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Modifications in activation of lower limb muscles as a function of initial foot position in cycling

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ABSTRACT

Cyclic movements, such as walking/cycling, require the activity of spinal-circuits, the central-pattern-generators (CPG). To our knowledge little work has been done to investigate the activation of these circuits, e.g., the muscular and kinematic activity during cycling initiation. This study aims to detail the muscle output properties as a function of the initial lower limb-position using a simple cycling paradigm. Therefore, subjects were required to pedal on a cycle-ergometer in seated position starting at different-crank-angles (0–150°). Surface-electromyography was recorded from the *gluteus major* (GL), *vastus lateralis* (VL), and *gastrocnemius medialis* (GM), while crank position was recorded using a linear-encoder. *Gluteus major* peak-activity (PA) occurred at 65.0 ± 12.4° when starting with 0° initial crank position (ICP), while occurred maximally at 110.5 ± 2.9 when starting with 70° ICP. *Vastus lateralis* PA occurred at 40.7 ± 8.8° with 0° ICP, whereas with 70° ICP PA occurred at 103.4 ± 4.0°. Similarly, GM PA occurred at 112.0 ± 10.7° with 0° ICP, whereas with 70° ICP PA occurred at 142.5 ± 4.2° PA. *Gluteus major* and *gastrocnemius medialis* showed similar PA phase shifts, which may suggest they are controlled by same local circuitry, in agreement with their common spinal origin, i.e., motoneurons pool in S1–S2.

1. Introduction

Large efforts have been devoted to the identification of variables used by the brain to plan the sequence of motor contractions in a goal-directed task (Mutha et al., 2012). The central nervous system (CNS) modulates motor output on the basis of different elements. The initial joint position and the targeted final joint position are acknowledged as relevant elements (Kargo and Giszter, 2000). Moreover, further tuning of the motor output occurs based on the estimation of torque forces producible at various joint angles (Prodoehl et al., 2003; Sargeant et al., 1981) using two strategies: (i) prolonged agonist muscle activation, and (ii) a phase shift of peak activation of antagonist muscles (Prodoehl et al., 2003).

The short latency required for these adjustments suggests either the involvement of spinal-circuits or a pre-planned response initiated by supra-spinal structures including motor cortex and cerebellum (Jahn et al., 2008; Khan et al., 2007). The spinal or supraspinal origin of these adjustments is important, because their modifications could help the clinician to focus on which brain region is involved in a neurological condition. Moreover, this knowledge might help to envisage new neuro-feedback systems in the rehabilitation programs after spinal or supraspinal damages.

In this framework, it is now compelling to understand whether these predicted motor patterns apply to more complex movements such as multi-joint, rhythmic movements. In this case, it is plausible an interaction between spinal components (that prompt rhythmic patterns *via* central pattern generators) and supra-spinal components (which prompt movement initiation and coordination). There are evidences that even simple movements such as index-finger flexion spinal components are modified by supra-spinal control (Caronni and Cavallari, 2009) and that the supra-spinal control is drastically modified by the initial position of the limb (Dominici et al., 2005). In the presence of more complex, multi-joint, rhythmic movements such an interaction could be revealed by a phase shift of agonist muscle activation to optimize performance to a given kinematic outcome.

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The influence of joint position in multi-joint movements can be studied by constraining the trajectory of the limb such that it follows a specific, mono-planar path with constant velocity and amplitude. Though movements in normal conditions are never truly mono-planar, this model simplifies the analysis and makes it highly reproducible. A simple example of this type of movement includes the closed trajectory of the foot when pedalling a bicycle. During this pedalling movement, if workload and acceleration (from zero velocity) are maintained constant across the trials, the effect of the initial joint position can be investigated by manipulating the initial crankshaft position. In the present paper, we use this strategy to investigate the effect of the initial position of the foot (and therefore the muscle length) on the timing and amplitude of agonistic muscle activation. Specifically, the timing of muscle activation was investigated using the multi-muscle, multi-joint movement of pedalling. It was hypothesized that modifying the initial crank position would induce a phase shift in the peak of activation of agonist muscles, in order to obtain optimal torque production.

2. Methods

2.1. Subjects

Eight male volunteers novice to cycling (age 35.0 ± 4.2 yrs, height 177.0 ± 4.2 cm, weight 69.0 ± 4.1 kg and BMI 22.1 ± 1.5 kg m^{-2}) participated to the study. Novice cyclists were preferred to expert ones to gather results valid for study models different from cycling as well. Only male subjects were selected in the study to avoid possible influences of the menstrual cycle in females. Participants were healthy and had no musculoskeletal injury at the time of participation in the study. Participants were free of neurological injury or condition that would affect motor control. The study conformed to the Declaration of Helsinki and informed consent was obtained from all participants prior to participation in the study. The study was conformed to the local ethics committee guidelines.

2.2. Setup

The participants were asked to pedal on a spin cycle (Schwinn, Johnny G Pro Spin Bike, Chicago, IL, USA; with 17 cm crank length), while wearing low-heeled athletic shoes. Crank inclination was considered 0° when the crank was aligned with the vertical and clockwise rotation was considered positive. The pedal was connected to a linear encoder/surface electromyography integrated system (100 Hz, MuscleLab 4020e, Bosco System™, Langesund, Norway), which recorded the vertical displacement of the pedal, synchronized with the surface electromyography (sEMG) signals. The vertical displacement of the pedal was then converted into the angular position of the pedal as previously described (Padulo et al., 2012). The angular resolution of this set up was determined to be 0.03°.

Surface electromyography data were collected using pre-amplified tri-polar leads consisting in silver–silver chloride (Ag/AgCl) surface electrodes (diameter of 1 cm; inter-electrode distance 1.2 cm). The following muscles were analysed: *gluteus major* (GL), *vastus lateralis* (VL), *gastrocnemius medialis* (GM). The electrodes were positioned longitudinally with respect to the direction of the muscle fibres and located according to the recommendations of SENIAM (Hermens et al., 2000). Before electrode application the skin was shaved, abraded and cleansed with alcohol to reduce impedance. To prevent cable artefacts, cables were secured using elastic bands (Vetrap™, 3M, Rome, Italy).

2.3. Experimental procedure

Subjects were firstly asked to warm-up (2-min cycling at up to 100 W). Then, to analyse the effect of the initial position of the leg on sEMG activity, they performed starts at different crank angles (0–150°) in randomized order, with their dominant leg monitored. A start was defined as the participant beginning to cycle in a seated position on a stationary crank at a given initial crank position (ICP). Specifically, for each ICP, participants repeated four standing starts. Between trials, participants were asked to stop completely. Conditions to re-start were to rest for at least three minutes and participant's availability to re-start. The same load settings, equal to 0.075 kg (kg body mass)$^{-1}$, were used for all participants, which were asked to start pedalling as fast as possible (Hureau et al., 2014).

To minimize the variability intra- and inter-subjects of the EMG pattern, we adopted the two following procedures:

(i) We asked subjects to continue pedalling after the standing start, at freely chosen cadence, for a minimum of 10 consecutive pedalling cycles. This procedure was chosen to avoid a premature stop of the EMG output towards the end of the first cycle (in a pilot study we realized that, when required to perform only a single standing start, the subjects decrease the muscular activity very soon after the movement of the pedal, in a very unpredictable manner).
(ii) As an additional *criterium*, we analysed only trials during which the subsequent 10 pedalling cycles had a frequency range of 1.0 ± 0.1 Hz. Such a pedalling frequency range was chosen as it has been previously demonstrated to correspond to pedalling frequencies within 2 standard deviations from the average cycling pedalling frequency (Padulo et al., 2012). This selection ensured that the standing starts performed at an inadequate velocity have been eliminated.

Since the aim of the study was focused only on the initiation of the cyclical task, we did not actively control (e.g., with a metronome) for the rpm in the subsequent 10 pedalling cycles.

2.4. Data analysis

The filtered sEMG signal was sampled at 1500 Hz and band-pass filtered at 8–1200 Hz. The filtered sEMG signal was then rectified and smoothed converting it to its root mean square (RMS) with a 20-ms smoothing window as previously reported in the literature (Padulo et al., 2013a,b). Root mean square signal was then re-sampled at 100 Hz using a 16-bit A/D converter, and synchronized with the linear encoder used to determine the pedal position. Variables of interest included the crank-angle at which the peak activity of muscle occurred (degrees) and its sEMG amplitude (mV). Previous studies showed that during cycling, the sEMG signal of a muscle shows activation onset at specific crank angles followed by peak activation and residual activity ("tail" activity) until coming back to baseline (i.e., an offset) (Hug and Dorel, 2009; Li and Caldwell, 1998). Therefore, a potential problem when investigating a start is the differentiation between peak activity and tail activity, particularly when ICP occurs at crank angles greater than normal peak activation ones. Therefore, identification of the peak activation cannot rely simply on the greatest sEMG signal magnitude during the pedalling cycle. Additional criteria were used. Specifically, to be identified as peak value, sEMG activity was needed to be greater than a specific threshold, identified in this study as one standard deviation below all trials maximal sEMG value. Thus, when maximal sEMG amplitude was lower than that threshold, no peak was identified and trial was not considered for analysis.