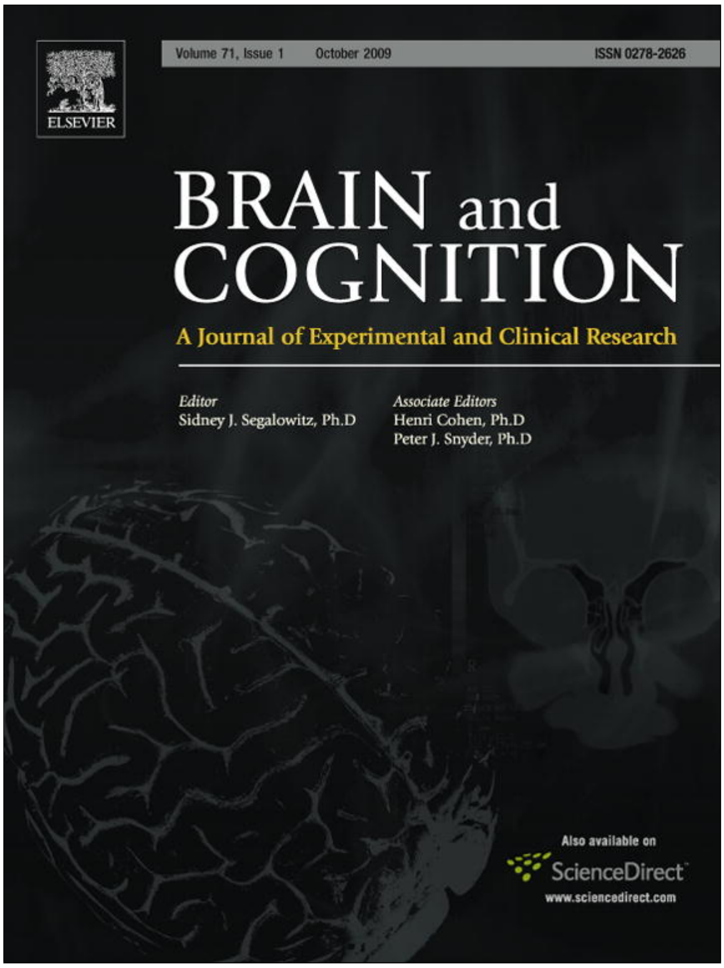
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# The time course effect of moderate intensity exercise on response execution and response inhibition

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ABSTRACT

This research aimed to investigate the time course effect of a moderate steady-state exercise session on response execution and response inhibition using a stop-task paradigm. Ten participants performed a stop-signal task whilst cycling at a carefully controlled workload intensity (40% of maximal aerobic power), immediately following exercise and 30 min after exercise cessation. Results showed that moderate exercise enhances a subjects' ability to execute responses under time pressure (shorter Go reaction time, RT without a change in accuracy) but also enhances a subjects' ability to withhold ongoing motor responses (shorter stop-signal RT). The present outcomes reveal that the beneficial effect of exercise is neither limited to motor response tasks, nor to cognitive tasks performed during exercise. Beneficial effects of exercise remain present on both response execution and response inhibition performance for up to 52 min after exercise cessation.



## 1. Introduction

The idea that physical exercise confers a number of health benefits dates back at least as far as the fourth or fifth centuries BC (Buckworth & Dishman, 2002). In the framework of experimental cognitive psychology, the effect of exercise on cognitive performances has been studied using a wide variety of cognitive tasks and many physiological interventions during the last 20 years (for a reviews, see Tomporowski, 2003; Tomporowski & Ellis, 1986). However, despite extensive investigation in this area, results relating to the influence of exercise on cognitive functioning have been highly inconsistent with some researchers reporting that exercise has no effect on cognition (Collardeau, Brisswalter, & Audiffren, 2001; Lemmink & Visscher, 2005; McMorris & Graydon, 2000), and others suggesting a facilitative effect of exercise on certain aspects of cognition (Davranche, Audiffren, & Denjean, 2006; Kashihara & Nakahara, 2005; Tomporowski, 2003). Regrettably, the diversity of the protocols employed has contributed to the inconsistent findings, and has not facilitated the synthesis of results. However, this inconsistency emphasises the necessity to use a rigorous methodology to highlight any effect of exercise on specific aspects of cognition. Several reviews have explored the association between exercise and cognitive performance. An early review by Tomporowski and Ellis (1986) failed to find empirical support for a positive relationship between participation in physical activity and cognitive performance, whilst, more recently a review conducted by Tomporowski (2003), concluded that sub-maximal aerobic exercise of a duration between 20 and 60 min can facilitate aspects of information processing both during and following exercise. However, extended periods of exertion, which lead to dehydration, generally have a degrading effect on cognitive performance, highlighting the importance of the type of exercise protocol used.

### 1.1. Cognitive performances during exercise

When the cognitive task is performed concomitantly with exercise, the literature now recognises a fragile but consistent positive effect of moderate exercise and suggests that either perceptual, decisional and motor information processing stages are altered (e.g., Chmura, Krysztofiak, Ziemba, Nazar, & Kaciuba-Uścilko, 1998; Davranche & Audiffren, 2004; Davranche, Burle, Audiffren, & Hasbroucq, 2005; Davranche, Burle, Audiffren, & Hasbroucq, 2006; McMorris & Graydon, 1996; Yagi, Coburn, Estes, & Arruda, 1999). However, even if an effect of exercise on basic cognitive processes (simple reaction time and choice reaction time) is now well documented (for reviews, see McMorris & Graydon, 2000; Tomporowski, 2003), the effect of exercise on higher-cognitive processes such as cognitive control requires further consideration.

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For example, Colcombe and Kramer's (2003) meta-analysis supports the idea that exercise selectively and preferentially benefits tasks that require executive control, whereas, Dietrich and Sparling (2004) highlighted a selective impairment on prefrontal-dependent cognitive tasks during exercise of 70–80% maximal HR. Though the research on exercise and executive control tasks is still in its infancy, several studies (Coles & Tomporowski, 2008; Davranche & McMorris, 2007; Dietrich & Sparling, 2004; Joyce, 2008; Pontifex & Hillman, 2007) that have examined a wide range of executive functioning tasks have considerably advanced our understanding of the effect of moderate acute exercise on these higher-cognitive processes, and results suggest that cognitive processes are differently sensitive to the effect of exercise, which it seems is specific rather than general (Davranche & McMorris, 2009).

A limited number of studies have assessed the effect of acute exercise on higher-cognitive functions whilst exercising and at the moment results are somewhat equivocal. For example, Pesce, Capranica, Tessitore, and Figura (2003) and Pesce, Tessitore, Casella, Pirritano, and Capranica (2007) found an improvement in performances on discriminative reaction time (RT) tasks requiring attentional orientation and cognitive flexibility during sub-maximal exercise, whilst, Pontifex and Hillman (2007) found that moderate aerobic exercise reduced response accuracy for incongruent trials of an Eriksen flanker task, compared to rest. This task requires a great amount of executive control, and the authors concluded that the attentional effort required during exercise may lead to inefficient allocation of neural resources, which leads to poorer interference control on the task. These results support the idea that a decline in performance on executive control tasks during exercise will occur as a result of the competition for available resources imposed by a dual-task environment (Dietrich & Sparling, 2004).

Therefore, the first aim of this study was to attempt to clarify the effect of a dual-task environment on a specific aspect of cognitive control. Cognitive control can be described as the ability to behave in accord with rules, goals, or intentions, even when this runs counter to reflexive or otherwise highly compelling competing responses (Rougier, Noelle, Brave, Cohen, & O'Reilly, 2005). The cognitive task employed in this study specifically measures response inhibition, which is considered as a prerequisite for adaptive and goal directed behaviour. It is described as the ability to withhold and interrupt ongoing or planned actions in response to sudden changes in the environment (van den Wildenberg et al., 2006). The stop-signal task which provides a direct behavioural assessment of the efficiency of both response execution and response inhibition, is the most widely used and appropriate task for this purpose (van den Wildenberg et al., 2006), and was therefore, employed in this study. As participants are invited to abort any motor response when they detect a stop-signal, the manipulation of response inhibition in the present study also provides the opportunity to consider whether the beneficial effect of exercise is limited to motor response tasks.

### 1.2. Time course effect after exercise cessation

Despite the widespread implications of a potential benefit in areas such as aviation, military life, competitive sports or academic endeavours, very few researchers have attempted to examine the time course effect of exercise on cognitive functioning. Heckler and Croce (1992) investigated speed and accuracy of mathematical problem solving immediately, 5 min and 15 min after a 20-min and a 40-min run at 55% of maximal oxygen uptake ($VO_2$ max). Results showed that, regardless of the fitness level, participants' cognitive performance remained heightened 15 min after exercise cessation. Kashihara and Nakahara (2005) have also explored the duration of the potential cognitive enhancement after 10 min cycling at lactate threshold intensity using a 20-min CRT task. Results highlighted a beneficial effect over the initial 8 min after exercise cessation, followed by a gradual return to baseline performance. The second aim of this study was to explore further the time course over which exercise affects specific aspects of cognitive functions (i.e., response execution and response inhibition). To this aim, the stop-signal task was performed using a specific design which allowed us to track the effects of exercise during, immediately after and 30 min after exercise cessation.

To sum up, the main purpose of this study was to attempt to clarify the effect of an acute exercise simultaneously performed with a complex cognitive task and to assess the time course of this effect after exercise cessation. To this aim, a stop-signal task, requiring a general response inhibition, was performed whilst cycling but also after exercise (just after until 52 min after exercise cessation) during the same study. Given that the stop-signal task provides a direct behavioural assessment of the efficiency of both response execution and response inhibition, the second aim of this study was to determine whether the beneficial effect of exercise could be observed during cognitive tasks which do not require motor components.

## 2. Method

### 2.1. Participants

Before taking part in the experiment, all participants (seven men and three women) were fully informed about the protocol and signed written consent forms. All participants were university students, but had no previous exposure to cognitive testing. Participants had medical histories free from neurological problems and were not under medication. This experiment was approved by the local ethics committee.

### 2.2. Procedure

Participants were required to report to the laboratory for testing on four separate sessions. As the tests could be influenced by circadian rhythms, testing for each participant was carried out at the same time of day as their previous session.

### 2.3. Preliminary protocols

The experiment began with two preliminary sessions which served (i) to individually determine the exercise workload for the following exercise session and (ii) to reach a stable level of performance on the cognitive task in order to minimise potential learning effects. The first session consisted of a continuous incremental protocol until volitional exhaustion on a cycle ergometer (Lode Excalibur, Netherlands). After a 5-min warm-up at 75 W, the workload progressively increased until exhaustion (25 W/min for males and 15 W/min for females). The pedal rate and heart rate were continuously recorded and participants were verbally encouraged to achieve their maximal level. During the last minutes of the test, 1-min collections of expired gases were collected in Douglas bags (Plysu Protection Systems Limited, Milton Keynes, UK). The expired fractions of oxygen (FEO2) and carbon dioxide (FECO2) were recorded using calibrated gas analysers (Series 1400 gas analyser, Servomex, Crowborough, UK), volumes were measured (Harvard dry gas metre, Harvard Apparatus Ltd., Edenbridge, UK) and volumes of oxygen ($VO_2$) were calculated. The maximal aerobic power (MAP) reached during the last 15 s of this maximal effort test served to determine the individual exercise workload (i.e., 40% of MAP). Participants' anthropometrical and physiological characteristics are presented in Table 1.

**Table 1**
Participants' anthropometrical and physiological characteristics.

| Variables | Mean ± SD | | |
|---|---|---|---|
| | All | Female | Male |
| Sample size | 10 | 3 | 7 |
| Age (years) | 23 ± 2 | 23 ± 1 | 23 ± 2 |
| Height (cm) | 175 ± 9 | 163 ± 2 | 180 ± 3 |
| Weight (kg) | 73 ± 6 | 67 ± 5 | 75 ± 6 |
| HR baseline (bpm) | 69 ± 10 | 71 ± 9 | 67 ± 10 |
| HR max (bpm) | 193 ± 7 | 195 ± 10 | 192 ± 7 |
| $VO_2$ max (ml/kg/min) | 43 ± 5 | 37 ± 5 | 46 ± 2 |

The second session consisted of a familiarisation session on the stop-signal task during which participants were required to complete six blocks of 104 trials (three blocks performed at rest and three blocks whilst cycling).

### 2.4. Apparatus and design

During the following two sessions (exercise and rest), participants were required to complete three sets of five blocks of the stop-signal task. During the first set, participants sat on the cycle ergometer (Lode Excalibur, Netherlands), equipped with soft padding supports to comfortably support their arms, opposite a computer screen placed 1 m in front of him/her. Two response keys were fixed on the right and left handles of the ergometer's handlebar. For the duration of the second and third sets, the participant was provided with hand held response keys and the stop-task was carried out sitting on a chair 1 m away from the computer screen.

During the exercise session, the first set consisting of five blocks of 104 trials was performed whilst cycling after a 4-min warm-up period. A 1 min 'cognitive rest' interval was given between each block during which participants continued to cycle. At the end of the first set, 4 min additional cycling was performed to bring the total cycling time to 30 min for each participant. Immediately after exercise cessation, participants dismounted the ergometer, sat on a comfortable chair and the second set of trials was administered. At the end of the second set, an approximate 8-min resting period was given until 30 min had elapsed since exercise cessation. Then, the third set was performed (see Fig. 1). The same procedure was followed for the rest session with the exception that during the first set of blocks the participant was seated on the cycle ergometer without cycling. The order of exercise and rest was counter-balanced across subjects.

It should be noted that the first block of each set, used to stabilize the staircase-tracking algorithm, was considered as practice and was systematically discarded from the subsequent analyses. The staircase-tracking algorithm was used to dynamically adjust the timing of the stop-signal (or stop-signal delay, SSD) in such a way that, overall, inhibition would succeed in about half of the stop trials. This dynamic tracking was based on the outcome of the previous stop trial and separate tracking was used for the left and the right hands. The initial SSD started at 200 ms and varied from ±50 ms according to the success of the preceding stop trial. When the SSD duration was short, the stop-signal was presented straight after the response signal and the response was quite easy to withhold. On the contrary, when the SSD duration was longer, the stop-signal was presented later after the response signal and the response was difficult or impossible to withhold. According to Band, van der Molen, and Logan (2003), an inhibition success rate of 50% allows for the accurate estimation of the stop-signal reaction time (SSRT) based on the "horse-race model". Performance on the stop-signal task has been conceptualised as being dependent on the outcome of a race between go and stopping processes (Logan, 1981). During the go-signal trials, participants go through several stages of information processing. They must firstly recognise the stimulus, make a response choice and then prepare and execute the motor response. However, during the stop-signal trials participants must detect the stop signal and then abort the pre-planned motor response. If the go process wins the "race" then the motor response will be executed, however, if the stopping process is victorious then the participant will successfully inhibit the pre-planned response (for a more detailed review, see Logan, & Cowan, 1984). The "horse-race" is a very useful tool for estimating SSRT, because it can measure an internally generated inhibitory process regardless of the fact that no overt behaviour occurs during successful inhibitions (van den Wildenberg et al., 2006).

### 2.5. Stop-signal task

In the stop-signal task, participants are required to respond as quickly and as accurately as possible by pressing a left or a right key according to the direction of a left- or right-pointing green arrow (go trials) which appears on a computer screen. Each trial began with the presentation of a white square, which acted as a fixation point. After a randomised fore-period duration (1250 ms, 1375 ms, 1500 ms, 1625 ms or 1750 ms), a green arrow was presented and the participant had to respond according to the direction indicated by the arrow (go trials). On 30% of the trials the arrow changed from green to red upon which the response should be withheld (stop trials). If a response was not given within 1 s, the stimulus disappeared and the next trial began.

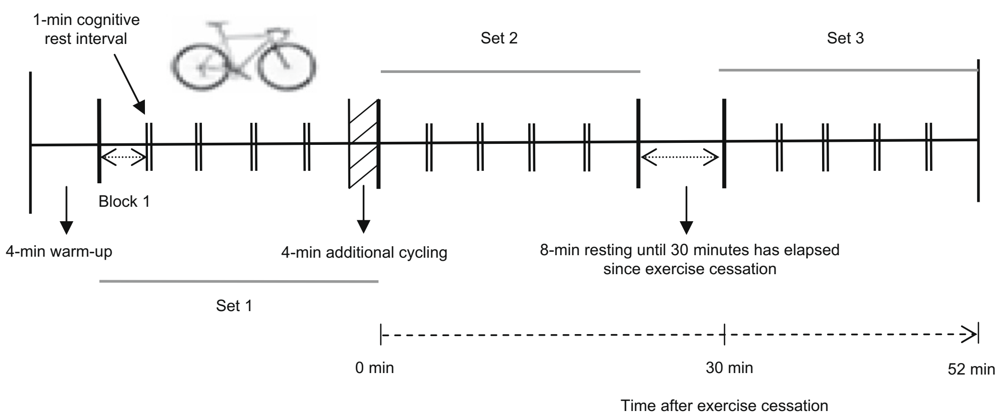


**Fig. 1.** Time course of the stop-signal task during the exercise session.

### 2.6. Data analysis

The first four trials of each block, considered as warm-up trials, were discarded from the statistical analysis as well as the decision error trials. Response execution was assessed using the mean RT from the go trials and the accuracy of responses (percentage of decision error). Response inhibition was estimated using the percentage of successful inhibit (SI) trials and the stop-signal reaction time (SSRT), which was computed using the "horse-race" model as suggested by Logan and Cowan (1984) (for details see, van den Wildenberg et al., 2006). Separated repeated measures analyse of variance (ANOVA) were carried out for each period of time (Set 1, Set 2 and Set 3) with session (rest and exercise) and block (B1, B2, B3 and B4) as within-subject factors to evaluate the time course effect of exercise through each period of time. Greenhouse–Geisser degree of freedom correction was applied. Newman–Keuls post-hoc tests were performed on each significant interaction and on main effects when necessary. Because the number of trials did not allow estimation of the effect of exercise on response inhibition block by block, the arcsine transforms of SI trials percentage and mean SSRT were submitted to one-way ANOVAs with session (rest and exercise) as within-subject factors for each period (Set 1, Set 2 and Set 3). Planned comparisons were conducted on the effect of exercise for each set. Effect sizes were calculated using partial Eta square ($\eta_p^2$). Significance was set at $p < .05$ for all analyses. All error bars on the figures represent standard errors of the mean.

## 3. Results

The means and the standard deviation of RT, SSRT, percentages of error and SI trials are presented in Table 2 for each session according to the time periods.

### 3.1. Errors

Decision error corresponding to incorrect overt responses occurred in 1.23% and anticipation responses (RT < 200 ms) occurred in 0.45% of the total number of the go-signal trials. The percentage of decision error did not differ as a function of the session, nor as a function of time period and there was no interaction between the two factors (*Fs* < 1). Thus, the response execution improvement observed during exercise could not be explained by a speed-accuracy trade-off. Decision error trials and anticipation responses were excluded from further analyses.

### 3.2. Response execution

Separate ANOVAs carried out on each period of time showed a significant session × block interaction during the first set ($F(1.62,14.59) = 4.18$, $p < .05$, $\eta_p^2 = .32$). Newman–Keuls analysis revealed that 17 min 30 s after the beginning of the cycling task, exercise shortened RT (fourth block: −32 ms, $p < .05$) and this beneficial effect obtained whilst exercising was maintained until the end of the set (fifth block: −55 ms, $p < .001$) (Fig. 2). Furthermore,

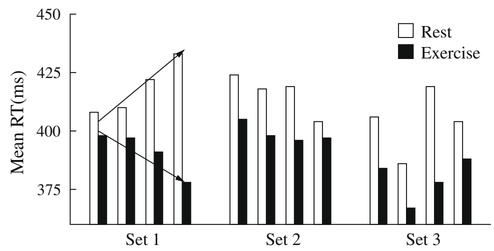


**Fig. 2.** Mean reaction time (RT in ms) block by block during rest (white bars) and exercise (black bars) sessions as a function of the period of time.

there was a difference in the evolution of the response performance through the first set. As suggested by Fig. 2, the polynomial contrast analysis confirmed a linear–linear interaction ($F(1,9) = 5.77$, $p < .05$, $\eta_p^2 = .39$). The slope indicates that performances are impaired during the rest session and enhanced during the exercise session. No significant effect was observed immediately following exercise. However, 30 min after exercise cessation analysis revealed a significant main effect of exercise ($F(1,9) = 5.37$, $p < .05$, $\eta_p^2 = .37$) indicating that the benefits observed during exercise were still effective after the recovery period. As indicated by a non significant interaction between the exercise and block ($F(1.55,13.97) = 0.71$, $p = .47$, $\eta_p^2 = .07$), the beneficial effect of exercise on response execution was of the same magnitude for the four blocks of trials which respectively, begun 34 min 30 s, 39 min, 43 min 30 s at 48 min after exercise cessation.

### 3.3. Response inhibition

The ANOVA carried out on the percentage of SI trials confirmed that participants were able to withhold 50% of the stop trials (±2.46%, ranging from 40% to 55%). The percentage of the SI trials did not differ as a function of the session ($F < 1$), nor as a function of time period ($F(1.16,10.42) = 1.52$, $p > .05$, $\eta_p^2 = .14$) and there was no interaction between the two factors ($F < 1$).

Analysis of mean SSRT analysis revealed that exercise improved the speed of response inhibition ($F(1,9) = 11.10$, $p < .01$, $\eta_p^2 = .55$) (Fig. 3). The beneficial effect of exercise on response inhibition was of the same magnitude for the three sets (Table 2), as indicated by a non significant interaction ($F < 1$).

## 4. Discussion

The purpose of this study was to test the effects of acute steady-state moderate intensity exercise on response execution and response inhibition using a stop-signal task, and to investigate the time course over which exercise influences these specific aspects of cognitive control. The main findings of this experiment were that exercise enhances subjects' ability to execute responses under time pressure (shorter Go RT) and to inhibit responses to stop-signals (shorter SSRT). Moreover, results also suggest that beneficial

**Table 2**
Means go-signal RT (Go RT in ms), means stop-signal RT (SSRT in ms), error percentages, successful inhibit (SI) trial percentages, and standard deviations as a function of experimental session (Exercise vs. Rest) per period of time (Set 1, Set 2 and Set 3).

| Period of time | Experimental session | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Exercise | | | | Rest | | | | Effect size | |
| | Go RT | SSRT | Error (%) | SI (%) | Go RT | SSRT | Error (%) | SI (%) | Go RT | SSRT |
| Set 1 | 391 ± 54 | 184 ± 22 | 1 ± 1.1 | 50 ± 1 | 418 ± 78 | 196 ± 31 | 1.2 ± 1.4 | 51 ± 2 | –28 | −11 |
| Set 2 | 399 ± 55 | 192 ± 21 | 1.4 ± 1.4 | 50 ± 1 | 416 ± 77 | 202 ± 25 | 1.2 ± 1.3 | 50 ± 2 | –17 | −10 |
| Set 3 | 379 ± 52 | 192 ± 38 | 1.5 ± 1.5 | 51 ± 2 | 404 ± 65 | 202 ± 25 | 1.5 ± 1.4 | 49 ± 3 | –24 | −10 |

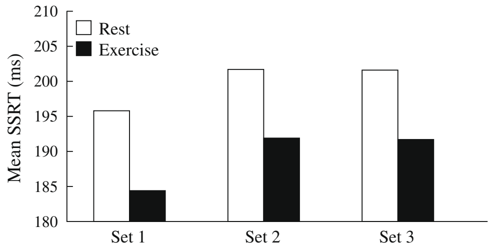


**Fig. 3.** Mean stop-signal reaction time (SSRT in ms) during rest (white bars) and exercise (black bars) sessions as a function of the period of time.

effects can still be observed on cognitive performances for up to 52 min after exercise cessation.

### *4.1. Cognitive performances during exercise*

As expected, current results showed that moderate exercise improves response execution speed and confirmed the beneficial effect already widely observed in simple and choice RT paradigms (for reviews, see McMorris & Graydon, 2000; Tomporowski, 2003).The literature has advanced several possible mechanisms that underlie the relationship between cognitive functioning and exercise. The influence of exercise on cognitive performance has been explained by the action of an intermediary factor (Brisswalter, Durand, Delignières, & Legros, 1995), which has been variously proposed to be the level of nervous system activation (Chmura, Nazar, & Kaciuba-Uscilko, 1994; McMorris & Graydon, 2000), blood acidosis or the accumulation of metabolic wastes and/or the involvement of different metabolic systems (Fleury & Bard, 1987), or modification in humoral functioning (Brisswalter et al., 1995). It is also possible that the improvement could be due to a greater efficiency of the peripheral motor processes (i.e., better synchronisation of the motor units discharge) and the peripheral sensorial processes (Davranche et al., 2005; Davranche, Burle, et al., 2006).

Participants' ability to respond under time pressure was faster during the exercise session compared to the rest session (391 ms vs. 418 ms, respectively), and this beneficial effect appeared to be more pronounced when the time spent on task increased. In fact, RT performances at rest and during exercise evolved in reverse directions. With regards to the time spent on task, performances at rest decreased probably due to the monotonous character of the task, although exercise seemed to counteract this boring effect and contributed to the maintenance of a high level of performance despite the repetitive nature of the task. This boredom effect is consistent with previous results reported by Davranche, Audiffren, et al. (2006) which showed a larger facilitating effect at the end of a 20-min exercise session performed at 90% of the ventilatory threshold, compared to at the start.

Present results also showed that, during exercise, participants required less time to interrupt ongoing actions in response to sudden changes in the environment. Indeed, stop-signal inhibition was facilitated during exercise compared to rest (184 ms vs. 196 ms, respectively). This original finding is particularly interesting because it demonstrates that (i) even if most of the exercise-induced improvements are generally explained by more efficient motor processes, the effect of exercise is not limited to motor response tasks and (ii) exercise can also improve specific aspects of higher-cognitive functions, like cognitive control. The fact that cognitive control processes are improved by exercise argues in favour of a beneficial effect of acute steady-state moderate exercise on higher-cognitive functions. However, the disparate findings of the literature are suggestive of a specific rather than a general effect of exercise on cognitive functions, thus it seems unreasonable to generalise the present results across different cognitive tasks.

It would seem possible that dopamine (DA) plays a critical role in the response inhibition process and its function merits further investigation. According to Hershey, Black, Hartlein, Braver, and Barch (2004) the frontal lobe circuits play a crucial role in the inhibition of pre-planned responses and these circuits are innervated by DA. In clinical studies it has been found that drugs that exert their influence via dopaminergic mechanisms have positive effects on response inhibition (Chamberlain, Muller, Robbins, & Sahakian, 2006). According to Bilder, Volavka, Lachman, and Grace (2004), increases in tonic DA may serve to enhance maintenance of task rules or goals, which Aron and Poldrack (2004) suggest is one of the components that may contribute to the speed at which people abort a pre-planned motor response, along with the maintenance of alertness/vigilance for the unpredictable stop-signal, the processing of the stop-signal and the inhibition itself. Research suggests that during exercise, feedback from the musculature and cardiorespiratory systems results in increased cerebral concentrations of DA (Gerin & Privat, 1998). McMorris, Collard, Corbett, Dicks, and Swain (2008) found that during moderate intensity exercise (40% MAP) there was an increase in the plasma concentrations of homovanillic acid (HVA) which is a metabolite of DA. This is indicative of increased use of DA in the brain (Kuhar, Couceyro, & Lambert, 1999). Moreover, McMorris et al. (2008) showed a significant relationship between changes in HVA concentrations and performance of a cognitive task. This suggests that the improvement in SSRT could be due to the potential usage of HVA by the frontal lobe circuits. However, one must be cautious with such a claim as no neurochemical measures were taken.

### *4.2. Time course effect after exercise cessation*

Concerning the time course of the facilitating effect observed on response execution, results suggested that the benefits observed during exercise could be maintained 30 min post-exercise and sustained for at least 52 min after exercise cessation. However, despite the fact that visual inspection of Fig. 2 suggests a positive effect immediately after exercise (Set 2), the probability level did not reach significance prior to Set 3. Nevertheless, current results show a clear picture of response inhibition improvement throughout the entire experimental session. The positive effect observed on cognitive control whilst cycling was maintained until the end of Set 3 (52 min after exercise cessation). Collectively, the present findings suggest that 30 min of exercise performed at 40% of MAP (mean HR about 130 bpm) is sufficient to influence cognitive functioning for at least 52 min post-exercise.

It is reasonable to envisage that the exercise duration, as well as the exercise intensity, should influence the size and the length of the effect of exercise on cognitive functioning. Consequently, one issue for future research is to define the parameters of exercise that optimally could facilitate cognitive performances. Extension and replication of the current findings using various exercise characteristics, different fitness level populations and diverse cognitive tasks will be important to confirm the causal relationship between exercise and specific cognitive processes. Furthermore, this study measured cognitive function for 52 min after exercise cessation; this rather short duration of time is not easy to transfer into a meaningful benefit in real life. Therefore, the period of testing time following exercise needs to be extended.

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