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DIFFERENT PROACTIVE AND REACTIVE ACTION CONTROL IN FENCERS' AND BOXERS' BRAIN

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Abstract—Practicing sport at top level requires excellent physical and cognitive skills. The goal of the present study was to investigate whether specific sport practice may affect the preparation–perception–action stages of processing during a visuo-motor task requiring perceptual discrimination and fast response. We recruited 39 participants (two groups of professional fencers and boxers, and a control group; *N* = 13 for each group) and measured behavioral performance and event-related potentials (ERPs) while performing a go/no-go task. Results revealed that athletes were faster than controls, while fencers were more accurate than boxers. ERP analysis revealed that motor preparation, indexed by the Bereitschaftspotential (BP), was increased in athletes than controls, whereas the top-down attentional control, reflected by the prefrontal negativity (pN) component, was enhanced only in fencers when compared to controls. Most of the post-stimulus ERPs *i.e.* the N1, the N2, the P3, and the pP2, were enhanced in fencers. Combat sports require fast action execution, but the preparatory brain activity might differ according to the specific practice required by each discipline. Boxers might afford to commit more errors (as reflected by high commission error (CE) rate and by a small pN amplitude), while fencers have to be as much fast and accurate as possible (thanks to an enhanced pN amplitude). Although the possible influence of repetitive head blows on cerebral activity cannot be excluded in boxers, our results suggest that cognitive benefits of high-level sport practice might also be transferred to the daily (i.e., no sport-related) activities.

Key words: decision-making, motor behavior, sport, exercise performance, ERP.

INTRODUCTION

The effects of motor experience on cognitive functions have received growing attention in the field of both sport science and neuroscience. Cognitive functions of frontal lobes, like proactive anticipatory processing, inhibitory control, decision-making skills and conflict solving can benefit from sport practice and long-term sport-related training (see Voss et al., 2010 for a review), suggesting a relationship between motor training and cognitive performance especially on executive functions. Investigating whether expertise in a particular sport discipline affects the performance during general cognitive tasks could be very useful to understand the cognitive processes influenced by sport practice outside of the sport context. Shedding light into the relationship between sports and cognitive functions might have implications for athletic programs and physical education. Indeed, if the practice of a specific sport correlates with higher cognitive ability more than others, then coaches, physical educators and public health may encourage specific activities especially in adolescents and in populations with cognitive deficits or elderly.

It has been previously shown that elite athletes perform cognitive tasks requiring problem solving, motor planning and decision-making with higher proficiency than non-athletes (e.g. Vestberg et al., 2012). According to the cognitive skill transfer theory (Taatgen, 2013), increased performance in top-level athletes during no-sport-related cognitive tasks might be justified by the "broad transfer" hypothesis. Accordingly, extensive practice of specific skills (such as sport-related skills) improves individual components of cognition that are also present outside the specific sport context (Furley and Memmert, 2011), as in the case of improvements on laboratory response time tests after video game training (Green et al., 2010). Since response time (RT) represents a temporal aspect of the information-processing efficiency (e.g. Massaro, 1989), it has been also used as an indirect index of sport expertise (e.g. Williams and Walmsley, 2000; Wang et al., 2005). Although behavioral studies are useful to reveal the performance advantages in athletes, they lack the possibility to explore the cerebral mechanisms that make expert performance "superior". Using electrophysiological measures with high temporal resolution, such as event-related potentials (ERPs), during laboratory cognitive tasks, it is possible to draw conclusions about brain activity that might account for the behavioral performance.

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Abbreviations: ANOVA, analysis of variance; BP, Bereitschaftspotential; CE, commission errors; ERPs, event-related potentials; ICV, intra-individual coefficient of variation; iFg, inferior frontal gyrus; IPAQ, International Physical Activity Questionnaire; MRCP, movement-related cortical potentials; OM, omission errors; pN, prefrontal negativity; RT, response time; SAT, speed-accuracy tradeoff; SD, standard deviation; SMA, supplementary motor area.

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Previous ERP studies in athletes (e.g. Nakamoto and Mori, 2008; Taddei et al., 2012) suggested that long-term training for sports requiring fast reactions to the continually changing environment might promote several neurocognitive processes, such as: (1) enhanced visuospatial attention, as reflected by modulation of the P1 component (Delpont et al., 1991); (2) improved visuodiscriminative attention, as reflected by increased N1 amplitude (Di Russo et al., 2006); (3) efficient inhibitory control (Di Russo et al., 2006; Zhang et al., 2015) reflected by larger N2 amplitudes, although this component has also been associated to conflict monitoring processes (Donkers and van Böxtel, 2004) and, more recently, to motor preparation activity (Di Russo et al., 2016); (4) better task-oriented attention, indexed by increased P3 amplitude (Hamon and Seri, 1989; Polich and Lardon, 1997), and better efficiency in elaboration processes, indexed by earlier P3 peak latency (Rossi et al., 1992).

The go/no-go paradigm is a well-studied perceptual discriminative task that involves many cognitive processes, such as motor preparation (Rinkenauer et al., 2004; Berchicci et al., 2012), sensory evidence accumulation (Burle et al., 2004; Perea et al., 2010), decision-making (Schall, 2001; Heekeren et al., 2008), proactive and reactive inhibition (Aron et al., 2004; Aron, 2011) and behavioral execution. Although lots of studies did use either visual or auditory go/no-go tasks to demonstrate improved performance in professional athletes (e.g. Kida et al., 2005; Fontani et al., 2006; Nakamoto and Mori, 2008), only few were conducted with ERP measures (Radlo et al., 2001; Di Russo et al., 2006, 2010; Di Russo and Spinelli, 2010; Taddei et al., 2012; Zhang et al., 2015). However, the aforementioned studies mainly focused on the cerebral activities associated with sensory perception and action-monitoring processes, that is, the stage of processing that follows stimulus presentation, neglecting the investigation of the preparatory pre-stimulus stage. Moreover, previous electrophysiological studies demonstrated the improved premotor preparation in athletes, but they did not adopt the go/no-go paradigm: for example, in a sport-related task (Del Percio et al., 2008), fencers and karatekas showed differences in movement-related cortical potentials (MRCP) compared to non-athletes, elite table tennis players exhibited an increase in the amplitude of the readiness potential (RP) during performance of a Posner-style attention task (Hung et al., 2004), elite rifle shooters exhibited a reduction in MRCP compared to non-athletes during a self-paced finger movement (Di Russo et al., 2005).

The novelty of the present study is the investigation of both pre- and post-stimulus ERPs in athletes while performing a visual go/no-go task. This method allows investigating not only reactive sensory-motor processes, but also proactive motor preparation and cognitive anticipation (Perri et al., 2014; Berchicci et al., 2015; Di Russo et al., 2016; Lucci et al., 2016).

Indeed, according to the dual-mechanism of control theory (see, Braver, 2012), individuals can engage in either proactive or reactive modes of cognitive control: proactive control relies on anticipation and prevention of interferences before the presentation of a critical event, whereas reactive control is implemented after the stimulus presentation. In combat sports both proactive and reactive controls are determinant, because these athletes have to prevent hasty actions, but they also have to react as fast as possible to unexpected events. In fencing, action control is critical in order to shoot a thrust and at the same time avoid to be touched; in boxing, action control is important for delivering punches at the most appropriate time, trying to avoid to be punched back. A study on pre-attentive mechanisms preceding action execution in boxing (Ottoboni et al., 2015) found that boxers were influenced by unrelated task information concerning boxing stimuli compared to non-athletes. However, the authors adopted a task with sport-related stimuli, where the individual expertise does account for the observed effects on performance.

Since the go/no-go paradigm represents a suitable laboratory task to test discrimination ability, we selected professional athletes (i.e. boxers and fencers) belonging to the open-skill class of sports (externally paced, see Singer, 2000) where the environment is unpredictable and constantly changing, requiring adaptability and quick decision making in response to external cues. Boxers and fencers often have to execute extremely fast responses while dealing with cues or "fakes" intended to misdirect their attention. Thus, it is likely that one main feature of these athletes is the anticipation ability: the more they prevent in advance the more they succeed. Since action preparation requires the interaction between motor and prefrontal areas (e.g. Lu et al., 1994), we expect that during the preparation phase of a discriminative motor task, athletes with high experience in proactive-sport skills might reveal advantages in behavioral performance that may be accompanied by electrophysiological differences in those brain areas.

To test this hypothesis, we considered two brain activities preceding the stimulus onset, that is, the *Bereitschaftspotential* (BP) and the *prefrontal negativity* (pN). The BP is a well-known slow negative wave representing motor readiness and preparation in premotor cortex as the supplementary motor area (SMA) (e.g. Shibasaki and Hallett, 2006); enhanced premotor activity was previously associated with the response speed (Sangals et al., 2002; Band et al., 2003) and, more relevant for the present study, the BP was positively correlated with the response speed in a go/no-go task (Perri et al., 2014). The pN, whose source was localized in the inferior frontal gyrus (iFg) (Di Russo et al., 2016), has been recently described in go/no-go tasks (Berchicci et al., 2012); this negative slow wave, concomitant to the BP and bilaterally distributed on prefrontal sites, was associated with cognitive preparation during execution of discriminative response tasks. It was suggested that the larger the pN, the more attentional resources are involved (Berchicci et al., 2012, 2014; Perri et al., 2015), and this anticipatory negative component was also associated with proactive inhibition (Perri et al., 2016) and top-down control (Perri et al., 2015) on task execution.