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Abstracts presented within:

Oral Session 6 – Motor control

O35 - Reducing external perturbation proportionally to operator's wrist muscle co-contraction reduces tracking error and energy consumption

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INTRODUCTION

Many working activities require limb stiffening to stabilize interactions with the environment. An external device (i.e. exoskeleton) could generate the required stiffness, relieving the operator from muscle co-contraction to counteract instabilities [1]. This study tested, in terms of performance and energy consumption, the response when an external perturbation, whose amplitude is reduced proportionally to wrist muscle co-contraction, was applied during a tracking task.

METHODS

Nine subjects (age 27.7 ± 4.0), participated to the study, after signing informed consent. Subjects had their right hand and forearm connected to a haptic device (Hi5 [2]) allowing movement and generating torque at the wrist flexion/extension joint. Wrist angular position, torque and sEMG signal from Flexor Carpi Radialis (FCR) and Extensor Carpi Radialis (ECR) muscles were recorded. sEMG signals were normalized to the maximum voluntary co-contraction as in [2].

Subjects first exerted flexion and extension maximum voluntary torque. They were then instructed to move their wrist to track a target moving with a sinusoidal law (f = 0.23 Hz) whilst a sinusoidal torque perturbation (f = 3 Hz) was applied. Subjects performed the task in three conditions: (a) Baseline, (b) Assistive and (c) Control. The perturbation had (a) fixed amplitude during Baseline, (b) amplitude linearly decreasing with to the level of co-contraction (defined as the minimum between the normalized activations of FCR and ECR) in the Assistive condition. If the level of co-contraction was higher than 0.25 the amplitude of the perturbative torque was set to 0. (c) No perturbation was applied during Control. The tracking error was defined as the RMS of the difference between wrist and target angles. The energy consumption was defined as the sum of the squared FCR and the ECR signals. A Lilliefors test at 5% significance was performed to identified whether the tracking error and the energy consumption were normally distributed among the subjects. A paired t-test was applied to compare the tracking error and the energy consumption recorded during the Assistive condition, with the ones recorded during the Baseline and the Control conditions.

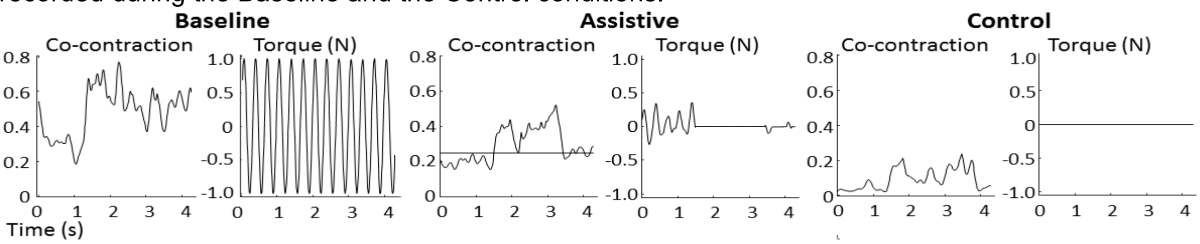

Figure 1. Examples of the level of co-contraction and torque perturbations. The line reported in the Assistive condition represents the boundary of 0.25 above which no torque were exerted.

RESULTS

The tracking error was calculated for all the conditions (Baseline: 7.16 ± 1.70°; Assistive: 3.63 ± 1.07°; Control: 3.24 ± 0.85°) together with the energy consumption (Baseline: 2.27 ± 0.10; Assistive: 1.13 ± 0.60; Control: 0.83 ± 0.93). The Lilliefors test identified that both the tracking error and the energy consumption were normally distributed among the subjects. The t-test showed that both tracking error and energy consumption, calculated during the Assistive condition had significantly different values with respect to Baseline (tracking error p-value: 0.001; energy consumption p-value: 0.012), but not respect with the Control condition (tracking error p-value: 0.294; energy consumption p-value: 0.428).

DISCUSSION

Subjects performed better and with a lower energy consumption in the Assistive condition. While further analyses are required for assessing the learning effect, these results suggest that an exoskeleton controlled by muscle co-contraction might be effective to reduce fatigue in workers during unstable manipulations.

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O36 - Modular motor control of the contralateral limb in trans-femoral amputees' gait

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INTRODUCTION

Muscle activity during walking is produced by the activation of a small set of motor modules [1]. The analysis of the composition and time activation profiles of such modules can help with the characterization of pathological gait. During the rehabilitation process, trans-femoral amputees (TF) adapt their walking pattern to their new physical conditions. Previous studies have shown that the most significant differences in muscle activity of both legs are present during the swing phase of the prosthetic limb [2]. In the present study, modular motor control strategies in TF gait are investigated.

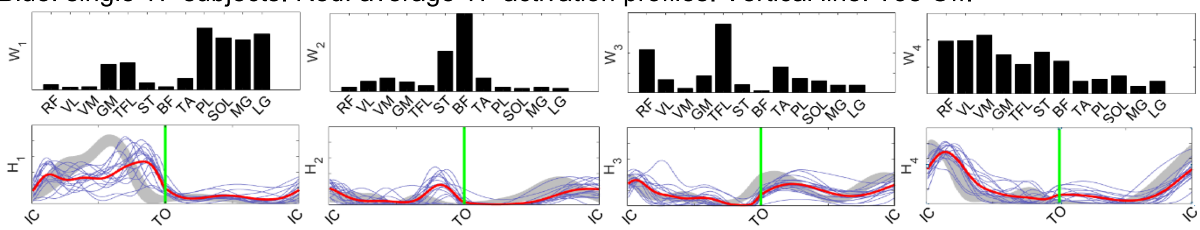
METHODS

Data were collected in a Movement Analysis Laboratory at the Rome branch of INAIL Prosthesis Centre. 8 healthy subjects (58.5 ± 12 years old) and 16 trans-femoral amputees (52.5 ± 15 years old, wearing different kinds of prostheses) participated in the study. sEMG data were recorded from 12 muscles of the sound limb. Kinematic data were recorded with a BTS SMART DX 6000 stereophotogrammetric system. The experiment consisted of 12 repetitions of walking along a 9m walkway at a comfortable self-selected walking speed. Muscle synergies were extracted by means of Non-Negative Matrix Factorization (NNMF), as to obtain synergy vectors W and synergy activation coefficients H.

RESULTS

Four modules were able to account for more than 90% of the variability in muscle activation for each subject. All four synergy vectors W have been found to be highly similar between the two populations (average normalized scalar product = 0.8), and modules extracted from TF amputees could well reconstruct muscle coordination of control subjects (through Non-Negative Reconstruction [3], applying NNMF with fixed synergy vectors). H1 and H2 were found significantly different in shape between populations, while all H coefficients showed a significantly delayed activation in TF.

Fig 1. Average synergy vectors W and H profiles, in arbitrary units. Grey: range of control subjects. Blue: single TF subjects. Red: average TF activation profiles. Vertical line: Toe Off.



DISCUSSION

Results suggest that both populations share the same set of synergies. The difference in the activation of W2 might indicate a compensation, by means of an increased hip extension moment, of the reduced propulsion force during the swing of the prosthetic leg. The prolonged activation of W1 might reflect an ankle stabilization mechanism during the swing phase of the prosthetic leg. Further investigations are needed to differentiate the effect of different types of prostheses and different elapsed time from the first prosthesis implant, in order to provide a quantitative indication for a proper choice of the prosthetic device and for the most adequate treatment.

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O37 - Towards performance indices for neuromuscular synergy in patients with intellectual disability

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INTRODUCTION
The diagnostic and statistical manual (DSM V) of mental disorders [1] emphasizes the need of using standard clinical methodologies to classify the impairment of patients with intellectual disability (ID) on their functional ability rather than on their intellectual quotient (IQ). Indeed, the ID often influences the motor component, resulting in poor muscular synergy and smoothness of movements. Despite the literature proposes the use of inertial sensors to evaluate kinematic parameters and smoothness of movements [2], there is no information available on adults with ID. This study aims at evaluating kinematics performance indices for smoothness movement in ID subjects by comparing their motor performances with respect to typically developed subjects (CO) of equal age.

METHODS
Twelve ID adults (age 36.92 ± 8.27; 3F, 9M) and twelve CO adults (age 36.17 ± 8.44; 3F, 9M) have been involved and classified based on their level of motor activity. To make the two groups homogeneous, three subgroups of four elements (1F, 3M) have been defined: agonists (membership of their respective federations), trained (regular training sessions, at least 3 days/week), unskilled (do not performing any activity). Subjects with other concomitant pathologies, with high level of disability and/or taking psychopharmacological drug, were excluded from this study. The participants were asked to perform as fast as possible a 30-m linear run test. During the experiments, photocells (Polifemo Light Radio, MicroGate) were used to accurately measure the duration of the test. A triaxial inertia sensor (G-Sensor, BTS) was used to record data. The sensor was placed in correspondence to the L5 vertebra, which approaches to the center of mass of the body. Spatial-temporal parameters as step frequency (f), velocity, step length over height ratio (ρ) [3] have been extracted. The following smoothness performances indices have been obtained: normal total jerk for the anterior/posterior linear movements (μ), total spectral arch length (σ) and log normal total jerk for the rotations around the vertical axis (κ) [4]. The differences between the groups and subgroups have been evaluated by one-way ANOVA and Tukey test ($p<0.05$), after verifying the homogeneity of the variance with the Levene's test.

RESULTS
The differences between the two groups have been evaluated through the p-value. Significant differences have emerged on the duration of the tests, on ρ, and on the parameters regarding the fluidity of the movements around the vertical axis (σ and κ). These differences are even more evident for the two trained subgroups. No significant difference emerged for the f and μ values.

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*

DISCUSSION
In this study, the ID subjects show a worse performance if compared to CO subjects, in terms of a lower step amplitude and a lower rotational smoothness around their vertical axis. The reason might be attributed to the reduced internal interrelations (afferent and efferent channel) of the praxia and of the neuromuscular postural synergies. Further developments will investigate the influence of performing experiments on paths with growing difficulty on these indices, eventually with the integration of electromyographic data.

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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 minutes 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. 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±4% of variance) was obtained when muscle synergies of NW were used to reconstruct the EMG data of conventional walking.

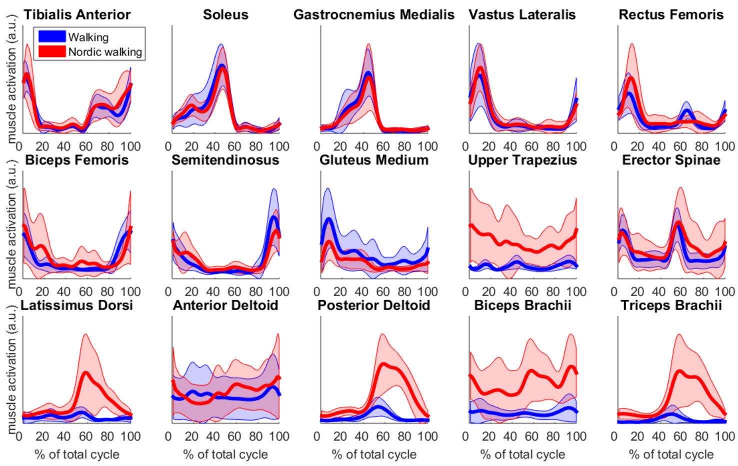

Figure 1.
Average and confidence intervals of muscle activations (envelopes) in NW and conventional walking.

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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