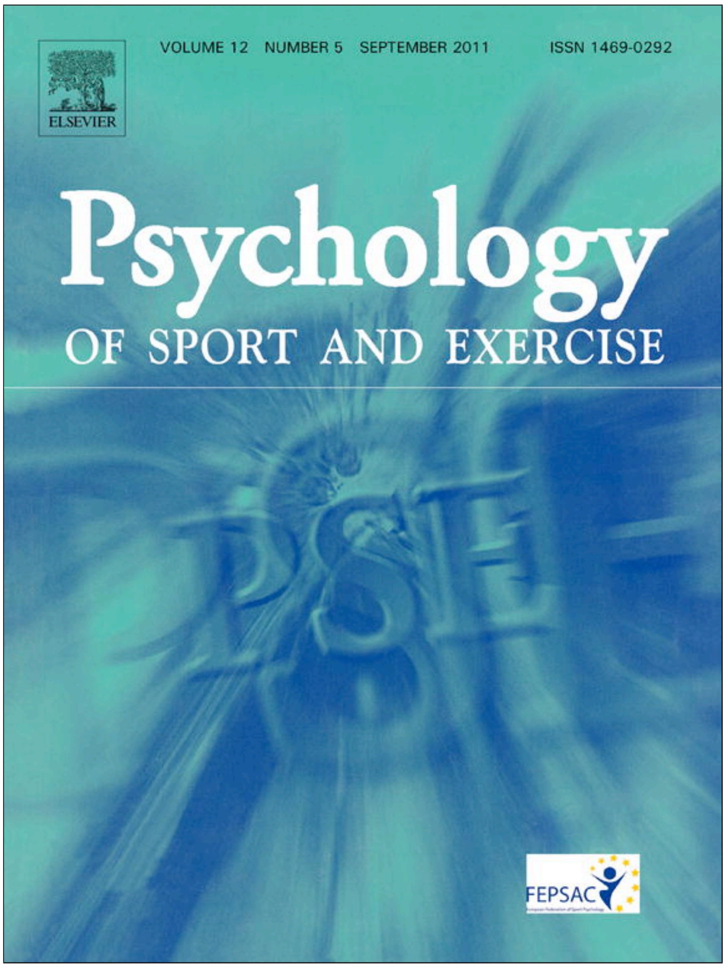
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Effects of acute aerobic exercise on exogenous spatial attention

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ABSTRACT

Objectives: This study investigates the effect of acute aerobic exercise on exogenous spatial attention and executive control.
Designs and Method: Participants performed an exogenous cueing discrimination task in three situations: at rest, while exercising, and immediately after exercising. The stimulus–response compatibility effect was also measured at each exercise condition.
Results: The results in the rest session showed the typical facilitation effect at the 100 ms Stimulus Onset Asynchrony (SOA) and the inhibition of return (IOR) effect at the 1000 SOA. While the facilitation effect was present in the three exercise conditions and there was not any significant difference in the magnitude of the effect between them, the IOR effect was significant only in the rest session. The stimulus–response compatibility effect was of a similar magnitude in the three exercise conditions.
Conclusions: This study demonstrates that, compared to a rest condition, an acute bout of aerobic exercise performed during or even immediately before the spatial task, modulates the deployment of exogenous spatial attention.

The relation between exercise and cognitive performance is a current topic of research (see McMorris, Tomporowski, & Audiffren, 2009, for a review). In the present study we investigated the effect of an acute bout of aerobic exercise, performed during and prior to the cognitive task, on the deployment of exogenous visual spatial attention, measured by means of a typical exogenous cueing task, and on executive control. Executive control, considered as the mechanism involved in decision making, error detection, generation of novel responses and inhibition of automatic unwanted responses (Posner & DiGirolamo, 1998), was measured by means of the response compatibility or Simon effect. That way, we obtained an index of the difficulty in inhibiting an automatically-activated response. In effect, when a stimulus is presented to the right visual hemifield, participants respond more rapidly with their right hand than with their left hand. In that case, when a left response is required, the automatically-activated right-hand response has to be inhibited.

The ability to move and focus attention across space is crucial in sport contexts, to select and give priority to the processing of stimuli that are relevant for behaviour (Allard, Brawley, Deakin, & Elliott, 1989). In the laboratory, it has been repeatedly shown that cueing participants to a specific spatial location speeds up reaction time (RT) to a target presented at the cued location and often enhances response accuracy on cued location trials as compared to uncued location trials (e.g., Posner, Snyder, & Davidson, 1980). Note that visuospatial attention can be driven endogenously, by means of central symbolic and informative cues, or exogenously, by means of peripheral (informative or not informative) cues. When the peripheral direct cue does not predict the target location, as in the present study, the cueing effect is purely exogenous in nature and depends on the time interval between the cue and target presentation, i.e., the cue-target Stimulus Onset Asynchrony, or SOA. At short SOAs participants typically perform better on cued location trials than on uncued trials. However, the reverse pattern of data is typically found at long SOAs (i.e., longer than 250 ms), an effect that has been termed inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985).[1] The facilitation effect observed at short SOAs is

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[1] The particular pattern of RT as a function of SOA on exogenous cueing tasks does depend on other factors such as the type of task (detection, discrimination). Note though that a comprehensive review on exogenous visual spatial attention effects goes beyond the scope of this brief report. See Klein (2000) or Lupiáñez (2010) for such a review.

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considered the result of the automatic capture of attention by the cue. The IOR effect observed at longer SOAs is typically interpreted as a cost in returning to an already attended spatial location (Klein, 2000). However, recent research has shown that IOR can be observed even when attention does not have to return to previously cued locations (see Lupiáñez, 2010 for a review). Thus, the IOR effect is interpreted as a cost in detecting the appearance of the target, due to the habituation of attention at the location where it was previously captured (Dukewich, 2009). In other words, the target would be less novel and therefore would capture attention to a lesser extent when it would appear at the previously cued location, as compared to when it would appears at new (i.e., uncued) locations.

The facilitation and IOR effects have been typically measured in controlled laboratory environments where participants performed the task at rest. However, in various sport situations spatial attention is deployed while the observer is under physical load that increases his/her physiological activation. To the best of our knowledge, there are not studies in the literature that have investigated the effect of exercising 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., a tennis player that has to focus his/her attention on the ball ignoring all type of peripheral stimuli that may appear abruptly, such as a camera flash. The closest approximation to this issue comes from studies that have compared performance between sportsmen/women and non-athletes in a visual spatial exogenous attention task, but always at rest (e.g., Lum, Enns, & Pratt, 2002).

In contrast, numerous studies have investigated the effects of exercise on executive control (see Hillman, Erickson, & Kramer, 2008; Tomporowski, 2003; for reviews of chronic and acute exercise). For instance, Pontifex, Hillman, Fernhall, Thompson, and Valentini, (2009) showed that participants' RT in a working memory task (that involved executive control) improved during an acute bout of aerobic exercise as compared to a rest condition. However, other studies have shown the reverse pattern of data, with an impaired performance on incongruent trials on a flanker (control) task while exercising (e.g., Pontifex & Hillman, 2007). Meanwhile, Davranche, Hall, and McMorris (2009) failed to show any effect of acute aerobic exercise on participants' performance on congruent or incongruent trials in a flanker task. Therefore, the effect of exercise on executive control is currently not clear (see Etnier & Chang, 2009, for discussion on this issue).

The present study was designed to investigate the effect of acute aerobic exercise on the deployment of exogenous visual spatial attention and on executive control. Executive control plays an important role in open sports given the complexity and variability of situations that typically require emitting novel responses and, in some occasions, the inhibition of automatic behaviours. In contrast with previous accounts (although see Audiffren, Tomporowski, & Zagrodnik, 2009; Del Giorno, Hall, O'Leary, Bixby, & Miller, 2010; Lambourne, Audiffren, & Tomporowski, 2010), we measured participants' performance in the cognitive task in three different situations in the same experiment: At rest, while exercising, and immediately after an acute bout of aerobic exercise, when participants returned to their baseline heart rate.

Pesce and co-workers (e.g., Pesce, Capranica, Tesittore, & Figura, 2002, 2003) have suggested that performing a visual endogenous attention task (i.e., with predictive cues) while exercising induced an increased 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 following an invalidly cued trial. Assuming that aerobic exercise has similar effects on exogenous attention (note that, contrary to Pesce et al., we used non-predictive peripheral cues) we predict that the acute bout of aerobic exercise will increase the cueing effect at the short SOA and reduce, or even eliminate, the IOR effect at the long SOA with respect to performance on the visual spatial task at rest. Additionally, we will investigate whether exercising can affect the deployment of visual attention even when the exercise is performed immediately before the cognitive task. We did not have a priori hypotheses regarding the modulation of the response-compatibility effect by exercise given the contradictory results present in the literature.

Methods

Participants

Twenty undergraduate students (two females; age range: 18–29 years old; mean age: 22 years old) from the Faculty of Physical Activity and Sport Sciences (University of Granada, Spain) took part in the study in exchange of course credits. All of the participants informed to practice at least 2–3 (1-h aprox.) sessions of sport/fitness per week. All reported normal hearing and normal or corrected-to-normal vision. The experiment reported in this paper was conducted according to the ethical requirements of the local committee.

Apparatus and materials

Participants were fitted with a S610i Polar monitor (Polar Electro, Finland) to control their heart rate during the threshold session and the experimental session. A Monark 864 cycloergometer was used to obtain participants' aerobic (AET; Mean = 116 b min^{-1}; SD = 14 b min^{-1}) and anaerobic (ANT; Mean = 152 b min^{-1}; SD = 18 b min^{-1}) thresholds and to conduct the experiment proper. The cycloergometer was adapted to accommodate each participant's height. A Lactate Pro lactate test meter and Lactate Pro strips (ARKRAY, Inc., Japan) were used to measure participants' levels of blood lactate during the threshold session. A 19" LCD laptop Toshiba PC was used to present the stimuli in the spatial attention task. The centre of the laptop screen was situated at 60 cm (approx.) from the participants' head and at his/her eye level. The stimuli consisted of two boxes ($3.80° \times 4.80°$) with their border in light grey colour displayed on a black background, one to the left and the other to the right of the fixation point, a cross ($0.4° \times 0.4°$) displayed in light grey colour at the centre of the screen. The inner edge of these placeholder boxes (where the target was presented) was at 5.5° from the fixation point. The cue consisted of the flickering (increasing the line-width of the border) of one of the boxes for 50 ms. The target was an X or an O (1°) displayed in white colour for 100 ms at the centre of one of the boxes. Two response buttons connected to the computer USB-2 port were used to collect participants' left and right responses. The E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA) was used to control for stimulus presentation and response collection.

Procedure and design

The participants visited the lab in four separate occasions, always at the same time of the day (between 4 pm and 7 pm). In the first session, the threshold session, their AET and ANT were obtained using the Astrand protocol (Astrand & Rodahl, 1986) with the cycloergometer. Prior to the start of the effort test, the participant was told to rest for 10 min approximately and then his/her basal heart rate was annotated. The Astrand protocol consisted of a submaximal incremental effort test with a fix cadence of 60 revolutions min^{-1}, starting with a power of 75 W and with increments of 25 W every 2 min. The level of blood lactate was measured 30 s before every power increase, once the heart rate was stable at the current power so changes in the level of blood lactate could be measured. The level of blood lactate was also measured 3, 5 and 10 min after the effort test. The effort test was stopped as soon as the participant reached the 4 mmols level of blood lactate corresponding to his/her theoretical anaerobic threshold (see Kindermann, Simon, & Keul, 1979). The AT and ANT thresholds were obtained from the participants' heart rate data and his/her levels of blood lactate data. We used the Individual Anaerobic Threshold method (Stegmann, Kindermann, & Schnabel, 1981) with the data of blood lactate concentration at each phase of the incremental test and during the recovery phase, plotting them with the heart rate data of the participant at each of these phases. In the second session (rest session) the participant performed the spatial attention task while pedalling with no resistance in the cycloergometer (note that the participants heart rate was close to his/her baseline heart rate during this session). This session was considered as baseline and control condition and performed in first place to avoid any effect of the order of presentation of the sessions, thus maximizing the likelihood of obtaining the typical cueing effect (i.e., faster RT on cued than on uncued trials) at the short SOA and the IOR effect (i.e., faster RT on uncued than on cued trials) at the long SOA.

Importantly, the rest session also served to measure the duration of the task, that lasted for about 20 min. In the next two sessions, the participants performed the task during the acute bout of aerobic exercise (online-effort session) or immediately after the acute bout of aerobic exercise (post-effort session). The order of presentation of the two sessions was counterbalanced across participants. In the online-effort session, the cycloergometer was set-up to a power corresponding to the power level at which the participant was, approximately, at the 85% of his/her ANT (mean heart rate across participants of 88% of the ANT, standard deviation of 2.3%). The participant was then instructed to maintain the revolutions min^{-1} cadence and to perform the spatial attention task at the same time. The experimenter controlled the participant's heart rate throughout the session to ensure that it was (approximately) constant (i.e., by reducing or incrementing the power exerted by the cicloergometer in steps of 5 W). In the post-effort session, the cycloergometer was set-up again to the same power, and the participants' heart rate controlled, as described for the online-effort session. The participants were instructed to pedal at a cadence of 60 revolutions min^{-1} for 20 min (i.e., the same time as in the online-effort session, corresponding to the duration of the spatial attention task). They were then told to rest until their heart rate reached their basal level (all of the participants reached that level within 5–10 min). They had then to perform the spatial attention task while pedalling with no resistance in the cycloergometer, similar to the rest session described above. All of the participants completed the rest, online-effort and post-effort sessions in three consecutive days.

Verbal and written instructions were given to the participant prior to the start of the spatial attention task in every session, stressing that they had to fixate on the fixation cross, try not to move their eyes, and respond as fast as possible trying to avoid errors. The spatial attention task consisted of the presentation of the fixation point and the two boxes for a random duration between 500 and 1500 ms. The boxes and the fixation point remained on the screen for the whole duration of the trial. The cue was then presented for 50 ms. After a SOA of 100 or 1000 ms (with a 50% probability of occurrence of each SOA) the target appeared for 100 ms, either at the cued location (cued trials) or at the uncued location (uncued trials) with the same 50% probability. Participants were instructed to discriminate whether the target was an X or an O pressing the left or right button accordingly. The stimulus–response key assignment was counterbalance across participants. Compatible trials were those in which the target was presented at the same side of its corresponding response button. On incompatible trials the target was presented at the opposite side of its corresponding response button. The response window was set to 2000 ms and the inter-trial interval to 760 ms. Catch trials (11%), in which the target was not presented, were included to prevent response anticipations. Participants completed a practice block of 36 trials (not included in the analysis) in which feedback of response accuracy was provided and 7 experimental blocks of 36 trials in which no feedback was provided. Participants were forced to rest 5 s after each experimental block of trials.

The experiment constituted a within participants design with the factors Session (rest, online-effort, post-effort), SOA (100, 1000), Cueing (cued, uncued), and Stimulus–response compatibility (compatible, incompatible).

Results

Incorrect responses (4.76%), and trials with RT below or above 2.5 standard deviations from the mean (for every subject in every experimental condition; 3.9%) were also discarded from the analysis. A repeated-measures analysis of variance (ANOVA) was conducted on participants' mean RTs (see Table 1). The ANOVA revealed a significant main effect of Session, $F(2,38) = 28.53$, $p < .001$, $\eta_p^2 = .6$, with participants responding faster in the online-effort and post-effort sessions (494 ms and 505 ms, respectively) than in the rest session (562 ms; both ps $< .01$). The difference between the online-effort and post-effort sessions did not reach statistical significance, $p = .16$. The main effect of Stimulus–response compatibility was also significant, $F(1,19) = 8.49$, $p = .008$, $\eta_p^2 = .3$, with faster responses on compatible than on incompatible trials (513 ms and 527 ms, respectively). The interaction between SOA and Cueing was significant, $F(1,19) = 14.39$, $p = .001$, $\eta_p^2 = .43$. This interaction was due to participants responding faster on cued than on uncued trials at the 100 ms SOA, $p < .001$, while they were faster on uncued than on cued trials at the 1000 ms SOA, $p = .04$, i.e., the typical IOR effect. Crucially, there was a significant interaction involving Session, SOA and Cueing, $F(2,38) = 4.82$, $p = .01$, $\eta_p^2 = .20$. Planned comparisons were performed to explain this interaction further. These analyses revealed that the cueing effect (i.e., the difference between cued and uncued trials) at the 100 ms SOA was significant in the three sessions (rest = 17.8 ms, $p = .006$, online-effort session = 9.3 ms, $p = .048$, and post-effort session = 7.6 ms, $p = .04$) and that there were not significant differences in the magnitude of the effect between the

Table 1
Mean RT (ms) and percentage of errors as a function of Session (rest, online-effort, post-effort), SOA (50, 1000), Cueing (cued, uncued) and Stimulus–response compatibility (compatible-comp-, incompatible-Inc-).

	Rest				Online-effort				Post-effort			
	50		1000		50		1000		50		1000	
	Comp	Inc	Comp	Inc	Comp	Inc	Comp	Inc	Comp	Inc	Comp	Inc
Cued	547 (4.2)	564 (6.3)	562 (2.7)	576 (5.4)	483 (4)	498 (3.6)	494 (5)	503 (6)	496 (2)	509 (2.7)	499 (3.2)	513 (4.7)
Uncued	563 (3.6)	584 (7)	544 (3)	558 (6)	488 (4)	511 (5)	483 (2.6)	495 (5)	500 (2.6)	520 (4.4)	496 (2.7)	508 (4.4)

three sessions (rest vs. online-effort, $p = .23$; rest vs. post-effort, $p = .1$; online-effort vs. post-effort, $p = .74$). However, the IOR was significant only in the rest session (17.4 ms), $p = .009$ (IOR in the online-effort session = 9.3, $p = .12$, and in the post-effort session = 4.8 ms, $F < 1$). Moreover, the difference in the magnitude of the IOR effect was statistically significant between the rest and post-effort sessions, $p = .03$, and marginally significant between the rest and online-effort sessions, $p = .06$. The IOR effect was not statistically different between the online-effort and post-effort sessions, $F < 1$. None of the remaining terms in the ANOVA reached statistical significance. A similar ANOVA on participants' response accuracy did not revealed any significant term.

To investigate the temporal course of the effects described above and also the potential effect of practice in the outcome of this experiment we conducted a new ANOVA with the factors of Block, Session, SOA and Validity (cf. Lambourne & Tomporowski, 2010). Note that to obtain a valid number of observations in each condition we collapsed the data from the seven experimental blocks in three levels (1 = blocks 1–3; 2 = blocks 4–5; 3 = blocks 6–7). Crucially, there was again a significant interaction between Session, SOA and Validity, $F(2,38) = 4.5$, $p = .01$, $\eta_p^2 = .19$, that did not depend on the factor Block as revealed by the non-significant interaction between Block, Session, SOA and Validity, $F < 1$. A further experiment conducted to control for practice effects ($N = 22$ new participants; without physical workload) confirmed that the magnitude of the IOR effect was not modulated across two consecutive sessions (9 ms and 14 ms, respectively, $F < 1$) of the exogenous spatial task used in the present study (see also Lupiáñez, Weaver, Tipper, & Madrid, 2001).

Discussion

The results of the experiment reported in this study showed, for the first time, that aerobic exercise modulates the deployment of exogenous visual spatial attention. Acute aerobic exercise affected participants' performance both when it was concurrent to the cognitive task and when it was performed prior to the cognitive task. In the online-effort and post-effort sessions, the typical cueing effect was obtained at the short SOA while no IOR was reported at the long SOA. The lack of modulation of the stimulus–response compatibility effect by exercise adds to the controversy regarding the effect of acute aerobic exercise on executive control (see Etnier & Chang, 2009), supporting previous accounts (e.g., Coles & Tomporowski, 2008).

The present results support the hypothesis that acute aerobic exercise increased the participants' ability to refocus spatial attention on locations that had already been attended, eliminating the IOR effect. The effect of acute exercise occurred during a dual physical-attentional task and persisted after the end of the physical effort, at least until physiological arousal returned to basal levels This latter result suggests that the effect of exercise on exogenous visual attention lasts in time. Further research will be needed to determine the duration of the effect of physical exercise on exogenous visual spatial attention.

We argue that physical exercise in our study enhanced participants' attentional reactivity to peripheral stimuli so that target discrimination did not show the IOR effect. From the traditional view (see Klein, 2000), this would mean that exercise reduced the effect of the inhibition process that refrained spatial attention from returning to a previously visited location, or that it increased or extended in time the facilitation effect. This explanation is also consistent with recent theoretical approaches that consider the IOR effect either as the result of the habituation of the orienting response (e.g., Dukewich, 2009) or the cost in detecting the target (i.e., a reduced capacity of the cued location or object to automatically capture attention again; see Lupiáñez, 2010). Within this framework, our results would suggest that physical exercise stressed the attentional system making it more reactive to peripheral stimuli, by decreasing the likelihood of habituation of the orienting response to peripheral potential targets. In the open sport context, this would be beneficial, as it would improve the capacity of the attentional system to respond to stimuli appearing at a given location, no matter whether exogenous attention had been allocated in that location previously or not. Both relevant and irrelevant (potentially harmful) stimuli would be processed more efficiently.

In sum, our results represent the first evidence that an acute bout of aerobic exercise can modulate the deployment of exogenous visual spatial attention, presumably by enhancing the capacity of exogenous spatial attention to respond to peripheral stimuli.

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