**ORIGINAL ARTICLE**

# Static balance adaptations after neuromuscular electrical stimulation on quadriceps and lumbar paraspinal muscles in healthy elderly

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## Abstract

**Background** Strength training as neuromuscular electrical stimulation (NMES) is effective in counteracting age-related postural impairments in elderly. However, it remains unknown whether training different muscle groups would entail in different adaptations.

**Aim** To evaluate the effect of NMES training on balance function in healthy inactive elderly, targeting paravertebral muscles, in addition to thigh muscles.

**Methods** Eleven healthy elderly were trained with NMES for 8 week allocated to combined training (CT: quadriceps and lumbar paraspinal muscles) or to quadriceps training (QT), after completing lifestyle questionnaire and spine morphology measurements. Functional balance, static stabilometry, and isometric strength tests were assessed before and after the training period.

**Results and conclusion** The CT group showed a greater improve in static balance control, i.e., reducing the CEA of the CoP displacement from $99 \pm 38$ to $76 \pm 42$ mm$^2$ (Cohen's $d = 0.947$). Benefits for improving static balance through CT might be due to NMES training, which increases spinal stabilization.

**Keywords** Stabilometry · Spine anatomy · Physical stimulation · Exercise therapy · Combined training · Posture

## Introduction

Healthy skeletal muscle promotes a broad range of functions, including the maintenance of postural control, mobility, strength, and metabolic functions, which makes it an essential tissue for life [1–3]. Severe sarcopenia is known to increase the chances of developing a disability and premature death [4, 5]. Of particular concern in old age is the high incidence of falls, which can lead to devastating consequences [6]. Although postural function impairment is not viewed as a typical risk factor for falls, associations between posture and body balance or falls in the elderly have been shown [7, 8].

The postural output is closely associated with lower limbs' strength and power across all subjects [9]. Recently, Andrade and colleagues pointed out that the age-related impairment of postural control is mainly due to lower limb strength decline and not due to the changes in sensorial integration [10]. Furthermore, a growing body of evidence suggests that age-related postural changes in spine morphology contribute to the increased postural instability which in turn entails the increased risk of falls in the elderly [11–13]; for instance, Beserra Da Silva and colleagues [14] demonstrated on postmenopausal women that trunk extension strength is a predictor of falls. Indeed, to counteract the fall risk associated with age-related osteo-muscular diseases, in addition to the strengthening of lower limb muscles [15], and particularly knee extensors [16], it has been suggested to targeting trunk and core muscles [17].

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Neuromuscular electrical stimulation (NMES) previously proved to be effective in attenuating muscle mass and strength in both healthy adults [18] as well in people with muscle weakness who cannot perform volitional training [19]. However, it is still missing evidence about a possible enhancement of postural adaptations due to training on paravertebral muscles, in addition to the usual training of large muscle groups of lower limbs. It has been argued that supervised protocols of resistance training in older adults improved balance to a greater extent, rather than unsupervised protocols [20]. Therefore, NMES training may be prospectively useful for targeting strength protocols in elderly in a self-training modality in those conditions where active and supervised protocols are hard to implement.

Hence, in this study, we aimed to evaluate the effect of paravertebral and thigh muscles NMES training on balance function in healthy older people. The authors hypothesized that targeting at lumbar paravertebral muscles with electrical stimulation in elderly, which is difficult to stimulate with active protocols in elderly in addition to thigh muscles, will enhance the training-related benefits to postural health. The authors also hypothesized that changes in postural control in response to 8-week of NMES training would be detectable by stabilometry.

## Materials and methods

### Participants

Volunteers were recruited from the community according to the inclusion criteria: (a) > 65 years old, (b) availability to take part in a 8-week lasting training plan in our laboratory, (c) being able to carry out stabilometry assessment with closed eyes. The exclusion criteria were irregular ECG, osteoarticular pathologies, mild to medium cardio-circulatory pathologies, cancer, non-controlled hypertension, metabolic, psychiatric, respiratory, neuromuscular or genetic disease, and sarcopenia. Only one participant (the one coded as Q + Lm1 in the tables) suffered from a vestibular disease in the past. The current report refers to an experimental group of 11 Italian volunteers, aged 66–74 years, retired, living in Abruzzo region, Italy (see Table 1 for details). Our participants were not involved in physical activity or exercise protocols. None of them was taking any medication targeting muscle function. The study was approved by the Ethics Committee of the University "G. d'Annunzio" (n.16 of 05/09/2019), conforming to the ethical standards set by the Declaration of Helsinki and later amendments [21]. Informed consent was obtained from all individual participants included in the study. A medical anamnesis was applied to all the participants by a medical doctor prior to the effective recruitment.

**Table 1** Descriptive characteristics of volunteers

|  | Gender | Age (years) | BMI (kg/m$^2$) | FM (%) | PCS | MCS | PA | Waist-to-height | Waist-to-hip |
|---|---|---|---|---|---|---|---|---|---|
| Q + Lf1 | Female | 68 | 28.13 | 37.32 | 46.62 | 51.94 | 176 | 0.59 | 0.82 |
| Q + Lf2 | Female | 69 | 26.44 | 38.56 | 51.11 | 54.72 | 144 | 0.59 | 0.90 |
| Q + Lm1 | Male | 69 | 25.68 | 17.71 | 50.41 | 56.87 | 136 | 0.56 | 0.94 |
| Q + Lm2 | Male | 72 | 28.65 | 23.35 | 54.13 | 49.89 | 87 | 0.63 | 0.98 |
| Q + Lf3 | Female | 68 | 26.06 | 32.23 | 56.15 | 42.6 | 130 | 0.58 | 0.93 |
| Q + Lf4 | Female | 69 | 22.23 | 35.29 | 43.13 | 54.65 | 97 | 0.51 | 0.84 |
| Q + L group |  | 69.17 (1.47) | 26.20 (2.27) | 30.74 (8.39) | 50.26 (4.79) | 51.78 (5.11) | 128.33 (32.46) | 0.58 (0.04) | 0.90 (0.06) |
| Qm1 | Male | 69 | 29.81 | 27.13 | 44.40 | 62.97 | 99 | 0.64 | 1.08 |
| Qf1 | Female | 69 | 25.84 | 35.97 | 45.48 | 48.11 | 104 | 0.55 | 0.80 |
| Qf2 | Female | 66 | 30.04 | 40.39 | 47.70 | 57.46 | 165 | 0.58 | 0.81 |
| Qf3 | Female | 74 | 28.76 | 39.46 | 48.08 | 33.23 | 90 | 0.59 | 0.83 |
| Qm2 | Male | 74 | 27.53 | 22.72 | 49.10 | 52.61 | 146 | 0.61 | 1.08 |
| Q group |  | 70.40 (3.51) | 28.40 (1.74) | 33.13 (7.83) | 46.95 (1.94) | 50.88 (11.31) | 120.80 (32.77) | 0.59 (0.03) | 0.92 (0.15) |

FM was estimated from plicometry

PCS and MCS were calculated from SF-12 questionnaire; PA score was calculated by PASE questionnaire; Waist-to-Height and Waist-to-Hip are expressed as ratios. The first six subjects performed the combined training (Q + L quadriceps + lumbar paraspinal muscles), the following five ones performed the training of thigh (Q quadriceps) only

*BMI* body mass index, *FM* fat mass, *PCS* physical component summary, *MCS* mental component summary, *PA* physical activity

## Materials

The neuromuscular activation (warm-up) was performed pedaling on a stationary bike (XTPRO Bike600, Technogym, Gambetolla, Italy). The transcutaneous electrical stimulation was delivered through a set of four fully gelled electrodes with a contact area of $5 \times 5$ cm$^2$ using a customizable NMES device (Genesy 1200 Pro; Globus Srl, Codogne, Italy). Spine morphology was assessed through the 6TVC G.O.A.L.S. (Global Opto-electronic Approach for Locomotion & Spine) (Bioengineering & Biomedicine Company S.r.l., Italy) stereo-photogrammetric opto-electronic system, derived from Optitrack System (Natur- alPoint Inc. USA). 3D parametric biomechanical model was processed with the commercial software package ASAP 3D Skeleton Model (Bioengineering & Biomedicine Company S.r.l. Italy). They were then tested for spine morphology in the external Laboratory of the "Bioengineering and Biomedicine Company". In this study, a stabilometric and posturometric platform with related software (Lizard 3.01, Lizard S.r.l, Perugia, Italy) was used to record and report the CoP movements in the anterior–posterior ($y$) and lateral ($x$) directions. To assess bilateral isometric strength of quadriceps, we used Maximum Voluntary Isometric Contraction (MVIC) method on a leg extension machine (Nessfit NMI 1000, Bcube, Italy) equipped with a dynamometer (Tesys 800, Globus, Italy). The percentage of Fat Mass (FM%) was estimated based on the method of Jackson and Pollock [22]; skinfold thickness was measured with an accurate plicometer (Holtain Ltd, UK).

Physical activity (PA) levels were assessed by the Physical Activity Scale for Elderly (PASE) questionnaire. It is a brief tool that focuses on three domains (leisure, household and work-related), assessing the PA in older people over a 1-week time frame. It includes activities common to most oldest adults, providing a more comprehensive assessment of the overall physical activity of the elderly. In this study, the validated version of the original questionnaire adapted to Italian culture was used [23]. Health-Related Quality of Life (HRQoL) was assessed by the Short Form-12 (SF-12) questionnaire. It is a 12-item questionnaire that assesses generic health outcomes from the patient's perspective, including the impact of possible illnesses on a wide range of functional domains. In this study, the Italian version of the SF-12 questionnaire was used, and data were scored according to Ware et al. [24] to calculate Physical and Mental Component Summary (respectively, PCS and MCS) [25].

## Research design

This randomized non-controlled trial represents a pilot study, as a sub-set of the project "A.M.A. la terza età" (translation: "love the old age"), which addresses the exercise-related adaptations in elderly and the determinants of muscle healthy aging. Before starting with the training, participants underwent an inclusive check for sarcopenic status, controlling for walking speed and handgrip strength [26]. The eleven volunteers were randomly assigned to two groups and trained with NMES throughout an eight-week period to either a combined training (Q + L group: training of quadriceps and lumbar paraspinal muscles; six participants, age: $69.2 \pm 1.5$ years, BMI: $26.2 \pm 2.3$ kg/m$^2$) or to a training of quadriceps only (Q group; five participants, age: $70.4 \pm 3.5$ years, BMI: $28.4 \pm 1.7$ kg/m$^2$). All participants were tested at the beginning and the end of the 8-week training period to examine the static balance adaptations using stabilometry and the functional balance using single-leg static balance test (or One-Leg Stance test, hereinto Flamingo test) and stepping test (or Fukuda-Unterberger stepping test, hereinto Fukuda test). In addition, MVIC was measured to assess the leg strength of volunteers. At baseline, participants completed PASE and SF-12 questionnaire and underwent anthropometric measurement. In particular, body mass index (BMI) was calculated as weight-to-square height ratio, and %FM was estimated as reported in the "Materials" section. Physical activity levels, wellness components, and spine morphology were assessed to characterize the sample. In addition, we measured spine morphology as the assessment of structural components of posture is considered as a valid component of physical functions and health in elderly individuals [27]. At the end of the training, we provided the participants with a report of their results, including the baseline measures. On these bases, we suggested them the current recommendation for Active Aging [28] and specific tips based on our results.

## Procedure

### Intervention: NMES training

The NMES training consisted of three sessions per week for an 8-week period. All volunteers performed 5 min of neuromuscular activation (warm-up) pedaling on a stationary bike. NMES training of quadriceps muscle group was set according to our laboratory protocol previously described in [29], while NMES training of lumbar paraspinal muscles (targeting the lumbar multifidus) was experimentally set according to the previous work by the groups of Baek and Kim [30, 31]. In both cases, electrodes were placed following skin preparation with an alcohol wipe.

For the NMES of the quadriceps, volunteers were seated in a relaxed position with a knee joint fixed at a 90° knee extension. After cleaning the skin with an alcohol wipe, two active electrodes were placed over the motor points of vastus lateralis and vastus medialis previously identified by palpation, and two dispersive electrodes were placed

approximately 5 cm below the inguinal crease. The NMES training lasted 18 min in total. Rectangular wave pulsed currents (75 Hz frequency, 400 μs pulse width) were delivered with a rise time of 1.5 s, a steady tetanic stimulation time of 4 s, and a fall time of 0.75 s (total duration of the contraction: 6.25 s) with a rest interval of 20 s between contractions.

Volunteers undergoing the combined NMES training followed the quadriceps NMES by 15 min NMES of lumbar paraspinal muscles. Four electrodes were placed bilaterally at the vertebral levels of L4 and L5, as described by the groups of Baek and Kim [30, 31], identified previously by iliac crest palpation. Volunteers were seated in a relaxed position, which was empirically set based on a prior set of trials involving different volunteers trying different positions. Biphasic wave pulsed currents (50 Hz frequency, 300 μs pulse width) were delivered with a ramp-up for 1 s, a steady tetanic stimulation time of 8 s, and a ramp down for 1 s (total duration of the contraction: 10 s) with a rest interval of 10 s between contractions. Frequency and time were applied according to previous work by [30, 31]. The transcutaneous electrical nerve stimulation (TENS) [32] was applied for the rest interval. This novel setting was applied to provide a more comfortable experience for the elderly volunteers, which was again previously tested empirically.

For both NMES training protocols, the intensity was monitored during each session and gradually increased to reach the maximum tolerable intensity, corresponding to the individual's pain threshold. After the first instructed trials, volunteers were allowed to freely adjust the intensity during the training session without feeling discomforts. Maximum intensities reached at the end of the NMES training ranged from 25 to 35 mA and from 35 to 45 mA for quadriceps and lumbar multifidus, respectively.

### Variables: spine morphology measurements

We used the method described in [33] and [34]. In brief, recordings were based on a 6TV cameras (resolution 1.3 Mp, 120 fps) stereo-photogrammetric opto-electronic system. The calibrated acquisition volume was $3 \times 3 \times 2$ m with a computed mean error range of 0.3–0.4 mm. For data processing, a complete 3 day parametric biomechanical human skeleton model has been implemented. It is based on 27 passive retro-reflective markers accurately positioned and glued on the human body, referred to anatomical landmarks identified by palpation [35]. Participants were required to maintain the neutral standing posture, with the upper arms relaxed along the side of the body, eyes looking directly ahead in the horizontal plane, feet apart at about pelvis width, and heels aligned on a line parallel to the frontal plane. At least five subsequent two-second lasting acquisitions at 120 Hz sampling rate have been recorded. All measurements were taken between 12 noon and 7.00 pm. The subjects were asked to

avoid any intensive training and/or hard physical activity before the postural assessment. For the current study, we used four quantitative biomechanical parameters. In the frontal plane, we used the average frontal offsets (ASO) and the average frontal global offsets (AGO). These are the computed means of horizontal distances of each labeled spine landmark with respect to: the vertical axis passing by S3 (ASO), and to the vertical axis passing through the midpoint between the heels (AGO). In the sagittal plane, we used the kyphosis angle (KA) and the lordosis angle (LA), as the computed angles in the identified kyphosis and lordosis, properly identified according to real spine curvature spatial changes at the limit-vertebrae and not strictly limited to the thoracic and lumbar anatomical regions.

### Variables: static stabilometry

During the stabilometry, the room was silent, and the assessment was performed with the volunteer standing barefoot on the stabilometric platform (Lizard 3.01®, Italy). Arms were held at the sides, and volunteers stood still focusing on a target located directly ahead on the white wall, approximately 1.5 m apart. Heels were positioned apart, forming a 30° angle as described in [36], touching the baseline with the second metatarsal and the center of the heel of each foot on each of the two 15° reference lines. The standardization was provided by positioning the lateral malleolus perpendicularly to the smaller reference line (see Fig. 1). The studied stance was bipedal with the eyes open (EO) and eyes closed (EC), which was tested for 51.2 s. The parameters were: Path Length (PL), Mean Path Velocity (MVP), Confidence Ellipse Area (CEA), Variance of Speed (Var S), Load Distribution Difference (LDD), Confidence Ellipse Axis Ratio (AP/ML Range Ratio). Romberg Index (RI) of PL, MVP and CEA were calculated as (EC/EO) × 100. The test was performed only once [37], and the data were recorded by the Lizard processing software (Lizard 3.01®, Italy).

### Variables: functional balance measurements

The Flamingo test was applied following literature [38]. To be specific, volunteers were asked to stand freely on one foot for as long as possible, with the other foot raised, focusing on a spot on the wall at eye level in front of him with eyes open. The investigator interrupted the test after 30 s, or if the subject touched the floor with the raised leg. Compensatory arm movements were accepted during the test. To prevent falls or injuries, an investigator stood close to the volunteer throughout the experimental session. The investigator used a stopwatch to measure the amount of time the subject was able to stand on one limb. The best time of three trials was recorded for each limb.

The Fukuda test was applied following literature [39]. To be specific, volunteers stood in the center of one circle (drawn on the ground) with feet close together. They were asked to raise one leg and then the other and to step in place at normal walking speed, with eyes closed. Both arms were stretched in front of the individual and raised to 90°. When 50 steps were completed, volunteers were asked to remain standing, and the angle of rotation and distance of displacement were measured. The angle of rotation was the amount of turning of the body around its vertical axis. The distance of displacement was the distance the individual moved from the start position.

### Variables: maximum bilateral isometric contraction or leg strength test

The MVIC test was performed according to a previous study [40]. Briefly, volunteers sat on a leg extension machine (Nessfit NMI 1000, Bcube, Italy) equipped with a dynamometer (Tesys 800, Globus, Italy) with knee and hip joint angle positioned at 90°, fastened to the chair, and they were required to push as hard as possible for 5 s. The test was carried out three times with recovery time > 2 min, and the best performance was recorded and used for later statistical analysis.

### Statistics

The statistical analysis was carried out using GraphPad Prism Software, version 8 (GraphPad Software, La Jolla, USA), and the R-based open-source software Jamovi Version 1.2.5.0 (retrieved from https://www.jamovi.org). PL, MVP, CEA, Var S, LDD, and AP/ML Range Ratio, both in EO and EC condition were tested for the comparison (pre vs post-intervention) × (combined training vs quadriceps training). RIs and MVIC were tested for the (pre vs post-intervention) comparison. After the assumption checks for normality of distribution (Shapiro Wilk's test) and homoscedasticity (Levene's test), considering the number of repeated measures (two) and the absence of missing point, ANOVA for repeated measure was used [41]. Partial $\eta^2$ was used as the effect size measure. Tukey's correction for multiple comparisons was used for post hoc tests.

Considering the results of two reliability studies, one referred to young [42] and the other to elderly [43] volunteers, PL, CEA and LDD were analyzed further. To be specific, each experimental group was tested with Bayesian paired-sample $t$ test, hypothesizing a reduction of the values after the training period. Cauchy's distribution with $\lambda = 0.707$ was used arbitrarily for a priori distributions. Bayes Factor ($BF_{10}$) was calculated, and BF robustness checks were performed across a wide range of prior

distributions. Considering the small sample size, Cohen's $d$ was adjusted to Cohen's $d_{unbiased}$ [44] as follows:

$$d\,unb = d\left(1 - \frac{3}{4df - 1}\right).$$

## Results

The volunteers were compliant to the proceeding of the study and successfully concluded the training period. Anthropometric characteristics of the participants revealed 1 out of 11 obese (9%), 9 overweight (82%) and 1 with normal weight, according to the typical BMI cut-offs (18–25, 25–30, and > 30 kg/m$^2$ for normal weight, overweight, and obese, respectively). Waist-to-hip ratio, an index for predicting the risk for non-communicable diseases in elderly has been widely established (Corrêa, Thumé, De Oliveira & Tomasi, 2016), ranged from 0.51 to 0.64. Their waist-to-hip ratio was higher than the typically recommended value of 0.50 [45] in all the participants. Mean PASE total score was 124.90; this result cannot be used to contextualize physical activity levels of our participants, as usually PASE scores are used to stratify on tertiles the participants [46, 47]; our participants reported a PASE score lower than the Italian reference [23] ($125 \pm 31$ and $159 \pm 78$, respectively). The SF-12 questionnaires results were: Physical Component Summary (PS) = $48.8 \pm 4.0$ and Mental Component Summary (MS) = $51.4 \pm 8.0$; basing on large references [48], these results identify our participants healthy, both for physical and mental components. Compared to the data obtained from ten countries about volunteers aged 65–74 years, the mean PCS of our participants was higher than all the references, while the mean MCS was higher than 3 out of 10 references, including the Italian one [49].

Results of spine morphology measurements are shown in Table 2. Concerning spine morphology, the participants had greater angles (both for frontal and sagittal plane measures) than normative values of young healthy adults [33], reflecting, as expected, an impaired spine health. In particular, their spine morphology showed a high heterogeneity in the frontal plane deformities, and consistent and marked deformities in the sagittal plane; in particular, all of the tested volunteers had a kyphosis angle > then 40°, confirming the age-related hyperkyphosis [13].

Our participants showed a good balance status: only 2 out of 11 had lower values than normative values of one-leg stance (open eyes, best of three trials, clustered by age group and gender) [50]. Concerning the Flamingo test, after the training period were shown impairments in 3/6 and 1/5 participants (Q + L and Q group, respectively) and improvements in 1/6 and 2/5 participants (Q + L and Q

**Table 2** Postural characteristics of volunteers of both groups (Q+L: quadriceps+lumbar paraspinal muscles; Q: quadriceps; f: females; m: males), by the mean of frontal (ASO and AGO) and sagittal plane (KA and LA) measures [33]

|        | ASO (mm) | AGO (mm) | KA (degree) | LA (degree) |
|--------|----------|----------|-------------|-------------|
| Q+Lf1  | 9.1      | 28.0     | 53.6        | 53.7        |
| Q+Lf2  | N.A      | N.A      | N.A         | N.A         |
| Q+Lm1  | N.A      | N.A      | N.A         | N.A         |
| Q+Lm2  | −4.0     | −12.3    | 71.4        | 38.6        |
| Q+Lf3  | 1.8      | 9.7      | 45.2        | 32.1        |
| Q+Lf4  | N.A      | N.A      | N.A         | N.A         |
| Qm1    | −1.9     | 14.8     | 50.0        | 35.6        |
| Qf1    | −3.3     | −3.1     | 50.0        | 47.1        |
| Qf2    | N.A      | N.A      | N.A         | N.A         |
| Qf3    | −18.4    | −12.3    | 51.5        | 53.5        |
| Qm2    | −2.0     | 8.4      | 41.9        | 41.4        |

Regarding ASO and AGO, values < 0 give offsets towards the left side, > 0 towards the right side

*ASO* average frontal spinal offset, *AGO* average frontal global offset, *KA* kyphosis angle, *LA* lordosis angle

group, respectively) (see Table 3). Concerning the Fukuda test, the angle of rotation was reduced in 4/6 and 3/5 participants (Q+L and Q group, respectively) while the distance of displacement was reduced in 1/6 and 2/5 participants (Q+L and Q group, respectively) (see Table 3); to be specific, the distance of displacement moved from $110 \pm 38$ cm to $93 \pm 42$ cm after the training period in the Q+L group, and from $92 \pm 59$ to $89 \pm 39$ cm in the Q group, while the angle of rotation moved from $41 \pm 33°$ to $56 \pm 44°$ in the Q+L group and from $15 \pm 17°$ to $28 \pm 12°$ in the Q group.

Individual plus whole group values are shown in Table 3 (Q+L group) and Table 4 (Q group), and statistical comparisons are shown in Tables 5 and 6. MVIC did not significantly change after the training period, ranging from $381 \pm 108$ N to $373 \pm 133$ N in the Q+L group after the training period, and from $447 \pm 100$ N to $435 \pm 111$ N in the Q group. Taking into account RM-ANOVA results (Table 2), Bayesian statistics and $d_{unb}$ (Table 3), and Magnitude-Based Decision references [51], the Q+L training resulted better than the Q training in improving static balance control, with likely beneficial effect in reducing CEA (open eyes condition) and possibly beneficial effects in reducing PL (open eyes condition) and LDD (closed eyes condition). The achieved statistical power $(1 − β)$ for within–between interaction of CEA with open eyes was computed as 0.98 with the software G*Power Version 3.1.9.3 [52]. To be specific, volunteers of Q+L group reduced the CEA with open eyes after the training of 25% on average, ranging from $99 \pm 38$ to $76 \pm 42$ mm$^2$.

## Discussion

To our knowledge, this is the first study evaluating static balance adaptations in response to NMES training of lumbar multifidus and vastus lateralis in healthy elderly. All in all, the participants of the current study can be defined as healthy elderly, substantially inactive, with an anthropometric status linked with high cardiovascular and metabolic risk, with an unhealthy spine morphology, but with a high wellness status, good strength and functional mobility, and non-sarcopenic. We compared the effect of two NMES training protocols with regard to strength, stabilometry and functional balance measures. From our results, the effect of NMES for improving maximum strength (measured by MVIC test) was unclear, as well as for improving functional balance (measured by Flamingo test and Fukuda test). Instead, despite the failing of finding statistical significance, a comprehensive evaluation of statistical testing revealed the combined training (of quadriceps and lumbar paraspinal muscles), rather than quadriceps training, to be likely or possibly beneficial for improving static balance. To be specific, the most likely results involved a reduction of CEA with open eyes, followed by the reduction of LDD with closed eyes and the reduction of PL with open eyes. These parameters were shown to be reliable in young adults [42], allowing further wide studies aiming to define the age-related normative values.

Basing on these prospective pieces of evidence, and according to the repeatability results of stabilometry parameters in elderly [43], we support the use of CEA parameter to determine training-related adaptation of static balance. Indeed, despite the condition "narrow stand eyes closed" has been proved to be the most reliable position [43], measuring CEA with normal standing position (feet slightly apart with an open angle) could also be adopted. PL with open eyes and LDD with closed eyes deserve further evaluations. With this regard, it should be of interest to go ahead with the results of Bernard and colleagues, who demonstrated the ones with the lowest initial level of balance control obtain more benefits from a postural control training program [53], defining which parameters may be the most adequate in monitoring balance control adaptations in healthy and clinical elderly.

The importance of lower limb strength for allowing a good postural control in elderly has been demonstrated [10]. In addition, a systematic review conducted by Granacher and colleagues [17] concluded trunk muscle strength to be important in fall prevention and rehabilitation program, as an additional or alternative method to balance and resistance training. One of the reasons behind the likely more beneficial effect of the combined training may lie in the effectiveness

**Table 3** Dataset of stabilometry, balance, and strength tests of the combined NMES (Q + L: quadriceps + multifidus; f: females; m: males) group

| | Q + Lf1 | | Q + Lf2 | | Q + Lm1 | | Q + Lm2 | | Q + Lf3 | | Q + Lf4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Stabilometry—eyes open** | | | | | | | | | | | | |
| PL (mm) | 277 | 232 | 313 | 218 | 328 | 265 | 406 | 404 | 278 | 274 | 294 | 280 |
| MPV (mm/s) | 6.2 | 5.3 | 7.4 | 5.8 | 7.7 | 6.3 | 9.5 | 9.4 | 6.4 | 6.1 | 7.5 | 6.9 |
| CEA (mm$^2$) | 60 | 39 | 114 | 52 | 87 | 56 | 169 | 155 | 76 | 64 | 89 | 87 |
| VarS (mm$^2$/s$^2$) | 16 | 12 | 30 | 19 | 34 | 19 | 43 | 36 | 17 | 13 | 25 | 21 |
| LDD (%) | 6.8 | − 0.7 | 0.5 | 2.9 | 6 | 1.5 | − 5 | − 3.7 | 8.1 | 3.9 | − 7.1 | − 10.2 |
| AP/ML (%) | 36 | 15 | 61 | 31 | 22 | 31 | 68 | 46 | 64 | 32 | 35 | 54 |

Pre: PL = 316.00 ± 48.38; MPV = 7.45 ± 1.18; CEA = 99.17 ± 38.52; VarS = 27.50 ± 10.37; LDD = 1.55 ± 6.47; AP/ML = 47.67 ± 19.04

Post: PL = 278.83 ± 66.00; MPV = 6.63 ± 1.46; CEA = 75.50 ± 42.07; VarS = 20.00 ± 8.63; LDD = − 1.05 ± 5.24; AP/ML = 34.83 ± 13.59

| | Q + Lf1 | | Q + Lf2 | | Q + Lm1 | | Q + Lm2 | | Q + Lf3 | | Q + Lf4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Stabilometry—eyes closed** | | | | | | | | | | | | |
| PL (mm) | 250 | 211 | 291 | 282 | 592 | 306 | 395 | 335 | 423 | 402 | 402 | 336 |
| MPV (mm/s) | 5.8 | 4.8 | 6.6 | 7.3 | 13.4 | 7.8 | 8.9 | 7.9 | 10.0 | 9.5 | 10.7 | 7.9 |
| CEA (mm$^2$) | 53 | 37 | 72 | 66 | 232 | 69 | 134 | 74 | 174 | 169 | 231 | 117 |
| VarS (mm$^2$/s$^2$) | 16 | 9 | 20 | 36 | 124 | 32 | 31 | 25 | 58 | 46 | 120 | 30 |
| LDD (%) | 9.1 | 0.8 | 1.5 | 2.1 | 5.6 | 2.2 | − 2.2 | − 2.4 | 7.5 | 1.1 | − 5.6 | − 10 |
| AP/ML (%) | 56 | 35 | 75 | 46 | 27 | 20 | 55 | 34 | 50 | 54 | 46 | 23 |

Pre: PL = 392.17 ± 119.53; MPV = 9.23 ± 2.79; CEA = 149.33 ± 76.95; VarS = 61.50 ± 49.12; LDD = 2.65 ± 5.77; AP/ML = 51.50 ± 15.60

Post: PL = 312.00 ± 63.78; MPV = 7.53 ± 1.53; CEA = 88.67 ± 46.99; VarS = 29.67 ± 12.34; LDD = − 1.03 ± 4.70; AP/ML = 35.33 ± 13.05

| | Q + Lf1 | | Q + Lf2 | | Q + Lm1 | | Q + Lm2 | | Q + Lf3 | | Q + Lf4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Stabilometry—Romberg Index** | | | | | | | | | | | | |
| PL | 90 | 91 | 93 | 130 | 180 | 115 | 97 | 83 | 152 | 147 | 137 | 120 |
| MPV | 93 | 91 | 90 | 126 | 174 | 124 | 94 | 84 | 158 | 154 | 143 | 116 |
| CEA | 90 | 94 | 63 | 126 | 267 | 124 | 80 | 48 | 230 | 263 | 259 | 135 |

PL = 124.83 ± 37.23 to 114.33 ± 23.96; MPV = 125.33 ± 37.48 to 115.83 ± 25.52; CEA = 164.83 ± 96.66 to 131.67 ± 71.79

| | Q + Lf1 | | Q + Lf2 | | Q + Lm1 | | Q + Lm2 | | Q + Lf3 | | Q + Lf4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Fukuda stepping test** | | | | | | | | | | | | |
| Dis. (cm) | 40 | 35 | 125 | 150 | 100 | 120 | 130 | 55 | 114 | 93 | 150 | 103 |
| Rot | 43°l | 32°r | 90°l | 112°l | 68°l | 110°l | 18°r | 28°l | 16°r | 40°l | 9°l | 12°r |
| **One-leg stance test** | | | | | | | | | | | | |
| Right (s) | > 30 | > 30 | 13 | 24 | 10 | 7 | > 30 | 20 | > 30 | > 30 | 27 | > 30 |
| Left (s) | > 30 | 23 | > 30 | > 30 | 7 | 7 | > 30 | > 30 | > 30 | > 30 | > 30 | > 30 |
| **Isometric bilateral strength test** | | | | | | | | | | | | |
| MVIC (N) | 300 | 299 | 245 | 212 | 396 | 406 | 528 | 599 | 480 | 412 | 337 | 310 |

381.00 ± 108.28 to 373.00 ± 133.46

For LDD, positive values refer to higher load on right foot, while negative values higher load on left foot

*PL* path length, *MPV* mean path velocity, *CEA* confidence ellipse area, *VarS* variance of speed, *LDD* load distribution difference, *AP/ML* antero–posterior/medio–lateral ratio, *Dis.* linear displacement, *Rot.* rotation (*l* towards left side, *r* towards right side), *MVIC* maximum voluntary isometric contraction

of NMES training for improving the spinal stabilization, thanks to an enhanced activation of the deep fibers of multifidus [32], as demonstrated also in patients with lumbar degenerative kyphosis [31]. Aging of the spine contributes to the development of painful and debilitating disorders, due to the main pathophysiological processes of degeneration and bone mass reduction [54]. We think that the time course of adaptations related to middle-term training protocols,

as in the current study, did not allow to counteract these processes. However, targeting trunk extensor muscles may have caused a greater control of core, resulting in a reduced instability during static posture. NMES has the potential to increase muscle mass, both in quadriceps and lumbar muscles; interestingly, improving muscle mass of paravertebral muscles likely benefits spine morphology and posture maintenance [55].

**Table 4** Dataset of stabilometry, balance, and strength tests of the group who performed NMES training of thigh only (Q: quadriceps; f: females; m: males)

| | Qm1 | | Qf1 | | Qf2 | | Qf3 | | Qm2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Stabilometry—eyes open** | | | | | | | | | | |
| PL (mm) | 214 | 310 | 295 | 298 | 247 | 218 | 230 | 196 | 265 | 256 |
| MPV (mm/s) | 5.3 | 8.4 | 6.7 | 6.9 | 5.7 | 5.4 | 5.3 | 4.6 | 6.2 | 5.9 |
| CEA (mm²) | 40 | 102 | 69 | 68 | 50 | 41 | 47 | 35 | 59 | 61 |
| VarS (mm²/s²) | 14 | 55 | 17 | 21 | 21 | 13 | 12 | 8 | 13 | 16 |
| LDD (%) | −2.9 | 0.6 | 1.3 | 0.5 | −0.4 | −0.4 | 0.7 | 1.9 | 7.8 | 5.9 |
| AP/ML (%) | 61 | 38 | 53 | 34 | 30 | 46 | 35 | 49 | 41 | 47 |

*Pre*: PL = 250.20 ± 31.44; MPV = 5.84 ± 0.61; CEA = 53.00 ± 11.25; VarS = 15.40 ± 3.65; LDD = 1.30 ± 3.97; AP/ML = 44.00 ± 12.81

*Post*: PL = 255.60 ± 49.30; MPV = 6.24 ± 1.47; CEA = 61.40 ± 26.48; VarS = 22.60 ± 18.72; LDD = 1.70 ± 2.49; AP/ML = 42.80 ± 6.46

| | Qm1 | | Qf1 | | Qf2 | | Qf3 | | Qm2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Stabilometry—eyes closed** | | | | | | | | | | |
| PL (mm) | 404 | 663 | 617 | 575 | 357 | 260 | 229 | 209 | 374 | 320 |
| MPV (mm/s) | 9.4 | 15.9 | 14.5 | 13.3 | 8.2 | 6.5 | 4.2 | 4.7 | 8.9 | 7.3 |
| CEA (mm²) | 45 | 635 | 361 | 257 | 123 | 63 | 45 | 38 | 123 | 98 |
| VarS (mm²/s²) | 45 | N.A | 290 | 109 | 34 | 24 | 11 | 10 | 42 | 30 |
| LDD (%) | −0.3 | 5.7 | 3.2 | −0.9 | 0.9 | −1.9 | 2.7 | 2.7 | 7.1 | 3.4 |
| AP/ML (%) | 24 | 12 | 53 | 36 | 26 | 24 | 24 | 33 | 54 | 90 |

Pre: PL = 396.20 ± 140.36; MPV = 9.04 ± 3.68; CEA = 139.40 ± 129.87; VarS = 84.40 ± 115.70; LDD = 2.72 ± 2.82; AP/ML = 36.20 ± 15.82

Post: PL = 405.40 ± 201.33; MPV = 9.54 ± 4.80; CEA = 218.20 ± 248.11; VarS = 43.25 ± 44.63; LDD = 1.80 ± 3.14; AP/ML = 39.00 ± 30.00

| | Qm1 | | Qf1 | | Qf2 | | Qf3 | | Qm2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Stabilometry—Romberg Index** | | | | | | | | | | |
| PL | 189 | 214 | 209 | 193 | 145 | 119 | 100 | 106 | 141 | 125 |
| MPV | 179 | 189 | 217 | 192 | 143 | 119 | 79 | 103 | 143 | 123 |
| CEA | 111 | 620 | 521 | 379 | 249 | 154 | 95 | 109 | 209 | 161 |

PL = 156.80 ± 42.94 to 151.40 ± 48.62; MPV = 152.20 ± 51.10 to 145.20 ± 42.04; CEA = 237.00 ± 171.48 to 284.60 ± 214.81

| | Qm1 | | Qf1 | | Qf2 | | Qf3 | | Qm2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| **Fukuda stepping test** | | | | | | | | | | |
| Dis. (cm) | 150 | 148 | 5 | 56 | 60 | 71 | 122 | 110 | 121 | 60 |
| Rot | 3°r | 18°l | 18°r | 16°r | 9°l | 40°r | 3°l | 22°r | 43°r | 42°r |
| **One-leg stance test** | | | | | | | | | | |
| Right (s) | > 30 | > 30 | > 30 | > 30 | 22 | > 30 | > 30 | N.A | > 30 | > 30 |
| Left (s) | 24 | > 30 | > 30 | 24 | 17 | 26 | 19 | N.A | > 30 | > 30 |
| **Isometric bilateral strength test** | | | | | | | | | | |
| MVIC (N) | 495 | 466 | 307 | 324 | 466 | 483 | 396 | 322 | 571 | 581 |

447.00 ± 100.30 to 435.20 ± 111.43

For LDD, positive values refer to higher load on right foot, while negative values higher load on left foot

*PL* path length, *MPV* mean path velocity, *CEA* confidence ellipse area, *VarS* Variance of speed, *LDD* load distribution difference, *AP/ML* antero–posterior/medio–lateral ratio, *Dis.* linear displacement, *Rot.* rotation (*l* towards left side, *r* towards right side), *MVIC* maximum voluntary isometric contraction

Whereas the training of lower limbs, as well as upper limbs, can be performed in healthy elderly with several active methods, the training of back muscles represents a more difficult challenge and, often, the presence of back pain or functional mobility impairments severely limits the possibility of active training, unless it is tutored by physiotherapists and clinicians [56]. Even more in several clinical conditions, where passive training represents the most suitable method to produce muscular exercise [57]. With this regard, it has been demonstrated the effectiveness of trunk extension strength in limiting the risk of fall [14], a major problem in elderly. Therefore, NMES training of back muscles can be adopted where core training, resistance training or balance training [58] are severely limited or impossible. Since the time course on mobility function in elderly due to NMES training varies across tasks [59], both in training

**Table 5** Statistical comparison of stabilometry and quadriceps strength

| | Eyes | RM $p\,(\eta^2_p)$ | RM×group $p\,(\eta^2_p)$ | Group $p\,(\eta^2_p)$ | Q+L $p$ | Q $p$ |
|---|---|---|---|---|---|---|
| PL | Open | 0.275 (0.131) | 0.150 (0.216) | 0.146 (0.220) | 0.247 | 0.992 |
| MPV | Open | 0.566 (0.038) | 0.121 (0.246) | 0.176 (0.193) | 0.372 | 0.871 |
| CEA | Open | 0.358 (0.095) | 0.073 (0.315) | 0.136 (0.229) | 0.188 | 0.877 |
| VarS | Open | 0.984 (0.000) | 0.102 (0.269) | 0.417 (0.074) | 0.549 | 0.632 |
| LDD | Open | 0.272 (0.132) | 0.149 (0.217) | 0.670 (0.021) | 0.244 | 0.992 |
| AP/ML | Open | 0.281 (0.128) | 0.366 (0.091) | 0.725 (0.014) | 0.447 | 0.999 |
| PL | Closed | 0.366 (0.091) | 0.258 (0.140) | 0.524 (0.047) | 0.424 | 0.998 |
| MPV | Closed | 0.493 (0.054) | 0.236 (0.152) | 0.630 (0.027) | 0.491 | 0.981 |
| CEA | Closed | 0.882 (0.003) | 0.275 (0.131) | 0.345 (0.099) | 0.875 | 0.810 |
| VarS | Closed | 0.083 (0.328) | 0.667 (0.024) | 0.554 (0.045) | 0.639 | 0.447 |
| LDD | Closed | 0.076 (0.308) | 0.260 (0.138) | 0.561 (0.039) | 0.152 | 0.947 |
| AP/ML | Closed | 0.220 (0.162) | 0.094 (0.280) | 0.593 (0.033) | 0.154 | 0.981 |
| RI of PL | N.A | 0.382 (0.086) | 0.754 (0.012) | 0.145 (0.220) | 0.795 | 0.977 |
| RI of MPV | N.A | 0.329 (0.106) | 0.861 (0.004) | 0.241 (0.149) | 0.805 | 0.937 |
| RI of CEA | N.A | 0.900 (0.002) | 0.492 (0.054) | 0.125 (0.242) | 0.971 | 0.938 |
| MVIC | N.A | 0.477 (0.058) | 0.889 (0.002) | 0.372 (0.089) | 0.969 | 0.930 |

For each parameter, repeated measures (RM)-ANOVA was used to test the intervention (RM: pre vs post)×group (quadriceps+lumbar paraspinal muscles vs quadriceps only) comparison. Partial $\eta^2$ ($\eta^2_p$) is reported as effect size. Post-hoc tests are reported for both groups

*Q+L* combined training (quadriceps+lumbar muscles), *Q* quadriceps training, *PL* path length, *MPV* mean path velocity, *CEA* confidence ellipse area, *VarS* variance of speed, *LDD* load distribution difference, *AP/ML* antero–posterior/medio–lateral ratio, *RI* Romberg Index, *MVIC* maximum voluntary isometric contraction of bilateral leg extension, *N.A.* not applicable

**Table 6** Additional statistics of the three stabilometric parameters chosen basing on previous evidence about reliability [42, 43]

| Eyes | Mean diff | | SE diff | | 90% CI | | Cohen's $d_{unb}$ | | $BF_{10}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q+L | Q | Q+L | Q | Q+L | Q | Q+L | Q | Q+L | Q |
| PL (mm) | | | | | | | | | | |
| O | 37 | −6 | 15 | 24 | 6 68 | −55 44 | 0.834 | −0.085 | 3.506 | 0.341 |
| C | 80 | −10 | 42 | 64 | −5 −165 | −145 126 | 0.653 | −0.054 | 2.113 | 0.360 |
| CEA (mm²) | | | | | | | | | | |
| O | 23 | −8 | 8 | 14 | 6 40 | −38 21 | 0.947 | −0.215 | 4.757 | 0.282 |
| C | 61 | −79 | 27 | 129 | 7 114 | −354 196 | 0.786 | −0.219 | 3.070 | 0.280 |
| LDD (%) | | | | | | | | | | |
| O | 2.6 | −0.4 | 1.5 | 0.9 | −0.5 5.7 | −2.4 1.6 | 0.583 | −0.150 | 1.726 | 0.308 |
| C | 3.7 | 0.9 | 1.4 | 1.8 | 0.8 6.5 | −3.1 4.9 | 0.897 | 0.176 | 4.162 | 0.580 |

Mean and standard error of differences (mean diff. and SE diff., respectively) are reported, along with 90% credible intervals (CI), effect size (Cohen's $d_{unb}$) and Bayes Factor ($BF_{10}$)

*Q+L* combined training group (quadriceps+lumbar muscles), *Q* quadriceps training group, *PL* path length, *CEA* confidence ellipse area, *LDD* load distribution difference

and detraining periods, the time course of postural adaptation due to NMES training shall be investigated with larger sample studies.

The study did not come without limits. Internal validity is threatened in this study, since the absence of control group. However, there were difficulties in recruiting a control group

where the contextual variables affecting static balance were identical to our experimental group, such as physical activity level, sight and vestibular function, anthropometry, previous injuries, wellness, and lifestyle habits. Former physical lifestyle history may have biased the results, even though it has demonstrated that former athletic activity history provides no protection for the age-related-onset postural impairment, whereas current activity does [60]. Positively, participants were not aware of the effect of NMES on the static balance nor they received any feedback about their results of stabilometry before the end of the study protocol. One strength of this study was that we carefully controlled historical events during the training period, which may have influenced the outcomes, such as sight or vestibular diseases, or osteo-muscular disorders. Moreover, an 8-week period alone unlikely affects static balance in healthy elderly. External validity may also have been threatened in this study due to the general intrinsic limit of NMES interventions involving its intensity, which is based on individual threshold comfort [19].

Finally, larger sample would allow to discriminate the effectiveness of training diverse muscle groups, solely or combined, compared to a control group, and the time course of adaptations; to extend the results of this study, a third group who train only lumbar paraspinal muscles, plus a fourth group as control should be included.

## Conclusions

Healthy elderly, substantially inactive, with unhealthy anthropometric status and spine morphology, non-sarcopenic, benefit from a NMES training applied on both quadriceps and lumbar paraspinal muscles. We demonstrated a more beneficial effect of the combined training (quadriceps and lumbar paraspinal muscles) in respect to the training applied on quadriceps only. This was possibly due to the effectiveness of NMES training for improving spinal stabilization. Therefore, passive training on lumbar paravertebral muscles can be a suitable method for positively affecting postural control in elderly. The possible beneficial effect in improving static balance, as found in this study, should be translated and verified in those clinical conditions where active training could not be performed to produce muscular exercise.

## Declarations

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