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# Neuromuscular electrical stimulation can improve mobility in older adults but the time course varies across tasks: Double-blind, randomized trial

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## ABSTRACT

Declines in mobility with advancing age are often associated with a reduction in the use of lower leg muscles. We examined the influence of two interventions that involved neuromuscular electrical stimulation (NMES) applied to the triceps surae muscles on the mobility and muscle function of older adults. Thirty healthy older adults (73.5 ± 4.8 yrs) participated in a 6-week intervention comprising 3 weekly sessions of either narrow- or wide-pulse NMES. Motor function was assessed at Weeks 0, 4, 7, and 10. There were no statistically significant differences in the changes in mobility for the two groups of participants, so the data for the two groups were combined to examine changes across time. Time to walk 400 m decreased and maximal walking speed increased after 3 wks of NMES (Week 4) but did not change further at Weeks 7 and 10. In contrast, time to complete the chair-rise and rapid-step tests decreased progressively up to Week 7 but did not change further at Week 10. Moreover, the increase in plantar flexor strength was only observed at Week 7. NMES can elicit improvements in the motor function of older adults, but the time course of the adaptations differs across the mobility tests.

## 1. Introduction

Unless a person maintains an active lifestyle as they age (Ortega et al., 2014), walking performance will decline progressively and contribute to the eventual loss of independence (Bischoff et al., 2003; Cooper et al., 2011; Fritz and Lusardi, 2009; Vestergaard et al., 2009; Warren et al., 2016). At self-selected walking speeds, the adaptations exhibited by older adults include a slower gait speed with a shorter step length, briefer relative swing phase, less range of motion at the hip, knee, and ankle joints, and reduced lower extremity joint torques and powers compared with young adults (Anderson and Madigan, 2014; Begg and Sparrow, 2006; Kulmala et al., 2014). When walking at the same speed, the relative joint power is greater at the hip joint and less at the ankle joint for older adults than for young adults (Cofré et al., 2011; DeVita and Hortobágyi, 2000; Franz and Kram, 2014).

Despite these differences in joint torques and powers between young and older adults, Franz and Kram (2014) found that older adults could perform 44% more positive work about the ankle joint when walking uphill than they did when walking on a level surface, suggesting an increase in the activation of the plantar flexor muscles. Nonetheless, older adults accommodate the challenge of walking uphill by increasing the demand on the gluteus maximus muscle more than the plantar flexor muscles (Franz and Kram, 2013). Such findings have led to the suggestion that older adults should attempt to preserve power production capabilities of the muscles that cross the ankle joint to maintain independence in mobility (Franz and Kram, 2013; Burnfield et al., 2000; Kerrigan et al., 1998).

Given that older adults can increase activation of the plantar flexor muscles when walking uphill (Franz and Kram, 2014), our study was based on the premise that facilitation of plantar flexor activation could improve their walking performance over level ground. The approach employed neuromuscular electrical stimulation (NMES), which is a form of electrical nerve stimulation that can elicit action potentials in intramuscular motor and sensory axons. The responses evoked by NMES currents depend on the duration of the stimulus pulse and the frequency of stimulation. The standard approach is to use pulses in the range of 0.1 to 0.5 ms at frequencies of 50 to 100 Hz (Vanderthommen and Duchateau, 2007). Such protocols can maintain or increase muscle mass and improve motor function in young (Vanderthommen and Duchateau, 2007) and older adults (Amiridis et al., 2005). In contrast, longer stimulus pulses can engage a greater proportion of sensory axons and thereby evoke widespread responses throughout the central nervous system (Collins, 2007; Knash et al., 2003; Mang et al., 2012; Mang et al., 2011), which might enable spinal networks to improve that

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activation of plantar flexor muscles (Lagerquist et al., 2012). Moreover, the sensory volley evoked by wide-pulse NMES can augment the excitatory synaptic input received by motor neurons and thereby progressively increase the net motor unit activity, at least during relatively weak contractions (Collins, 2007).

The primary purpose of our study was to compare the influence of two 6-wk NMES protocols applied to the triceps surae muscles on the mobility of older adults (65–90 yrs). The NMES protocols involved either narrow stimulus pulses (0.26 ms) delivered at 50 Hz or wide stimulus pulses (1 ms) delivered at 100 Hz. The secondary purpose of our study was to compare the influence of the NMES protocols on measures of muscle function, muscle strength, and force steadiness. We hypothesized that the more widespread central effects of wide-pulse NMES protocol would induce greater improvements in mobility and function of the plantar flexor muscles than the narrow-pulse NMES protocol.

## 2. Methods

Thirty healthy, moderately active, older adults (65–90 years) were recruited for the study. The standardized Mini Mental Health Examination was administered after the informed consent had been signed to confirm English language competency and adequate cognition, with the requirement that all subjects score at least 27/30. All procedures were approved by the Institutional Review Board (Protocol #13-0687) and conducted in accordance with the Declaration of Helsinki.

### 2.1. Protocol overview

Subjects participated in a 6-wk intervention that involved 18 treatment sessions (3 sessions/wk) in which NMES was applied to the triceps surae. Prior to being enrolled in the study, participants visited the lab for familiarization with the protocol and equipment. The outcomes were assessed in evaluation sessions that were performed before the start of the intervention (Week 0), between weeks 3 and 4 (Week 4), after the completion of the 6-wk intervention (Week 7), and 3 weeks after the end of the intervention (Week 10).

### 2.2. Intervention

Subjects were randomized into one of two intervention groups: narrow-pulse (0.26 ms) NMES applied at 50 Hz or wide-pulse (1 ms) NMES applied at 100 Hz. Both stimulus frequencies are considered to be high frequencies in terms of muscle tension (Vanderthommen and Duchateau, 2007; Veldman et al., 2016; Maffiuletti et al., 2018). The group assignment was unknown to both the participant and the investigators responsible for performing the evaluation sessions and analyzing the data.

The NMES current was initially set at a low value to familiarize the subject with the sensations associated with the electrical nerve stimulation. With the subject's permission, the current was increased progressively to reach the maximal tolerable level during each session. Prior to each step increase in current, the subject was asked for permission to increase the current. At some point, which increased across sessions, the subject decided not to increase the current any further; this was defined as the maximal tolerable intensity and quantified with a visual analog scale (0 − 10), which never surpassed a score of 5. Reaching maximal current is critical to achieve peak NMES effectiveness (Veldman et al., 2016).

The current was delivered with the FDA-approved Vectra Genisys Therapy System (Chattanooga, DJO Global, LLC., Vista, CA), which can provide symmetrical, rectangular pulses, up to 80 mA. The electrodes (2 in. × 3 in. PALS Electrodes, Axelgaard Manufacturing Co., Ltd., Fallbrook, CA) through which the current was delivered were placed on the distal and proximal ends of the triceps surae (Fig. 1A). NMES was applied to the plantar flexors of each leg, in a randomized order, for 20 min in each treatment session (4 s on, 12 s off, 75 contractions/session). Subjects rested for 1–2 min after ~25 contractions had been evoked.

The maximal current subjects could tolerate was increased by requiring them to perform voluntary contractions with the triceps surae muscles at the same time NMES was applied. This was accomplished by having the subjects seated in a chair with their legs lifted parallel to the floor and pushing against a wall for the first (Sessions 1–6) and last (Sessions 13–18) two weeks of the intervention (Fig. 1B) and standing in a lunge position to stretch the triceps surae muscles during the middle two weeks (Sessions 7–12) (Fig. 1C). Returning to the seated position in the last two weeks reduced the progression of an increase in NMES current prior to the final evaluation sessions. This protocol is similar to that recommended for therapeutic application of NMES (Spector et al., 2016).

### 2.3. Evaluation

The evaluation sessions performed at Weeks 0, 4, 7, and 10 comprised assessments of mobility, muscle strength, and force steadiness. Descriptive statistics of the participants were obtained at Week 0.

#### 2.3.1. Mobility

Mobility was quantified as the 10-m walk time at maximal speed, 10-m walk time at preferred speed, 400-m walk time, time to complete a chair rise test, and performance of a rapid stepping task. Maximal walking speed and preferred walking speed were quantified as the time to walk the middle 10 m of a 20-m indoor walkway. An investigator counted down from 3 to begin each walking test and then counted down from 3 as the subject neared the end of the walkway. The average of three trials was used in data analysis.

The chair-rise test was performed on a standard-height chair that had no armrests (Bohannon et al., 2007). Starting in the seated position, the arms were kept placed across the chest while the participant stood up and sat down five times, as quickly as possible. Subjects rested for at least 1 min between trials. The average of three trials was used in data analysis.

The 400-m walk required subjects to walk 2.5 laps around an indoor track at a brisk pace. Rating of perceived exertion (RPE; 0–10 Borg scale) was measured before and after the 400-m walk and at every half lap during the test.

Balance was measured as the time taken to complete a rapid step test and the number of errors made during the test. The maximal step length was determined as the greatest distance the subject could step and return to the original location (Cho et al., 2004). Subjects were asked to step in a random direction (forward, sideways, or backwards) with one of their legs to marked targets equivalent to 80% of the maximal step length as quickly as possible and then to return to the center position. The test involved 19 individual reaching actions with a specified leg and direction. An error was defined as failure to reach the target, loss of balance, failure to return to the initial position in the center, or incorrect leg use or direction. Subjects rested for at least 1 min between trials. The average of three trials was used in data analysis.

#### 2.3.2. Muscle function

Muscle strength was measured during isometric contractions as the peak force achieved during 2–5 maximal voluntary contractions (MVC) with the ankle dorsiflexors, plantar flexors, knee extensors, knee flexors, and hip flexors. Each muscle group was tested by itself with the subject in a supine position. A strain-gauge transducer (MLP-300, Transducer Techniques, Tenecula, CA) was placed in series with a strap placed around the forefoot, shin, or thigh to measure the force exerted by the limb during each MVC. The MVC task required the subject to increase force from 0 to maximum over 3 s and hold the maximal force