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Exercise-induced arousal affects free-choices to inhibit

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ABSTRACT

Objectives: Previous research has demonstrated that exercise–induced arousal has the ability to improve the stopping of an already initiated response. So far the effects of arousal on response inhibition have been investigated with paradigms concerned with inhibition driven by external stimuli. Since in everyday life situations the origin of decisions to inhibit might be entirely internally driven, the present study aims to explore whether intentional action and inhibition responses depend on the physical exertion in a cycle ergometer test.

Design and method: While cycling in conditions of low and high exercise-induced arousal, participants were asked to respond to cued and free-choice targets following the presentation of three varieties of masked primes that could elicit congruent or incongruent prime-response conflicts.

Results: In condition of high exercise-induced arousal an improvement on reaction times was observed in both cued and free-choice action conditions and less omission errors in cued action trials. Concerning free-choice behavior, overall participants made more 'action' choices when compared to the low arousal condition.

Conclusions: Our results widen previous evidence by showing that as for externally driven cognitive processes, also intentional action and inhibition choices are modulated by exercise. Under specific conditions arousal helps individuals to perform the tasks rapidly and efficiently even when task' requirements are entirely internally driven. However higher-order processes, such as making a free-choice, resulted impaired.

1. Introduction

Response inhibition is generally considered a prominent sub-component of cognitive control which is part of executive functions (Bari & Robbins, 2013; Veen & Carter, 2006). Such higher-order supervisory and executive system has the ability to withhold lower-order behavioral impulses preventing responses that might lead to inappropriate or even dangerous outcomes. 'Go/No-go' and 'Stop Signal' tasks (SST) are frequently adopted to investigate inhibition (van den Wildenberg et al., 2010). These tasks require participants to stop an ongoing behavior in response to an external stimulus.

One of the questions attracting the interest of those working in this research field is whether modulating the level of arousal could influence higher-level cognitive functions such as response inhibition. For instance, Weinbach, Kalanthroff, Avnit, and Henik (2015) included an alerting cue (i.e., an irrelevant stimulus) in a SST to increase participants' level of arousal for a short period of time. Interestingly, the increase of the arousal induced by the alerting cue reduced reactions times (RT) to go stimuli on one hand and shortened the stop-signal reaction times (SSRT; which is a measure of efficacy of the inhibitory processes) on the other, indicating an improvement in response inhibition. In the authors' perspective, the results highlight the role of basic, lower-level mechanisms in modulating complex, higher-level cognitive processes such as inhibitory control to produce well-coordinated action (Weinbach et al., 2015).

Along the same lines it has been advanced that exercise–induced arousal has selective effects on cognitive processing. Exercise appears to facilitate certain aspects of processing such as response speed and accuracy and to enhance the processes involved in problem-solving and goal-oriented actions (Chang, Labban, Gapin, & Etnier, 2012; Tomporowski, 2003). Accordingly, a study by Chu, Alderman, Wei, and Chang (2015) tested the effects of acute exercise on the inhibitory aspect of executive function using behavioral and electrophysiological approaches. To examine the effects of exercise-induced arousal on motor response inhibition, college students underwent a SST following acute aerobic exercise. The level of exercise was determined via the

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submaximal treadmill walking test (SSTWT) carried out prior to behavioral testing. A sedentary control session, that involved reading, was also included. The main findings from this study suggest that acute exercise results in a shorter SSRT, but does not alter the go RT (Chu et al., 2015).

Overall, the aforementioned studies suggest that exercise-induced arousal has the ability to improve cognitive functions such as response inhibition. Much of the existing work examining the association of exercise and cognitive functions derives from 'arousal theories' (e.g., Hockey, 1997; Kahneman, 1973; Sanders, 1983; Yerkes & Dodson, 1908). The common denominator of these theories is the function assigned to arousal in facilitating the allocation of metabolic resources and attentional focus in order to meet the specific task demands (Audiffren, Tomporowski, & Zagrodnik, 2008). In particular, exercise would stimulate the arousal system in the brainstem, disinhibiting the production of neurotransmitters such as norepinephrine and dopamine thus improving the quality of task's execution by enhancing speed and accuracy (Robbins & Everitt, 1995). The gradual metabolic recovery and the higher level of arousal occurring after exercise facilitate cognitive processing (Audiffren et al., 2008; Tomporowski, 2003). Although a general positive effect on cognitive performances tested after exercise is well established, for cognitive performances tested during exercise a different explanation has been recently proposed. The transient hypofrontality theory (THT) posits that during exercise, higher-order computations of prefrontal cortices and the actual motor implementation compete for the allocation of limited metabolic resources (Dietrich, 2003, 2006). Since cognitive processing is set to a lower priority during exercise, available resources are drawn from the brain regions that are not essential to perform the exercise, provoking a decline in complex mental processing. However, cognitive performances that rely on more automatic brain processes (e.g., reaction times, response accuracy, stimulus detection) would be enhanced due to a downregulation of the frontal cortex and consequent disinhibition of the arousal networks in the brainstem. Depending on the different moderators that are taken into account (e.g., type of cognitive performance, fitness level, task duration), mixed finding are reported for cognitive abilities tested during exercise. In this respect, some results support the THT (Lambourne & Tomporowski, 2010) whereas others (Chang et al., 2012) do not.

So far, the effects of arousal on response inhibition have been investigated with paradigms concerned with inhibition driven by external stimuli (Logan & Cowan, 1984; Verbruggen & Logan, 2008). However, a recent line of research has proposed that along with inhibition driven by an external stimulus, a more intentional mechanism might be recruited to withhold from executing a pre-potent action tendency (Brass & Haggard, 2007; Filevich, Kühn, & Haggard, 2012). The so-called 'intentional inhibition' has been tested by means of specifically tailored experiments in which participants were free to decide whether to execute or inhibit a particular behavior (Kuhn, Gevers, & Brass, 2009). In this view, the term 'intentional inhibition' captures the process of deciding between intentionally performing and intentionally inhibiting a prepared action, up until the very last moment (Brass & Haggard, 2007, 2008; Filevich et al., 2012). Intentional inhibition has been conceptualized as a late veto before action execution, a final check that recruits cortical mechanisms partially distinguishable from those characterizing stimulus-driven inhibition (Kühn, Haggard, & Brass, 2009).

An attempt to behaviorally operationalize intentional inhibition comes from a study of Parkinson and Haggard (2014). This work was based on the notion that subliminal perceptual priming can manipulate the subjective experience of the agency of a "free" action (Aarts, Custers, & Wegner, 2005; Sato, 2009; Sebanz & Lackner, 2007; Wenke, Fleming, & Haggard, 2010) and influence a "free" decision regarding which action to select (Schlaghecken & Eimer, 2004; Teuchies et al., 2016). In this modified version of the Go/No-go task, participants made speeded key-press actions to a go target or withheld responses to a no-go target or made free, spontaneous choices whether to execute or inhibit a keypress when presented with a free-choice target. Prior to each target, subliminal masked prime arrows were presented. Primes could be congruent with the go or no-go arrows, or neutral. RTs and proportion of action choices were measured. Primes were presented at latencies that would give either positive or negative compatibility effects based on previous literature. Crucially, results showed that when go primes were presented at negative-compatibility latencies, "free" decisions to inhibit significantly increased (Parkinson & Haggard, 2014). Thus, it appeared that decisions to act or not can be unconsciously manipulated, at least by inhibitory mechanisms. The cognitive mechanisms responsible for intentional inhibition can be influenced by unconscious processing.

The present study capitalized on this paradigm to investigate whether arousal had the ability to modulate intentional inhibition as previously reported for external kind of inhibition (Chu et al., 2015; Weinbach et al., 2015). In particular, participants were required to respond to three possible target stimuli (arrows) in three different conditions: (i) cued action condition, in which the choice to act is indicated by a cue (cued go targets); (ii) cued inhibition condition, in which the choice not to act is indicated by a cue (cued no-go targets); or (iii) free-choice condition, in which participants were free to choose whether to act or not (free-choice targets). The targets were preceded by masked primes (arrows), whose direction could be congruent or incongruent with the go and no-go target (i.e., pointing to the same or the opposite direction) or neutral (i.e., pointing toward no specific direction). By asking participants to perform the task while pedaling on a cycle ergometer, the paradigm was administered at a different level of workload intensities with the specific purpose of eliciting different levels of exercise–induced arousal.

In line with previous evidence (Parkinson & Haggard, 2014), RTs to cued go targets are expected to be speeded up by congruent prime/target combinations and slowed down by incongruent prime/target combinations. The same pattern should characterize action trials in free-choice conditions. Consistently, in cued conditions a higher proportion of errors is hypothesized (omissions and false alarms) for incongruent prime/target combinations compared to congruent prime/target combinations. Moreover, go primes are expected to increase the proportion of free-choices to act, and no-go primes to increase the proportion of free-choices to inhibit the action, if compared to neutral primes. The effects of arousal are predicted to be twofold. On the one side arousal would modulate low-level processing enhancing RTs and accuracy. On the other side, according to the THT (Dietrich, 2003, 2006), free-choice performance should be disrupted by the arousal manipulation due to an impairment of high-level executive functions responsible for the decisional and attentional processing. Likewise, this is expected to boost the effect of subliminal primes. RTs of cued and free-choice trials would be shortened in the high arousal condition when compared to the low arousal condition. Further, the pattern induced by subliminal priming is expected to be consistent between low and high arousal conditions, namely faster RTs after a go prime and slower RTs after a no-go prime. In line with previous evidence, higher arousal is predicted to improve response accuracy reducing the number of errors in cued conditions (omissions and false alarms). With respect to the proportion of choices to act or to inhibit in free-choice trials a general increase of choices to act in high arousal condition is expected, due to enhanced impulsiveness and disinhibition in the decisional processes involved by the task. Although improved accuracy in cued trials is expected in the high arousal condition, when no specific control is required (i.e., in free-choice trials where there are no right or wrong responses) priming might affect responses differently. For this reason the impulsiveness and disinhibition of attentional resources elicited by the high arousal condition is expected to produce a stronger effect of the subliminal priming on the proportion of free-choices: go primes would increase the proportion of actions and no-go primes would increase the proportion of inhibition choices more for the high compared