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Synergistic parameters of motor adaptation in variable resistance cycling activities

A. M. Pertusa, I. Vujaklija, R. M. Sánchez-Pérez, E. Iáñez, A. Costa and A. Úbeda

Abstract— **Muscle synergies are a promising assessment tool in motor rehabilitation. In this study, we propose a basic experimental framework with minimum instrumentation and experiment duration for the evaluation of muscle synergies that can be easily translated to clinical application. To that end, we analyze synergistic parameters in cycling activities under different force constraints by modifying the resistance level of a stationary bike. Results suggest that the contribution of specific motor primitives changes with resistance as a result of motor adaptation to greater physical effort. In addition, we observe changes in the contribution of the different muscular groups, particularly the muscles of the posterior chain. These are interesting findings that are likely to be altered in patients with pathological motor conditions and thus can potentially serve as clinical biomarkers.**

I. INTRODUCTION

Repetitive motor primitives have been related to the activation of different muscular groups during the performance of specific tasks. This suggests that the Central Nervous System (CNS) divides muscular activation in simple modules to command more complex tasks [1]. These modules are called muscle synergies. This approach is particularly visible in motor activities that require periodical contractions of different muscle groups such as walking or cycling [2]. The application of muscle synergies in the assessment of motor rehabilitation can be well characterized through the estimation of motor primitives [1], [3]. In this study, we have evaluated muscle synergies during cycling activities as cycling provides an ideal constrained scenario where muscle synergies can be accurately computed while changing specific parameters such as velocity, torque or cycling style. The analysis of muscle synergies in cycling under different biomechanical constraints has been evaluated previously [4], but its clinical application remains laboursome and is limited to a few studies [2]. This preliminary study aims at establishing a set of synergistic parameters of motor adaptation in a very simple protocol with minimum instrumentation and experiment duration. To obtain the potential set of biomarkers different force conditions are evaluated on a group of able-bodied participants by modifying the resistance level of a stationary bike. The main goal is to design an experimental framework that can be successfully translated to the clinical evaluation of pathological motor adaptation of stroke patients.

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II. MATERIAL AND METHODS

A. Experimental design

Ten subjects (5 female and 5 male, aged 21.9±0.4 years) participated in the experiments. Experiments took place at University of Alicante. Informed consent following the Declaration of Helsinki was signed by all participants. Subjects sat on a stationary bike with a knee angle of 145º under a maximum possible extension. Electromyographic (EMG) data was measured from four bipolar electrodes (Noraxon MiniDTS) placed on four different muscles of the dominant leg. The selected muscles were Vastus Lateralis (VLAT), Biceps Femoris (BF), Tibialis Anterior (TA) and Gastrocnemius Medialis (GAM). Kinematic information of the pedal stroke was measured with an inertial sensor placed at the axis of the pedals. Subjects were shown a graphical interface indicating the linear speed with a moving red dot that could be freely controlled in the vertical direction by increasing or decreasing speed. Subjects were asked to mantain a speed of 20 km/h on each trial across 5 different resistance levels: 1-No resistance, 2-Very low, 3-Low, 4-Medium, 5-High. These levels were selected from the levels provided by the bike (up to 8). The experiment was divided into two phases: warm up and cycling. For the warm up phase, level 1 was selected and subjects performed three 30-second trials at the fixed speed with resting periods of 5 seconds in between and a preparation period of ten seconds right before each trial (135 seconds in total). For the cycling phase, three 30-seconds trials per level were performed (from levels 2 to 5). Levels were randomized using the same timing protocol as in the warm up phase (540 seconds in total). The total time of the experiment was around 15 minutes.

B. Muscle synergies analysis

EMG data was segmented and averaged using the method described in [5]. After applying this process, the non-negative matrix factorization (NMF) method was used to extract the non-negative coefficient matrix (C) and the weight matrix (W) for each resistance level and subject. Three synergies were extracted for each condition (average Variance Accounted For (VAF) of 96.5%, with a threshold VAF of 95%). Two parameters were evaluated in relation to the increase of resistance level: the relative proportion of each synergy

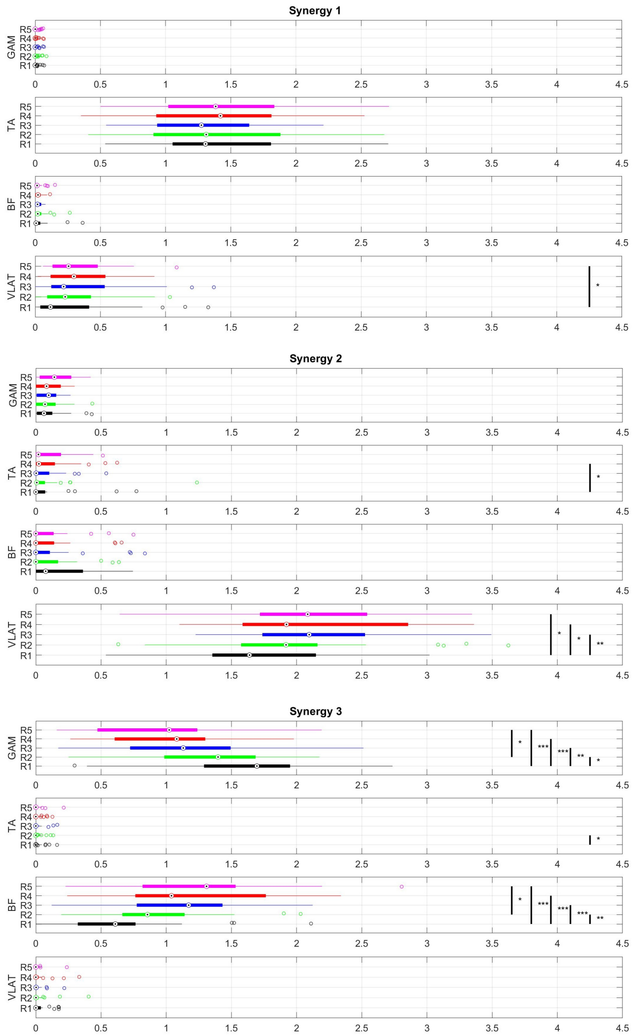

Fig. 1. Weight values of the contribution of the three different extracted synergies (circles represent outliers). Each graph shows the effects of the increase of resistance level for a distribution accross subjects (Significant differences: * p<0.05, ** p<0.01, *** p<0.001).

(in percentage) and the changes in behavior of the muscles (weight values). Paired tests across different resistance levels were computed for each of the parameters (Mann–Whitney U test).

III. RESULTS

Results showed a sequencial activation of the TA and the VLAT followed by the co-activation of the GAM and the BF. Figure 1 shows the change in weight values with the increase of resistance level. Synergy 1 remains stable, although VLAT slightly increases its activation (p<0.05). A similar behavior can be observed for synergy 2, with a greater increase of VLAT activity (p<0.05). More significant changes appear in synergy 3, where there is a clear exchange in the activity between GAM and BF with a rather significant increase in the weight of BF (p<0.001) and a similar significant decrease in the weight of GAM (p<0.001). Figure 2 shows the average contribution of each synergy for each different resistance

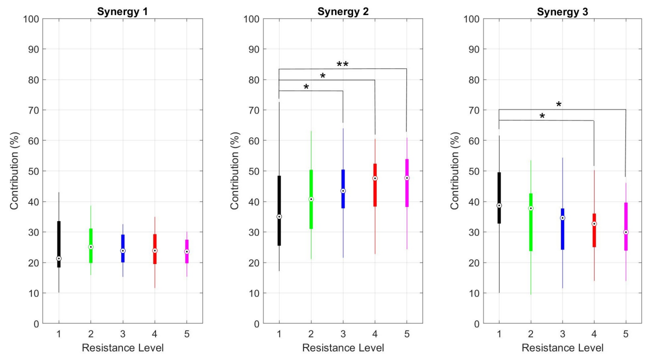

Fig. 2. Evolution of synergies contribution with the increase of resistance level (Significant differences: * p<0.05, ** p<0.01).

level. The first synergy is stable and stays in a range between 21% and 26% with no significant differences between levels (p>0.05). However, synergies 2 and 3 change in proportion with a significant increase of the contribution of synergy 2 from 35.01% to 47.70% (p<0.01) and a significant decrease of the contribution of synergy 3 from 38.68% to 29.93% (p<0.05).

IV. DISCUSSION AND CONCLUSION

Changes in muscle weights imply that for higher resistance levels, subjects readapt the recruitment of muscles of the posterior chain and increase the effort of BF muscle while decreasing activity on the GAM. An increase in the contribution of VLAT muscle is also observed together with a decrease in the combined contribution of GAM and BF. This is an interesting behavior that should be compared with pathological motor adaptation, for instance, in stroke patients, as very little analysis has been done on the behavior of muscle synergies and stroke during cycling activities. This study is limited by the small number of muscles measured as additional muscles could have influence in the synergies computation. However, the experimental framework presented in this study provides a good starting point to a successful clinical application to extract motor recovery biomarkers.

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