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Implications of Muscle Activation Patterns on Balance in the Elderly

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ABSTRACT

IMPLICATIONS OF MUSCLE ACTIVATION PATTERNS ON BALANCE IN THE ELDERLY

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More than one third of adults ages 65 years old and older fall each year in the United States. This can result in trauma, hospital admissions, and potential death. The purpose of this study was to investigate the effects of waist-pull perturbation training on balance in the elderly. There were two experimental groups, elderly non-fallers (n=9) and elderly fallers (n=5) between ages 65-86, and a control group comprised of young, healthy subjects (n=10) ages 21-31. All subjects underwent baseline and post-training measurements using EMG recordings of the tibialis anterior, gastrocnemius, vastus lateralis and semimembranosus. Training was performing using repeated waist-pull perturbations in the forward direction. Results have shown that there was no significant differences in muscle activation patterns between the groups, and no significance in the direction of perturbation on muscle activation patterns as well. The results of this study suggest muscle activation patterns may not be affected by waist-pull perturbation training; further research may be necessary.

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Introduction

Balance can be defined as an individual's ability to maintain their body position and center of gravity within specific spatial boundaries.[1] Maintaining balance in response to a perturbation involves many systems including the musculoskeletal and neuromuscular systems; both of which play a crucial role in preventing falls. Falls are the leading cause of non-fatal injuries, hospital admissions and death in the elderly population.[2] Utilizing simple scales, Buatois identified that as an individual reaches age 65, there is an increased risk of recurrent falls,[3] and that in the United States, thirty-three percent of all falls occur to individuals greater than 65 years.[4] Therefore, it is imperative to conduct research to determine the most effective and viable method to train the elderly population to improve their balance and thus prevent falls.

The linear relationship between increased age and falls can be contributed to an overall decline in muscle mass and function with age. Previous studies determined that there is a 30 to 50 percent decline in muscle mass between 30 and 80 years of age[5] in addition to significant loss of type II muscle fibers with aging [6] thereby affecting the force generating capacity of the skeletal muscles. These changes in muscle properties result in weakening of the muscles and an inability to produce sufficient force, which is crucial in the maintenance of balance and fall prevention. It has also been demonstrated that sequencing and latency of the recruited muscles can play a significant role in maintaining balance. Elderly subjects demonstrate an overall delay in onset of postural muscle activation when compared to younger counterparts.[7] This slowing in the response time following a perturbation can be caused by a delay in central processing, resulting in loss of balance. [8] Additionally, elderly subjects demonstrate occasional disruption to the organization of the recruitment pattern by recruiting proximal muscles before distal muscles.[9] In response to a forward perturbation, the postural muscles on the posterior lower extremity should be activated in an ascending pattern while the postural muscles on the anterior lower extremity should be activated in the same sequence in response to backward sway.[10] This sequencing of muscle recruitment does not occur consistently in the elderly resulting in loss of balance. Therefore, the combination of the amplitude, latency, sequence and duration of muscle activation pattern can play a crucial role in balance in the elderly.

Responding to an unexpected perturbation is a challenging task that requires immediate and efficient motor response through the means of muscle activation patterns. Therefore, trends that are seen in the elderly population demonstrate increased risk for fall in response to perturbation.[11,12] Individuals utilize a continuum of strategies to maintain balance. These strategies range from those in which both feet remain in contact to the ground to strategies in which one foot initiates a step, increasing the individual's base of support. Terminologies often used to describe these events include the following: corrective versus protective, fixed support versus change in support, and feet in place versus stepping.[13] Studies show that the force threshold that the elderly can withstand is significantly lower when asked to use the "feet in place" ankle strategy than if they are allowed to take a step to maintain their balance.[14] A study performed by Pijnappels *et al* in 2007 investigated the control of support limb muscles in maintaining balance in response to a disturbance in balance. They focused on support limb, usually the left lower extremity, due to the fact that the support limb assists in balance recovery by counteracting any forward momentum induced by the perturbation or loss of balance.[15]

Perturbation training is an effective method which trains a specific system to improve balance and teach strategies needed to respond to unanticipated perturbation.16 Initial studies have demonstrated that both young and elderly adults can learn to resist loss of balance with repeated exposure to perturbations. Subjects achieved a significant reduction in the incidence of falls following a single session of 24 backward perturbations, with significant retention of this ability at six-month follow-up.[17] Patients who underwent perturbation training during a four-week treatment period showed significant decrease in time to stabilization of center of pressure after a perturbation compared to baseline assessments, and learning was retained at one-month follow-up. [18] Similarly, patients who underwent a six-week perturbation training program through support surface translations demonstrated decrease in multi-step reactions in response to perturbation. [19]

The current study investigates the effects of waist-pull perturbation training on muscle activation patterns in three groups: elderly fallers, elderly non-fallers, and healthy control subjects, with the utilization of "the stay in place" strategy following a waist-pull perturbation. The purpose of this study was to determine whether muscle activation patterns differ between the experimental groups, and whether the direction of the perturbation, forward or backward, affects the muscle activation response pre- and post-perturbation training. It was hypothesized that in elderly fallers, the latency of muscle activation would be delayed, the sequence of muscle activation patterns would be altered, and the amplitude of muscle activation would be decreased. Additionally, it was theorized that waist-pull perturbation training would improve latency amplitude and duration in all three test groups.

Methods

Participants

Twenty-four participants, regardless of gender, were recruited via flyers and word of mouth. Flyers were distributed at a friendship club located in Staten Island, New York, recruiting community-dwelling elderly adults. All subjects were residents of New York or New Jersey. The complete protocol for a single participant was performed in one day at a physical therapy lab at the College of Staten Island. Participants were screened for reported history of falls; a fall was defined as any event that led to an unplanned contact with a supporting surface. A subject was defined as a faller if he or she had experienced at least one fall in the year preceding the study, and a non-faller as an elderly individual with no history of falls. Prior to the date of the experiment, the purpose of the study and the protocol was clearly explained to each participant, and once informed each participant signed a written consent form. The participants were then divided in three groups: control subjects, elderly non-fallers, and elderly fallers. The control group consisted of ten participants (F=6, M=4); ages 21-31 (25.9 +/- 2.7) who had no reported history of falls. The elderly non-faller group consisted of 9 elderly adults (F=7, M=2) ages 65-85 (83.6 =/- 10.1), who reported no history of falls. The elderly faller group consisted of 5 elderly adults (F=3, M=2) ages 65-85 (71.6 +/- 6.5), who reported at least one fall in the year prior to the study. Study exclusions for all groups included history of neurological disorder, complaints of significant lower extremity pain, and orthopedic surgeries within the past year limiting the patients' ability to maintain balance. Body weight over 300 pounds due to belt limitations, pregnant woman or woman who suspect they may be pregnant, and reported use of vestibular medications on the day of the experiment. The experimental protocol was approved by the Institutional Review Board (IRB) committees of the City University of the New York.

Waist Pull Perturbations

A Force Release System (FRS) was designed to provide controlled perturbations. Each participant was secured with a belt around their waist, a force gauge (used to measure applied force to each individual) was attached on one end of the belt. Once a desired force (outlined in the protocol) was reached, a magnet attached to the force gauge was released, providing a perturbation. A goniometer sensor was attached to the releasing dock, indicating initialization of the perturbation. This allowed for the initiation of the perturbation to be marked consistently in the EMG tracings. The participants were instructed to maintain his/her balance without stepping. Trials in which the participant utilized the stepping strategy were discarded. Results only evaluated trials in which the participant utilized the hip and ankle strategy; three trials of each measurement were recorded.

Experimental Protocol

All participants were instructed to appropriate clothing to allow for exposure of the body parts involved in the study i.e. the upper and lower leg on the left lower extremity. If hair was present on the area where surface electrodes were to be attached, it was removed via shaving, then the area was cleaned using alcohol pads. In order to record involuntary muscle activity, single differential bipolar surface electromyographic (EMG) sensors connected to an EMG amplifier were placed on the muscle belly of the tibialis anterior, medial head of the gastrocnemius, semimembranosus, and vastus lateralis muscles of the left lower extremity. The muscle belly of each study muscle was found by resisting the motion the muscle performs and palpating for the muscle belly. The ground electrode was placed on the left patella. All EMG signals were obtained with the Digitimer D360 8-Channel Amplifier System.

Once the sensors were placed in the appropriate position, baseline EMG measurements were performed. The participant was instructed to stand barefoot a five-foot distance from the FRS. Participants were instructed to stand facing in a forward or backward direction in reference to the FRS. The forward direction was determined as the direction facing away from the FRS and the backward direction facing the FRS. The belt attached to the FRS was secured at the participant's waist. The participant was instructed to step or lean until the appropriate force magnitude was noted on the force gauge. For the forward perturbation measurements, a force of 62-67 Newton range was indicated, and for the backward perturbation a force of 53-58 Newtons was indicated. The participant was cued to stand in an upright posture with hands at side, head up, focusing on a designated spot, and they should avoid taking a step. Once the participant demonstrated appropriate posture, and the pre-determined force was reached, the magnet was released. To ensure safety of the experimental subject, two members of the research team guarded the participant. The above process was repeated until a total of three trials both in the backward and forward direction were obtained and recorded without stepping.

Once baseline measurements were recorded, all subjects underwent perturbation training utilizing a training apparatus. The training protocol was comprised of repeated rounds of predictable waist-pull perturbations in standing. A gauge attached to a padded belt secured around the participant's waist measured the exact force of the perturbation. We used a force of

106 Newtons for the training protocol. The therapist stood approximately at a two-foot distance behind the participant, and initiated a forward perturbation. The training consisted of 70 repetitions of perturbation and subsequent balance recovery. Each perturbation was initiated once the participant regained balance, and returned to midline. Each participant was also instructed to avoid taking a step during the training. Throughout this process, the participant was guarded to ensure safety as well. Following the training protocol, participants were provided with a four-minute rest period. Post-training EMG measurements were obtained and recorded adhering to the pre-training protocol.

Data Collection/Analysis

EMG analysis was performed utilizing LabChart Reader Version 8.0, and the data was transferred to a Microsoft Excel spreadsheet. In Microsoft Excel, the averages across the three trials for latency, amplitude and duration were calculated for each muscle pre- and post-testing. The difference between the pre- and post-testing results of the forward and backward directions were determined and used for data analysis.

SPSS version 20.0 was utilized for data analysis. The threshold for significance was a 95% confidence interval with p-values < 0.05 for significance. A two-way ANOVA with repeated measures was conducted using a linear model to analyze all the factors of the data. The within-subject factors was perturbation (forward perturbation and backward direction) and the between-subject factors was group (control, elderly fallers and elderly non-fallers).

Results

Initial results showed decrease in amplitude, duration and latency between all groups post-training in both the forward and backwards directions, as seen in Table 1, and figures 1-4. However, additional analysis showed no significance as seen in Table 2.

A total of twelve two-way ANOVA statistical tests were conducted using a linear model with repeated measures. Comparisons were made for each factor (latency, amplitude, and duration), each variable (forward and backward perturbation), for each muscle (tibialis anterior, medial head of gastrocnemius, semimembranosus and vastus lateralis), and for each subject. Between-subject factors (between groups) yielded p-values above 0.05, or no significant results. Within-subject factors (between perturbations) yielded p-values above 0.05, or no significant results.

Table 1: Samples of Initial Averages

Muscle	**Variable**	**Direction**	**Group**	**Pre**	Post
Tibialis Anterior	Latency	Forward	Control	367 ms	183 ms
			Faller	399 ms	215 ms
			Non-Faller	481 ms	383 ms
Vastus Lateralis	Amplitude	Forward	Control	1508 mv	1373 mv
			Faller	3425 mv	2292 mv
			Non-Faller	1187 mv	1107 mv
Medial Gastrocnemius	Duration	Backward	Control	761 ms	652 ms
			Faller	563 ms	250 ms
			Non-Faller	1027 ms	978 ms
Vastus Lateralis	Amplitude	Backward	Control	1680 mv	1377 mv
			Faller	3750 mv	3160 mv
			Non-Faller	1894 mv	1648 mv

Table 1 shows group averages for pre and post training values indicating decreases latency amplitude and duration in specific muscles

Figure 1.

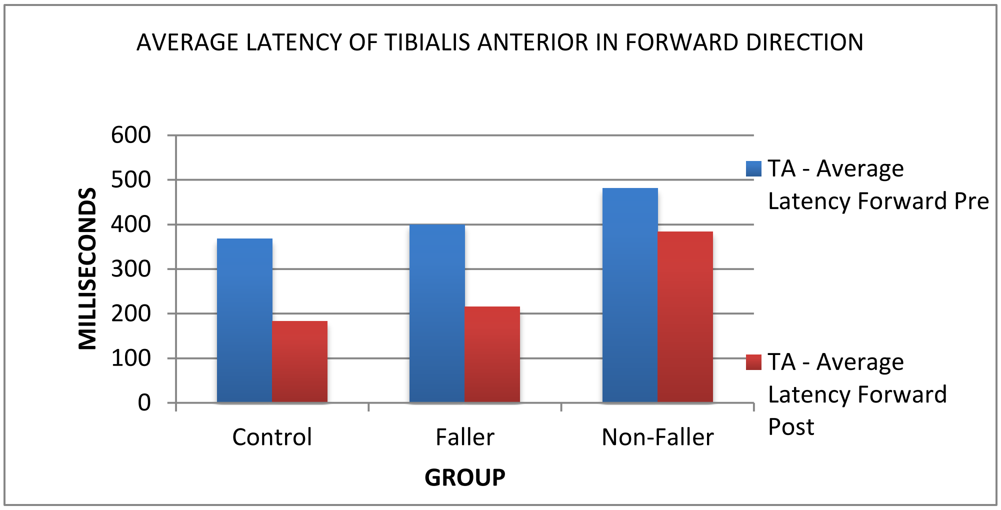

Figure 1 depicts the comparison between pre and post testing values for the average latency of the tibialis anterior in the forward direction for all 3 experimental groups.

Figure 2.

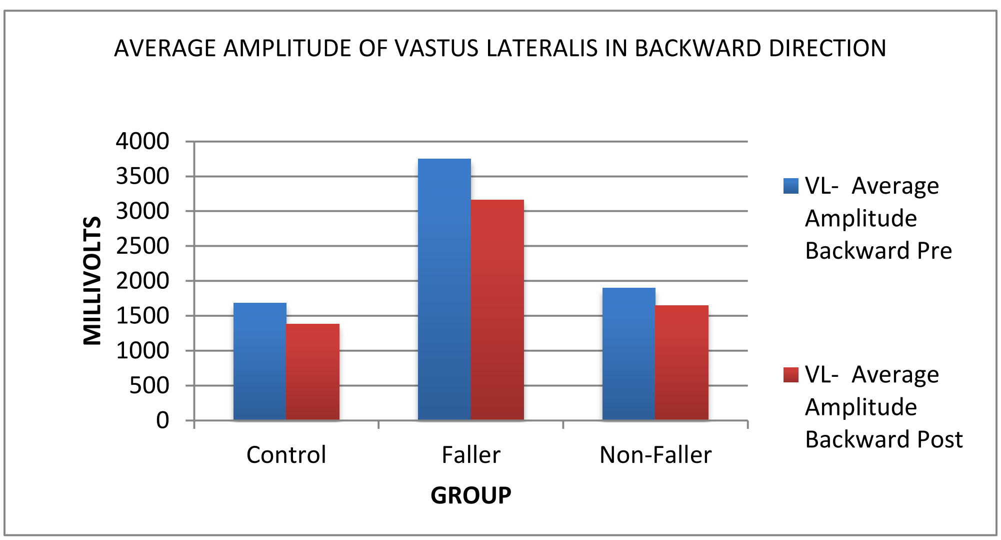

Figure 2 depicts the comparison between pre and post testing values for the average amplitude of the Vastus Lateralis In the backward direction for all 3 experimental groups.

Figure 3.

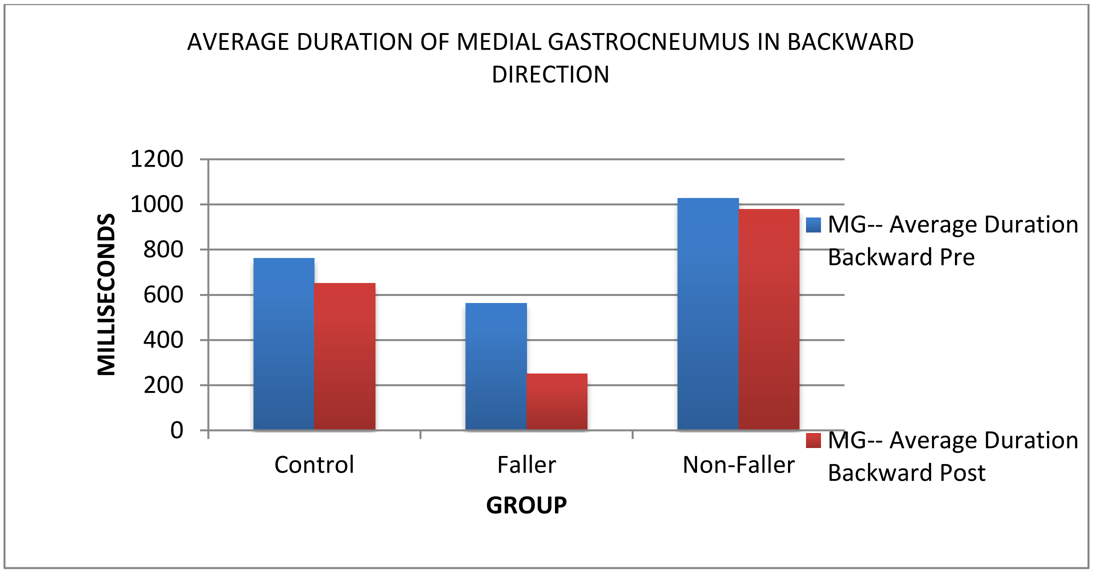

Figure 3 depicts the comparison between pre and post testing values for the average duration of the medial Gastrocnemius in the backward direction for all 3 experimental groups.

Figure 4.

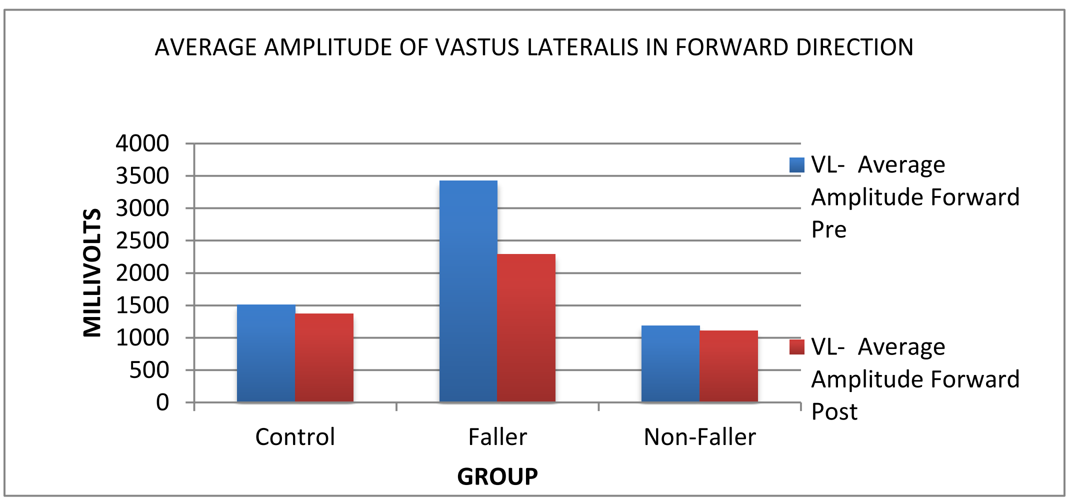

Figure 4 depicts the comparison between pre and post testing values for the average amplitude of the Vastus Lateralis in the forward direction for all 3 experimental groups.

Table 2. P values and F Values from SPSS Two Way Anova

Muscle	Variable	Factor	P Values	F Values
Tibialis Anterior	Latency	Perturbation	0.175	1.971
		Group	0.994	0.006
	Amplitude	Perturbation	0.459	0.569
		Group	0.815	0.207
	Duration	Perturbation	0.783	0.198
		Group	0.661	0.641
Medial Gastrocnemius	Latency	Perturbation	0.267	1.299
		Group	0.890	0.117
	Amplitude	Perturbation	0.282	1.221
		Group	0.235	1.552
	Duration	Perturbation	0.783	0.078
		Group	0.893	0.114
Vastus Lateralis	Latency	Perturbation	0.383	0.794
		Group	0.638	0.459
	Amplitude	Perturbation	0.874	0.026
		Group	0.812	0.210
	Duration	Perturbation	0.757	0.098
		Group	0.783	0.248
Semimembrinosus	Latency	Perturbation	0.523	0.421
		Group	0.823	0.196
	Amplitude	Perturbation	0.200	1.750
		Group	0.166	1.961
	Duration	Perturbation	0.126	2.541
		Group	0.102	2.551

Table 2 shows P and F values for the four muscles studied for all three variables for both within subject and within group factors.

Discussion

This aim of this study was to investigate the effects of perturbation training on muscle activation patterns in three groups namely elderly fallers, elderly non-fallers, and healthy control subjects, utilizing the "stay in place" strategy following a waist-pull perturbation. The purpose of this study was to determine whether there are differences in muscle activation patterns between the experimental groups, and whether the direction of the perturbation, forward or backward, affects the muscle activation response pre- and post-perturbation training. We hypothesized that in

Further, it was theorized that in all three test groups that there would be overall improvements in the latency, amplitude and duration following waist-pull perturbation training. Statistical analysis of data collected has shown that there were no significant results between- and within-subject factors.

Intuitively, it would be expected that young, healthy individuals, that comprised the control group, should have demonstrated a difference in factors such as latency, amplitude and duration of muscle activation compared to elderly non-fallers and particularly elderly fallers. We expected to see decreased latency, amplitude and duration with training all three groups and differences particularly between healthy adults and elderly fallers with the former group demonstrating lower values across all three variables. However, our study did not find evidence to support that hypothesis.

Our study failed to show any difference among the aforementioned factors possibly for several reasons. Waist-pull perturbation training was performed for a short period (a total of 70 perturbations) and may not have been sufficient time to allow for training of the lower extremity muscles tested in this study which were tibialis anterior, medial head of gastrocnemius, vastus lateralis and semimembranosus to improve balance. Secondly, the entire protocol i.e. pre- and post-training data were collected on the same day, in fact almost immediately following training (a 4-minute break between training and post-training measurements). Perhaps perturbation training on multiple days which could have allowed for muscles to be trained to respond to unanticipated perturbation and improve balance and reduce falls and risk of falls. Thirdly, waist-pull perturbations may not be the most effective technique to train lower extremity muscles to respond to unanticipated perturbations thus improving overall balance.

Further, EMG data was collected in both forward and backward direction but training was only performed in the forward direction. We were expecting to see carryover from training in the forward direction to the backward direction in all factors measured as well. However, training in the forward direction did not result in any significant results in that same direction either. Another deduction that could be drawn is that our perturbation training equipment was not effective in creating perturbation training that resulted in significant improvements in muscle activation patterns in any of the subject groups, but there are doubts regarding this assumption because any system that provides a perturbation during a training period should have potential to improve responses in subsequent trials. Lastly, the muscles chosen to be tested may not have been the best combination of muscles to study activation patterns involved in balance i.e. perhaps vastus lateralis instead of vastus medialis, and lateral hamstring instead of medial hamstring muscles.

Limitations of the study included insufficient participants in the elderly faller group (n=5) to compare to elderly non-fallers (n=9) and healthy control subjects (n=10). There were difficulties recruiting elderly fallers within the specified age range that met all inclusion and exclusion criteria. EMG values were collected via a manual technique, versus an automated system, and by four different researchers which could lend itself to human errors such as low inter-rater reliability. However, for the majority of participants, all measurements for an individual were recorded by a same researcher maintaining consistency within subjects, i.e. good intra-rater reliability. Additionally, patient set-up with surface electrode placements were performed by different members of the research team which could possibly influence muscle responses if electrodes were not placed directly over the muscle belly. Additionally, an effort was made to consistently use the specified forces in Newton's in the protocol for both the backward and forward direction, however, in a few instances where a subject was unable to sustain the force secondary to overall muscle weakness, frailty, or for other reasons, it was adjusted to a slightly lower value to allow for completion of the experiment, that is, utilizing the "stay in place" strategy.

Future research can be focused on a longer training period spanned over several days or weeks, the use of a different device for perturbation training, or a different form of perturbation training beside waist-pull perturbation. Also, data collection should be automated to minimize errors with measurements. The enrollment of a greater total number of participants and a more even distribution of participants within each experimental group may provide significant results. Lastly, waist-pull perturbations may not be effective in training lower extremity muscles to improve balance using the "stay in place" strategy. It is also possible that different strategies for maintaining balance predominate in different age groups. We have noticed that while individuals in the control group were less likely to take a step to maintain their balance following the perturbation, older individuals utilized stepping as a way of recovering from a perturbation and avoiding a fall.

Conclusion

This study has provided no evidence to support the hypothesis that there are differences in the muscle activation patterns between elderly fallers and non-faller compared to healthy young adults with regard to latency, amplitude and duration between pre- and post-training measurements in either direction forward and backward directions. All p values were greater than that set for significance for our study which was $p<0.05$. We believe that there is a difference in at least one of these factors (latency, amplitude or duration) in at least one of the lower extremity muscles important in maintaining balance without taking a step. A more appropriate study design, a greater number of participants, the use of more effective devices (training and otherwise), or a different form of perturbation training could potentially be the key to obtaining significant results.

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