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The Impact of a Rotating Balance Platform on Leg Neuromuscular Activity in Healthy Young Adults

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ABSTRACT

Balance is a functional activity that must be implemented in every type of rehabilitation for the back and lower extremities' injury and pathology. With issues in these regions, balance is lessened, requiring exercises that enhance the patient's stability. **Purpose:** To determine the impact of activities on a rotating balance platform with tracking tasks for lower limb muscle activation. **Method:** Twenty-five participants performed seven tasks on a balance board with a fixed middle fulcrum. For each trial, activation of the gastrocnemius and tibialis anterior muscles was recorded using surface electromyography. Upon examination of the EMG data, the following variables were quantified: time to peak muscle activation, time to decay of muscle contraction, and time of muscle contraction duration. **Results:** A repeated measures ANOVA revealed that TA exhibited significant modifications ($P<0.001$) with less time to peak, duration, and decay, whereas GA only notably compensated ($P<0.001$) with shorter duration and decay. **Conclusion:** For subjects with balance alterations due to slower nerve conduction or muscle weakness in the lower limb, we suggest incorporating activities with rotational movements on the balance board, where muscle activation is challenged due to surface and tracking activities. When endurance is prescribed, front-to-back tasks contribute to prolonged muscle activation. Balance rehabilitation should consider muscle activation timing with tracking tasks for more precise and targeted muscle execution.

Keywords: Balance Control; Tibialis Anterior; Gastrocnemius; Neuromuscular Adaptation; Tracking input

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Introduction

Balance can be characterized in mechanical terms as the proficiency to conserve the center of gravity (CoG) within the area of the base of support (BoS) [1]. When the CoG falls outside of the BoS, it can be assumed that the person becomes unbalanced and falls unless actions are taken to recover the CoG within their BoS limits. For the human body, the CoG is broader than the BoS in an upright standing posture, requiring humans to utilize several postural control mechanisms via their muscles to maintain balance and prevent falling [1]. Both static and dynamic balance include muscle recruitment, varying from the proximal trunk muscles to the distal ends of the body segments to execute postural control mechanisms.

Balance can be assessed and quantified with various measurements and devices; some require external equipment, while others involve subjective testing and criteria. One of the more frequent assessments to estimate standing balance is the Berg Balance Test, which consists of a battery of examinations scored by a clinician on the participant's ability, or lack thereof, to accomplish given tasks utilizing a tests pecific scoring system. This type of balance assessing test is straightforward to administer with minimal equipment necessary, while also incorporating a subjective factor conducted by the clinician [2].

Objectively, balance measurement can be achieved using force platforms, gyroscopes, and accelerometers. Force platforms can analyze and track the center of pressure (CoP) and how they are displaced by converting them into postural control measurements via calculations. Other measurements, such as gyroscopes and accelerometers, are designed to capture a subject's stance and orientation, combined with the non-gravitational velocity during dynamic and static balance [3]. This type of measurement can be relevant when clinicians and researchers seek to provide external perturbation and evaluate its influence on balance. Overall, when examining balance, several factors must be considered, such as the time available to administer the test, funds accessible to the clinician/ researcher, and balance analytics desired for the individual. For instance, an independent elderly adult might not require measurements taken on a force plate to discover postural alterations; therefore, the Berg balance test would be the most practical assessment in this scenario. In contrast, a recovering professional athlete's score on the Berg might be substantially above average, but with force plate analytics, postural modifications could be identified [4].

In addition to balance, which requires several rhythmic muscle activations to remain stable, the visual, somatosensory, and vestibular systems must function in unison to maintain balance operation correctly. When one or more of these systems do not work synchronously, postural instability is the outcome. Researchers utilize motor control theories, such as dynamic system theory, to comprehend the interplay between the sensory systems, illustrating how the three sensory systems need to interact efficiently to maintain dynamic or static balance, even when the systems are challenged [5]. When one or more systems are challenged or impairments in one or more of the systems, sensory reweighting occurs to enable the other systems to take over while maintaining posture [5].

Clinicians use multiple modalities to manage and improve balance, many of which have been deemed useful, although various queries have emerged from these established balance/ postural control studies. For instance, regarding the balance board, what are the neuromuscular mechanisms of the ankle complex during balance-board training with different tracking tasks? Additionally, is it possible to target the ankle complex's specific muscles, such as the TA or GA, during specific tracking tasks/posture strategies? These inquiries aim to identify neuromuscular ankle complex musculature strategies, the tibialis, and gastrocnemius, during various tracking tasks while maintaining postural control on a balance board with a fixed fulcrum.

Taking the aforementioned into consideration, it can be inferred that balance training on balance boards is an effective method for improving postural control. Understanding the neuromuscular activation pattern of postural muscles, such as in the TA and GA cases, will provide promising insights and aid in tailoring specific balance interventions that focus on neuromuscular rehabilitation. With this, we aimed to identify distinct neuromuscular activation timing characteristics for the TA and GA musculature during different balance activities that incorporate tracking tasks. In recognizing which balance tasks provide a longer duration and a quicker time to peak activation, interventions for subjects requiring muscle endurance or strengthening will be further guided.

Methods

Participants from the Texas Woman's University (TWU) Dallas campus were enrolled in the study after a member of the research team publicized the request for participants through word of mouth. All partakers were drafted via convenience sampling from physical therapy cohorts at the TWU in Dallas, TX. Following delineation of the participant's role in the investigation by a member of the research team and participants' agreement to participate in the study, approved informed consent forms were signed. Participants' demographics and general information (age, gender, weight, and height) were obtained during the individual interviews.

The inclusion criteria consisted of participants being youthful adults between the ages of 18 and 45 years old; this age range was used because of its potential to circumvent age related differences in balance and posture that are seen in older adults due to the normal aging process. Exclusion criteria were developed to avoid confounding characteristics that could misrepresent the results. Therefore, the exclusion criteria were: 1) significant balance problems resulting in the inability to maintain balance for 30 seconds, (2) untreated severe visual acuity, (3) BMI > 40, as this is classified as morbidly obese under the BMI classification table; (4) hypertension; (5) trunk or lower extremity trauma within the last six months; (6) use of drugs that induce drowsiness 24 hours before participating in this study; and (7) pregnant women or those who believed they could be pregnant.

Participants:

Data were collected from a total of 25 participants, 4 males and 21 females, between the ages of 22 and 32 (average age 24.64 ± 2.34 SD) with an average BMI of 24.40 ± -2.71. The complete demographic profile of the participants is presented in Table 1.

Table 1: General information and demographics data of all participants

Characteristics	Study Subjects n=25
Age	24.6 +/2.3 years
Gender	Male= 4; Female = 21
Height	M= 66.4+/-3.7 inches
Weight	151.8+/-28.6 pounds
BMI	24.4± 2.7 kg/m^2

Each participant's dominant leg was selected to establish electromyography (EMG) electrode placement. Of the 25 participants, two were left-leg dominant, while the remaining 23 were right-leg dominant. All data were collected at the TWU T. Boone Pickens Institute of Health Sciences in Dallas, Texas.

Measures:

Data were collected using an EMG surface electrode system (Delsys Inc. Boston, MA) on the tibialis anterior and gastrocnemius muscles. The EMG electrodes were positioned on the TA and GA according to the suggestions of Sacco and Kasman, and the activities of the two muscles were acquired at 1,000 Hz. During a series of balance trials, these measurement devices were used by utilizing tracking tasks from the M-Pad balance trainer. This balance board has a fixed middle fulcrum that is adjustable to various heights to alter the difficulty level. Additionally, the M-Pad has a cell phone and tablet application (app) with several tasks and tracking activities, which require the subjects to follow a target to activate or engage core and posture musculature in various directions and on the level of difficulty, as shown in Figure 1.

Procedures:

The participants signed an informed consent document before testing and screening. Demographic information, including height, weight, age, and foot dominance, was compiled. Next, an EMG surface electrode was placed on the dominant leg over the TA and GA. If necessary, areas of the dominant leg were shaved with a non-electric razor to attach and secure the placement of the EMG electrodes worn for testing. Both the screening and M-Pad protocols required a 30-minute time commitment for each participant.

Balance Assessment:

The EMG assessed muscle activation and strategies during seven different balance activities performed on the M-Pad balance board. Twenty-five participants participated in this investigation, all of whom performed each of the seven balance activities after removing their shoes. Each task was 17 s long, with a 10-second practice interval preceding each task.

The tasks were completed using a balance board to track a target through the M-Pad balance board app, projected onto a television screen located 10 feet away from the board. The seven balance tasks were as follows:

1. bullseye (BE)consisted of maintaining the target ball in the middle of the screen by balancing the board and keeping the board steady.
2. side-to-side (SS)shadowing the target ball with left and right movements in a coordinated pattern.
3. front-to-back (FB)tracing the target ball with front and back movements in a coordinated pattern.
4. clockwise (CW)tagging the target ball in circular patterns in a clockwise rotational direction.
5. counter-clockwise (CCW)chasing the target ball in circular patterns in a counterclockwise rotational direction;
6. front twist (FT)tracking the target ball using a quick semicircle in the posterior anterior direction, and
7. rear twist (RT)trailing the target ball by a quick semicircle in the anterior-posterior direction.

Data Analysis

TA and GA muscle activation was recorded using EMG works software for each trial. During the EMG data analysis, the variables measured were: 1) duration of muscle contraction, 2) time to peak muscle activation, and 3) time to decay of muscle contraction. Considering that the average postural balance transpired in the ankle complex using anterior and posterior sway, ankle dorsiflexion, and ankle plantarflexion, we considered the front and back (FB) task to be the baseline or less challenging balance activity. To identify the distinct neuromuscular activities and patterns, we performed repeated-measures ANOVA with all variables of interest comparing FB tasks to the remaining six balance activities (SS, CW, CCW, FT, RT, and BE), as depicted in Figure 1. Given the repeated nature of the statistical analysis, this study identified significance using the P-value (P ≤ 0.01).

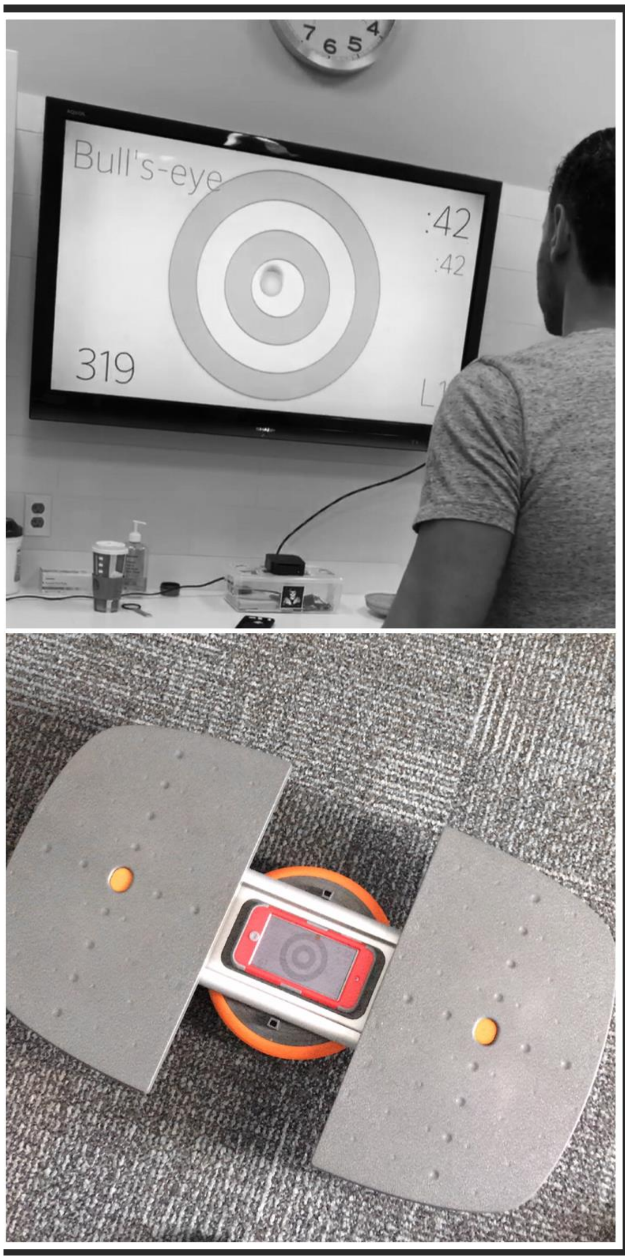

Figure 1: Balance Setup for M-Pad and Bull's Eye Tasks. Upper panel shows the screen projection of the tracking activities for the M-Pad app. Lower panel, depicts the M-pad balance platform with iPod required to play/use the application.

Results

A comparison of the GA's neuromuscular timing during FB balance tasks compared to the other six activities is shown in Table 2. Time to peak activation was comparable among the different tasks; however, muscle activation showed more significant differences, followed by a decay in the GA muscle. Additionally, the GA exhibited a shorter duration in the six more challenging activities, along with a shorter decay in half of the remaining activities than the FB tasks. The less challenging activity, which showed no difference in the GA's neuromuscular timing, was the BE task.

Table 2: Comparisons of Gastrocnemius EMG variables during all tasks.
Results of repeated measure ANOVA performed comparing EMG variables. Significance level is set at p≤0.01.

N=	Means and SD	Means and SD	P-Value
TP	FB: 0.07+/-0.18	SS: 0.09+/-0.06 CC:0.01+/-0.01 CCW: 0.03+/-0.03 RT: 0.01+/-0.01 FT: 0.01+/-0.01 BE: 0.2+/-0.3	1.00 1.00 1.00 1.00 1.00 1.00
Decay	FB: 0.16+/-0.21	SS: 0.12+/-0.07 CC:0.01+/-0.007 CCW: 0.03+/-0.04 RT: 0.12+/-0.43 FT: 0.01+/-0.01 BE: 0.20+/-0.38	1.00 0.01 0.05 1.00 0.01 1.00
Duration	FB: 0.23+/-0.14	SS: 0.21+/-0.09 CC:0.02+/-0.01 CCW: 0.06+/-0.06 RT: 0.02+/-0.01 FT: 0.02+/-0.02 BE: 0.4+/-0.05	1.00 0.001 0.001 0.001 0.001 1.00

SD=Standard Deviation; BE= bullseye; SS= side-to-side; FB=front-to-back; CW=clockwise; CCW=counterclockwise FT=front twist; TP=timed to peak

The distinct TA neuromuscular timing during the FB balance tasks was distinguished from the other six activities, as shown in Table 3. In contrast to GA, TA exhibited quicker neuromuscular modifications during the time to peak activation. In addition, the TA demonstrated adaptations during the same events, distinctly the tasks with a rotational component, with shorter duration and decay.

Table 3: Comparisons of Tibialis Anterior EMG variables during all tasks.
Results of repeated measure ANOVA performed comparing EMG variables. Significance level is set at p≤0.01.

N=	Means and SD	Means and SD	P-Value
TP	FB: 0.08+/-0.06	SS: 0.07+/-0.05 CC:0.01+/-0.004 CCW: 0.05+/-0.06 RT: 0.009+/-0.007 FT: 0.01+/-0.01 BE: 0.14+/-0.15	1.00 0.001 0.85 0.001 0.001 1.00
Decay	FB: 0.13+/-0.08	SS: 0.11+/-0.08 CC:0.02+/-0.01 CCW: 0.05+/-0.05 RT: 0.007+/-0.004 FT: 0.03+/-0.11 BE: 0.14+/-0.15	1.00 0.001 0.001 0.001 0.01 1.00
Duration	FB: 0.22+/-0.10	SS: 0.18+/-0.10 CC:0.02+/-0.01 CCW: 0.1+/-0.09 RT: 0.02+/-0.01 FT: 0.02+/-0.01 BE: 0.3+/-0.4	1.00 0.001 0.01 0.001 0.001 1.00

SD=Standard Deviation; BE= bullseye; SS= side-to-side; FB=front-to-back; CW=clockwise; CCW=counterclockwise; FT=front twist; TP=timed to peak

The M-Pad application score among the different balance tasks is illustrated in Table 4, in which a higher score indicates better handling or control of the balance board with the incorporation of the tracking tasks. The only distinction found was between FB and BE (p<0.01), which presents BE as having the highest score. The remaining tasks were comparable (P>0.01).

Table 4: Comparisons of M-Pad score application system for all tasks.
Results of repeated measure ANOVA performed comparing EMG variables. Significance level is set at p≤0.01.

N=	Means and SD	Means and SD	P-Value
TP	FB: 16.2+/-10.2	SS: 12.3+/-6.5 CC:22.3+/-10.9 CCW: 23.5+/-10.3 RT: 15.4+/-8.9 FT: 14.6+/-6.9 BE: 28.2+/-17.2	1.00 0.97 0.54 1.00 1.00 0.01

SD=Standard Deviation; BE= bullseye; SS= side-to-side; FB=front-to-back; CW=clockwise; CCW=counterclockwise FT=front twist; TP=timed to peak

Discussion

The present study sought to investigate and comprehend the neuromuscular activation modifications of the tibialis anterior and gastrocnemius postural muscles on a balance board while incorporating the impact of tracking tasks during the execution of diverse tasks. Our results illustrated that the TA muscle has more adjustments than the GA while standing on a stability board and receiving tracking input. It was also found that tracking input played a crucial role in the postural response and muscle activation pattern of both the TA and GA muscles among the subjects in this investigation. In the current study, we considered FB as the baseline because of its dorsiflexion and plantarflexion nature, which required a quicker response, as demonstrated by the shorter time-to-peak among the other tasks.

Postural strategies require continuous adjustment at the ankle joint, hip articulation, or when the perturbation suffices to displace the CoP outside the BoS, which leads to a further considerable adjustment in posture, the stepping strategy [5]. The GA and TA are muscles with considerable roles, not only in standing postural stability but also during gait, thus establishing the demand for devices and rehabilitation approaches as critical. To restore balance when perturbation emerges, an ankle, hip, or stepping strategy must be employed to avert falls. Specifically, the ankle strategy is advantageous when disturbances are of moderate amplitude in standing sway, in which muscle activity appears from muscles that intersect the ankle joint. During standing sway, a peak neuromuscular activity interrelationship can be observed between the gastrocnemius and tibialis anterior and the deep compartment of the leg musculature [6]. Likewise, when anterior sway occurs in postural static standing, the GA peaks in activation, yet during posterior sway, the TA activity peaks [7].

Considering the factors outlined above, as well as aspects of the impact of the M-Pad trainer and the distinctive tracking inputs being previously unknown, we focused on studying the influence of this equipment on the GA and TA ankle musculature. In doing so, we singled out FB balance activity as the baseline to compare the remaining and more sophisticated exercises, as the FB activity solicits the anterior-posterior sway and ankle strategies.

This study had two main findings. First, while both muscles changed their muscle activation timing, the GA exhibited minor adjustments. Both GA and TA decreased muscle activation by reducing the duration and decay of most of the complex balance activities related to FB. These findings suggest that in targeting endurance in the GA and TA muscles, the preferred activity should be FB, as it generates a longer duration and decay than rotational balance tasks, such as CW, CCW, and FT. In contrast, when the intervention's objective is to improve strengthening, which requires shorter periods of muscle activation, rotational balance tasks such as CW, CCW, and FT tasks should be employed.

Related findings were established in Rosario and Mathis's study [8] when an effective alternative to stimulate the GA muscle for strengthening purposes was considered. In contrast to our present investigation, the researchers incorporated a sled pushing device to highlight the increase in muscle activation in the GA muscle [8]. However, Mandalidis and Karagiannakis [9] documented that dynamic balance challenging activities engage musculature, such as the TA, comparable to the present research. Postural standing primarily employs postural musculature, similar to the GA. Therefore, the authors established that postural stability can be determined more accurately under dynamic conditions [9].

The second finding of this study focused on the anterior tibialis muscle. Contrary to the GA, the TA demonstrated quicker neuromuscular adjustments in the time to peak activation and faster activation recruitment with further compound movements when measured solely with FB. Targeted activation while avoiding muscle fatigue is conceivable when decreasing the number of repetitions or the extent of muscle contraction is brief [10]. It has been established that TA is a fundamental muscle for postural control [5]; therefore, individuals with a weak or injured TA, such as those with HIV [11] and subjects with hemiparesis suffering from drop foot [12], will improve from a directed, yet short, activation of the TA muscle while using this mpad balance platform.

In another study, Rosario [13] reported similar timing adjustments in the time to peak for the TA; however, their results were found from participants pushing a resistance sled device, which hindered the ability to isolate and target the TA to enhance strength. Building upon this implication, when an intervention intends to strengthen the GA and TA, mainly TA, while avoiding muscle fatigue, we propose employing the M-Pad balance board with rotational activities. In contrast, when addressing the musculature illustrated above to solicit endurance, which requires a significant activation duration, the FB activity utilizing dorsiflexion and plantar flexion is our suggested prime balance activity.

One limitation of our current investigation was the absence of data recording the proximal musculature, such as the hip or core muscles. Future studies should explore the impact of the abdominal muscles, erector spinae, gluteus maximus (hip extensor), and gluteus medius (hip abductors) to further discern the impact of the stability board with tracking tasks. Additionally, to study the effects of fatigue on postural muscles, we advocate for subsequent inquiries to extend the balance protocol's duration to at least 1 min per task. We also propose examining the effect of this balance board on various pathologies affecting balance, such as diabetes [14] and HIV [14]. For those with lower limb injuries that preclude them from running or pushing activities, for those that distance poses a challenge to, or for clinics or research labs that lack a runway, we recommend employing this balance board alongside the activities above. Finally, since GA activation occurs when swaying anteriorly [7], for people with balance complications with a propensity to sway or fall forward, we suggest the utilization of this balance board accompanied by tracking tasks.

Conclusion

The results of this research confirm that using the M-Pad Trainer as a postural control training tool provides neuromuscular advantages aside from the efficacy of traditional balance boards in stability training. This study calls for identifying or creating a low-cost portable device that targets distinct muscles, such as the GA and TA, to allow for different applications with novel interventions. Neuromuscular timing modifications that emerge from standing on the balance board have now been proven to occur with specific tracking tasks, highlighting the suggestion that clinicians can target specific neuromuscular control patterns, potentially allowing for more time dedication of the ankle muscles that are essential for balance and gait control [5]. We believe that more natural front-to-back tracking tasks will focus on promoting endurance associated with slower muscle recruitment and prolonged duration. In contrast, complex rotational tracking activities might target strengthening related to faster muscular activation recruitment over a shorter period, thus delaying the onset of muscle fatigue, specifically in the TA muscle. We endorse previous investigations focusing on balance training benefits, including those reducing falls in specific populations [15], by utilizing the M-Pad balance board to obtain similar objectives. Discerning the effects this board can have on various components of the muscles responsible for gait and posture is helpful for clinically relevant applications in distinct populations. Future studies should emphasize different pathologies and populations and recognize the functionality that results from various combinations of these tracking tasks.

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