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Functioning of the Attentional Networks at Rest vs. During Acute Bouts of Aerobic Exercise

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The present study explored the effects of three different activity conditions on three attentional functions: alerting, orienting, and executive control. A group of highly experienced cyclists performed the Attention Network Test–Interactions (Callejas, Lupiáñez, & Tudela, 2004) at rest, during moderate aerobic exercise, and during intense aerobic exercise. Results indicated that aerobic exercise accelerated reaction time and reduced the alerting effect compared with the rest condition. However, aerobic exercise did not modulate the functioning of either the orienting or the executive control attentional networks. No differences in reaction time or attentional functioning were observed between the two aerobic exercise workloads. The present results suggest that moderate aerobic exercise modulates the functioning of phasic alertness by increasing the general state of tonic vigilance.

Keywords: aerobic exercise, attention, alerting, orienting, executive control

Attention is one of the most important cognitive functions in sport, given that it mediates the player's abilities to capture environmental information (e.g., visual field, ball, playmates, or object location), which seems to be a key factor underlying the vast majority of perceptual and motor actions (see Cox, 1985; Weinberg & Gould, 1995).

In the current study, attention is considered as a network. This approach is different from that of previous accounts, both in psychology in general (see reviews by LaBerge, 1995; Parasuraman & Davies, 1984) and in the sport literature (see Memmert, 2009). Such accounts conceptualized attention as a unitary mechanism in charge of selecting the relevant information, orienting in space, or allocating cognitive resources. The present study follows the proposal made by Posner and Petersen (1990), whereby attentional functions are fulfilled by three attentional subsystems (the executive control network, the orienting network, and the alerting network), which work in cooperation to adapt information processing to the demands of the environment.

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The executive control network plays an important role in sports since it is involved in situations where planning, decision making, error detection, execution of novel responses, or overcoming habitual actions are needed (Miller, 2000). Executive control has been one of the attentional functions that has received the most interest by researchers (for reviews of chronic and acute exercise, see Hillman, Erickson, & Kramer, 2008; Tomporowski, 2003). However, the literature shows contradictory findings regarding the nature and direction of the effect of acute bouts of aerobic exercise on this attentional function. For instance, Audiffren, Tomporowski, and Zagrodnik (2009) reported that executive control (measured by a random number generation task) was enhanced when participants were exercising under a moderate aerobic workload (60% VO_2max). However, the neuroelectric findings of Pontifex and Hillman (2007) showed impaired conflict resolution under exercise as compared with a rest condition. Moreover, Davranche, Hall, and McMorris (2009) failed to show any differential effect of acute aerobic exercise on participants' performance between congruent and incongruent trials in a flanker task (see Etnier and Chang, 2009, for a discussion on this issue).

The orienting network selectively allocates attention to a potentially relevant object or area of the visual field, enhancing its processing while ignoring locations/objects that are irrelevant. Attentional orienting to a target stimulus (object or person) may be either voluntarily guided by the person according to expectations of relevant locations or object features ("voluntary" or "endogenous" attentional orienting) or take place in a reflexive manner because of the salient properties of stimuli (e.g., color, form, size, location). This is known as either *attentional capture*, *reflexive*, or *exogenous* attentional orienting (see review by Corbetta, Patel, & Shulman, 2008). A series of studies by Pesce et al. (2002, 2003, 2004, 2007a, 2007b, 2011) using a modified Posner spatial cueing paradigm (Posner, 1980) has revealed that aerobic exercise can enhance flexibility in shifting the attentional focus in space. Such studies were performed using peripheral predictive cues (80% valid), thus exploring endogenous attentional orienting. However, to the best of our knowledge, no studies in the literature have explored the effects of acute bouts of aerobic exercise on the deployment of exogenous visual spatial attention. This is rather surprising given the relevance of exogenous spatial attention in multiple sport situations (e.g., the movement of a member of the audience capturing the attention of a tennis player serving). The closest approximation to this issue comes from comparative studies between sportsmen/-women and nonathletes using a visual spatial exogenous attention task, but always at rest (Lum, Enns, & Pratt, 2002).

Finally, the alerting network provides the general activation of cortical and thalamic areas that is necessary for the other cognitive functions to operate, thus preparing the organism for fast reactions through changes in the norepinephrine system. According to the literature, there are two types of alertness. Phasic extrinsic alertness is related to the nonspecific activation (related to the orienting response defined by Oken, Salinsky, & Elsas, 2006) experienced when a warning signal is presented before the target. In a different way, tonic intrinsic alertness or vigilance refers to sustained activation over a (relatively long) period of time with a characteristic circadian variation (see Posner, 2008, for a review). The literature about the modulation of alertness by acute exercise also shows apparently contradictory results. For instance, Mahoney, Hirsch, Hasselquist, Lesher, and Lieberman (2007) observed that participants' accuracy in responding to phasic alerting auditory stimuli was lower when the task was performed in an intense activity condition than in a rest condition. On the other hand, Smit, Eling, Hopman, and Coenen (2005) observed that exercise enhanced the state of tonic vigilance.

Given the lack of consistency in the literature mentioned above, the current study provides an opportunity to test the effect of exercise on attention within the context of a multifunctional attentional task. The functioning of the three attentional networks has typically been measured in controlled laboratory environments where participants performed the task at rest.[1] Although researchers have identified separate anatomical substrates for each of the three attentional networks, pointing to the independence between them, the three networks have also been shown to interact (Callejas, Lupiáñez, & Tudela, 2004; Callejas, Lupiáñez, Funes, & Tudela, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002).[2] For instance, in the case of athletes who perform prolonged exercise and have to respond quickly to external challenges, the abovementioned alerting, orienting, and executive control functions have to work in cooperation to maintain a high psychomotor performance during fatiguing exercise. However, to the best of our knowledge, no studies in the literature have explored the effect of in-task exercise on attentional performance considering the three different networks simultaneously.

The present study was conducted with this purpose. It examined whether various acute bouts of aerobic exercise would influence the functioning of the different attentional networks (alertness, exogenous spatial orienting, and executive control). To reduce the competition for available resources imposed by a dual task environment and to isolate the effect of exercise on attentional performance, a sample of experienced cyclists were recruited for the study (see the findings of Abernethy, 1988, and Stroth et al., 2009, about how motor expertise and physical fitness can modulate the cognitive resources allocated to a motor task).

The relationship between reaction time (RT) and acute exercise effect has generally been related to the intensity of the workloads used. Chmura, Krysztofiak, Ziemba, Nazar, and Kaciuba-Uscilko (1998) suggested that psychomotor performance is enhanced with increasing workload until a certain workload is reached and decreases dramatically after this. From a psychophysiological point of view, the efficiency of the central nervous system appears to be modulated by physiological exercise-induced changes (e.g., blood flow and lactate, adrenaline, and noradrenaline concentrations in blood plasma), which affect some brain areas and systems involved in cognitive arousal and available resources. Some studies by Chmura and colleagues (Chmura, Nazar, & Kaciuba-Uscilko, 1994; Chmura et al., 1998; Chmura, Nazar, Kaciuba-Uscilko, & Pilis, 2002) used heart rate (HR) and its relationship to anaerobic or lactate threshold (LT)[3] to study the effect of exercise intensity on cognition. Their results showed that cognitive performance during exercise increased even with workloads exceeding LT, suggesting a U-shaped curve in which RT decreases with the increase of plasma catecholamine concentration until it reaches a "critical point" located at workload intensities above LT. In the current study, both exercise intensities selected were below LT. Therefore, faster responses were expected with increasing exercise intensity (from rest to moderate aerobic and from moderate to intense aerobic exercise) due to the exercise-induced enhancement of cognitive resources.

Alerting seems to be the attentional function most directly linked to physiological state of readiness and cognitive arousal (Posner, 1978). As mentioned above, it is well known that exercise is an "arousing" activity that stimulates catecholamine secretion (see review by Zouhal, Jacob, Delamarche, & Gratas-Delamarche, 2008) and increases neuroelectric activity (Pontifex & Hillman, 2007). Therefore, the functioning of the alerting network was expected to be modulated by activity. It was hypothesized that if the physiological state of readiness (tonic vigilance) is lower at rest than under exercise conditions, the phasic alerting effect induced by the acoustic stimuli will be greater at rest than under physical load. Therefore, the alerting effect was expected to be lower in the exercise conditions than in the rest condition.

Regarding the effect of acute bouts of exercise on exogenous visual spatial orienting, Pesce, Capranica, Tessitore, and Figura (2002, 2003) have suggested the following: performing a visual endogenous attention task (i.e., with predictive cues) while exercising induces a faster allocation of attentional resources when participants have to focus on local or global stimulus features after a validly cued trial, and a greater ability to refocus these resources after an invalidly cued trial. If exercising has similar effects on exogenous attention (note that, contrary to Pesce et al., nonpredictive peripheral cues will be used), it is predicted that both acute bouts of physical exercise will increase the cueing (cost and benefit) effects compared with the rest condition.

Given the inconsistency of previous accounts on the effect of acute bouts of aerobic exercise on cognitive control, no a priori hypotheses were developed regarding this attentional network.

Method

Participants

Thirty experienced male cyclists (age range: 15–21; $M = 17$ years) from the Spanish Specialized Center for High Performance Cycling were initially recruited to participate in this study. All of them completed both an ethical clearance form and a statement regarding informed consent and institutional approval of the protocol. Seven participants did not complete the three experimental sessions and therefore their data were excluded from the analyses. Out of the 23 remaining participants, data from three participants were excluded from the analyses because the error rate in at least one experimental condition exceeded the standard deviation of the mean error rate (and approached chance levels). Finally, data from two participants were also excluded because they could not complete the experiment within the predefined intersession time (different sessions were scheduled with a minimum of 4 days and a maximum of 30 days between them, $M = 18$, $SD = 14$ days). Anthropometrical and physiological characteristics of the remaining 18 participants (age range: 16–20; $M = 17$ years), who completed the three sessions in a perfectly counterbalanced order, are presented in Table 1.

Procedure

Participants went to the laboratory on four separate occasions (with at least 48 hr between sessions).

Cycling Parameter Estimation Test. On the first visit, participants were informed about the details of the study and gave written informed consent. Next, participants

Table 1 Anthropometrical and Physiological Characteristics of Participants

Variables	Mean ± *SD*
Age (years)	17 ± 2
Weight (kg)	66 ± 6
Height (cm)	176 ± 7
HR baseline (bpm)	54 ± 3
Predicted HR_{max} (bpm)	196 ± 1
LT ($mmol·L^{-1}$)	4 ± 1
Workload at LT (W)	254 ± 31
Relative workload at LT ($W·kg^{-1}$)	4 ± 1
HR at LT (bpm)	174 ± 5
HR at LT (% HR_{max})	90 ± 23

Note. HR = heart rate; HR_{max} = maximum predicted heart rate; LT = lactate threshold; bpm = beats per minute.

were fitted with a Polar 721 heart rate monitor (Polar Electro Ltd., Kempele, Finland) and the magnetically braked cycle ergometer (Cardgirus Medical, G&G Innovación, La Bastida, Alava, Spain) was adjusted to accommodate them to perform a graded submaximal test according to the recommendations of Craig et al. (2000). After a 7-min warm-up, the test started at an initial workload of 100 W, with increments of 30 W every 4 min. The test was terminated when participants acknowledged voluntary exhaustion, could not maintain the minimum cadence of 60 $rev·min^{-1}$, or when their HR reached 95% of their HR_{max} obtained from the age-predicted equation (Tanaka, Monahan, & Seals, 2001): $HR_{max} = 208 - 0.7 \times \text{age}$.

Next, participants cycled until their heart rate was under 120 beats per minute (bpm) before getting off the cycle ergometer. Earlobe capillary blood samples were collected in the last 15 s of each stage and were analyzed by a blood lactate test meter (Lactate Pro LT-1710, Arkay KDK, Japan). Power output and heart rate were monitored continuously using a sampling rate of 1 Hz. Determination of the LT was based on the criteria established by Craig et al. (2000). Workload at LT was defined as the power output elicited by the stage before LT. Heart rate at LT was estimated as the statistical mode value of HR at the stage before LT.

Cycling Protocol. The following three sessions were designed to assess the effects of three different physical workloads (rest, moderate aerobic exercise, and intense aerobic exercise) on the attentional networks. Experimental sessions, whose order was counterbalanced across participants, were completed at approximately the same time of the day (before starting the afternoon training session; i.e., between 15:00 and 18:00). In the rest condition, participants completed the attentional task while sitting on the cycle ergometer but without pedaling. In both the moderate and intense aerobic exercise conditions, and after a 10 min incremental warm-up, participants performed the attentional task while cycling on the ergometer at 80% (moderate) or 95% (intense) of their workload at LT. During both exercise sessions, the corresponding initial moderate or intense target power output was manually adjusted to keep the selected physiological response to the exercise (HR) corresponding to 80% and 95% of LT in a steady-state zone.[4]

Attentional Task (ANT-I). Participants completed the ANT-I (Callejas et al., 2004)[5] at approximately 60 cm from the computer monitor in a dimly lit room. All visual stimuli were presented at eye level. A headphone set was used to deliver the acoustic alerting signal. Two computers connected to 15-inch color screen monitors were used. One of the computers, running E-Prime software (Schneider, Eschman, & Zuccolotto, 2002), was used for presentation of stimuli, timing operation, and collection of responses; the other one was used for adjusting and registering HR and power output data. Participants' responses were collected using the keys placed to the left and right of the handlebar.

Participants had to respond by pressing as quickly and accurately as possible either the left or right key depending on the direction (right or left) of the target stimulus (a target arrow 0.55° long) that appeared above or below the fixation point (a plus sign, "+", displayed in white with a variable duration of 400–1600 ms) located at the center of the screen. Participants were strongly encouraged to keep their eyes fixed on the fixation point throughout the trial. The target was always flanked by two arrows (identical to the target) on each side (0.06° away from each other). The interference variable was defined according to the congruency of the direction of the flankers and target arrows: congruent trials, when the target was flanked by arrows pointing in the same direction, and incongruent trials, when the flanking arrows pointed in the direction opposite to that of the target. In two thirds of the trials, the target display was preceded 100 ms by the orienting signal or asterisk cue (0.6°), shown for 50 ms above or below the fixation point. The orienting variable was thus established according to the presence of the cue (cued location trials, when the cue was presented at the same location as the target; uncued location trials, when the cue was presented at the opposite location to the target), or absence of cue (no-cue trials, when the cue was not presented). The alerting signal (a 2000 Hz and 50 ms sound) was presented 500 ms before the onset of the target in only half of the trials. The alerting variable was established according to the presence (tone) or absence (no tone) of the alerting sound. The sequence of events for each trial is shown in Figure 1. The target was presented until the participants' response or for 1700 ms. After the response, the fixation point was presented for a variable duration (depending on the RT of the preceding trial and the duration of the initial display for that trial) so that all trials were equally long.

Initially, participants completed a practice block of 48 trials, followed by five experimental blocks with resting intervals of about 1 min between them, but maintaining constant cycling parameters in the two cycling sessions. Thus, participants performed the ANT-I for approximately 25 min in each experimental session. Both the moderate and intense exercise sessions required a longer time (about 35 min) because the warm-up stage was necessary to reach the physiological steady state to perform the 25 min of continuous cycling at the preestablished HR and exercise workload. In addition, the 25-min exercise period seems to be a reasonable compromise to obtain a sufficient amount of data (240 trials) while avoiding fatigue in the highly skilled sample.

At the end of the last experimental session, participants were debriefed on the purposes of the study; they were also given an explanation of their physical and cardiovascular fitness and attentional performance with easily understandable data.

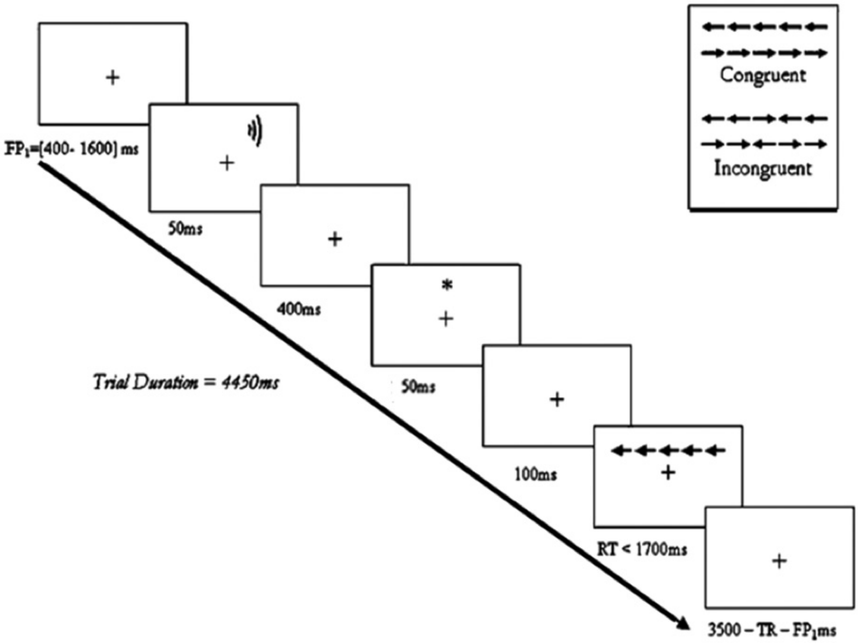

Figure 1 — Schematic view of the temporal course of a trial sequence. From top to bottom right, example of a tone, cued, and congruent trial.

Statistical Analysis

A within-participants repeated-measures design was used with the factors Activity (rest, moderate, intense), Alerting (tone, no tone), Orienting (uncued, no cued, cued), and Interference (congruent, incongruent). Each combination of the alerting, cueing, and interference factors (along with target location) was represented equally and randomly within each (practice and experimental) block of 48 trials. Therefore, each session included twenty trials per experimental condition.

Results

Preliminary Analysis

Participants' average HR values were recorded in each of the three experimental sessions. Moreover, average power output and lactate accumulation (taken immediately after finishing the attentional task) were registered during both moderate and intense activity conditions. Mean and standard deviation values per experimental session are displayed in Table 2.

To confirm that participants were under different physical workloads in the three activity sessions, separate ANOVAs were performed for each dependent variable.

Table 2 Workload and Physiological Response to Each Activity Experimental Condition

	Mean ± *SD*		
Variables	**Rest**	**Moderate**	**Intense**
Workload (W)	—	187 ± 26	239 ± 29
Relative workload ($W \cdot kg^{-1}$)	—	3 ± 0	4 ± 0
Lactate accumulation ($mmol \cdot L^{-1}$)	—	1 ± 0	3 ± 0
HR (bpm)	75 ± 6	144 ± 6	166 ± 6
HR (% HR_{max})	39 ± 3	75 ± 3	86 ± 3
HR (% HR at LT)	43 ± 4	83 ± 4	96 ± 4

Note. HR = heart rate; HR_{max} = maximum predicted heart rate; LT = lactate threshold; bpm = beats per minute.

The ANOVA on participants' average HR in the three sessions (rest, moderate, and intense) showed a significant main effect of Activity, $F(2, 34) = 1107.8$, $p < .001$, indicating that HR increased by 69 bpm from the rest to the moderate condition, $F(1, 17) = 1010.63$, $p < .001$ and by 22 bpm from the moderate to the intense condition, $F(1, 17) = 124.21$, $p < .001$. These changes in physiological response to exercise were verified by corresponding ANOVAs on average values of lactate accumulation and power output during moderate and intense activity conditions. Results confirmed that lactate accumulation, $F(1, 17) = 229.80$, $p < .001$, and relative workload, $F(1, 17) = 69.90$, $p < .001$, were higher (1.8 $mmol \cdot L^{-1}$ and 0.7 $W \cdot kg^{-1}$, respectively) at intense than at moderate activity levels (Figure 2).

Cognitive Performance

Participants' median RTs for correct responses were calculated.[6] Median RTs were introduced into a 3 (Activity) × 2 (Alerting) × 3 (Orienting) × 2 (Interference) repeated-measures ANOVA. It was not possible to analyze the accuracy data (mean accuracy of 97% overall) owing to a lack of variance (0% errors) in some experimental conditions. Means of median values (and error percentages) per experimental condition are displayed in Table 3.

The ANOVA revealed a marginally significant main effect of activity, $F(2, 34) = 2.99$, $p = .063$. Planned pairwise comparisons (*t* tests) showed a facilitating RT performance (18 ms) in the intense exercise compared with the rest condition, $F(1, 17) = 4.66$, $p < .05$. The faster RT (15 ms) in moderate aerobic exercise compared with the rest condition did not reach statistical significance, $F(1, 17) = 2.88$, $p = .10$. No differences between the two exercise conditions were found ($F < 1$).

Regarding the attentional measures, the results of the ANOVA replicated the typical main effects described in the literature (see review by Posner & Rothbart, 2007). Likewise, the interactions between the attentional networks reported by Callejas et al. (2004, 2005) were also observed.[7]

Two further ANOVAs were performed to analyze the functioning of the attentional networks during exercise in greater detail. Fernández-Duque and Posner (1997) showed that visual cues already induced an enhancement of alerting, thus

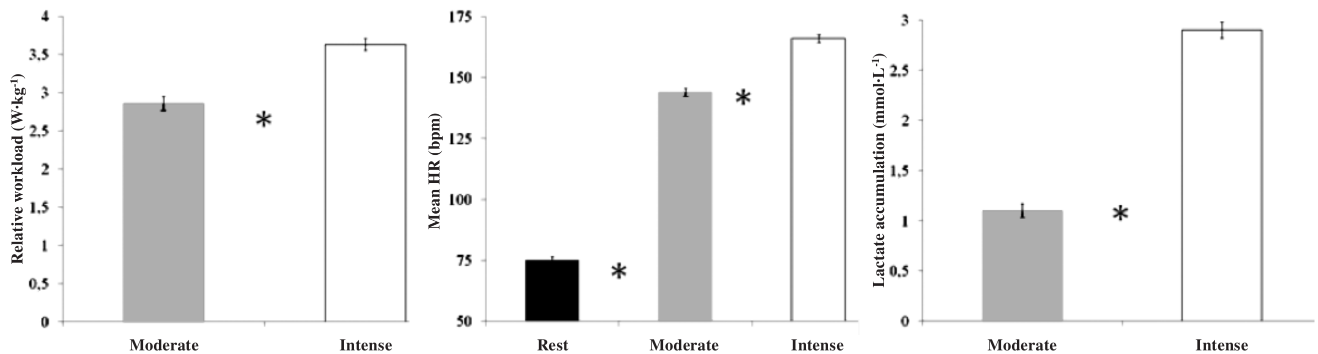

Figure 2 — Mean and standard error of workload and physiological response in each activity condition. From left to right, relative workload ($W \cdot kg^{-1}$), heart rate (in bpm), and lactate accumulation ($mmol \cdot L^{-1}$). *$p < .001$.

Table 3 Mean of Median RT (in Milliseconds) and Percentage of Error (Given in Parentheses) for Each Experimental Condition

	No Tone			Tone		
	Uncued	No Cue	Cued	Uncued	No Cue	Cued
Rest						
Congruent	455 (0.2)	475 (1.0)	420 (0.5)	446 (1.2)	425 (1.1)	405 (0.8)
Incongruent	542 (0.7)	537 (3.5)	485 (3.7)	545 (11.6)	494 (2.7)	475 (3.9)
Moderate						
Congruent	437 (0.0)	454 (1.1)	412 (0.2)	432 (0.8)	420 (0.2)	401 (0.2)
Incongruent	526 (7.4)	508 (4.1)	471 (3.3)	526 (9.0)	482 (3.1)	459 (5.1)
Intense						
Congruent	436 (1.9)	454 (1.6)	415 (1.1)	424 (0.8)	410 (2.1)	388 (1.3)
Incongruent	516 (7.6)	513 (4.5)	474 (4.1)	525 (12.6)	478 (4.4)	457 (3.2)

reducing the net effect produced by the auditory alerting cue. Thus, a 3 (Activity) × 2 (Alerting) × 2 (Interference) repeated-measures ANOVA was performed on no-cue trials to analyze the effect of activity on the pure alerting effect itself (see Callejas et al., 2005, for a similar analysis). Results replicated the previously mentioned significant main effects of Activity, $F(2, 34) = 3.84$, $p < .05$, and Alerting, $F(1, 17) = 122.10$, $p < .001$. More importantly for the purpose of the current study, the interaction between these two factors was also significant, $F(2, 34) = 3.50$, $p < .05$. Planned comparisons highlighted a 16-ms reduction of the alerting index[8] in the moderate exercise as compared with the rest condition, $F(1, 17) = 6.86$, $p = .01$. Further analyses showed that comparing moderate exercise to rest, exercise facilitated RT only in no-tone trials, $F(1, 17) = 8.46$, $p < .01$; this facilitating effect of exercise was not observed in tone trials, ($F < 1$), or when compared with intense exercise, ($F < 1$). The alerting index did not significantly change between rest and intense exercise, $F(1, 17) = 1.13$, $p = .30$, or between the moderate and intense exercise conditions, $F(1, 17) = 2.5$, $p = .12$ (see Figure 3).

Because it was not possible to measure visual orienting in no-cue trials, a 3 (Activity) × 2 (Alerting) × 2 (Orienting) × 2 (Interference) repeated-measures ANOVA excluding no-cue trials was performed to investigate the effect of activity on the orienting network. This analysis replicated the same attentional effects observed in the main overall analysis, but no interaction involving the factor Activity reached statistical significance (all Fs < 1).

Discussion

The present research is the first to assess attention considering its multifunctional nature (alerting, orienting, and executive control) during acute bouts of different exercise intensities. Attentional functioning at rest was compared with two clearly different steady-state exercise intensities. Crucially, RT results indicated that aerobic exercise improves RT performance (i.e., shorter RT) in the ANT-I task. Regarding the attentional networks, a reduced alerting effect was found in the exercise condi-

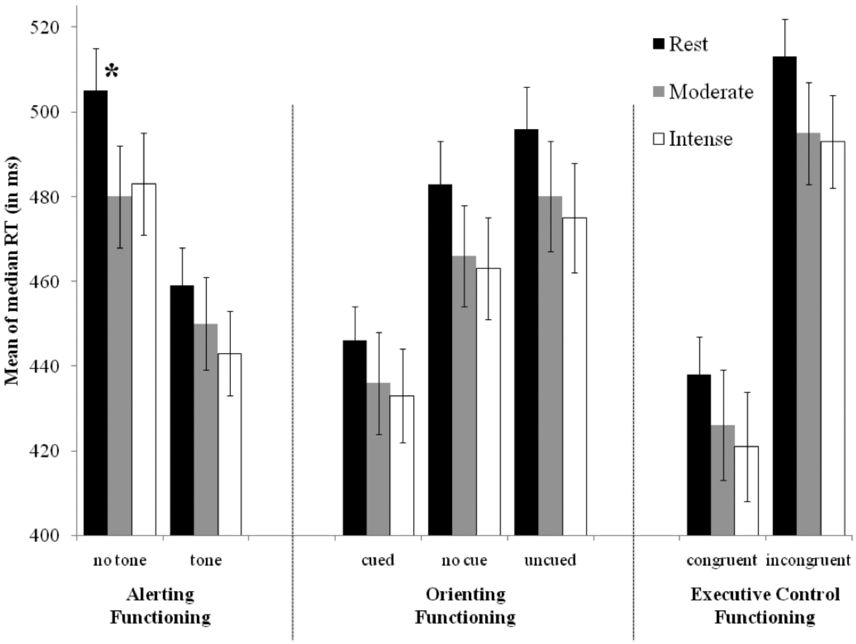

Figure 3 — Mean of the median RT and standard error (in milliseconds) for each type of trial during rest, moderate, and intense aerobic exercise. Given that visual cues modulate alertness (Fernández-Duque & Posner, 1997), the alerting function was measured in no-cue trials. Orienting and executive control network functioning were assessed including all the experimental conditions. *$p < .05$.

tions compared with the rest condition. In contrast, no modulatory effect of exercise was found on either the orienting or the executive control networks.

Moderate and intense aerobic exercise were defined according to both cardiorespiratory (HR) and metabolic (lactate accumulation) physiological responses to exercise. The use of both selected exercise workloads (approximately 80 and 95% of HR at LT and for 25 min) was based on the review of previous studies by Davranche et al. (Davranche & Audiffren, 2004; Davranche, Burle, Audiffren, & Hasbroucq, 2005; Davranche, Burle, Audiffren, & Hasbroucq, 2006; Davranche et al., 2009) that explored the effect of exercise on cognition. Both the workload intensities and the duration of the exercise made it possible to obtain the required amount of data from the attentional task during exercise maintaining a physiological steady state while avoiding fatigue. Preliminary results (Table 2) confirmed the high level of stability of the variables used for measuring physiological response to exercise.

In line with previous accounts (e.g., Davranche & Audiffren, 2004; Pesce et al., 2002, 2003), the current study suggests that an acute bout of aerobic exercise is beneficial for response performance. However, the lack of differences in participants' overall RTs between the moderate and intense workloads somewhat contrasts with previous research. A series of studies by Chmura et al. (1994, 1998, 2002), using an incremental multistage exercise design, found that exercise shortened RT gradually, reaching its minimum level at approximately 75% VO_2max (corresponding workloads exceeding LT), and then increased rapidly. According to this hyperbolic U-shaped relationship between RT and exercise intensity, one would have expected significant shorter RTs from rest to moderate exercise and from moderate to intense exercise activity levels in the current study. The current results corroborated only the first observation. However, the preliminary results of the current study (Table 2 and Figure 2) confirmed that the two aerobic exercise workloads used (below LT) induced differential changes in physiological variables (HR and lactate accumulation). The lack of differences in attentional functioning between the two aerobic exercise conditions in the current study could be related to the peculiarity of the participants of the sample (i.e., expert cyclists). As noted earlier in this article, Abernethy (1988) suggested that motor expertise can modulate the cognitive resources allocated to the physical movements inherent in exercise and thus minimize dual task effects. Alternatively, Stroth et al. (2009) suggested that changes in cognitive functioning attributed to exercise may be more directly linked to neurophysiological changes associated with individual physical fitness, rather than being a specific effect of an acute bout of exercise. Physiological parameters certainly revealed that participants in the current study were under two different workloads, when comparing the moderate and intense exercise conditions. However, this difference in physical load was probably not enough to induce a change in cognitive performance in the expert cyclists, perhaps owing to their ability to cope with the dual task demands, mostly in the intense aerobic exercise condition. In any case, this remains speculative and further research will be needed to clarify this issue.

As expected, and consistent with previous evidence in the literature (e.g., Mahoney et al., 2007; Smit et al., 2005), results revealed that the alerting function was modulated by activity (i.e., a lower alerting index was found in both exercise conditions than in the rest condition, although it reached statistical significance only between the moderate and rest conditions). This is coherent with the hypothesis put forward by Aston-Jones and Cohen (2005) whereby the locus coeruleus–norepinephrine system is activated in a similar manner both by exercise and alerting stimuli.

Faster RTs in the moderate aerobic exercise condition than in the rest condition were obtained in both tone and no-tone trials. However, the magnitude of the exercise effect was larger in no-tone trials than in tone trials, where it did not reach statistical significance. This latter result seems to suggest that, since the physiological state of readiness (tonic vigilance) was already high in the moderate aerobic exercise, the presence of the tone induced a smaller effect in that condition than in the rest condition. In other words, it appears that once a certain level of activation/arousal is reached, the presence of a tone has less impact on RT performance. The opposite (i.e., a larger phasic alertness effect) should happen in conditions of reduced tonic vigilance (such as morning-type individuals when tested in the evening; Matchock and Mordkoff, 2009).

Regarding the functioning of the executive control and orienting networks, the present results did not show any modulation by exercise. The results differ from others in executive control, given that they showed an enhancement of this function when participants were exercising under moderate aerobic workloads (e.g., Audiffren et al., 2009); they also differ from studies showing an impairment in conflict resolution in exercise as compared with rest conditions (e.g., Pontifex & Hillman, 2007). By contrast, the present results are consistent with those obtained by Davranche et al. (2009) or Lambourne, Audiffren, and Tomporowski (2010), in which no effect of activity on executive control was observed using aerobic exercising conditions similar to those of this study. Likewise, the present data did not reveal any modulation of the cueing effect by activity. This finding somehow contrasts with studies by Pesce et al. (2003, 2004, 2007a, 2007b, 2011), which suggest that aerobic exercise might enhance flexibility in shifting a broad attentional focus both in the peripheral visual field and at parafoveal locations. However, peripheral predictive cues (80% validity) were used in the abovementioned studies, whereas the current study used nonpredictive cues. Therefore, endogenous and nonexogenous spatial orienting may be responsible for the effects observed in the studies by Pesce and colleagues. To our knowledge, no studies in the literature have explored the deployment of exogenous visual spatial attention while exercising (although see Sanabria et al., 2011).[9] Thus, further research is needed to unveil the potential effect of exercise on the deployment of exogenous spatial visual attention. Nevertheless, combining orienting and executive control results, the observed pattern of data supports the assumption that exercise facilitates RT but does not influence attentional orienting or executive control. This facilitating effect, which is unrelated to attentional functioning, was explained by Davranche et al. (2005, 2006) in terms of exercise-induced increases in physiological arousal or activation and consequently a better efficiency of peripheral motor processes during exercise. However, this assumption remains to be verified by further research analyzing the relationship between electromyographic response and executive control network functioning during exercise.

In any case, it seems difficult to compare results and conclusions obtained from the various studies on the relationship between acute exercise and attentional functioning, mainly because of the diversity of protocols used and the different aspects of attention measured (see Etnier and Chang, 2009, for a discussion on this issue).

In summary, the outcomes of the current study reveal that the alerting function was affected by an acute bout of moderate aerobic exercise. Results also suggest that aerobic exercise speeded up responses compared with a situation in which the cognitive task was performed at rest. Further research comparing groups of participants with different motor expertise or physical fitness will be needed to clarify the specific rather than general effect of acute exercise on attentional functioning. The present findings, along with future research, will certainly add to the knowledge about the effects of different physical efforts on specific aspects of attention that are relevant for sports performance.

Notes

1. The typical pattern of data for the functioning of the attentional networks (see review by Posner & Rothbart, 2007) shows faster RT in trials (1) where the auditory signal is presented compared with trials with no auditory signal (alerting effect), (2) where the target is presented in the same location as the orienting cue compared with trials where no cue is presented (benefit effect) or where it is presented at the opposite location (cost effect), and (3) where congruent

flankers are presented compared with trials where incongruent flankers are presented (conflict or interference effect).

2. These studies described some interactions between networks: (a) the executive control network was inhibited by the alerting network, showing a larger congruency effect when the auditory signal had previously been presented than when it had not; (b) the orienting network increased the efficiency of the executive control network (larger congruency effect for uncued location trials than for cued location trials); and (c) the alerting network influenced the orienting network, showing a larger orienting effect under alerting conditions.

3. Lactate threshold (LT) is defined as the intensity of exercise at which there is an abrupt increase in blood lactate levels. Lactate threshold is one of the most useful physiologic parameters in the diagnosis of endurance performance and control of training workload in sports (see the recent review by Faude, Kindermann, & Meyer, 2009).

4. According to Chmura et al. (1998), the efficiency of some brain areas and systems involved in cognitive arousal and cognitive resources is related to physiological exercise-induced changes. Heart rate is related to some of these variables (e.g., blood flow and lactate, adrenaline, and noradrenaline concentrations in blood plasma; see the review by Christensen and Galbo, 1983). Therefore, during the exercise sessions, it was decided to manipulate the exercise power lightly to maintain HR in a moderate or intense steady-state zone.

5. The ANT-I is a modified version of the Attentional Network Test (Fan et al., 2002) aimed at measuring the functioning and interaction of the three attentional networks and considering the complex interplay between them. In the ANT-I, the efficiency of the orienting and executive networks is measured by combining a cued RT task (Posner, 1980) and a flanker paradigm (Eriksen & Eriksen, 1974), adding an auditory alerting signal before the orienting visual cue to measure the alerting network (see Ishigami & Klein, 2010, for a review on the benefits of the ANT-I compared with the ANT).

6. Median RTs were used because of the disproportional contribution of outliers in mean RTs for different participants. Moreover, the median is the appropriate measure under such conditions as long as RT differences, not absolute RT, are relevant. In the current study, the main effect of activity was not significant using mean RT, (p = .200), although descriptive data showed the same pattern: slower responses at rest than in moderate and intense exercise, with no differences between the two exercises. In the same way, the Activity × Alerting interaction was marginally significant (p = .08) using mean RT. Further planned comparisons showed similar results using mean RT (p = .02) or median RT (p = .01), showing the reduction of the alerting effect from the moderate condition compared to the rest condition. No differences in other statistically significant terms were observed using either means or medians. Median RT analysis highlights the statistical significance of the main finding of this study.

7. Results showed the following main effects: alertness, $F(1, 17) = 60.78$, $p < .001$; orienting, $F(2, 34) = 160.53$, $p < .001$; and interference, $F(1, 17) = 349.01$, $p < .001$. The results of the interactions, including all the levels of the attentional variables, were Alerting × Orienting, $F(2, 34) = 51.92$, $p < .001$; Orienting × Interference, $F(2, 34) = 31.44$, $p < .001$; and Alerting × Interference, $F(1, 17) = 3.82$, $p = .067$. See Callejas et al. (2004) for an extended report of a similar data pattern.

8. Based on the finding of Fernández-Duque and Posner (1997) on the alerting effect of visual cues, and similarly to Fan et al. (2002) and Callejas et al. (2005), the alerting index was defined by subtracting trials with a tone from trials without a tone considering only no-cue trials.

9. Sanabria et al. (2011) explored the effect of acute aerobic exercise on exogenous spatial attention using 100-ms and 1000-ms stimulus onset asynchrony (SOA). Results showed that exercise modulated exogenous spatial orienting only at the long SOA. The present study used a 100-ms SOA, showing no effect of activity on orienting. Therefore, the present finding is consistent with the only evidence found on this topic.

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