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The postural control can be optimized by the first movement initiation condition encountered when submitted to muscle fatigue

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ABSTRACT

We investigated whether and how the movement initiation condition (IC) encountered during the early movements performed following focal muscle fatigue affects the postural control of discrete ballistic movements. For this purpose, subjects performed shoulder flexions in a standing posture at maximal velocity under two movement IC, i.e., in self-paced conditions and submitted to a Stroop-like task in which participants had to trigger fast shoulder flexions at the presentation of incongruent colors. Shoulder flexion kinematics, surface muscle activity of focal and postural muscles as well as center-of-pressure kinematics were recorded. The initial IC and the order in which subjects were submitted to these two conditions were varied within two separate experimental sessions. IC schedule was repeated before and after fatigue protocols involving shoulder flexors. The aim of this fatigue procedure was to affect acceleration-generating capacities of focal muscles. In such conditions, the postural muscle activity preceding and accompanying movement execution is expected to decrease. Following fatigue, when subjects initially moved in self-paced conditions, postural muscle activity decreased and scaled to the lower focal peak acceleration. This postural strategy then transferred to the Stroop-like task. In contrast, when subjects initially moved submitted to the Stroop-like task, postural muscle activity did not decrease and this transferred to self-paced movements. Regarding the center-of-pressure peak velocity, which is indicative of the efficiency of the postural actions generated in stabilizing posture, no difference appeared between the two sessions post-fatigue. This highlights an optimization of the postural actions when subjects first moved in self-paced conditions, smaller postural muscle activation levels resulting in similar postural consequences. In conclusion, the level of neuromuscular activity associated with the postural control is affected and can be optimized by the initial movement IC experienced post-fatigue. Beyond the fundamental contributions arising from these results, we point out potential applications for trainers and sports instructors.

1. Introduction

During training and competitions, athletes are confronted with a variety of temporal/cognitive constraints and, in addition, have to face the inevitable and progressive implementation of muscle fatigue. Training in conditions of muscle fatigue can also be intentional, the aim being to learn to respond to a barrage of motor situations regardless the muscular state. However, little is known on the effects of temporal and cognitive demands on motor control efficiency and adaptation processes during fatigue.

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Muscular fatigue, which arises from intense and/or repeated muscle contractions, is generally defined as a decreased muscular capacity to generate force (Gandevia, 2001), because of interrelated peripheral and central failures (Millet, 2011). When performing fatiguing activities, working muscles are less responsive to neural excitation because of fatigue-related biomechanical and metabolic changes. These peripheral modifications are sensed by free terminal endings of metabosensitive muscular receptors and result in increased discharge rate of thin sensory reafferent fibers, namely III and IV afferents. Integration of these afferents at a central level may lead to decreased spinal motoneuron outputs (Gandevia, 2001) and lower motor cortical outputs (Taylor, Petersen, Butler, & Gandevia, 2000).

In a motor control issue, these modifications are critical as they modify the relationship between motoneuron outputs and the muscular mechanical responses as compared to unfatigued conditions (Takahashi et al., 2006). That is, during a movement performed with the maximal current capacities (e.g. throw a javelin as far as possible), although motor intention can be similar, neural outputs will not produce the same mechanical performance post-fatigue. This mismatch is particularly critical during discrete ballistic movements during which no feedback can be used to correct movement parameters on-line, as this could lead to important motor errors and potentially to injuries (Côté, Raymond, Mathieu, Feldman, & Levin, 2005). In sports contexts, such discrete movements are frequently performed and generally require the involvement of postural components which are fundamental to the actions of the upper limbs. For instance, when hitting a forehand in tennis, an appropriate postural control is necessary to ensure balance maintenance and facilitate the energy transfer to the arm. The efficiency of these postural actions is especially dependent on postural actions preceding and accompanying the focal movement, namely anticipatory postural adjustments (APAs) and simultaneous postural adjustments (SPAs). APAs represent the predictive activation of postural muscles relative to a voluntary focal movement. They aim to compensate the mechanical effects of focal movements in a proactive fashion and have been shown to adapt to focal movement characteristics. For instance, during shoulder flexions, APAs scale to the focal movement peak acceleration with decreased amplitude at lower acceleration level (Bouisset, Richardson, & Zattara, 2000; De Wolf, Slijper, & Latash, 1998; Lee, Buchanan, & Rogers, 1987). Regarding SPAs, they intervene after APAs and represent the postural actions concomitant with focal movement execution. Contrary to APAs, they can be regulated based on feedback loops. They have a dual propulsive and stabilizing role and, similarly to APAs, adapt to focal movement velocity (Fourcade, Le Bozec, & Bouisset, 2016).

In previous works, we studied the central nervous system (CNS) capacity to anticipate the aforementioned mismatch between the generated motor commands and the mechanical output (Monjo & Forestier, 2014a, 2014b) during muscle fatigue. For this purpose, standing subjects performed focal movements (i.e., bilateral shoulder flexions) *at maximal velocity* before and after muscle fatigue was induced in the prime movers. The aim was to evaluate whether APAs would scale to the lower fatigue-induced peak acceleration. In a first experiment, subjects performed these movements in *self-paced conditions*, i.e., without reaction time (Monjo & Forestier, 2014b). In this initiation condition, APAs decreased during the very first movement post-fatigue and scaled to the lower acceleration. In a second experiment, subjects had to trigger their focal movement in *choice reaction time conditions* using a Stroop-like task (Monjo & Forestier, 2014a). More precisely, subjects had to perform with the shortest reaction time bilateral shoulder flexions or extensions at the presentation of incongruent and congruent color words, respectively. Following fatigue of the shoulder flexors, APAs associated with flexion movements were greater than expected from the lower peak acceleration and typically remained unchanged as compared to control trials. These results indicate that the initiation condition (IC) of a movement performed following fatigue can affect the postural control. Indeed, it appears that APA magnitude (and by extension the neuromuscular cost associated with APA execution) is influenced by the level of temporal and cognitive demands surrounding movement triggering.

Following these results, we found interesting to question the consequences of facing both IC during a particular fatigue session on potential adaptation and transfer processes. We especially sought to determine whether the initial IC experienced (Stroop-like task vs. self-paced) would affect the predictive postural strategies adopted when moving in the other IC. This issue is all the more interesting that predictive motor control is known to be affected by recent motor experiences. For example, during object manipulation tasks in which object properties vary in a trial by trial fashion, anticipated grip force is directly modulated as a function of the previously experienced objects (Witney, Vetter, & Wolpert, 2001). In this study, participants performed movements in the two previously presented IC, i.e., in self-paced conditions and submitted to a Stroop-like task. The reason for using this task is that it approximates sports situations during which individuals have to decide which movement to perform based on a visual analysis of environmental variables. The initial IC and the order in which the IC were presented to subjects varied within two separate experimental sessions.

The primary aim was to evaluate whether and how the first IC experienced post-fatigue affects the feedforward postural control over the subsequent movements performed in the other condition. As in previous works (Monjo & Forestier, 2014a, 2014b), we expected to observe different postural responses as a function of the IC. We also hypothesized that the postural behavior adopted during the initial condition experienced would transfer to the other movement condition. More precisely, we expected to observe no APA adaptation if subjects were first to be exposed to the Stroop-like task with a transfer to the subsequent self-paced movements. In contrast, we predicted that APAs would decrease and adapt to focal movement intensity if subjects were first to move in a self-paced manner and that this would transfer to the Stroop-like task. In addition to APAs, SPA analyses were carried out to quantify the global level of neuromuscular activity associated with the postural control under these different experimental conditions.

2. Methods

2.1. Participants

This study included fifteen volunteer healthy young adults [eleven males and four females, age, 22.7 ± 0.5 years; height, 1.75 ± 0.03 m; mass, 71.4 ± 2.8 kg (mean ± SEM)] from the physical education department of the Savoie Mont-Blanc University.