Muscle synergies and activation in Nordic walking compared with conventional walking

Table 1
Kinematics parameters for the two groups, ID and CO (statistical differences * $p < 0.05$).

Performance indices	ID	CO	p-Value
Duration [s]	6.27 ± 1.08	5.39 ± 0.73	0.020*
f [step/s]	3.85 ± 0.24	3.92 ± 0.35	0.399
ρ [−]	0.75 ± 0.07	0.85 ± 0.08	0.004*
μ [−]	69.26 ± 39.25	55.55 ± 9.16	0.229
σ [−]	−44.20 ± 9.96	−35.20 ± 3.72	0.008*
κ [−]	146.04 ± 18.17	128.12 ± 12.72	0.009*

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O38

FES-augmented treadmill training based on muscle synergies to improve locomotion in chronic stroke patients. A pilot randomized control trial

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Introduction: Functional Electrical Stimulation (FES) is a useful tool for the rehabilitation of post-stroke chronic patients [1]. In this study, during treadmill training, patients underwent a multi-channel FES treatment that leverages inertial sensors and muscle synergies to optimize the treatment by stimulating the impaired synergies exactly when they should have been recruited [2]. The aim of the current pilot work was to evaluate the efficacy of this treatment in improving gait in patients with chronic stroke.

Methods: Ten adult subjects with hemiparesis occurring more than 6 months after stroke underwent a three-week (12 sessions of 30 min each) gait training on treadmill. Patients were randomized into two groups: experimental (sex: 3 M and 2 F; age: 58.2 ± 6.6 years; Functional Independence Measure (FIM): 105.0 ± 10.4; Motricity Index paretic lower limb (MI): 52.6 ± 10.5) and control (sex: 4 M and 1 F; age: 53.8 ± 8.3; FIM: 120.6 ± 1.9; MI: 67.8 ± 12.5). For the experimental group, treadmill training was combined with a multi-channel synergy-based FES treatment [3]. At the beginning (T1) and at the end (T2) of the treatment, each participant was asked to perform 10 repetitions of the 10-meter Walking Test (10-m WT) while recording lower-limb kinematics (2 inertial sensors) and electromyography (9 muscles per side: Gluteus Maximum, Rectus Femoris, Vastus Medialis, Medial and Lateral Hamstrings, Medial Gastrocnemius, Soleus, Tibialis Anterior, Erector Spinae) [2]. The 4 synergies of rectilinear walking (weight acceptance, push off, trunk balance, leg deceleration) [3] were extracted and compared to those of healthy adults in terms of similarity.

Results: For all patients, treadmill speed was gradually increased during training and the final value was greater than the subject's overground self-selected speed. The main results are reported in Table 1 (mean ± strandard deviation values).

Table 1
Treatment results for the two groups.

	Experimental group	Control group
Training Gait Speed on treadmill (m/s) (T1)	0.48 ± 0.11	0.68 ± 0.05
Training Gait Speed on treadmill (m/s) (T2)	0.75 ± 0.12	0.94 ± 0.10
Gait Speed for 10-meter Walking Test (m/s) T1	0.61 ± 0.17	0.80 ± 0.15
Gait Speed for 10-meter Walking Test (m/s) T2	0.71 ± 0.17	0.83 ± 0.18
Weight Acceptance Similarity (T1)	0.58 ± 0.30	0.91 ± 0.04
Weight Acceptance Similarity (T2)	0.74 ± 0.11	0.91 ± 0.03

Discussion: Our results confirm the effectiveness of the intensive treadmill training in improving walking speed in chronic post-stroke patients. Such an improvement is larger when training is combined with FES treatment. Indeed, the average gait speed increase for patients in the experimental group was 0.1 m/s, compared to an increase of 0.03 m/s for the control group. The reported minimal clinically meaningful change for post-acute stroke patients in literature is 0.06 m/s [4], a value reasonably greater than the one for chronic patients. At the moment, we cannot exclude that the larger increase of gait speed in the experimental group may be partially due to the overall small sample size and the lower gait speed shown by the experimental group at T1, compared to the control one.

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O39

Muscle synergies and activation in Nordic walking compared with conventional walking

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Introduction: Nordic Walking (NW) has increased in popularity in the last decades as a form of exercise for health [1]. Additional benefits of Nordic Walking compared with traditional brisk walking (W) is due to the use of the poles that requires the engagement of upper body. While metabolic responses have been widely studied, upper body muscular involvement and complexity of the gesture compared with W should be investigated. The first aim of this study was to evaluate force exerted through the pole and level of muscle activation responses to NW. Moreover, we aimed to assess whether NW, nevertheless it included a poling action, and therefore an additional task with respect conventional walking, relies on the same muscle coordination of the latter.

Methods: Eleven NW instructors volunteered to execute NW and W at 5.5 km h^{-1} on a treadmill. Body segments kinematics, poling force, and electromyographic (EMG) signals from 15 muscles of upper and lower body were measured during locomotion. EMG signals were also acquired during maximal voluntary contractions (MVC) to normalize muscle activation during locomotion.

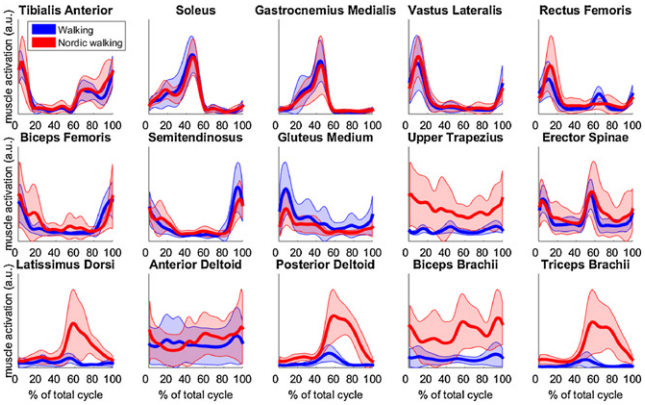

Fig. 1. Average and confidence intervals of muscle activations (envelopes) in NW and conventional walking.

Non-negative matrix factorization (NNMF) method was applied to EMG data to identify muscle synergies [2].

Results: Muscular activation of arm flexors (Anterior Deltoid, Biceps Brachii) and arm extensors (Latissumus Dorsii, Posterior Deltoid and Triceps Brachii) was found to be significantly higher for NW compared to W. In NW, muscular engagement was around 3% of MVC for arm flexors and 11–14% for arm extensors muscles. Both in W and NW, five muscle synergies were identified (accounting for more than 90% of EMG variance). The correlation coefficients between muscle weightings were high for all synergies (all $r \geq 0.87$) and furthermore, a good cross-reconstruction (accounting for $83 \pm 4\%$ of variance) was obtained when muscle synergies of NW were used to reconstruct the EMG data of conventional walking (Fig. 1).

Discussion: NW elicited upper body muscle engagement much more than conventional walking. We reported for the first time the muscle activations with respect to the MVC. Regarding muscle synergies, NW did not profoundly change the spatial organization of conventional walking. Thus, being based on the same coordinative pattern, NW can be performed by subjects with low motor skill and thus can be included in adapted physical activity programs.

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O40

Interaction forces and step synchronization during side-by-side walking with hand contact

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Introduction: Handholding can naturally occur between two walkers. When people walk side-by-side, either with or without hand contact, they often synchronize their steps [1,2]. Force interaction cues during walking may also be advantageous for postural stability (e.g., in infants, during unstable walking conditions, etc.), sport-training or physical rehabilitation. Relatively small interaction forces may communicate movement goals during cooperative physical interactions [3]. However, despite the importance of haptic interaction in general and the natural use of hand contact between humans during walking, few studies have investigated forces arising from physical interactions [3–5], as well as they were not quantified for walking. Such studies may also provide insights into the role of interaction forces in the dyad's ability to communicate and interpret intended motion during locomotion.

Methods: Eight pairs of adult subjects participated in this study. They walked on side-by-side treadmills at 4 km/h independently and with hand contact. Only hand contact-related sensory information was available for unintentional synchronization, while visual and auditory communication was blocked by obstructing peripheral visual feedback of another participant and using headphones that supplied white noise to block out sounds. The height of the partners was matched to limit the effect of different leg lengths. Subjects walked at their natural cadences. In separate trials, one partner in the dyad was instructed to follow a metronome (with a frequency that was 20% higher or lower that his/her natural cadence). The duration of trials was 1 min. Limb kinematics, hand contact 3D interaction forces and bilateral EMG activity of 10 upper limb muscles were recorded. Kinematics was recorded at 200 Hz by means of the Vicon system (Vicon, UK). Interaction forces and EMG activities were recorded at 1 kHz using a force/torque transducer (Nano 25, ATI Industrial Automation, Apex, NC, USA) and a wireless EMG System (Trigno, Delsys Inc., Boston, MA, USA), respectively. A gait synchronization index was calculated over 5-s intervals to quantify the timing of synchronization of the gait rhythms [1,2]. The total interaction force as well as its three components (in the reference frame determined by the subject's upper limb orientation) were analyzed.

Results: Overall, unintentional step frequency locking was observed during about 50% of time in 88% of pairs walking side-by-side with hand contact. When compared with an estimate of synchronization expected to occur by chance, synchronization of stepping was significantly greater, as it was also shown in previous studies for other sensory modalities [1,2]. On average, the amplitude of oscillations of the contact arm decreased while the contralateral (free) arm oscillated in the same way as during normal walking at 4 km/h. Interestingly, EMG activity of the shoulder muscles of the contact arm did not decrease despite substantial reduction of arm swinging. When the cadence of one partner was imposed to be higher or lower (by 20% using the metronome) than the natural cadence, only 10% of trials were synchronized. The amplitude of interaction forces and of trunk oscillations was similar for synchronized and non-synchronized steps, though the synchronized steps were characterized by significantly more regular (and thus more predictable) force interaction waveforms.

Discussion: Our results further support the notion that gait synchronization during natural walking is common, and that it may occur through interaction forces when two humans are in hand contact and audiovisual feedback is not available. Conservation of the proximal muscle activity of the contact (not oscillating) arm is consistent with neural coupling between cervical and lumbosacral pattern generation circuitries ('quadrupedal' arm-leg coordination) during human gait. Overall, the findings suggest that individuals might integrate force interaction cues to communicate and synchronize steps during walking.

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