

Effects of Transcutaneous Electrical Nerve Stimulation (TENS) on Changes in Postural Balance and Muscle Contraction following Muscle Fatigue

HWI-YOUNG CHO, PT, MSc¹⁾, SUN HYUN LEE, PT, MSc¹⁾, TAE SUNG IN, PT, MSc¹⁾,
KYOUNG JIN LEE, PT, MSc¹⁾, CHANG HO SONG, PT, PhD¹⁾

¹⁾Department of Physical Therapy, Sahmyook University: 26-21, Gongneung 2-dong, Nowon-gu, Seoul,
139-742, Republic of Korea.
TEL: +82 2-3399-1630, FAX: +82 2-3399-1638, E-mail: chsong@syu.ac.kr

Abstract. [Purpose] The purpose of this study was to investigate the effects of transcutaneous electrical stimulation (TENS) applied to fatigued muscles on postural imbalance and decline in muscle strength following fatigue of the gastrocnemius. [Subjects] Eighteen subjects with muscle fatigue were allocated to either a sensory threshold group or a 2~3 times sensory threshold group and the study followed a randomized single-blind cross-over design. [Methods] Muscle fatigue of the gastrocnemius was induced by repeated exercise. After inducing fatigue, TENS was applied to the fatigued muscle. The postural sway length (PSL), postural sway velocity (PSV) and maximal voluntary contraction (MVC) were measured before and after the induction of fatigue, and during the application of TENS to the fatigued muscles. [Results] Muscle fatigue increased postural imbalance as expressed by length and velocity of body sway and decreased muscle strength, while TENS improved the postural imbalance and partially reversed the muscle strength decline induced by muscle fatigue. [Conclusion] Muscle fatigue is an important factor in postural balance control and muscle voluntary contraction, and TENS can be effective at relieving muscle fatigue.

Key words: Muscle fatigue, Postural balance, Transcutaneous electrical nerve stimulation (TENS)

(This article was submitted Jul. 5, 2011, and was accepted Jul. 19, 2011)

INTRODUCTION

Muscle fatigue (MF) is commonly caused by exercises or activities in daily life, and is defined as transient decrease in the performance capacity of a muscle or an exercise-induced decrease in maximal voluntary contraction generated by a muscle¹⁾. There are central and peripheral mechanisms behind the cause of MF. The peripheral mechanism causes MF in daily living activities by interrupting the blood flow, hindering the supply of nutrition and oxygen to muscles²⁾. MF delays muscle reaction time in the reflex reaction and has an adverse effect on proprioception, resulting in the loss of pain and decrease in joint stability and kinematics^{3,4)}.

Postural control is performed by combining sensory information from the visual, vestibular and somatosensory systems in the CNS, and choosing a reaction appropriate to the context from the motor system⁵⁾. The somatosensory sense is the most vital sense for maintaining balance among the three types of afferent sensory input, and proprioception as its submodality greatly contributes to maintaining balance and postural control by controlling joint-position sense and limb movement sensation⁶⁾. Furthermore, adequate recruitment of muscle strength, a prerequisite for postural control, is required to maintain a desirable action

or activity⁷⁾. MF causes changes in movement and postural control by altering the efficiency of muscle strength and proprioception information, and MF occurs in the aged who experience frequent falls as well as patients with various diseases^{8, 9)}. Even though MF is commonly caused by exercise or labor in daily life, research on declines in motor functions such as muscle strength and postural sway is still insufficient.

Recently, a number of studies have shown that it is possible to improve balance control by changing somatosensory inputs, using light tactile¹⁰⁾, mechanical¹¹⁾ or electrical stimuli¹²⁾. Transcutaneous electrical stimulation (TENS) is an electrical stimulation method which is easy to apply both at home and in clinics, and is used to reduce pain via sensory feedback. It has recently been shown that TENS affects the autonomic nervous system¹³⁾, relieves spasticity and increases motor performance¹⁴⁾. Also, Dickstein et al. applied high-frequency TENS stimulation to the gastrocnemius of healthy subjects and reported it decreased postural sway¹²⁾. Mulvey et al. showed that stimulating somatosensory inputs, such as proprioception, was helpful for perceptual embodiment of prosthetic limbs¹⁵⁾. Nevertheless, there is no definitive research on the effect of TENS on the somatosensory system including proprioception and maintenance of balance. In particular,

there is no research currently available on how TENS affects MF induced during exercise, everyday activities or labor, which can result in various kinds of damages.

Therefore, this study sought to confirm that MF induces postural imbalance and decreases muscle strength, and also to investigate the effect TENS has on changes in postural control and muscle contraction caused by MF.

SUBJECTS AND METHODS

Twenty-one healthy graduate school students (10 males and 11 females) of S University in Seoul, between 25–29 years of age, 155–180 cm in height and 41–90 kg in weight were recruited for this study. Those who had neurological or orthopedic disorders, or balance disorders due to impaired vision or vestibular problems were excluded. Subjects were selected from those who did not take any medication or alcoholic beverage 24 hours before the experiment. We began the research only after explaining adequately to participants the method and purpose of the experiment, and had acquired their full agreement to participation. Three participants were dropped from the test as they could not maintain a unipedal stance on the balance trainer, so the study was conducted with 18 subjects (10 males and 8 females).

This study used a randomized single-blind cross-over design, and subjects were allocated to either a sensory threshold group, or two to three times sensory threshold groups according to their intervention sequence. The sensory threshold is the lowest level of intensity of variation which subjects can recognize. Two to three times sensory threshold is the level of intensity 2–3 times stronger than the threshold. After therapeutic intervention with TENS or placebo TENS, a tester who did not know which treatment had been administered evaluated subjects' spasticity and balance ability.

The postural sway length (PSL), postural sway velocity (PSV) and maximal voluntary contraction (MVC) of the 18 subjects were measured before and after induction of fatigue, and also during the application of TENS to the fatigued muscles. PSL and PSV were used as indices of balance ability, and MVC was conducted to verify the changes in muscle strength following muscle fatigue with/without intervention. After measuring changes in postural sway induced by MF and applying TENS afterwards, subjects were given a week to recover; then their muscle strength was measured again after inducing MF via the same method. After conducting an electrical stimulation test at a certain intensity, subjects were given a week to recover, and then the same test was carried out but at a different intensity.

Subjects conducted the heel-raise to induce fatigue in the gastrocnemius. They stood on a 20 cm-high stool, raised heels to the maximum, maintained the position as long as they could, and repeated the exercise until they could no longer maintain the posture with their heels raised. The examiner instructed the participants to "raise heels as long as possible", and the MF trigger was confirmed by inspection and performance of heel-raises.

Subjects were examined after induction of MF; then

TENS was applied to the muscle belly of the gastrocnemius. Electrical stimulation was delivered at the intensity of the sensory detection threshold or two to three times sensory threshold¹⁴⁾, and then were examined PSL, PSV, MVC. TENS stimulation was performed using a dual channel TENS (TENS-7000, Koalaty Products Inc., USA) at a frequency of 100 Hz and pulse width of 200 μ s. In order to measure each participant's sensory threshold prior to the experiment, their threshold was examined by delivering electrical stimulation at different intensities, starting from 0.01 mA to the point where they felt the stimulation. Based on this, participants were stimulated at the intensity of the individual's sensory threshold or at 200–300 % of the threshold value^{12,14)}.

Postural sway was measured with a 3D motion analyzer and balance trainer (Posturo-med, Germany). Participants stood on the balance trainer with two ultrasonic heads attached to them, which were used by the 3D motion analyzer. Movement of participants on the balance trainer was measured as a 3D path, which was summed and averaged, and the mean of the velocity of each measurement point's movement was also calculated. A 3D motion analyzer, CMS10 (Zebris, Germany), was used to receive the ultrasonic signals, and Win posture (V0.12) was used to analyze these signals.

The motion analyzer (CMS-10) was used to find out the balance ability of subjects by evaluating postural sway. PSL and PSV, parameters of postural sway in the unipedal stance, were measured three times for 30 seconds each, before and after induction of MF and during the application of TENS, and their means were calculated. Before the actual measurement took place, participants were given five attempts to familiarize themselves with the task. After the practice session, they rested for 10 minutes, and those who used lower limbs or torso to maintain balance in the unipedal stance were asked to re-do the task⁷⁾.

To minimize stimulation of the subjects' vestibular system, all experiments were carried out in a silent area. On the examiner's command of "Ready," subjects on the balance trainer held the safety bar and stared at a focal point in front of them. On the command "Start," they crossed their arms and balanced on the dominant leg while lifting the other leg. If subjects maintained balance using their upper limbs or lower limbs during the task, or lost balance in less than 15 seconds, they were asked to re-do the task.

A manual muscle tester (MMT, Model 01163, Lafayette, USA, 2003) was used to measure the MVC of gastrocnemius. The MMT can measure in the range of 1–136.1 kg to an accuracy of 0.2 kg, and in the range of 0–22.6 kg to an accuracy of 0.1 kg, with $\pm 1\%$ error. The head of the MMT was attached to the plantar surface of foot, and the subjects were asked to extend their knees while lying prone, and push the head with maximum plantarflexion of their ankle starting from the angle of 0°. Intra-examiner reliability was $r=0.84\sim0.99$, inter-examiner reliability was $r=0.84\sim0.94$, and inter-examination reliability was $r=0.98\sim0.99$. The mean was calculated by repeating the measurement for three times after one practice session¹⁶⁾.

Statistical analyses were performed using SPSS (v 15).

Table 1. Subject characteristics

	Subjects
Gender (male/female)	18 (10/8)
Age (years)	26.8 ± 1.22
Height (cm)	167.5 ± 7.4
Weight (kg)	59.7 ± 12.7

Note. Values are expressed as mean ± standard deviation (SD).

The Shapiro-Wilks test was used to confirm the normality of the data. One way repeated ANOVA was carried out to compare PSL, PSV and MVC values of before and after the induction of MF, and during TENS. Post-hoc tests were performed using the LSD test. The independent t-test was performed to compare the two sensory threshold groups. The level of significance was chosen as 5% for all statistical analyses.

RESULTS

The general characteristics of the 18 subjects are shown in (Table 1).

MF induced in the gastrocnemius increased PSL by approximately 93% and PSV by 98%. Stimulation by TENS at the sensory threshold significantly decreased postural sway by approximately 25%, and there was an even more

significant decrease in postural sway of 43% when stimulation was delivered at two to three times the sensory threshold (Tables 2 & 3).

MVC changes induced by MF and the effects of TENS on these changes are shown in (Table 4).

MF significantly decreased MVC by nearly 30%. TENS stimulation at the sensory threshold partially reversed the decline of MVC caused by MF by some 11%, and that of two to three times the sensory threshold significantly reversed it by approximately 26% ($p < 0.05$).

DISCUSSION

This study demonstrated the effect of TENS on the changes in postural control and muscle strength caused by MF.

We showed that MF in the gastrocnemius increased postural imbalance and decreased muscle strength. In this study, fatigue was induced in the gastrocnemius and the consequent difficulty with voluntary movement increased postural sway by almost 93–99%. This result corresponds with findings of other researchers that MF in the lower limbs causes postural sway. Yaggie et al. reported that MF in the ankle-joint muscles, such as plantarflexors and dorsiflexors, increased the length and velocity of postural sway from 35 cm and 14 mm/s to 40 cm and 16 mm/s¹⁷. Gribbles et al. reported MF in the lower limbs increased

Table 2. The changes of Postural Sway Length following muscle fatigue and TENS application in fatigued status

Experimental groups	Baseline	Fatigue status	TENS application
Sensory threshold	780.8 ± 320.8 [#]	1508.4 ± 518.9*	1138.2 ± 421.2* [#]
2–3 times sensory threshold	757.2 ± 265.6 [#]	1468.5 ± 489.3*	834.3 ± 293.2 [#] ^{\$}

Note. Values are expressed as mean SD. * means a significant differences from the baseline value and [#] indicates a significant differences compared with fatigue status. ^{\$} represents a statistically significant differences relative to sensory threshold group ($p < 0.05$).

Table 3. The changes of Postural Sway Velocity following muscle fatigue and TENS application in fatigued status

Experimental groups	Baseline	Fatigue status	TENS application
Sensory threshold	24.6 ± 9.9 [#]	48.9 ± 16.7*	36.9 ± 13.6* [#]
2–3 times sensory threshold	24.0 ± 7.7 [#]	47.5 ± 15.5*	27.1 ± 9.2 [#] ^{\$}

Note. Values are expressed as mean SD. * means a significant differences from the baseline value and [#] indicates a significant differences compared with fatigue status. ^{\$} represents a statistically significant differences relative to sensory threshold group ($p < 0.05$).

Table 4. The changes of Maximal Voluntary Contraction following muscle fatigue and TENS application in fatigued status

Experimental groups	Baseline	Fatigue status	TENS application
Sensory threshold	32.1 ± 9.1	22.1 ± 7.6*	24.6 ± 7.7*
2–3 times sensory threshold	31.5 ± 9.5 [#]	22.8 ± 7.9*	28.8 ± 9.2 [#]

Note. Values are expressed as mean SD. * means a significant differences from the baseline value and [#] indicates a significant differences compared with fatigue status ($p < 0.05$).

PSV in the frontal plane from 36 mm/s to 40 mm/s, and in the sagittal plane from 34 mm/s to 36 mm/s¹⁸). Also, Vuillerme et al. showed that MF of a degree similar to that used in this study in both gastrocnemius muscles increased the difference of foot pressure variance between the front and the rear, and the right and the left by almost 100 %¹⁹). Ledin et al. reported that MF in both gastrocnemius muscles similarly resulted in an increase in postural sway compared to the control group⁷). The reason for MF causing postural sway can be attributed to a decline in proprioception in the ankle joints and changes in motor function²⁰). MF in the calf muscles delayed the response to mechanical perturbation, which lead to a decline in changes in the range of ankle joint movement²¹). Furthermore, MF caused an increase in co-contraction of agonists-antagonists, leading to joint stiffness and increased restriction in reactive movement, resulting in postural sway.

While some recent studies have shown that postural sway caused by MF increased by approximately 14% from 6%^{17, 18}), this study showed an almost 99% increase in MF-induced postural sway. The difference can be attributed to the fact that the earlier studies measured static balance using a force-plate to measure postural sway, compared with this study's measurement of dynamic balance on PosturalMed, on which it is harder to keep balance. Also, unlike this study, some previous studies failed to induce changes in postural sway with MF of the ankle joints^{18, 22}). Harkins et al. found out that the degree of MF is a factor which affects the degree and maintenance of postural sway²³). The methods used to induce MF in previous studies varied greatly, ranging from electrical stimulation to muscle contraction such as heel-raises and toe-raises^{8, 17, 18, 23}). Thus, the results were influenced by differences in method and degree of MF, as well as the different muscles targeted for fatigue. Especially since the study by Vuillerme et al., which used a similar degree of MF as this study, reported an approximate 100% increase in postural sway¹⁹), MF seems to be an important factor for maintenance of balance.

Postural control was measured in the unipedalstance in this study. Postural control has been studied in the bilateralstance, unipedalstance and tandemstance, and the bilateralstance has been most frequently used due to its stability⁸). The unipedalstance, which is usually used to verify the clinical difference between normal subjects and patients with musculoskeletal problems in the lower limbs¹⁸), has a smaller base of support and requires greater activity of the muscles for balance than the bilateralstance²⁴). Onambele et al. demonstrated postural sway at different ages. The length of the gastrocnemius and muscle characteristics, such as MVC, of healthy people showed a 12% increase in the bilateralstance, and a 50% increase in the unipedalstance and increased by 21% in older people compared to young people⁸). The unipedalstance was the most sensitive for postural sway measurement and showed changes in muscle characteristics, while the bilateralstance does not show age-dependent changes in muscle characteristics or postural sway measurement⁸). In this study, we performed measurements in the unipedalstance rather than the bilateralstance; therefore, comparisons of our results with the bipedal stance

may not be valid. Nonetheless, we did demonstrated that the unipedalstance is a valid method for measuring changes in postural sway induced by MF.

In addition, MF decreased MVC by some 30%. Repeated movement augments anaerobic glycolysis to produce energy and increases the amounts of pyruvic acid and hydrogen ions, which enhances the production of lactic acid. Lactic acid disturbs ATP production and lowers intracellular pH, which in turn interrupts excitation-contraction of muscles and decreases muscle strength²). Decreased muscle strength restricts postural control, causing postural imbalance evidenced increased postural sway. Previous studies have shown a nearly 27% increase in PSV among those with MF and 6% lower MVC⁹), and increased postural sway in older people with 52% lower MVC than young people⁸). In this study, the correlation coefficient between PSL and MMT was $r = -0.322$ ($p < 0.01$), and PSV and MMT showed a negative correlation with $r = -0.324$ ($p < 0.01$). Therefore, we think muscle strength an important factor in postural control.

This study demonstrated that TENS is effective at improving postural imbalance and muscle weakness due to MF. TENS stimulation decreased postural sway by 25~43% and increased MVC by 11~26%. Previous studies also reported that TENS improved the average of PSV and PSV in the frontal and sagittal planes of healthy university students by 4%, 6% and 7% respectively in the bilateralstance¹²), and a 27% improvement in postural imbalance due to hemineglect among stroke patients²⁵). The results of this study and others indicate that TENS has a greater effect on stroke patients than on healthy subjects, and this may be due to the differences in physical baseline such as diseases, disorders and physical defects. Thus, TENS can be used to improve postural imbalance caused by physical defects and diseases as well as on decreased muscle strength.

Balance ability is affected by somatosensory inputs from the lower limbs, in particular, proprioception²⁶). TENS may have increased somatosensory inputs from the gastrocnemius with MF-impaired proprioception to the CNS, enhancing standing balance control and maintenance. The somatosensory and motor cortex areas of the brain are connected via neural circuits, which are able to influence the motor cortex with sensory input alone²⁷). Therefore, it is possible that TENS of the fatigued gastrocnemius reorganized the motor cortex in brain with increased somatosensory input, resulting in enhanced motor output and consequently, improved balance ability. Moreover, we assume that TENS improved postural imbalance caused by MF-impaired proprioception by stimulating proprioception.

TENS improved motor function by increasing voluntary contraction and reducing spinal reflex, which controlled co-contraction of agonists-antagonists in hemiplegic patients²⁸), and high-frequency electrical stimulation increased stepping force in animal study as well²⁹). TENS stimulation on gastrocnemius increased H-reflex amplitude, the parameter for spinal motor neuron excitability³⁰). This study also showed an 11% and 26% increase in MVC with TENS stimulation at sensory threshold and at two to three times intensity of it, respectively. Therefore, TENS

stimulation is assumed to be effective on postural control by boosting muscle strength.

In conclusion, this study demonstrated postural imbalance and decreased muscle strength by triggering MF on gastrocnemius, and proved that TENS stimulation is effective to control muscle strength and postural control caused by MF. According to our results, TENS can be an effective method to mediate MF, commonly occurred in everyday activities and during exercises or labor.

REFERENCES

- Bigland-Ritchie B, Woods JJ: Changes in muscle contractile properties and neural control during human muscular fatigue. *Muscle Nerve*, 1984, 7: 691–699.
- Westerblad H, Bruton JD, Katz A: Skeletal muscle: energy metabolism, fiber types, fatigue and adaptability. *Exp Cell Res*, 2010, 316: 3093–3099.
- Pline KM, Madigan ML, Nussbaum MA: Influence of fatigue time and level on increases in postural sway. *Ergonomics*, 2006, 49: 1639–1648.
- Hawkins RD, Fuller CW: An examination of the frequency and severity of injuries and incidents at three levels of professional football. *Br J Sports Med*, 1998, 32: 326–332.
- Keshner EA, Allum JH, Pfaltz CR: Postural coactivation and adaptation in the sway stabilizing responses of normals and patients with bilateral vestibular deficit. *Exp Brain Res*, 1987, 69: 77–92.
- Hiemstra LA, Lo IK, Fowler PJ: Effect of fatigue on knee proprioception: implications for dynamic stabilization. *J Orthop Sports Phys Ther*, 2001, 31: 598–605.
- Ledin T, Fransson PA, Magnusson M: Effects of postural disturbances with fatigued triceps surae muscles or with 20% additional body weight. *Gait Posture*, 2004, 19: 184–193.
- Onambele GL, Narici MV, Maganaris CN: Calf muscle-tendon properties and postural balance in old age. *J Appl Physiol*, 2006, 100: 2048–2056.
- Paillard T, Maitre J, Chaubet V, et al.: Stimulated and voluntary fatiguing contractions of quadriceps femoris differently disturb postural control. *Neurosci Lett*, 2010, 477: 48–51.
- Watanabe S, Kobara K, Ishida H: Influence of fingertip contact with a wall on postural sway and electromyographic activity of the soleus muscle. *Electromyogr Clin Neurophysiol*, 2010, 50: 229–233.
- Ross SE: Noise-enhanced postural stability in subjects with functional ankle instability. *Br J Sports Med*, 2007, 41: 656–659, discussion 659.
- Dickstein R, Laufer Y, Katz M: TENS to the posterior aspect of the legs decreases postural sway during stance. *Neurosci Lett*, 2006, 393: 51–55.
- Cramp FL, McCullough GR, Lowe AS, et al.: Transcutaneous electric nerve stimulation: the effect of intensity on local and distal cutaneous blood flow and skin temperature in healthy subjects. *Arch Phys Med Rehabil*, 2002, 83: 5–9.
- Ng SS, Hui-Chan CW: Transcutaneous electrical nerve stimulation combined with task-related training improves lower limb functions in subjects with chronic stroke. *Stroke*, 2007, 38: 2953–2959.
- Mulvey MR, Fawcner HJ, Radford H, et al.: The use of transcutaneous electrical nerve stimulation (TENS) to aid perceptual embodiment of prosthetic limbs. *Med Hypotheses*, 2009, 72: 140–142.
- Moss CL, Wright PT: Comparison of three methods of assessing muscle strength and imbalance ratios of the knee. *J Athl Train*, 1993, 28: 55–58.
- Yaggie JA, McGregor SJ: Effects of isokinetic ankle fatigue on the maintenance of balance and postural limits. *Arch Phys Med Rehabil*, 2002, 83: 224–228.
- Gribble PA, Hertel J: Effect of hip and ankle muscle fatigue on unipedal postural control. *J Electromyogr Kinesiol*, 2004, 14: 641–646.
- Vuillerme N, Burdet C, Isableu B, et al.: The magnitude of the effect of calf muscles fatigue on postural control during bipedal quiet standing with vision depends on the eye-visual target distance. *Gait Posture*, 2006, 24: 169–172.
- Forestier N, Teasdale N, Nougier V: Alteration of the position sense at the ankle induced by muscular fatigue in humans. *Med Sci Sports Exerc*, 2002, 34: 117–122.
- Rice CL, Cheng AJ, Davidson AW: The influence of muscle length on the fatigue-related reduction in joint range of motion of the human dorsiflexors. *Eur J Appl Physiol*, 2010, 109: 405–415.
- Paillard T, Bizid R, Margnes E, et al.: Effects of knee and ankle muscle fatigue on postural control in the unipedal stance. *Eur J Appl Physiol*, 2009, 106: 375–380.
- Harkins KM, Mattacola CG, Uhl TL, et al.: Effects of 2 ankle fatigue models on the duration of postural stability dysfunction. *J Athl Train*, 2005, 40: 191–194.
- Krause DA, Jacobs RS, Pilger KE, et al.: Electromyographic analysis of the gluteus medius in five weight-bearing exercises. *J Strength Cond Res*, 2009, 23: 2689–2694.
- Perennou DA, Leblond C, Amblard B, et al.: Transcutaneous electric nerve stimulation reduces neglect-related postural instability after stroke. *Arch Phys Med Rehabil*, 2001, 82: 440–448.
- Lord SR, Clark RD, Webster IW: Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc*, 1991, 39: 1194–1200.
- Farkas T, Kis Z, Toldi J, et al.: Activation of the primary motor cortex by somatosensory stimulation in adult rats is mediated mainly by associational connections from the somatosensory cortex. *Neuroscience*, 1999, 90: 353–361.
- Levin MF, Huichan CW: Relief of hemiparetic spasticity by tens is associated with improvement in reflex and voluntary motor functions. *Electroencephalogr Clin Neurophysiol*, 1992, 85: 131–142.
- Hahn TS: The effect of 2 Hz and 100 Hz electrical stimulation of acupoint on ankle sprain in rats. *J Korean Med Sci*, 2007, 22: 347–351.
- Hardy SG, Spalding TB, Liu H, et al.: The effect of transcutaneous electrical stimulation on spinal motor neuron excitability in people without known neuromuscular diseases: The roles of stimulus intensity and location. *Phys Ther*, 2002, 82: 354–363.