

The Effect of Transcutaneous Electrical Nerve Stimulation (TENS) Applied to the Foot and Ankle on Strength, Proprioception and Balance: A Preliminary Study

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Abstract

Background: Transcutaneous electrical nerve stimulation (TENS) promotes upper motor neuron excitability which has the potential to improve function. As a precursor to clinical trials, we investigated the potential efficacy of TENS on strength, proprioception and balance in healthy older adults.

Method: Design: A paired-sample randomized crossover trial. No stimulation was the control. Intervention: A one-off session of TENS (Modulated frequency: 70-130Hz, 5 second cycle) via a conductive sock. Participants: 25 healthy older volunteers with no pre-existing balance or mobility limitations or contra-indications to TENS. Outcomes: Dorsiflexor and plantarflexor strength and proprioception using an isokinetic dynamometer and balance (postural sway and forward reach test). Analysis: Paired t-tests

Results: None of the parameters showed any significant changes with TENS ($p > 0.05$).

Conclusions: The stimulation of cutaneous sensory nerve endings of the foot with the application of TENS showed no immediate effect on the ankle proprioception, lower leg muscle strength, and postural stability. The concern that TENS would have a distracting impact on sensation and balance was not supported according to these results.

Keywords: Transcutaneous electrical nerve stimulation; Strength; Proprioception; Balance

Introduction

Transcutaneous electrical nerve stimulation (TENS) is a well-known intervention which differentially influence a variety of outcomes related to pain [1-3]. Physical function used to be part of this outcome domain [4]. It has been shown that TENS increased the balance function on the "Timed up and GO" test as well as reducing the pain level in people with osteoarthritis [5], but it was unclear if this improvement is related to the pain reduction effects or direct promotion of functional outcomes using TENS. This has led to the intriguing notion that TENS could be used to promote motor performance or recovery in people with disabling neuromotor conditions. Cortical excitability changes can alter the individual experience to interact with the environment. The new situation can result in either an improvement or detrimental effects on the functional performance [6]. There is some evidence that TENS to the lower limb can enhance gait speed, functional recovery, spasticity and reflex activity in people with stroke [7,8], joint position sense in people with knee osteoarthritis [9] and postural sway in healthy volunteers [10-13].

Foot and ankle complex is the only segment which is in direct contact with supporting surface and has an important role in collecting somatosensory feedbacks and regulating balance control [14]. Sensory impairments in the foot and ankle complex contribute to balance and activity problems in people with stroke [15]. Accessory sensory stimulation applied to the paretic hand improves the upper limb function in people with stroke [16]. If effective, the application of TENS at the foot and ankle has the potential to be a highly beneficial intervention as deficits of strength, joint position sense and balance control contribute to the increased risk of falls and limited mobility associated with older adults and many neurological conditions [17,18]. There is another debate that stimulation can be a distraction for people while they need their attention for keeping the balance and walking safe. Accordingly, it remains a major concern if applied TENS to the foot has any adverse effects on the balance parameters and how the people with disabling neurologic conditions would cope with this detrimental effect. To take this ethical issue into account, a preliminary study was needed to carry out with age-matched healthy controls. Augmenting plantar sensory feedbacks provides a potential mechanism to improve balance stability, even in the healthy subjects [19]. This exploratory trial was to check the components of the intervention and define the feasibility of a safe testing protocol according to the UK Medical Research Council Framework (MRC) for the evaluation of complex interventions [20]. Thus, as a precursor to

trials in patient populations, we investigated the effect of TENS in healthy older adults who are assumed to have a lesser risk of falls within the testings compared with people with neurologic problems. To our knowledge, none of other studies applied the TENS at the foot and ankle in healthy subjects. It was hypothesized that applying TENS to the foot and ankle complex would improve the balance and postural control. The aim of this study was to investigate any possible effects of TENS on balance control and its possible underlying mechanisms in the lower leg like proprioception [21,22] and muscle strength [23].

Method

A paired sample, randomized crossover trial of the immediate effects of TENS was used in which the participants acted as their own control and the randomization came from the order in which the TENS or control was given. All participants completed both control and stimulation conditions and all testing procedures. Ethics approval was obtained from the University of Salford's Research Ethics Committee (Manchester, UK).

Participants

We recruited a convenience sample of healthy volunteers from staff in the university and friends and relatives of stroke survivors who attended local community stroke groups and/or were on the Rehabilitation Research Group's database of study volunteers. Participants were over 50 years old, able to consent and had no conditions limiting balance or mobility or contradictions to TENS to the leg (cardiac pacemaker or skin lesions over the lower leg).

The intervention

TENS was delivered using a Biostim® M7 TENS unit (Biomedical Life Systems, Princeton, USA) with a conductive sock that stimulates the whole foot and ankle (iSock, TensCare Ltd, Surrey, UK) (Figure 1) on both feet. As this study was aimed to check the feasibility of the testing protocol for hemiplegic people, only the right foot was connected to the TENS machine (in all participants right foot was the dominant side) and proprioception and strength were tested in the right leg. The sock's manufacturer recommends that it should be dampened to maximize conductivity of the stimulation. However, pilot work showed that it was impossible to standardize the degree of dampness. Some participants found it unacceptable to wear a damp sock inside their shoe, so the sock was used in a dry condition if they felt the stimulation on the foot. A biphasic symmetrical stimulus with pulse duration of 50µs and ranging frequency of 70-130Hz over a 5 second cycle was used. This frequency modulation was to prevent habituation and cover the optimal frequency for all participants, which is specific to each individual but is around 100 Hz. Intensity of stimulation was increased until participant reported a gentle tingling over their foot and/or ankle without pain or muscle activation. As the objective was to evaluate the effects of TENS during activities, the duration of the stimulation was not specified, but participants were encouraged to use it until they felt comfortable and had "got used" to the sensation then we tested them while stimulated. Equally, when tested without the stimulation (the control condition) participants indicated when they felt the stimulation had "worn off" and were then tested. For the control treatment, the sock and TENS was applied in the same way and the machine was turned on but no stimulation was given. To blind the participants as far as possible to the treatment received they were told that they would receive two types of signal

which they may, or may not, be able to feel without specifying which we thought may be the more effective.



Figure 1: The conductive sock (left); and TENS unit (right).

Testing protocol

All testing was completed in a single session at the University's clinical research facility. After informed consent was obtained, the socks and TENS machine were applied and the participant was randomized (by them selecting a concealed envelope from a bag) to receive the stimulation or the control condition first. Then they moved around and familiarized themselves with the stimulation. When they felt comfortable and confident the following testing protocol was undertaken. The order of testing was randomized to avoid order effects. Participants were free to move around or rest at their convenience during and between testing. For all parameters, the test was explained and demonstrated to the participant who then practiced until they felt comfortable.

Proprioception and strength

Proprioception and strength of the right leg were tested with a Biodex® Isokinetic Dyanamoeter (Figure 2B), using standard operating instructions [18,24,25]. Movement detection threshold was measured as an outcome to evaluate proprioception at the ankle joint. The tests were repeated six times (three in each direction) and mean values calculated. Joint movement detection of the ankle was assessed in dorsiflexion and plantarflexion; the participant's ankle was passively moved from neutral into dorsiflexion or plantarflexion at 0.25°/s (to avoid any stretch on peri-articular structures and reduce cues from the footplate). Proprioception was tested with vision occluded. They indicated when they detected the movement using a handheld trigger that recorded the angle and verbally indicated the direction of movement. Maximum isometric plantarflexor and dorsiflexor strength was assessed with the ankle in a neutral position (90 degrees). For plantarflexion, participants pressed their foot as hard as possible against the footplate and then pulled it upward as strongly as possible (dorsiflexion).

Balance

Postural stability was measured as a parameter of balance function. It was measured during barefoot standing over an AMTI (Advanced Medical Technology Inc.) forceplate (AMTI Inc., Watertown, USA) with a sampling rate of 100 Hz. During the postural stability testing,

participants were asked to put their feet on the marked area (feet were apart and slightly turned out), arms relaxed at their sides and looking straight forward at a reference picture on the wall in front of them (Figure 2A). They were asked to maintain a quiet standing position for 40 seconds with and without the stimulation in two different standing conditions tested in a random order: 1) standing

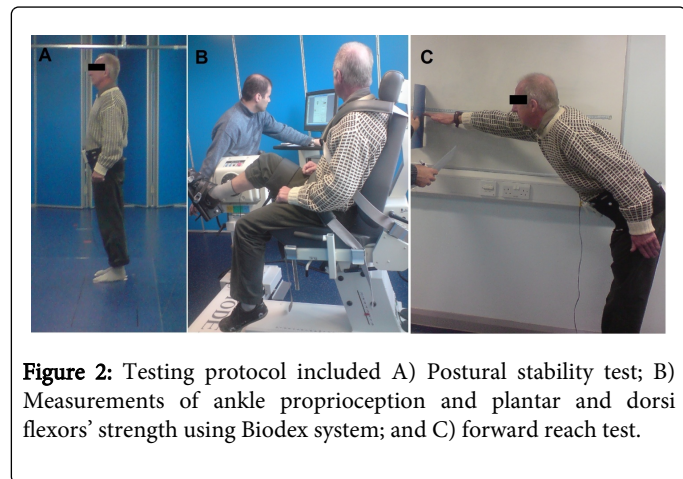


Figure 2: Testing protocol included A) Postural stability test; B) Measurements of ankle proprioception and plantar and dorsi flexors' strength using Biodes system; and C) forward reach test.

with open eyes and 2) standing with closed eyes. Three trials were recorded for each participant to be averaged and produce a representative value for their postural sway. The forceplate had been calibrated and reset before each testing to remove the offset signals. Between each repetition, the participants were allowed to have a two-minute break to prevent fatigue.

The Standing Forward Reach Test evaluated balance activity [26] by measuring the distance participant could reach beyond arm's length was measured with a yardstick set at the participant's shoulder height (Figure 2C). The first data were collected as a 'practice run' and then the test was repeated three times and means values calculated [27].

Data processing and analysis

The recorded force plate signals were quantified prior to statistical analysis. Postural sway was defined as the excursion of the centre of pressure (CoP) over the force plate [28]. The CoP signals were passed through a second degree curve filter with a 10 Hz cut-off frequency (using Qualysis® software). The first and last 5 seconds of all trials were cropped (remaining 30s, 3000 data points per time-series). This was to remove the effect of possible movement adjustments participants might have done to get situated over the forceplate at the beginning of tests or when estimating the end of recording time. The acquired CoP time-series had two components of anteroposterior (AP) and mediolateral (ML) in a coordinated system. The resultant distance (RD) was calculated from these point measures as following:

$$RD = \sqrt{(AP)^2 + (ML)^2}$$

Mean velocity (MV) was the average speed that CoP moves. It is calculated by dividing total excursion of the CoP to the recording time (T) [28]:

$$MV = \frac{\sum_{n=1}^{N-1} \sqrt{(AP_{n+1} - AP_n)^2 + (ML_{n+1} - ML_n)^2}}{T}$$

The statistical analyses were carried out using SPSS version 17. Paired t-test compared the outcome measures with and without TENS. Level of significance was at 0.05.

Results

Twenty-five healthy volunteers (12 women and 13 men; age 56.8 ± 14.5 years; weight: 78.6 ± 14.5 Kg; height: 171.2 ± 6.7 cm) were recruited. All tolerated the TENS which had no significant effect (either positive or negative on any of the parameters measured) (Table 1).

As none of the study outcome measures showed a significant change with and without stimulation, a power analysis was undertaken (using GPower Software 3.1) to explore the impact of the small sample size on the result. Mean velocity of CoP was selected as the representative parameter for this analysis as it had been shown to be the more reliable and sensitive measure of postural sway [29]. The power of the current study was acceptable [power (1-β error prob)=0.85]. Alpha level was adjusted at 0.15 rather than traditional level of .05, as recommended for small group size [30].

Outcome Measure	Mean ± SD	P-values (95% CI)
Mean Velocity of CoP (mm/s) (Open-eyes)	Control=15.2 ± 5.9 TENS=15.4 ± 4.7	0.281 (-1.7, 0.85)
Mean Velocity of CoP (mm/s) (Closed-eyes)	Control=23.3 ± 11.9 TENS=24.4 ± 11.5	0.884 (-2.5, 0.59)
Forward Reach (cm)	Control=26.7 ± 7.9 TENS=26.2 ± 6.7	0.738 (-2.3, -3.2)
Plantarflexor strength (Newton/m)	Control=54.3 ± 25.3 TENS=58.4 ± 25.3	0.139 (9.6, 1.45)
Dorsiflexor strength (Newton/m)	Control=21.5 ± 9.8 TENS=20.2 ± 10.9	0.179 (-0.6, -3.2)
JPS -Plantarflexion (degrees)	Control=1.58 ± 0.96 TENS=1.84 ± 0.9	0.182 (0.65, 0.13)
JPS -Dorsiflexion (degrees)	Control=2.66 ± 2.32 TENS=2.2 ± 1.6	0.207 (0.27, 2.92)

Table 1: The effect of TENS on balance, strength, and proprioception parameters (SD: Standard Deviation; CI: Confidence Interval; JPS: Joint Position Sense).

Discussion

The results of this study show no significant impact of TENS on ankle strength, joint position sense or balance control in healthy older adults. This is one of the very few reports of negative findings for supplementary sensory stimulation given via TENS or any other paradigm to healthy or disabled participants. It is impossible to ascertain whether this is merely due to reporting bias where other researchers have not published non-significant findings or due to methodological differences. Previous reports of TENS as a potential treatment paradigm in healthy adults used a similar paired-group randomized controlled design so it is unlikely that a different bias from the trial design is a contributor. However the previous reports on healthy volunteers used postural sway (a measure of balance impairment) as the primary outcome and gave stimulation to the knee or posterior calf [8,10,11] to influence the "ankle strategy" for standing postural which contrasts our stimulation of the foot and ankle using

strength, proprioception and balance activity outcomes. Further methodological differences were the involvement of young adults (university students) who received a similar dose of TENS [8,10] or older adults who received sub-sensory stimulation [11]. Study heterogeneity is such that it is not possible to identify methodological differences to explain the different response to previous trials. One potentially important difference with previous studies was the method of delivering the TENS. Using a conductive sock might reduce the deliverability of the stimulation compared to the gel electrodes. More recent reports however showed a significant improvement in functional outcomes using stimulation delivered through the same sock in people with neurological condition [31,32]. Thus, it is not clear whether the difference in response is due to heterogeneity in the participants selected, the stimulation paradigm applied or the outcome measures used. Similarly, studies of TENS in patient groups are too heterogeneous in terms of the stimulation protocols, the selected participants and the outcome measures to postulate hypotheses about the possible discrepancies of our findings. The TENS effect was measured during peak effect. This approach was thought to be more likely to show any possible effect. Previous research demonstrated that TENS has the greatest effects when it is on or immediately after switching it off [1,33].

Limitations

This study measured only the immediate effects of short term stimulation in healthy elders, whether there is any carry-over effect or whether longer term stimulation is more or less beneficial needs to be addressed in the future studies. Ankle joint proprioception can be improved with regular training over a longer time. A recent study has reported 12 weeks of proprioceptive training is necessary to improve the balance performance in the young healthy athletes [34]. Results also indicated that TENS did not show a distracting effect on proprioception accuracy or a detrimental effect on the balance performance and muscle recruitment (strength). The application of weak electrical signals on the foot is assumed to influence mainly cutaneous sensory nerve endings. Studies have shown that deeper sensory nerve endings (those placed in ligaments, joint capsule and particular padding tissue around the ankle) play more important role in sourcing the ankle proprioception [35,36]. In accordance to this assumption, a study on people with sural nerve harvesting showed no change in the detection of their ankle position, muscular reflex time, and postural stability parameters [37]. The findings can be considered as an exploratory study to establish a safe testing protocol, which is defensible for using in people who are at the risk of falls and should not be challenged with a distracting intervention. This was a ground work that covered a "proof-of-concept" to develop a new intervention [20]. Further research is needed to develop this potential intervention with subjects who had specific neurological conditions that may be more responsive to augmented sensory inputs during functional tasks.

Conclusions

In contrast to previous reports of postural control, we found that TENS did not affect the strength, proprioception and balance in healthy older volunteers. Further research is needed to systematically develop this potential intervention.

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