed in the results of the current study.

A study by Orozco *et al.* (2022) demonstrated an increased duration of biceps femoris activation with increased inclination, while QUADS demonstrated an increased duration only while walking with 0%

inclination. The increase in duration further indicates that the hamstring needs to remain or increased activation while walking on an incline. This HS pattern is due to the increase in hip extension required to compensate for the increase in trunk flexion. However, a study by Wall-Scheffler *et al*. (2010) showed an increase in rectus femoris activation compared to the hamstrings during increases in inclination during walking at a constant speed. The above led us to consider that people demonstrate varying muscle recruitment strategies at different speeds, changes in inclination, and surfaces, as mentioned by Rosario and Orozco (2022). Nevertheless, at similar speeds, inclinations, and surfaces, it seems the lower limb musculature patterns are comparable, as shown by the results of this study and the outcomes of Orozco *et al*. (2022).

One constraint of this study was the termination requirements of the Ross test, which may have created a ceiling effect. The termination requirements for the Ross test were as follows: the participant achieved a 75% maximum HR, reported lightheadedness, was requested to stop, experienced chest pain/angina, and reported pain in the lower extremities during the test. These termination requirements may have created a ceiling effect in healthy individuals, who may have experienced an increased heart rate but did not experience any remaining requirements before completing the five intervals. A study by Noonan and Dean (2000) explained that submaximal tests have been developed to meet the needs of people with various functional limitations and disabilities. Therefore, inappropriate selection may lead to either under-stressing or overstressing, leading to invalid conclusions due to ceiling or floor effects. Noonan and Dean (2000) found that measures of exertion, breathlessness, fatigue, discomfort or pain, and well-being in response to physical activity are essential because many people monitor and act on their complaints more readily and reliably than using measures such as HR to guide their activities or exercise intensity. Therefore, further research is needed to develop and refine the scales used to assess exercise responses.

Given that symptoms limit people that correlate with physiological measures, assessment of their symptoms can provide critical information about their exercise responses. Various strategies are employed for progressively inclined walking at a constant speed. This test has been used in people with HIV, and because of the termination requirements, using a 75% max HR may not be the most appropriate measurement to record the submaximal effort in special populations. Orozco and Rosario (2020) conducted a study that showed a statistically significant reduction in HR levels during the Ross Submaximal Treadmill Test in HIV patients. This study further proves that the termination requirements for maximum HR could create a limitation and ceiling effect when using this submaximal exercise protocol in diseased populations. Future research should focus on tailoring the Ross test to special populations, such as those living with HIV. Perhaps as future research, the Ross test should be shorter in duration and add other scales that complement the termination requirements, such as the Borg Rating of Perceived Exertion (Pfeiffer *et al*., 2002).

5. Conclusion

This study intended to determine lower extremity muscle activation in healthy young adults in response to a submaximal exercise evaluation performed on a treadmill. This work explores the neuromuscular adaptations of a cardiovascular submaximal analysis on a treadmill. The results displayed some tendencies in muscle activation. The tibialis anterior and HS muscles showed an augmented time needed to switch on and were active for a considerably extended period once activated. These findings are coherent with previous considerations suggesting that the tibialis anterior and hamstring muscle groups have an increased activation duration when walking on an incline equaled to the gastrocnemius and QUADS (Magrath *et al*., 2022; Orozco *et al*., 2022). We foresee that the information cited in this endeavor will serve as a baseline for future inquiries comparing distinctions in lower-extremity muscle activation during a submaximal treadmill test in diverse special populations, such as individuals living with HIV.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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