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Research Article

The Effects of Strengthening the Lumbar Multifidus and Transverse Abdominis in Healthy Individuals Using an Augmented Feedback System: A Randomized Control Trial

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Abstract

Purpose: A common musculoskeletal deficit is decreased core strength. Popular interventions to address this deficit include strengthening of core stabilization muscles, transverse abdominis (TrA) and lumbar multifidus (LM). The purpose of this study was to compare the effectiveness of using an augmented feedback (AF) device versus traditional core stabilization exercises at strengthening the TrA and LM.

Methods: Healthy university students were randomly allocated to two groups. The experimental group used an AF device, the control group performed traditional core stabilization exercises. Maximum voluntary isometric contraction (MVIC) of the TrA and LM at lumbar vertebrae levels L4 and L5 was tested using wireless electromyography (EMG). Both groups exercised 3 times a week for 20 minutes, returning after 8 weeks to retest MVIC.

Results: Paired-sample t-tests revealed significant improvements in MVIC from pre-test to post-test in the left and right L4 and L5 muscles for both groups, ($p < .05$, for all) after 8 weeks. To determine if improvements differed across exercise conditions, a series of analyses of covariance (ANCOVA) were used. Results of the analyses revealed no significant effect of exercise condition on change score left and right L4 and L5 muscles, ($p > .05$, for all).

Conclusion: This study demonstrated the AF device was equally effective at increasing EMG activity of the LM and TrA in healthy university students compared to traditional core stabilization exercises. An AF device could be used as an alternative to traditional core stabilization exercises to strengthen the TrA and LM.

Keywords: Stabilization; Biofeedback; Muscular Contraction

Abbreviations: TrA: Transverse abdominis; LM: lumbar multifidus; AF: augmented feedback; MVIC: maximum voluntary isometric contraction; PACES: Physical Activity Enjoyment Scale; EMG: electromyography

Introduction

Research suggests that core muscles provide protection to the spine, while also assisting in overall body stabilization, force generation, and injury prevention [1-3]. Core strength training has traditionally focused on the transversus abdominis (TrA) and lumbar multifidus (LM) [4-11]. The function of the TrA is similar to the body's own internal back brace or corset. The TrA is the deepest of the abdominal muscles and connects the lower ribs to the top of the pelvis. With the assistance of the other core musculature, the TrA stabilizes the spine and pelvis prior to initiating movement of the arms and legs. The LM also functions to stabilize and support the lumbar spine as it attaches to the spinous processes of each lumbar vertebrae providing segmental stability. The LM and the TrA are key in providing stability for the spine [4-11].

While research identifies the benefits for core stabilization training, adherence to an exercise routine can be challenging for some individuals. Research suggests that non-adherence with exercises in clients may be as high as 70% [12]. Exercise adherence can be affected by poor understanding of the home exercises or lack of confidence in performing the exercises. Schneiders et al [13] found that participants have significantly higher exercise adherence when they receive written and illustrated instructions of home exercises. Clients may also feel uncertain of proper form during home exercises as they do not receive continual feedback from their clinician which can lead to poor exercise adherence [14,15]. New forms of technology may address the factors that lead to reduced adherence.

A recent systematic review found that utilizing technology to promote exercise is a strategy that may be effective in increasing participation [16]; however, there is limited research at this time to demonstrate if new forms of technology are effective in strengthening the core musculature and if they are more enjoyable than a traditional home exercise program. Augmented feedback (AF) systems are an example of this new technology. Using cameras or movement sensors, AF systems record and translate participant's movement and link/sync to gaming systems or smartphones to provide real-time motion analysis feedback.

An AF device called the Valedo® uses two small movement sensors that attach through adhesive strips to the chest and the lumbar spine. The Valedo® uses Bluetooth® technology to sync to the participant's smartphone and associated free mobile application. The sensors pick up the movement of the participant and translate that movement into an avatar in a video game that plays on a downloadable app on the participant's smartphone. The video games are designed to put the participant through lumbar movements that can activate both the TrA and LM. The design of the Valedo® allows for portability and ease of participant use. Many individuals already own a smartphone or tablet that can easily connect to the Valedo®.

With advancing technology, clinicians have a growing list of options and tools for consideration to provide clients with exercise programs and feedback. Tools like the Valedo® provide feedback in real-time to the client while they perform the exercises at home. Hugli et al [17] found participants using Valedo® exercised for a greater amount of time each week compared to a traditional exercise group. The primary purpose of this study was to compare the effectiveness of using an AF device versus traditional core stabilization exercises at strengthening the TrA and LM in healthy participants. The researchers hypothesized that participants using an augmented musculoskeletal feedback system would achieve similar increases in EMG activity of the TrA and LM following an 8-week home training program compared to participants performing traditional core stabilization training. The secondary purpose of this study was to compare the level of exercise enjoyment using the Physical Activity Enjoyment Scale (PACES) for participants using an AF system or performing traditional core stabilization exercises over the course of an 8-week training period. The researchers' hypothesized that the use of the AF system would be just as enjoyable as performing traditional core stabilization exercises.

Methods

Participants

The recruitment of participants involved a purposive sample of 83 asymptomatic university students. These undergraduate students were invited to participate as they were healthy and familiar with exercise (see CONSORT flow diagram, Figure 1). The inclusion criteria for the study consisted of being between the ages of 18 and 25. The exclusion criteria included current pregnancy, back pain within the past six months, or past medical history of back surgery.

The experimental design conducted was a single-blind, randomized control trial. Ethical approval was obtained through the university prior to participant recruitment. The experiment was a single-blind, randomized control trial as the primary researcher was blinded to the measurement of EMG activity of the TrA and LM. Prior to the start of the experiment, participants were randomly assigned to either the experimental or control group.

Materials and Dependent Measures

EMG measurements of the TrA and LM were assessed using a wireless EMG device (Delsys Trigno™ Avanti Platform, Natick, MA). The device was calibrated in accordance with manufacturer specifications. EMG activity is a signal that detects electrical activity of muscles during contraction. The EMG activity represents neuromuscular activation of motor units near the EMG electrode [18]. Assessing EMG amplitude gives researchers a glimpse into the amount of tension that a muscle can generate. Strength training can lead to an increase in force and tension that is generated in a muscle during contraction. Strength training elicits both neurological and functional adaptations within skeletal muscles, leading to increases in EMG activity [19-23].

PACES (Physical Activity Enjoyment Scale)

The Physical Activity Enjoyment Scale (PACES) was used to examine the level of exercise enjoyment that the participants in each group experienced while performing the exercises during the 8-week training period. The PACES has been developed and validated as a tool to identify participants' enjoyment while performing exercise [24]. The scale contains 18 items and the responses are collected on a Likert-type scale. The scores range from 1 (totally disagree) to 7 (totally agree). The scale has demonstrated solid internal consistency [24] and construct validity [25]. Eleven of the 18 items are reverse scored, and the higher PACES scores reflect greater levels of enjoyment, with a maximum score of 126 [24].

Experimental Intervention

The experimental group within the randomized control trial used the AF system, the Valedo®. The Valedo® uses two small movement sensors that attach through adhesive strips to the chest and the lumbar spine. The Valedo® utilizes Bluetooth technology to sync to the mobile application on the participant's smartphone. The sensors pick up the movement of the participant and translate the movement into an avatar in a video game that plays on a downloadable app on the participant's smartphone or tablet. The video game is designed to put the participants through lumbar movements that activate both the TrA and LM. The participants in the experimental group advance through the levels of the Valedo® games, which increase in difficulty as participants complete each level, progressing from a low-intensity to a moderate-intensity. Participants were able to advance to the next level once they successfully passed the previous level based on accuracy of movement patterns performed by the participant. Movements included spinal flexion, extension, rotation, lateral flexion that were performed in the standing and quadruped positions to activate the LM and TrA. Participants in the experimental group were instructed to perform the exercises three times per week for 20 minutes; they were instructed to complete an abdominal draw-in maneuver during the exercises to contract the TrA.

Control

The control group completed traditional core stabilization exercises for 8 weeks. These traditional core stabilization exercises focused on contraction of the TrA and LM. Exercises were performed in the supine and quadruped positions and included: neutral abdominal bracing, marching, and opposite arm/opposite leg movements with abdominal bracing. Participants were instructed to complete an abdominal draw-in maneuver during the exercises to contract the TrA. Exercises were advanced every two weeks to higher level activities progressing from a low-intensity to a moderate-intensity to further challenge the TrA and LM. Participants in the experimental group were instructed to perform the exercises three times per week for 20 minutes.

Procedure

Participants arrived in the research lab and signed the consent form to participate in the research study. Next, participants completed a Readiness to Participate Questionnaire (Health History Questionnaire) to ensure they were healthy enough for exercise. Initial data collection consisted of taking anthropometric measurements which included the following: body weight, height, and body mass index (BMI). Body weight was measured (in duplicate and averaged) with a digital scale (Seca 876) to the nearest 0.1 kilogram. Participants wore light clothing and removed shoes and socks prior to weight measurement. Height was assessed (in duplicate and averaged) to the nearest 0.1 centimeter with a portable stadiometer (Seca 213) in light clothing without shoes or socks. Body Mass Index (BMI) was calculated by the standard method (body weight [kg]/ height [m]^2) from weight and height measurements. Following anthropometric data collection, each participant completed two physical tasks to identify EMG amplitude measurements of maximal resisted isometric exercises of the Tra and LM. Prior to conducting muscle activation evaluations, each participant was instructed on the procedures. After verbal understanding of the requirements of the exercise, EMG electrode site placement was prepared. Preparation of the skin was completed by cleansing it with 70% isopropyl alcohol and excess hair was shaved as necessary. Dual disposable silver/silver chloride surface recording electrodes were applied to the test subjects. EMG data was collected in all subjects on the LM bilaterally at L4 and L5 spinal levels. Two electrodes were placed on each side of the lumbar spine two centimeters lateral to the spinous process of L4 and L5 making a total of four electrodes on the lumbar spine over the LM muscle. The maximum voluntary isometric contraction (MVIC) of the LM was obtained in the prone position on a Rogue Glut Ham Developer®. Participants were asked to extend their lumbar spine maximally, gradually increasing the force of contraction against the researcher's locked out elbows and wrists with the researcher's hands stabilizing along the participant's thoracic spine. The participant maintained this contraction for five seconds in order to achieve MVIC [26]. The MVIC of the TrA was obtained in the seated position with the participant performing an abdominal hollowing maneuver [26-28]. Electrode placement was two centimeters medial and inferior to the anterior superior iliac spine [29].

Each exercise was conducted twice with one minute rest in between MVIC's. Confirmation of proper electrode placement was completed by observing EMG amplitudes during the MVIC. To increase internal validity between measurements, only one researcher collected EMG data. The sampling rate was set at 1200 Hz per channel. The raw EMG data was full-wave rectified, processed using a root-mean square algorithm, and smoothed with a 20 ms moving window. The amplitude was calculated from a 5-second window centered around the peak activity of the muscles for each of the MVIC's performed.

Following anthropometric data collection and completion of EMG amplitude measurements of MVIC, the groups were instructed to perform the exercises three times per week for 20 minutes. The participants were verbally instructed in the proper technique of the exercises by the head researcher, a Doctor of Physical Therapy, to ensure proper execution of exercises. Additionally, participants were verbally instructed in the frequency and duration that each exercise should be performed. Participants in the experimental group were taught how to put on the sensors and where to place them on their skin while exercising and were also instructed on proper use of the Valedo® system on their smartphone. Participants performed the exercises for 8 weeks independently and returned to the research lab for follow-up data collection.

Data Analysis

Paired-sample t-tests were used to determine whether the 8-week home exercise program led to significant improvements in MVIC in the overall sample. Furthermore, analysis of covariance (ANCOVAs) were used to examine the equivalence of the different exercise programs. Specifically, change scores in MVIC from pre- to post-exercise period for each muscle were entered as the dependent variable in each analysis, with the corresponding pre-test MVIC score entered as a covariate. The exercise condition was entered as the independent variable in each analysis. Significance was set at 0.05. IBM SPSS version 26 software was used for all data analysis.

Results

Participants

Eighty subjects were assessed for eligibility, none were excluded for the presence of recent injury or pain (*n=0*). The eighty participants were then randomly assigned to either the control or experimental group. Initial data collection was performed, and demographic data was collected (Table 1). Participants were instructed to return in eight weeks for follow-up data collection. Twenty-six participants did not return for follow up data collection.

Table 1: Baseline Characteristics of Participants that Completed the 8-Week Study.

		AF Group *n*=24	Traditional Core Stability Group *n*=30
Age [Years], (m, sd)		21 (.67)	21 (1.0)
Sex [*n*], (%)	Males	7 (29.2)	6 (20)
	Females	17 (70.8)	24 (80)
Height [cm], (m, sd)		170.03 (7.93)	167.58 (7.96)
Weight [kg], (m, sd)		71.36 (16.59)	68.65 (9.89)
BMI [kg/m^2], (m, sd)		24.59 (4.84)	24.45 (3.07)

n: subjects; AF: Augmented Feedback; m: mean; sd: standard deviation; kg: kilogram; cm: centimeter; BMI: body mass index

Effects of Exercise

Results of the paired t-tests indicated that participants had a significant improvement in MVIC from pre-test to post-test in the L4 and L5 LM in both groups. MVIC in the Left and Right L4 LM were significantly higher at the post-test assessment. Similar results emerged for the Left and Right L5 LM over the course of the 8-week exercise program. Improvements were found in MVIC for the Left and Right TrA muscles in both groups, however, improvements did not reach level of significance. Pre- and post-test MVIC scores can be found in Table 2.

Table 2: Pre- and Post-Test MVC Scores by Muscle.

Muscle		Pre-Test MVIC M	Pre-Test MVIC SD	Post-Test MVIC M	Post-Test MVIC SD	t	d
L4	Left	173.24	114.74	219.59	181.07	2.08*	0.28
	Right	152.29	75.8	210.33	168.57	2.34*	0.32
L5	Left	146.05	79.87	223.54	264.45	2.14*	0.29
	Right	153.34	86.69	196.92	136.53	2.41*	0.33
TrA	Left	174.56	150	212.7	188.16	1.63	0.22
	Right	182.97	135.26	211.25	203.43	1.11	0.15

Note: df = 52 for L4 and L5 muscles. df = 53 for TrA muscles.

MVIC: maximum isometric voluntary contraction; L4: lumbar vertebrae 4; L5: lumbar vertebrae 5; TrA: transverse abdominis; m: mean; sd: standard deviation. Paired t-tests; *p < .05

Exercise Condition

After examining the overall effects of the 8-week exercise program, the researchers examined whether there were differences in MVIC changes over time between participants performing the traditional core exercises compared to those exercising with the musculoskeletal feedback device. ANCOVAs revealed no significant

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effect of exercise condition on MVIC change score for Left (F(1,51) = .47, p = .50, = .01) or Right L4 (F(1,51) = .01, p = .95, = .00), Left L5 (F(1,51) = 1.72, p = .20, = .03) or Right L5 (F(1,51) = .18, p = .68, = .003), or the Left (F(1,51) = .03, p = .86, = .001), or Right TrA (F(1,51) = .00, p = .95, = .00). Estimated marginal means of change scores for each muscle across exercise conditions are shown in Figure 2.

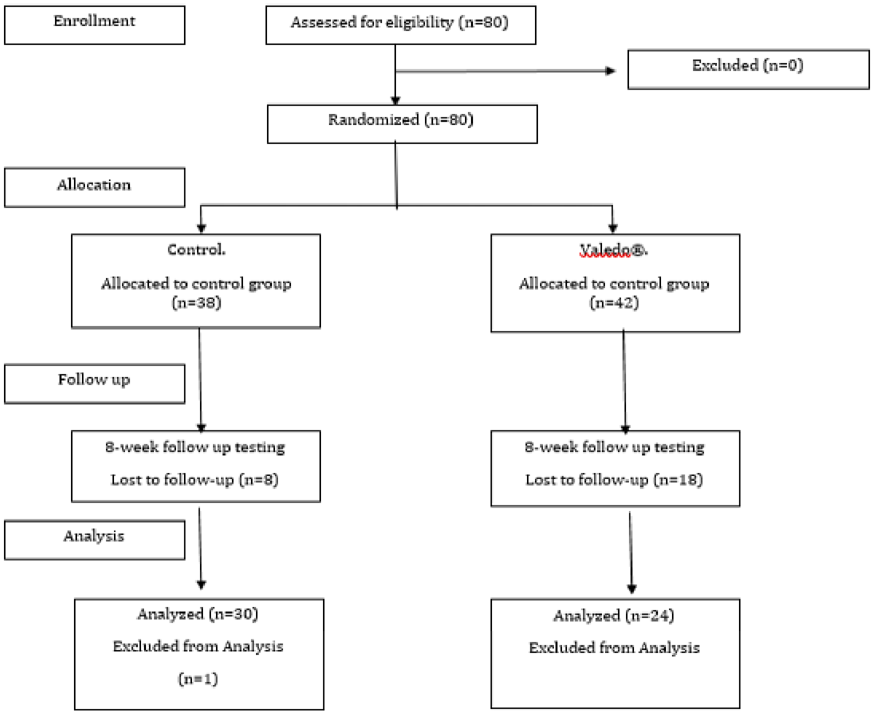
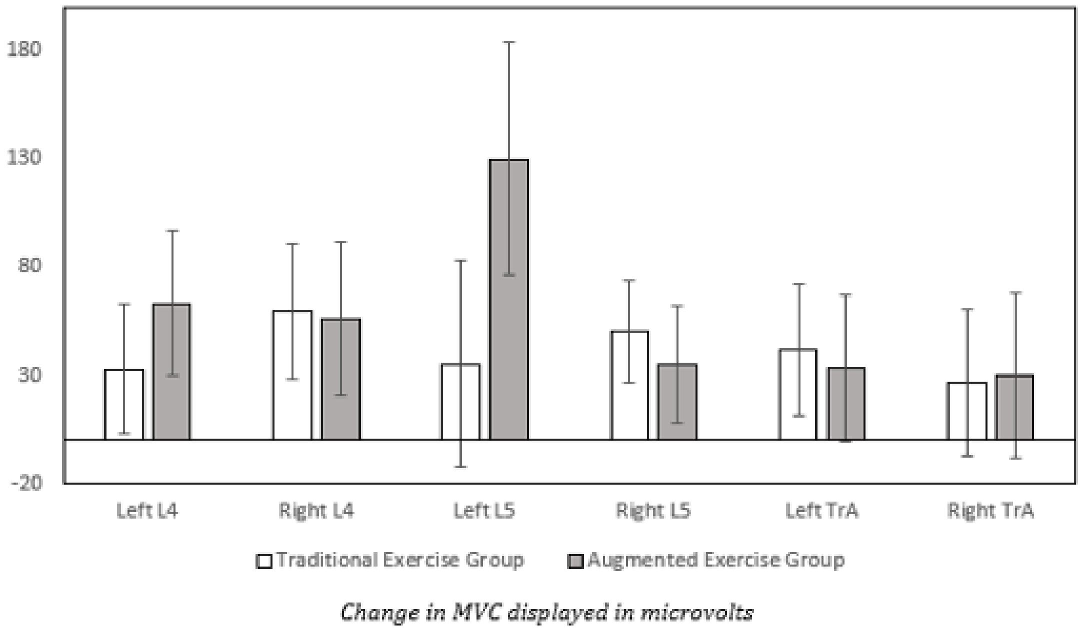


Figure 1: CONSORT.



Note: Bars represent estimated marginal means of change scores. Error bars represent standard errors.

Figure 2: MVC Change Scores across Experimental Condition.

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PACES

Enjoyment of exercise was compared across the different 8-week exercise programs using an independent samples t-test. Results indicate a significant difference in enjoyment between the experimental and control conditions ($t(52) = 2.72$, $p < .01$). Specifically, participants in the control condition reported significantly higher levels of enjoyment than participants in the experimental exercise program ($M_{Control} = 93.50$, $SD_{Control} = 19.00$; $M_{Experimental} = 80.71$, $SD_{Experimental} = 14.52$, $d = .76$).

Discussion

The primary focus of the study was to examine the effectiveness of an AF system compared to traditional core stabilization exercises at increasing the EMG activity of the TrA and LM over the course of an 8-week training period. The researchers' hypothesis was that the AF system would be as effective at increasing the EMG activity of the TrA and LM compared to traditional core stabilization exercises. The results of the study indicate participants had a significant improvement in MVIC from pre-test to post-test in the L4 and L5 LM in both exercise groups, thereby supporting the hypothesis. MVIC in the Left and Right L4 LM were significantly higher at the post-test assessment in both exercise conditions. Similar results emerged for the Left and Right L5 LM over the course of the 8-week exercise program. Improvements were also found in MVIC for the Left and Right TrA muscles in both groups; however, improvements did not reach a level of significance. Collectively, the results demonstrate an AF device is equally as effective as a traditional core stabilization program at activating the TrA and LM measured by EMG.

Although this study was performed on healthy university students, the results may suggest potential clinical implications with clients suffering from low back pain. Traditionally, clinical practice and treatment of low back pain have focused on core stabilization exercises [4-11]. The primary muscle groups that are targeted have been the LM and TrA. However, a recent systematic review reported that while strengthening the core musculature is important, generalized body movements and physical activity may be equally as important in the treatment of low back pain [30]. Using technology such as the Valedo® would allow individuals with low back pain to complete generalized body movements with feedback at their own convenience. The results of this study demonstrate that not only can AF devices provide an easy way to perform generalized movement, this new interactive technology is also effective in strengthening the LM and TrA.

The secondary focus of the study was to compare the level of exercise enjoyment using the PACES for participants using an AF system or performing traditional core stabilization exercises over the course of an 8-week training period. The researchers' hypothesis was that the AF system would be just as enjoyable as performing traditional core stabilization exercises. The results show that overall, the participants enjoyed performing the traditional core stabilization exercises more than using the AF system, thereby the results fail to support the hypothesis.

Although the results demonstrate that the AF device was just as effective as traditional core stabilization exercises at increasing core muscle activation, it appears that some participants did not enjoy using the AF device as much as traditional core stabilization exercises. Several factors are postulated to contribute to this finding. One possibility for the lack of enjoyment among the participants in the AF group is that the participants were healthy university students who may be accustomed to more intense exercise. Some of the statements from participants within the AF group included that while they were performing the movements with the AF device, they did not feel like the exercises were intense, or that they substantially exerted their muscles while completing the movements. However, even though their perceived level of exertion while exercising with the AF device was low, they were able to significantly increase the EMG activity of their LM. This anecdotal evidence may be valuable to the clinician that the exercises were perceived to be at a low intensity, but equally effective in strengthening the core musculature. Future research may consider examining its usefulness in clients such as those who may be suffering from pain or deconditioned due to a generalized lack of physical activity.

Clinical Relevance

While clinicians provide beneficial exercises for clients, exercise compliance and client participation can be a barrier to improved outcomes [31-34]. The current study provides insight to the possibilities for technology in fitness and healthcare. Future clients may benefit from and enjoy AF devices as an alternative approach to exercise. Innovative uses of AF devices may assist clinicians in this ever-changing world of technology. The use of AF devices could potentially provide affordable care to those in rural areas or those with limited access to healthcare facilities. Additionally, it could provide the clinician with the ability to expand their geographical reach to numerous clients in the surrounding areas via telehealth.

Accessibility to and compliance with exercise is an ongoing struggle for clinicians. Exploring potential options to aid in alleviating this issue is lacking, which is why this study is of significance. Moreover, technology may be able to aid in bridging the gap in home exercise using telehealth and the real-time feedback the Valedo® device is able to provide.

Limitations

The study conducted had multiple limitations, the first being the relatively small sample size of participants that completed the study. Another limitation is that multiple participants dropped out during the eight-week study. Numerous participants that dropped out cited reasons such as the lack of time to complete the exercises, school, and work schedule conflicts. Another potential limitation may be that the length of the study was eight weeks. Finally, the study only investigated the effects on healthy university students; future research may benefit from exploring alternative populations.

Future Research

Although the results of this study demonstrate that AF devices can be as beneficial as traditional core stabilization exercises in improving core muscle strength in healthy university students, future research needs to be conducted to ensure this type of technology would be beneficial for clients suffering from low back pain. Future research should focus on randomized control trials with clients suffering from low back pain by studying the AF system's ability to aide in the reduction in pain or improve mobility. Additional research could be conducted using various populations other than those suffering from low back pain. These could include sedentary individuals, the elderly, or the pediatric population.

Conclusion

This study demonstrated that the AF device was equally effective at increasing EMG activity of the LM and TrA in healthy university students. If future research demonstrates that AF devices can be an effective rehabilitation tool in reducing pain and improving mobility, this could be useful for clinicians. The ease-of-use and relative low cost associated with the Valedo® could provide an opportunity to reach numerous clients as an effective way to strengthen their LM and TrA as well as promoting generalized movement, leading to improvements in function and quality of life for clients.

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Conflict of Interest

Authors declare no conflict of interest.

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