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Trunk Muscle Training Augmented with Neuromuscular Electrical Stimulation Appears to Improve Function in Older Adults with Chronic Low Back Pain: A Randomized Preliminary Trial

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Abstract

Objectives—To assess the feasibility of a trial to evaluate a trunk muscle training program augmented with neuromuscular electrical stimulation (TMT+NMES) for the rehabilitation of older adults with chronic LBP and to preliminarily investigate whether TMT+NMES could improve physical function and pain compared with a passive control intervention.

Methods—We conducted a single-blind, randomized feasibility trial. Patients aged 60-85 years were allocated to TMT+NMES (n=31) or a passive control intervention (n=33), consisting of passive treatments, i.e. heat, ultrasound and massage. Outcomes assessed 3-months and 6-months post-randomization included Timed Up and Go Test, gait speed, pain and LBP-related functional limitation.

Results—Feasibility was established by acceptable adherence ($\geq 80\%$) and attrition ($<20\%$) rates for both interventions. Both groups had similar, clinically important reductions in pain of greater than 2 points on a numeric pain rating scale during the course of the trial. But, only the TMT+NMES group had clinically important improvements in both performance-based and self-reported measures of function. In terms of the participants' global rating of functional improvement at 6-months, the TMT+NMES group improved by 73.9% and the passive control group improved by 56.7% compared to baseline. The between-group difference was 17.2% (95%CI: 5.87-28.60) in favor of TMT+NMES.

Discussion—It appears that a larger randomized trial investigating the efficacy of trunk muscle training augmented with NMES for the purpose of improving physical function in older adults with chronic LBP is warranted.

Keywords

Low Back Pain; Exercise; Electrical Stimulation; Older Adults

Low back pain (LBP) is the most frequently reported musculoskeletal problem and the third most frequently reported symptom of any kind in people over the age of 75.¹⁻² In fact, 17.3% of all visits to physicians for LBP involve individuals over the age of 65.^{1, 3-4} As

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evidence of the societal impact of LBP in older adults, between 1991 and 2002, Medicare data indicates a 132% increase in LBP patients and a 387% increase in related charges for LBP.⁵ Despite the fact that LBP is a common problem for older adults and is associated with poor outcomes in this vulnerable age group⁶⁻⁹, little research has focused on LBP in people over the age of 65.^{1, 10} With minimal research available, clinicians are left without clear evidence-based guidance as to how they should manage older adults with LBP.

Although all older adults are at some risk for mobility limitations, it is becoming clear that those with significant LBP may be at a greater risk for functional decline. Reid et al. have demonstrated that restricting LBP is independently associated with declines in walking speed and chair rise performance in older adults.⁷ Hicks and colleagues have shown that a single report of moderate-severe LBP is associated with greater decline in function over three years among otherwise healthy older adults.⁹ With mounting evidence that older adults with LBP are at greater risk of decreased physical performance, it is becoming clear that management of LBP in the geriatric population should not only focus on pain reduction, but on improvement of physical function.

Recent work has demonstrated that older adults with poor trunk muscle composition (higher levels of intramuscular fat infiltration) appear to have a greater risk of reduced mobility-related function over a three-year timespan, especially in those with higher levels of LBP severity.⁸⁻⁹ Further, those individuals with the most severe LBP also had the highest levels of fat infiltration.⁸⁻⁹ Taken together, these factors indicate that a thoughtfully designed exercise program targeting the trunk muscles may be able to both improve physical function and reduce pain. While trunk muscle training (TMT) has been used in younger LBP groups, it is unproven in older adults and, alone, may not be sufficient to substantially improve physical function and symptoms, given the compromised state of aged muscle.

Typically, aged muscle has undergone a reduction in the total number of muscle fibers and a preferential atrophy of fast, type II muscle fibers, which results in slower muscle contractile properties.¹¹⁻¹³ Age-related altered motor unit discharge rates may be linked to the slower contractile properties as well.¹⁴⁻¹⁵ The sub-maximal or endurance-focused approach to training trunk muscles that is used for improving trunk stability in patients with LBP will primarily recruit slow, type I muscle fibers and will likely do little to induce muscle hypertrophy or change the ratio of muscle to fat in the trunk musculature. As a result, there is a need for examining ways to augment volitional exercise in older adults since the proportion of type II muscle fibers is known to decrease with aging, along with a concomitant decrease in muscle force-production capacity.¹³ Type II fibers provide greater force production than type I fibers and are important for sudden bursts of muscle activation. Volitional muscle contractions appear to utilize type I muscle fibers more readily and to a greater extent than type II fibers, and type II fibers most likely are not approaching their maximum force production capabilities even during near maximal voluntary contractions.¹⁶⁻¹⁸ Volitional exercise performed even at near maximum intensities may not provide enough tension through the atrophied type II fibers to induce hypertrophy of these fibers. There is mounting evidence to suggest that aged skeletal muscle does not hypertrophy with resistance training in the same way that younger muscle does¹⁹⁻²¹; and, as a result, aged muscle requires a higher training dose to increase muscle size.²²⁻²⁵

Neuromuscular electrical stimulation (NMES) has been shown to recruit type II muscle fibers and to induce increases in muscle strength.²⁶⁻²⁹ Although NMES has been traditionally used for muscle strengthening in young, physically active individuals, several studies have shown that it can also increase strength and function and is well tolerated in older patients.³⁰⁻³³ Therefore, it is possible that TMT augmented with NMES may provide greater improvements in muscle composition and performance than a volitional program alone, thus enhancing the opportunity for reducing functional limitations. Treatment of chronic LBP in older adults using an exercise intervention has been hypothesized as a way to prevent functional decline and the development of frailty; however, this hypothesis has yet to be experimentally explored or confirmed.

The objectives of this preliminary trial were: (1) to evaluate the feasibility and safety of an NMES-augmented trunk muscle training program (TMT+NMES) in older adults with chronic LBP, (2) to investigate whether TMT+NMES could improve physical function and pain compared with a passive control intervention in older adults with chronic LBP, and (3) to determine effect sizes to inform future trials. In this preliminary trial, the first objective was focused on exploring issues relevant to the feasibility of conducting a larger trial of the proposed intervention (i.e. treatment adherence, study attrition and safety); whereas, the second and third objectives were more aligned with typical pilot study issues (i.e. assessing whether treatment effects are consistent with investigator expectations). Altogether, the feasibility and pilot components of this preliminary trial will allow us to determine whether a large-scale trial of TMT+NMES is warranted.

Materials and Methods

Design Overview

This study was a single-blind, randomized feasibility trial designed to explore the potential effects of TMT+NMES compared to a passive control intervention. A statistician used statistical software to generate a randomization plan that ensured random assignment to each condition. After the randomization list was generated, treatment assignments were contained in sealed, numbered envelopes that were opened in sequential order as participants entered the study. In both groups, participants were to be seen twice weekly for 12 weeks by a licensed physical therapist. Each session was planned to last approximately 45 minutes.

Participants

Participants were eligible if they were between the ages of 60-85 years and had chronic LBP. Chronic LBP was defined as LBP of moderate intensity (3 out of 10 on a numeric pain rating scale) that occurs most days of the week (4 days per week) and has lasted greater than 3 months. Participants were excluded for the following: (1) a history of lumbar spine surgery; (2) prominent component of radicular pain with symptoms below the knee; (3) symptoms of non-mechanical LBP, including unrelenting night pain, sensation changes in the groin region, or bowel/bladder disturbances; (4) vertebral compression fractures; (5) recent trauma; (6) using an assistive device beyond a cane for community-mobility; (7) received treatment for LBP within the past 6 months; (8) acute or terminal illness; or (9) a progressive neurological disorder. Participants were recruited via advertisements in local

publications, as well as advertisements posted in local senior centers, retirement communities and health fairs. Participants were screened over the telephone using a structured questionnaire, then a licensed physical therapist validated the inclusion/exclusion criteria obtained by telephone on-site. Prior to the onsite screening, all participants were screened by a physician who gave approval for study participation. The University of Delaware Institutional Review Board approved the study, and all participants signed an informed consent form.

Interventions

Regardless of intervention, participants were seen by a licensed physical therapist twice weekly for 12 weeks in the University of Delaware Physical Therapy Clinic for a maximum of 24 supervised visits.

Trunk Muscle Training—The TMT program is a criterion-based program based on a protocol published by Hicks and colleagues³⁴ and grounded in evidence from biomechanical and EMG studies.³⁵ The previously published protocol was modified to suit a geriatric population while targeting the same muscle groups. The goal of this TMT program was to increase muscle stiffness and thereby create sufficient stability in the spine through motor control system re-education of the primary active stabilizers of the trunk: rectus abdominus,³⁵ transversus abdominus,³⁶⁻³⁷ oblique abdominals,³⁸ multifidus,³⁹ erector spinae^{35, 40} and quadratus lumborum.³⁵ TMT focused on encouraging repeated sub-maximal efforts that would mimic the function of these muscles in spine stabilization.³⁵ The exercises for each muscle group and criteria for progression are listed in table 1. Using the established criteria, the treating physical therapist progresses the participant through the criterion-based program. TMT treatment time was approximately 30 minutes.

NMES—Participants were positioned in prone with enough pillows placed under the pelvis and abdomen to flatten the lumbar lordosis. Then, the pelvis was strapped to the table in this position. Self adherent, flexible electrodes were placed over the subject's lumbar paraspinals bilaterally (L2-L5) to apply electrical stimulation. (Fig. 1) Muscular contractions of the lumbar paraspinals were generated using a clinical neuromuscular electrical stimulator, which was set to deliver a 2500Hz, alternating current, modulated at 50 bursts per second. The stimulus amplitude was increased to a minimum level that resulted in a full, sustained, isometric contraction of the lumbar paraspinals (no evidence of muscle fasciculations on visual inspection) and then further increased to the subject's maximum tolerance. Stimulus on/off time settings were 10 seconds on and 60 seconds off, to minimize muscle fatigue during the training program. These stimulus parameters were based on stimulus parameters used in previously published studies.⁴¹⁻⁴² Each participant received 15 electrically stimulated contractions of the lumbar paraspinal muscles per treatment session. NMES treatment time was 15 minutes.

Passive Control Intervention—The passive control intervention consisted primarily of a passive treatment approach often prescribed for older adults with LBP. Treatment consisted of 20 minutes of moist heat to their lower back, 7 minutes of sub-therapeutic ultrasound (continuous pulse, 25 watts/cm²) to the lumbar paraspinal region, 8 minutes of light

effleurage massage to the thoracolumbar region and 5 minutes of upper extremity stretching exercises focused on the shoulder girdle and upper back. Total treatment time was 40-45 minutes which was quite similar to the intervention group.

Outcome Measures

A trained research assistant, who is a licensed physical therapist, administered all outcome measures at baseline, prior to randomization and initiation of treatment. The outcomes assessor remained masked to treatment group assignment throughout the follow-up period of the study. Participants were asked not to discuss any aspects of their treatment with the research personnel collecting the outcome measures. Follow-up data collection was performed within one week following the last treatment session at 12 weeks, in order to determine the immediate effects of the exercise intervention, and three months after the last treatment, in order to gather preliminary information on the duration of treatment effect.

Feasibility was assessed by adherence to the supervised interventions, attrition during the course of the study and adverse events. Adherence was calculated as the number of treatment sessions attended out of the 24 possible treatment sessions in each treatment group. Attrition was calculated as the number of participants remaining at the end of the trial in each treatment group divided by all participants that began in that group. Intervention safety was assessed from adverse event reports submitted during the course of the study. A larger randomized trial would be considered feasible if the adherence to treatment was at least 80% and attrition was less than 20%.⁴³ An adverse event was defined as any physical injury that occurred during the course of the study either in the context of the treatment sessions or when they were outside our facilities. The number of adverse events in each group was recorded.

Timed Get Up-and-Go (TUG): This test measures the time it takes a person to rise from a standard height chair (seat height 46 cm), walk 3 meters, and return to a seated position in the same chair. The TUG test is a reliable and valid measure of physical function in community-dwelling older adults.⁴⁴

Gait Speed: The GaitMat II™ system (E.Q. Inc., Chalfont, PA), a computerized 4 meter long walkway, was used to collect and analyze gait speed data. At either end of the walkway, there are inactive segments (1 meter) which allowed for walking acceleration and deceleration. After performing two practice trials, each participant walked on the GaitMat II™ three times at their self-selected walking speed for the final data collection.

Modified Oswestry LBP Questionnaire⁴⁵ (OSW): The OSW is a disease-specific measure of LBP-related functional limitation. This questionnaire has been used extensively in randomized trials of patients with LBP. The ten following areas of function comprise the questionnaire: pain severity, lifting, sitting, standing, walking, sleeping, personal hygiene, social life and traveling. Scores range from 0 to 100% with higher scores representing greater limitation. This questionnaire demonstrated excellent reliability and good construct validity in comparison to other pain and disability measures.⁴⁵⁻⁴⁶

Pain severity: Pain severity was assessed using the Pain thermometer, which has been shown to be reliable in older adults.⁴⁷⁻⁴⁸ Scores ranging from 0-10, with higher scores representing greater pain.

Tampa Scale of Kinesiophobia: The objective of this questionnaire is to chart fear of movement or re-injury where greater scores indicated greater fear.⁴⁹

Global Rating of Functional Improvement: Participants were asked to list the three functional activities that were most limited by their LBP at baseline. At the follow-up assessments, participants were asked to rate their improvement on each of these functional limitations on a scale from 0-100%, where 100% indicates complete recovery. Ratings on each of the 3 items were averaged to give an overall global rating of improvement.

Data Analysis—All analyses were done on complete cases and were performed using SPSS 22 (SPSS, Inc. Chicago, IL). Descriptive analyses were performed for both treatment groups, including demographic characteristics, as well as measures of physical function, pain-related disability, pain severity, and quality of life. Given that this was a feasibility trial, formal sample size calculations were not made to establish efficacy of the TMT+NMES intervention for improving performance-based physical function. We planned to recruit 31 participants per treatment arm.

To evaluate feasibility, treatment adherence rates were compared between groups using independent t-tests and attrition rates were compared using chi square analysis. Within each treatment group, change scores and 95% confidence intervals (CI) for each outcome were calculated from baseline to the 3 month follow-up visit (immediately post-treatment) and from baseline to the 6 month follow-up visit (3 months after the last treatment session) to assess within-group change. Point estimates and 95% confidence intervals for changes in all outcome measures were compared between groups at both follow-up time points to assess between-group differences in response to the interventions. Standardized between-group effect sizes (ES) were also calculated [(TMT+NMES – Passive control)/pooled SD]. The effect sizes were interpreted based on Cohen d values where .20 indicates a small effect, .50 indicates a moderate effect, and .80 indicates a large effect.⁵⁰ Additionally, the minimum clinically important difference (MCID) values for select outcomes were used to determine the proportion of participants in each treatment group that had clinically important changes. These data were then used to estimate numbers needed to treat (NNT) for TMT+NMES to achieve a clinically important improvement.

Results

Two hundred eleven older adults with LBP were screened for study eligibility (Figure 2). Of these potential participants, 36 (17%) declined to participate in the study and 111 (53%) did not meet criteria for inclusion. Sixty-four older adults with chronic LBP were enrolled into the study, underwent baseline assessment and were randomized (30% recruitment rate). Of the 64 participants, 31 were randomized to TMT+NMES and 33 to the passive control group. Table 2 displays the baseline characteristics of the sample based on treatment group. There were no differences between groups at the start of the intervention ($p>.05$).

For the passive control intervention, adherence was 87% (21 visits, SD=5.15); and, TMT +NMES adherence was 80% (19 visits, SD=7.22). There was no statistical difference in adherence rates between groups ($p=.20$). While the overall attrition rate was 11%, there were differences in the attrition rates for the two treatment groups with rates of 6% for the passive control group and 16% for TMT+NMES; but, these differences were not statistically significant ($p=.29$). Two of the participants in the TMT+NMES group discontinued participation due to the fact that they felt that their buttock/posterior thigh symptoms were not resolving with this treatment. There was one adverse event during the course of the study; one participant tripped and fell during the course of standardized performance testing. This fall was unrelated to the intervention and did not result in an injury.

Table 3 presents baseline to 3-month and baseline to 6-month within-group changes, as well as between-group differences at both 3- and 6-month follow-up assessments. Both groups had a similar reduction in time to perform the TUG at the first follow-up; but, at the 6-month visit, TMT+NMES appeared to have a greater improvement (between-group difference=.75 sec, ES=.46). On average, TUG change scores for TMT+NMES exceeded the minimum clinically important difference (MCID) of 1.4 seconds⁵¹; whereas the MCID was not reached for the passive control group. Using the minimum clinically important difference (MCID) of 1.4 seconds⁵¹ as our definition of treatment response, 48% of the TMT+NMES group and 26.7% of the passive control group exceed this threshold, respectively; thus, the absolute difference between the active and passive treatments was 21.3%. The numbers needed to treat (NNT) for TMT+NMES to reach the MCID was 4.7. Self-selected gait speed progressively increased by .06m/s over the course of the entire trial in the TMT+NMES group, while there was no change in the passive control group. Using the MCID of .05m/s⁵² as our definition of treatment response, 56% of the TMT+NMES group and 26.7% of the passive control group exceed this threshold, respectively; thus, the absolute difference between the active and passive treatments was 29.3%. The NNT for TMT+NMES to reach the MCID was 3.4. By the 6-month follow-up, OSW scores were decreased by 18% in the passive control group and by 32% in the TMT+NMES group. Using the MCID of 30%⁵³⁻⁵⁴ as our definition of treatment response, 48% of the TMT+NMES group and 34% of the passive control group exceed this threshold; thus, the absolute difference between the active and passive groups was 14%. The NNT for TMT+NMES to reach the MCID was 7.1. Pain severity scores had similar clinically important decreases of more than 2 points. Based on the effect sizes presented in table 3, there was no clear evidence of benefit for TMT+NMES at the 3-month evaluation; but, at the 6-month evaluation, the moderate-sized effects for all measures of function suggest that TMT+NMES may offer benefit compared to passive control group.

In terms of the participants' global rating of functional improvement, the two groups had nearly identical improvement of 62% from baseline to 3-months; but, at 6-month assessment, the TMT+NMES group improved by another 11.4% and the passive control group worsened by 5.5%. The between-group difference was 17.24% (95%CI: 5.87-28.60) in favor of TMT+NMES.

Discussion

To our knowledge, this is the first randomized clinical trial of a trunk muscle training intervention specifically focused on older adults with chronic LBP and it is the first trial utilizing NMES to augment paraspinal muscle training in individuals of any age with chronic LBP. The findings of this preliminary trial demonstrate the feasibility of recruiting and retaining older adults with chronic LBP into an active exercise intervention. Given that our attrition rates were less than the a priori threshold of 20% and adherence rates exceeded the threshold of 80%, it seems feasible that we could successfully conduct a larger study to assess the efficacy of the TMT+NMES intervention. Further, our preliminary findings of clinically important changes in physical function associated with TMT+NMES suggest that additional studies are needed to refine the intervention and to fully test its efficacy as a clinical intervention for older adults with chronic LBP.

The first objective of our study was to explore the safety and feasibility of conducting a full-scale trial of TMT+NMES in older adults with chronic LBP; and our results suggest that TMT+NMES is both safe and feasible. In clinical realms, there has often been a misconception that older adults with chronic LBP are more suited to a passive treatment approach, i.e. massage and thermal modalities; but, this study has demonstrated that older adults with chronic LBP are able to fully participate in an active approach to managing their LBP. It is important to note that this type of high-intensity NMES, used for muscle strengthening, can be quite uncomfortable for many patients; but, in general, it was well-tolerated by our study participants. While two of 31 participants in the TMT+NMES group discontinued participation due to a desire for a different treatment approach, it should be noted that two participants in the passive control group also discontinued for the same reason. Further, there were no adverse events associated with the use of NMES in this study. These findings bolster our confidence that NMES to the paraspinal muscles can be safely delivered to older adults with chronic LBP and that its use will be acceptable to and well-tolerated by this population.

Our preliminary results indicate that TMT+NMES may have the potential to reduce functional limitations in older adults with chronic LBP over a six month period of time. In regards to performance-based measures of function, the absolute benefit increase associated with TMT+NMES was 21.3% and 29.7% for TUG and gait speed, respectively, at 6 months. These functional outcomes were consistent with our expectations for the TMT+NMES intervention given that impaired trunk muscle composition and function has been linked to gait difficulties.^{9, 55} Given these preliminary findings, we will likely use both the TUG and gait speed as our main performance-based functional outcomes in future trials. In regards to perception-based measures of function in this study, TMT+NMES was associated with significantly greater improvement in functional limitations as compared to the passive control intervention (74% vs. 57%) when using the global rating of functional improvement outcome. It is interesting to note that relative to the between-group difference of 17.24% (95%CI: 5.87-28.60) for the global rating at 6 months, the confidence interval did not include zero; this finding suggests a statistically significant between-group difference when using an outcome focused on the specific functional limitations of the individual older adult with chronic LBP. Initially, we thought that the Oswestry Disability Questionnaire would

emerge as the best primary perception-based outcome measure for use in future trials. However, we learned an important lesson about the use of the Oswestry Questionnaire as our primary self-reported outcome; it does not appear to fully represent the spectrum of limitations deemed to be most important by this sample of older adults with chronic LBP. Allowing participants to nominate their own functional limitations with the global rating of functional improvement gave us much more insight into this issue. In future studies, we believe it will be important to consider using the Patient Specific Functional Scale⁵⁶ as our primary patient-reported outcome as it is a validated measure that allows the patient to nominate and rate their own level of function at each visit.

While the passive control intervention appears to offer pain relief and short term functional improvements, it appears that TMT+NMES may be needed for longer term function gains along with pain relief. The larger between-group differences at 6 months suggest that changes in trunk muscle function may be responsible. Once the passive control intervention was stopped, functional improvements waned, whereas functional improvement continued for TMT+NMES well after treatment ended. Given that the performance-based outcomes used in this trial are typically thought to be driven by lower extremity (LE) performance, we want to highlight that the focus of this intervention was on the trunk muscles. In typical interventions focused on LE strengthening, the change in gait speed is usually closer to .01-.02 m/s⁵⁷, where as our change was .05m/s. These preliminary findings lend credence to our previous work demonstrating that trunk muscle composition, independent of thigh muscle composition, plays an important role in maintaining mobility in older adults with significant LBP.⁹ It is interesting to consider what type of functional gains might be seen if a significant component of LE training were added to TMT+NMES. While we do not yet know if TMT+NMES actually led to changes in muscle composition and whether these changes are linked to functional improvement, pre-planned secondary analyses of magnetic resonance imaging data are underway to clarify these questions.

This preliminary trial has several distinct strengths, including: a well characterized, community-dwelling sample of older adults with chronic LBP; inclusion of reliable and valid performance-based outcome measures; systematic training of outcomes assessors and therapists delivering the interventions; and balanced patient-therapist interactions between groups. There are also several limitations which must be considered. First, our small sample size did not allow us to appropriately explore the possibility that there are sub-groups of patients with LBP who would particularly benefit from TMT+NMES. For example, we had a relatively high functioning cohort given that only 25% would be considered at risk for functional decline based on scores of <9 on the Short Physical Performance Battery. It may be important to consider whether functional improvement associated with TMT+NMES might be greater for those with greater baseline limitations. Another limitation is the relative racial/ethnic homogeneity of the sample which limits our generalizability. Recruitment of more diverse participants is an area for further work. Another factor that could be seen as a limitation is that our study design in which we compare our active TMT+NMES intervention to a passive control intervention does not allow us to examine the potential independent effects of TMT and NMES; however, this 2-group study design allows us to determine the feasibility of a TMT+NMES intervention and gives us some idea of whether this intervention could impact functional outcomes. If the combined intervention were not

deemed worthy of continued examination, then it would be unlikely that either intervention on its own would be worth exploring. A final limitation is that we do not have any measures of trunk muscle strength or endurance on which to evaluate the impact of TMT+NMES. At the time of study implementation, we did not believe that we could safely capture trunk strength or endurance in this population; since this time, we have established a protocol for safely and reliably measuring trunk endurance. Further, there is recent evidence to suggest that trunk endurance is a better measure to capture relative to mobility function in the geriatric population.⁵⁸⁻⁵⁹

In conclusion, this preliminary investigation has demonstrated that TMT+NMES is a safe and acceptable intervention that may have the potential to improve physical function in older adults with chronic LBP. It is particularly interesting to note that TMT+NMES appears to have the potential to result in longer term functional improvements than our passive control approach which was grounded in the use of passive treatments. This preliminary work has provided us with valuable insight to further refine the TMT+NMES intervention and to sharpen the design of future trials. Now that we have some indication that the combined TMT+NMES intervention may have potential to improve function, more work is needed to understand the independent effects of the TMT and NMES interventions on muscle composition and physical function in older adults with chronic LBP. Based on our preliminary findings, we believe that a larger randomized trial investigating the efficacy of trunk muscle training augmented with NMES for the purpose of improving physical function is warranted.

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Figure 1.
Set-up for delivery of neuromuscular electrical stimulation to the lumbar paraspinal muscles.

Figure 2.

Overview of study recruitment and randomization of participants to treatment groups. TMT +NMES=Trunk muscle training augmented with neuromuscular electrical stimulation

Figure 3.

Participants' global rating of functional improvement since treatment initiation in the two treatment conditions at each follow-up time point. TMT+NMES=Trunk muscle training augmented with neuromuscular electrical stimulation.

Table 1
Trunk Muscle Training Program

Muscle Group	Importance of Muscle	Examples of Exercise Progression
Transversus Abdominus	<ul style="list-style-type: none"> Draws in abdominal wall, increases intra abdominal pressure w/o flexing the trunk TrA may activate in a feed-forward mechanism to stabilize the trunk for extremity motions³⁷ 	<p>Abdominal Bracing in supine>></p> <p>Bracing in hook-lying with leg movements>></p> <p>Bracing in hook-lying with bridging>></p> <p>Abdominal Bracing in standing</p> <p><i>Possible Substitutions:</i> holding breath</p>
Erector Spinae/Multifidus	<ul style="list-style-type: none"> Extend the spine Segmental extensors co-contract w/ antero-lat. abdominals to stabilize trunk 	<p>Single arm or leg lifts-standing with elbows leaning on counter>></p> <p>Opposite arm and leg lifts standing with elbows on counter >></p> <p>Single arm or leg lifts-prone over bolster^{35, 60}>></p> <p>Opposite arm and leg lifts-prone over bolster>></p> <p>Same exercises performed in quadruped</p>
Rectus Abdominus	<ul style="list-style-type: none"> Primary flexor of the trunk 	Curl ups as described by McGill ³⁵ --careful to maintain neutral spine and avoid excessive flexion
Oblique Abdominals	<ul style="list-style-type: none"> Co-contracts w/ multifidus for trunk stabilization, generates side-bending and rotation forces in trunk Obliques activate in anticipation of extremity movement 	<p>Remedial side bridge against wall>></p> <p>Remedial side bridge with leg lift on floor/bed</p> <p>Horizontal side bridge (hips and knees fully flexed >> knees flexed >> knees extended)^{35, 61}</p>
Quadratus Lumborum	<ul style="list-style-type: none"> Suggested to be the primary stabilizer of side-bending movements³⁵ 	Same as above for obliques

Table 2
Participant Characteristics

Characteristics	Passive (n=31)	TMT+NMES (n=26)
Age, yrs	69.5 (7.0)	70.7 (6.8)
Female gender, n (%)	16 (51.6)	15 (58.1)
Race, n (%)	28 (90.3) White	24 (92.3) White
	3 (9.7) Black	2 (7.7) Black
Married, n (%)	22 (70.9)	16 (61.5)
College Education, n (%)	13 (42)	16 (61.5)
BMI, kg/m ²	30.0 (4.5)	28.8 (6.9)
LBP Duration, months	35.2 (3.4)	33.5 (6.9)
Analgesic Use, n (%)	17 (54.8)	14 (53.8)
Short Physical Performance Battery (0-12)	10.24 (1.7)	10.23 (2.1)
Outcomes at Baseline		
Timed Up and Go, sec	9.1 (2.9)	9.3 (3.5)
Gait Speed, m/sec	1.07 (.23)	1.05 (.21)
Oswestry LBP Questionnaire (0-100)	33.2 (8.9)	34.9 (11.1)
Numeric Pain Rating (0-10)	6.2 (2.1)	5.7 (1.7)
Tampa Scale of Kinesiophobia (17-68)	23.8 (6.5)	25.7 (6.1)
Outcomes at 3 Months		
Timed Up and Go, sec	7.9 (2.3)	8.2 (3.3)
Gait Speed, m/sec	1.11 (.23)	1.12 (.23)
Oswestry LBP Questionnaire (0-100)	25.6 (11.4)	22. (11.1)
Numeric Pain Rating (0-10)	3.9 (2.6)	3.7 (2.1)
Tampa Scale of Kinesiophobia (17-68)	23.0 (7.5)	23.8 (4.8)
Outcomes at 6 Months		
Timed Up and Go, sec	7.8 (2.4)	7.5 (3.9)
Gait Speed, m/sec	1.09 (.26)	1.14 (.24)
Oswestry LBP Questionnaire (0-100)	27.8 (10.1)	23.1 (14.4)
Numeric Pain Rating (0-10)	3.5 (1.9)	3.2 (2.3)
Tampa Scale of Kinesiophobia (17-68)	24.2 (8.2)	25.7 (6.1)

Data represent mean and SD unless otherwise noted.

Within-Group Changes and Between Group Differences Based on Treatment Group

Table 3

	Baseline-3 Month Within Group Change (95% CI)	Baseline-3 Month Between Group Difference(95%CI)	Baseline-3 Month Between Group Effect Size	Baseline-6 Month Within Group Change (95% CI)	Baseline-6 Month Between Group Difference(95% CI)	Baseline-6 Month Between Group Effect Size
<u>Timed Up and Go(s)</u>		-0.14 (-0.61,0.90)	0.08		-0.75 (-1.51,0.01)	0.46
<u>Passive</u>	-1.04 (-1.64, -0.43)			-1.08 (-1.67, -0.48)		
TMT+NMES	-1.18 (-2.56, -0.48)			-1.83 (-2.56, -1.09)		
<u>Gait Speed (m/s)</u>		0.04 (-0.03, 0.10)	0.27		0.06 (-0.01, 0.14)	0.48
<u>Passive</u>	0.01 (-0.04, 0.06)			0.00 (-0.08, 0.07)		
TMT+NMES	0.05 (-0.01, 0.11)			0.06 (0.01, 0.12)		
<u>Oswestry</u>		-4.79 (-9.67,0.11)	0.44		-5.11(-10.05, 0.17)	0.46
<u>Passive</u>	-7.67 (-11.73, -3.63)			-5.97 (-9.52, -2.41)		
TMT+NMES	-12.46 (-16.82, -8.05)			-11.08 (-16.2, -5.99)		
<u>Pain</u>		0.10 (-0.99, 1.20)	0.04		0.23 (-0.84, 1.31)	0.10
<u>Passive</u>	-2.07 (-3.10, -1.03)			-2.65 (-3.60, -1.71)		
TMT+NMES	-1.96 (-2.76, -1.16)			-2.42 (-3.32, -1.51)		
<u>TSK</u>		-1.14 (-3.92,1.64)	0.19		-2.61 (-5.46,0.24)	0.42
<u>Passive</u>	-0.74 (-3.67, 2.18)			0.66 (-1.96, 3.26)		
TMT+NMES	-1.89 (-3.13, -0.64)			-1.95 (-4.15, 0.24)		

Between-Group Differences=TMT+NMES – Passive