Bilateral features of the EMG patterns during walking in young and elderly people: preliminary study

V. Monaco, A. Ghionzoli, P. Dario and S. Micera

Abstract - **Neuroscientists have been testing the hypothesis that few muscle synergies manage the many degrees of freedom of the musculoskeletal system. Since ageing involves several modifications during locomotion, the authors hypothesized that muscle synergies in elderly people may provide outcomes concerning age-related muscle activation strategy. This work was aimed at highlighting the strategy yielding the bilateral muscle activations in young and elderly people, during walking at six different cadences (40, 60, 80, 100, 120 and 140 steps per minute). Five young and five elderly healthy men were involved in the experiments. EMG data regarding six bilaterlal pairs of muscles (Tibialis Anterior, Gastrocnemius Lateralis, Vastus Medialis, Rectus Femoris, Biceps Femoris, Soleus) were processed by Factor Analysis in order to extract primitive signals. Results showed that, although the counterparts had similar behaviour, ageing involved a more symmetrical distribution of the muscle activations on the primitive signals. Moreover, first and second factors were respectively loaded by plantar flexors and knee extensors in all the young and three elderly subjects whereas, two seniors were characterized by the opposite features. These findings may be in agreement with the age-related neuromuscular adaptation involving the change of the roles among the leg extensors during locomotion. Furthermore, the cognitive goal of the walking task, consisting in keeping the right cadence, may have required greater efforts in elderly people to modify their strategy during locomotion.**

I. INTRODUCTION

One of the common assumptions in gait analysis is that human walking can be considered a symmetrical motor task such that researchers have usually observed the behavior of one leg inferring general conclusions concerning, among the others, motor control behavior.

For instance, neuroscientists have been testing the hypothesis that the many degrees of freedom of the musculo-skeletal system are managed by a reduced number of primitive signals [1-3], sometimes called synergies [4]. This hypothesis would suggest that the Central Pattern Generator (CPG), if it exists, yields few signals which combined would provide the appropriate muscle patterns through the organization of muscle synergies [5-6]. Literature showed that the activation of a number of muscles between 12 and 18, measured only on one leg, can be described by 4 or 5 primitive signals [2, 5].

At the same time, several evidences have been provided concerning asymmetries during locomotion. In particular, Onunpuu and Winter [7], analyzing EMG data from both the legs, observed that symmetry in muscle activation can be not verified looking at an individual subjects. Arsenault and colleagues [8] also reported that, although a high correlation of the EMG profiles of soleus and rectus femoris between the two legs, lateral-related differences existed. Another study carried out by Sadeghi and colleagues [9] concluded that gait asymmetry in able-bodied subjects should be considered functional and should also be aimed at controlling the balance and the body movement.

As far as Electro Myographyc Signals (EMG) on both the legs are concerned, it has been showed that the bilateral control of the muscle activations can be described by synergies similar between the two legs [6], such that, from eight bilateral muscles, Olree and Vaughan [3] extracted five factors. Two bilateral couples were strongly correlated to each others describing the the propulsion phase and the loading response, whereas the fifth was related to the leg coordination, maintaining the phase shift between left and right sides. Authors [3] hypothesized that the CPG may consist of a spinal oscillating network, generating the primitive fundamental patters of human locomotion.

Note that all the carried out experiments involved healthy young subjects in order to provide evidences of CPG behavior in reducing the complexity of musculoskeletal system during locomotion.

To our knowledge nobody tried to verify whether factorization methods, analyzing different categories of subjects, provide different outcomes.

This study started from the assumptions that the SNC use a modular architecture of movements through wich generate muscular activations by suitable primitive signals managing the main subtasks involved in locomotion (e.g., loading response, propulsion, etc.) and generating functional asymmetries. The synergies leading to the entire set of muscle activations reflect plasticity of the brain in dealing with the balance control during different type of locomotion tasks as reported by literature [10].

The aim of this work was to compare bilateral muscle activations between young and elderly people. It had the two fold objective of understanding whether:

- ageing involves a greater bilateral coherence in muscles activation;
- elderly people can be characterized by different primitive signals than young.

In particular, it has been already showed [11] that elderly people have more consistent EMG patterns than young ones which was interpreted as a lack of neural plasticity. In our opinion, the age-related consistence of muscle activation could be highlighted, looking at bilateral muscles and it may reflect the neuromuscular adaptation due to ageing. Therefore, complementary to the hypothesis of lack of neural plasticity [11], we believe that it is possible to gather the same features in young and elderly people, even though they may describe each

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subtask in different ways.

I. Material and Methods

A. Subjects

Five young and five elderly health men, without any known fall or neuromuscular disease history participated at the study after providing informed consent. Table 1 summarizes anthropometric data and age. Unpaired t-test was carried out in order to verify the significance of the differences between anthropometric measurements.

Group	Young	Elders
Age [years]	24.4[1]± 2.3[2]	70.4± 5.3
Height [m]	1.76± 0.04	1.70± 0.06
Weight [Kg]	74.7± 21.3	75.0± 1.6
Leg Length [m]	0.82± 0.06	0.79± 0.07

Table 1: Anthropometric and age comparison; [1] average, [2] standard deviation.

B. Experimental setup and Protocol

Activity of six bilateral muscles, Tibialis Anterior, *TA*, Gastrocnemius Lateralis, *LG*, Vastus Medialis, *VM*, Rectus Femoris, *RF*, Biceps Femoris, *BF*, Soleus, *SOL*, was recorded on both the legs, by using superficial electromyography (NORAXON, Telemyo 2400T, V2). Electrodes were placed on the skin previously shaved, sample rate was 1000 Hz and gain of the amplifier was 1000. Subjects wore shoes provided by foot switches in order to record the heel strike for both the feet.

After electrode placement, subjects were asked to walk in a 15 m long room at the following different cadences ([steps/min]) beaten by a metronome: C_1=40, C_2=60, C_3=80, C_4=100, C_5=120, C_6=140. Compared with the previous works in which people were asked to walk at a selected speed [3], in the presented study, we decided to adopt cadence as a metric to make data comparable, because elderly people usually walk with faster cadence than young even though at the same speed [12]. The use of walking speed as metric could generate different muscle activations between the counterparts, due to the different frequency at which young and elderly people carried out the motor task. Trials were performed in a random order.

C. Data Analysis: preprocessing and factorization

For each subject and each trial, data regarding the first and the last three steps were not used, because these were related to the transitory phases. From the remaining steps (minimum 4 and maximum 12 steps) EMG records were fully rectified and low-pass filtered using a zero-lag Butterworth filter with a cut-off frequency of 15 Hz. For each gait cycle, data were time-interpolated over 200 points and the averaged values on the remaining steps were calculated. The pre-processing phase provided a matrix which dimensions were 200x12 for each subject and each trial. The rows were related to the gait cycle and columns were related to the muscles.

Each set of data was post-processed by using *Factor Analysis* (FA) according to literature [13]. Briefly, from each set of data, the eigenvalues of the covariance matrix were evaluated in order to individuate those whose greater than 1. The ones with value smaller than 1, usually considered as describing the noise, were discarded. Successively, from the same data set the *Principal Components,* related to the accounted eigenvalues, were extracted and rotated by using *varimax* criteria, obtaining the *factors*. The relationship between the initial data set and the *factors* can be represented by an algebraic linear transformation characterized by a weight matrix according to the Expression:

$$F_{rxk} = M_{rxc} \cdot W_{cxk} \quad (1)$$

in which M is the matrix of the initial data, r=200 and c=12 are its dimensions, W is the matrix of the weights, k (k<c) is the number of the eigenvalues chosen, and F is the matrix of the factors.

The variance accounted by each factors was analyzed for each group by using a two-way ANOVA, in which subjects and cadences were supposed to be the source of variability of the data set. The unpaired t-test was then used to compare the factor related variance between the groups. Significance was set to α=0.05.

All the numerical analyses were performed by using custom Matlab (The MathWorks, Inc. Natick, MA, USA) scripts.

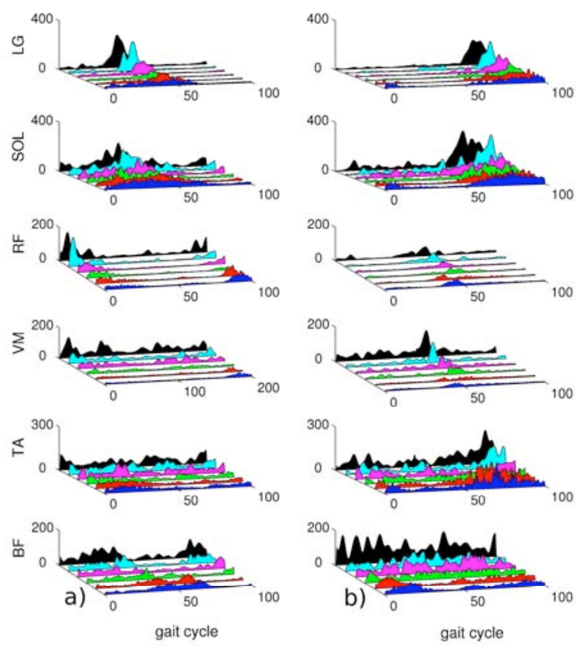

Figure 1: Representative EMG signals regarding right (a) and left (b) leg of a young subject walking at the different cadences (C1, blu; C2, red; C3, green; C4, magenta; C5, ciano; C6, black). Data are represented in according to right heel strike.

II. Results

Comparison between young and elderly people anthropometric measurements (Table 1) showed that there were not any statistical difference between the counterparts.

Muscle activations (Figure 1) were comparable with literature even though some discrepancy occurred looking at the single subjects [11], [14]. EMG amplitude increased with the cadence (Figure 1) also in agreement with previous published results [15].

According to the *eigenvalue>1* criteria, the amount of variability of the data set could be described by four factors at all the cadences, both in young and elderly people. On average, the first four factors accounted about the 85% of data variance (Figure 2).

For both groups, the ANOVA showed that the variability accounted by each factor did not significantly depend on the cadence, whereas it was different among the subjects. The comparison of the variability accounted by each factor did not provide any significant evidence of statistical differences between the counterparts (Figure 2).

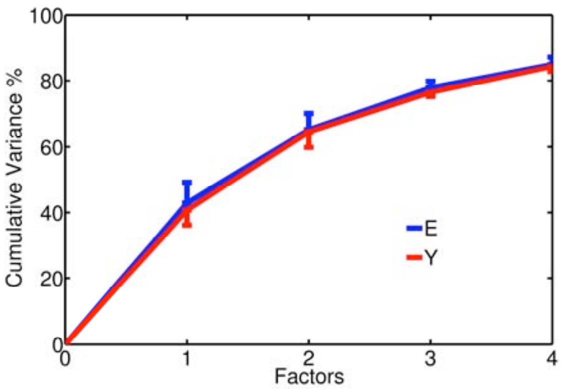

Figure 2: Cumulative variance % in elderly (E) and young (Y) people.

The matrix of weight coefficients (Figure 3) was characterized by a systematic distribution of the bilateral muscles meanly loading the factors 1 and 2 which accounted about the 65% of the whole variability, moreover each couple of muscles loaded one factor.

The factor 3 and 4 were loaded less systematically than the main two factors, providing less interpretable results above all in the elderly group. One important difference between the counterparts was in the muscles which loaded each factor. As showed in Figure 3, in elderly people the factor 1 was mainly loaded by knee extensors and the factor 2 was mainly loaded by the plantar flexors.

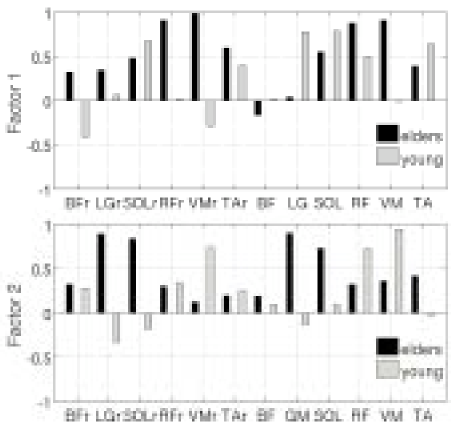

Figure 3: Representative comparison of the weight coefficients between young and elderly people related to the first two factors. Muscles labeled with "r" refer to the right leg and muscles without label refer to the left leg.

Conversely, first and second factor of young people were loaded respectively by plantar flexor and knee extensors.

Concerning symmetry, on average, the muscles loaded symmetrically factor 1 and 2 both in young and in elderly people. Nevertheless, elders' weight coefficients were more symmetrically distributed between the two legs, than in the young people. The figure 3 shows a comparison between young and elderly weight coefficients, in which the difference in the bilateral distribution of the weights is strongly evident.

Finally, looking at the score of the first two factors, calculated at all the cadences (Figure 4), results provided interesting features on age-related modifications in muscle activation. The factors of three elderly subjects behaved like in young people. Instead, in two elderly subjects the first factor assumed higher values across the heel strike (between the 90 and the 15% of the gait cycle) and the second factor assumed higher values close to the 50% of the gait cycle. This behavior was observed at all the cadences unless the slowest and the fastest ones. At these speeds, factors behaved in the opposite way (figure 4). On the other hand, the first factor of young subjects assumed higher values across the 45% of the gait cycle, while the second factor showed two peaks, one during the loading acceptance and the other one at the 60% of the gait cycle (figure 4). For young people this behavior characterized all the cadences.

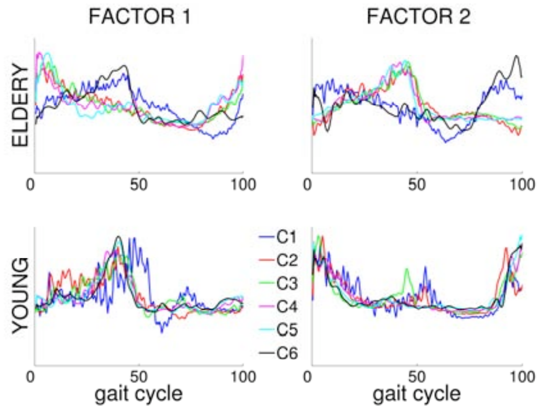

Figure 4: First two factors scores observed between two groups at different cadences. Elderly graphs refer to the two seniors behaving in different way to the others subjects.

III. Discussion

The aim of this work was to compare the bilateral muscle activation in young and elderly people providing evidences concerning symmetry and features of the age-related modifications in muscle activation. Results showed that both young and elders had similar behavior. Nevertheless, age-related modification of the factors occurred in two elderly subjects consisting in different set of muscles loading the first two factors. Moreover, factors were generally symmetrically loaded both in young and in elderly people, even though, in elders, there was a more consistent symmetry.

The main limit of the presented work was the small number of subjects involved in the experiments. Since the ageing increased the variability of the data set, our work will be considered as a preliminary study, and further investigations should be carried out in order to verify if really exists systematic differences between the counterparts.

Presented results supported the hypothesis concerning the existence of a subtle reduction of the complexity related to the muscle activation patterns by using fewer primitive signals. Moreover, derived factors were easily associable with the two sub functions *loading response* and *propulsive action* both looking at the weight coefficients (Figure 3) and observing the factor shapes (Figure 4). Nevertheless, cadence influenced the features of each factors above all in elderly people. In particular, for two elderly people in the intermediate range of cadences, the factor 1 had higher peaks across the heel strike, whereas, at C1 and C6, the factor 1 looked like being plantar flexor related. Conversely, the factor 2 in elderly people had opposite behavior than factor 1. In the young counterpart, factors 1 and 2 were similar to the results showed in literature [2], [5] and, in particular, it seemed to be respectively related to the propulsive action and the loading response at all the cadences.

The different behavior of the counterparts can be due to two mean reasons.

From one hand, it could depend on the neuromuscular adaptation due to ageing consisting in a different age-related role of proximal and distal extensors. De Vita and Hortobagyi [12] found that ageing causes a redistribution of the kinetics among the leg joints leading to an increased work of the proximal extensors, mainly at the hip joint. Sadeghi and colleagues [16], [17] showed that the main task of the knee is different between young and elderly people. In particular in young group knee was mainly dedicated to maintain balance and to propel the body, whereas in elderly people it was mainly used to guarrantee a stable locomotion. Speculating on these topics, in elderly people the role of the distal extensors during the locomotion may also be mainly related to the stabilization of the leg by stiffening the distal leg joints. In this way, the propulsive action could be provided by the proximal extensors which are characterized by a greater size, than the distal ones. This hypothesis may be in accordance with the well described, due to age related reduction in the performance of the calf muscles due to weakness [18], and the reduced amplitude of the action potential Hoffmann reflex [19]. In particular, the declined performance in ankle plantarflexor muscles, due to ageing, could be compensated requiring greater efforts of the proximal extensors, mainly providing propulsion, and smaller efforts at distal ones, mainly consisting in stiffening the leg.

From the other hand, the constrained cadence could involve a greater cognitive effort on seniors. In fact, literature showed that the attention demand of balance control changes depending on the complexity of a cognitive task performed during a motor task [20]. For instance, a cognitive task could reduce the variability of elderly step [21], reflecting a more conservative gait patterns. Literature showed that elderly people are, in fact, more affected than young people by the resource sharing due to the dual task [20] such that, in the presented results, elders may have adopted a strategy focused on the following beats modifying the motor patterns. In other words seniors may have paid greaterr attention in following the required cadence performing a less smooth motor task and, consecutively, using different muscle activation strategies than young. Further evidence, accounting step parameters, will be able to explore and validate this conclusions.

The slowest and the fastest cadences in two elderly subjects evidenced a different behavior, the first two factors behaving differently than at the intermediate speeds. In particular factor 1 was related to the propulsive action whereas factor 2 was related to the loading response. These results were not common in all the seniors, but they may suggest that elderly people could change strategies according to efforts required by the motor task. Nevertheless, an higher number of subjects in the experimental group and further gait related parameters could highlight more systematical features of age related modifications in the EMG patterns during walking tasks.

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