scientific reports

OPEN

Benefits of a light- intensity bout of exercise on attentional networks functioning

Enrique Sanchis-Navarro[1], **Fernando Gabriel Luna**[2], **Juan Lupiáñez**[3] & **Florentino Huertas**[4]✉

The effects of physical exercise on attentional performance have received considerable interest in recent years. Most of previous studies that assessed the effect of an acute bout of exercise on attentional performance have generally been approached by analysing single attentional functions in isolation, thus ignoring the functioning of other attentional functions, which characterizes the real perception-action environmental conditions. Here, we investigated the effect of two different intensities (light vs. vigorous) of acute exercise on attentional performance by using the ANTI-Vea, a behavioral task that simultaneously measures three attentional functions (phasic alertness, orienting, and cognitive control) and the executive and arousal components of vigilance. 30 young (age = 20.93; *SD* = 1.51 years*)* physically active participants (21 men and 9 women) completed three experimental sessions: the first one to assess their physical fitness and baseline performance in the ANTI-Vea, and the other two sessions (in counterbalanced order) to assess changes in attentional and vigilance performance after an acute bout of light- intensity vs. vigorous- intensity physical exercise. Beneficial effects on some accuracy scores (i.e., overall higher accuracy in the attentional sub-task and fewer false alarms in the executive vigilance sub-task) were observed in the light- intensity exercise condition compared to baseline and vigorous- intensity. Additionally, the RT score of phasic alertness was increased after the light- intensity exercise in comparison with baseline. The present findings suggest that a bout of acute exercise at light- intensity might induce some short-term beneficial effects on some aspects of attention and vigilance.

Keywords Exercise, Attention, Cognitive control, Orienting, Phasic alertness, Vigilance

Attention comprises a set of cognitive processes highly involved in daily life activities, such as working, studying, and sports practice. The attentional networks model by Posner and colleagues proposes that attentional functions are supported by three independent but interactive networks, i.e., alerting, orienting and cognitive control[1,2]. The cognitive control network, its function also known as a "executive function", is involved in the inhibition of irrelevant information and cognitive flexibility by a set of process such as planning, decision making, error detection, and execution of novel responses[3]. The orienting network regulates allocation of attention over a target or location in a voluntary-endogenous or involuntary-exogenous way, enhancing target processing while ignoring irrelevant objects/locations[4]. The alerting network is responsible of maintaining a general arousal and preparatory state for the quick detection of, and reaction to, the expected stimulus. The alerting network supports two different functions: phasic alertness and sustained attention. Phasic alertness is modulated by warning signals and increases arousal momentarily to act quickly. Instead, sustained attention, also known as vigilance, is responsible of maintaining a continuous state of activation during long periods, to correctly detect and quickly react to stimuli in the environment[5,6].

In the past few years, it has been proposed that vigilance can be considered to include two dissociated components, which modulate different behavioral responses of sustained attention[7–10]. On the one hand, executive vigilance (EV) can be defined as the ability to sustain attention for monitoring and detecting rare but critical events over an extended period of time. On the other hand, arousal vigilance (AV) rather reflects the capacity to quickly react to stimuli in the environment over long periods, without much control over responses[7].

[1]School of Doctorate, Catholic University of Valencia "San Vicente Mártir", Valencia, Spain. [2]Facultad de Psicología, Universidad Nacional de Córdoba, Córdoba, Argentina. [3]Department of Experimental Psychology, Mind, Brain, and Behaviour Research Centre (CIMCYC), University of Granada, Granada, Spain. [4]Department of Physical Education and Sport Sciences, Faculty of Physical Education and Sport Sciences, Catholic University of Valencia "San Vicente Mártir", Valencia, Spain. ✉email: florentino.huertas@ucv.es

How physical exercises affects these attentional functions either during[9,]], immediately after[11], or even after several days[12], or weeks[13], has been studied in previous years[14–16]. However, and critically, the effects of acute and chronic exercise on attentional networks' functions seem to be relatively diverse, depending on the characteristics of the exercise condition demanded (i.e., intensity[17] or duration[18]), the attentional function assessed[19], or even the cardio-respiratory fitness of participants[14,16,20].

Previous experimental research has shown that a single bout of exercise may be feasible to modulate the attentional networks functioning[11,21]. However, other studies did not observe an effect of a single bout of different intensities of exercise on attentional networks performance[22]. Empirical[17,23,24] and meta-analytical[14] research has shown that, although acute light to moderate exercise has in general a positive impact on attentional networks, there is a great variability in the observed outcomes, which seems to depend on, among other factors, the time relation between physical exercise and the cognitive task used, exercise intensity, and exercise mode.

Previous studies have examined the effects of different exercise's nature (i.e., resistance and endurance) and intensities on attentional networks' functions using single behavioral tasks, with particular interest on the assessment of cognitive control. A study by Altermann et al. compared the effects of three different modes of an acute bout of exercise (endurance, strength, and coordination) with a control group without exercise on cognitive control in adolescents, using the revised d2-test of attention[25]. The results indicated that all three exercise groups exhibited similar improvements in performance compared to the control group. In another study, Engeroff et al. compared different intensities of resistance exercises, showing that cognitive control improved after exercising at 75% and 90% of the one repetition maximum (1RM)[11]. Regarding endurance exercise, according to ACSM[26], exercise intensity is classified into five levels, very light (< 57% of HR_{max}), light (57–63% of HR_{max}), moderate (64–76% of HR_{max}), vigorous (77–95% of HR_{max}), and near maximal ((≧96% of HR_{max}). However, this classification has the difficulty that studies use different measures and labels of exercise intensity, as observed in the different studies mentioned in this manuscript such as Stroth et al.[22]. In a study conducted with cyclists comparing different exercise intensities, it was observed that cognitive control improved only after the most vigorous- intensity 95% of the Maximum Mean Power (MMP) and in the shortest duration (~ 3 min) condition[17]. Moreover, Mehren et al.[27] used a Go/No go task and a Flanker task to examine the effect of continuous vs. interval training endurance exercises, showing that cognitive control was improved after a moderate 30 min of very light to moderate exercise at 50–70% of maximum heart rate (HR_{max}) compared to 21 min of moderate to vigorous- intensity interval training.

Regarding the alerting network, the effect of acute exercise at different intensities was compared on phasic alertness in physically active elderly women[28]. The study by Córdova et al. found that acute cycling at 60% (moderate), 90% (vigorous), or 110% (vigorous) of anaerobic threshold accelerated responses in a simple reaction time (RT) task, a result that the authors interpreted as increased phasic alertness[28].

Concerning the orienting network, Llorens et al.[29] examined the effect of a bout of intense exercise on exogenous spatial orienting under three different conditions: at rest (without prior effort), immediately after an incremental moderate to vigorous exercise until reaching heart rate at the anaerobic threshold (HR_{AT}), and after recovery period following intense exercise. Conversely to the positive effects of acute exercise observed on phasic alertness and cognitive control, the results did not reveal any effect of moderate acute exercise on the exogenous spatial task´s performance. The effects of an intense bout of exercise on attentional orienting were also examined on performance in a visual search task: at rest vs. immediately after an acute bout of moderate to vigorous exercise (15 min at HR_{AT})[30]. Again, the results did not reveal any significant effect of the exercise condition on the detection of new objects. However, Sanabria et al. found that an acute bout of a light to moderate intensity exercise at 85% of anaerobic threshold modulates orienting, showing that the inhibition of return effect was eliminated under physical (aerobic) workload, and more interestingly, that such effect vanishes even when the exercise was performed prior to the cognitive task[31].

Taking into consideration physiological mechanisms such as Heart Rate (HR), catecholamines, and brain-derived factors influencing cognitive factors, the intensity level of the exercise is important for determining the changes in these physiological mechanisms and their behavioural effects[20,32]. Physiological evidence also predicts an inverted -U effect, where moderate- intensity exercise leads to increased cognitive performance, whereas vigorous exercise causes neural noise and consequently poor cognitive performance[20,32,20]. Additionally, the reticular-activating hypofrontality (RAH) model accounts for the psychological consequences of acute exercise, which benefits cognitive performance up to certain exercise intensities, at with point exercise deactivates the prefrontal cortex, leading to impairments in executive function[33].

Considering these previous findings, results are relatively diverse on how such acute exercise intensity modulates the different attentional functions, showing positive effects as an increase in accuracy, especially in cognitive control[17,34], or even null effects in other attentional functions[11,27]. It should be noted that most previous research analyzing the effects of acute exercise on attentional networks' functioning have mainly used behavioral tasks measuring a single attentional function in isolation. However, in the last decades, there has been a growing effort in behavioral research to develop suitable tasks for simultaneously assessing multiple attentional functions, such as the attentional networks test (ANT) and its variations (for a review, see de Souza Almeida and colleagues[35]). Therefore, the use of these attentional networks tasks are useful to overcome this methodological limitation. By assessing several attentional functions under the same participants' physical and attentional state, thus reducing variability of outcomes between studies that measures one attentional state, thus reducing variability of outcomes between studies that measures one attentional component at the via single behavioral tasks. Note that measuring several attentional functions under the same participant' physiological state (manipulated by the within-participant exercise condition) can contribute to dissociate modulatory effects of internal or external factors on one or several attentional components[5]. In previous research conducted in our lab, we observed that anodal transcranial direct current stimulation on the right fronto-parietal network specifically mitigates executive vigilance loss across time-on-task but not arousal vigilance nor modulates phasic alertness, attentional orienting, or cognitive control effects[8,36]. Moreover, we have also observed that changes in alpha but not delta, theta, beta, or gamma power anticipate failures in executive but not arousal vigilance[10]. Therefore, analyzing multiple effects measured at the same time in a task like the ANTI-Vea provides the possibility of examining beneficial or detrimental modulations by other factors on attentional networks' functioning under the same participant' state. Research using this methodology is scarce compared to those studies measuring one attentional component at the time with single tasks. By measuring several attentional functions simultaneously, it is easier to investigate whether exercise affect one, several, or none attentional function, while controlling for different participants' trait and state variables.

However, studies that have analyzed the effects of acute bout of exercise on attention performance using variations of attentional networks tasks are considerably scarce. For instance, Chang et al. compared the after-effects of from moderate to vigorous- intensity spinning for 30 min at 70–85% of HR_{max} against reading a book on attentional networks measured with the ANT[37]. The authors observed that physical exercise improved cognitive control but did not modulate phasic alertness nor orienting. A recent study investigated the effects of an acute bout of moderate exercise at 65% of HR_{max} under different cognitive challenges conditions on attentional networks functioning using the ANT-Revised task[37]. Results revealed a beneficial effect of exercise on cognitive control after the high-challenge condition.

A series of studies about the effects of exercise intensity on attentional networks functions have been also conducted in our labs, showing different effects as a function of exercise condition. Using the ANT for Interactions task (ANTI), Huertas et al.[39] explored the effects of three different activity conditions with a group of cyclists. They observed that, during moderate- intensity aerobic exercise (75% HR_{max}), there was an acceleration in RT and a reduction in the phasic alertness effect. Later on, using the same attentional task, the effect of caffeine intake on attentional networks' functioning during moderate- intensity cycling (80% of lactate threshold) or rest were examined[40]. Results showed that exercise led to faster RT and a reduced orienting effect. Similarly, in a recent study using the ANT for Interactions and Vigilance –executive and arousal components, (i.e., the ANTI-Vea, see Sect. 2.4 for a detailed description), it was found that moderate exercise intensity at 80% of second ventilatory threshold specifically improved RT for EV but not AV, compared to light- intensity exercise (80% of first ventilatory threshold), without impairing error rates[9]. Note however that the above cited studies[9,38,39] analyzed the effect of physical effort during exercise or at rest, but not after ending exercise. Indeed, to the best of our knowledge, there are no studies that have analyzed the effects of different intensities of acute bout of exercise after finishing it when multiple attentional and vigilance functions are simultaneously measured.

Considering the relative contradictory outcomes on how acute exercise affects the functioning of the attentional networks when measured by single attentional tasks and noting that only a few studies have addressed the effects of exercise intensities on several attentional functions measured at the same time, we decided to conduct the present study. We aimed to analyze the effects of an acute bout of light vs. vigorous exercise on phasic alertness, orienting, and cognitive control, as well as on executive and arousal components of vigilance just after finishing exercise. Following the previous literature[11,17,20,29,30,32,33], we expected to observe improved overall performance (i.e., faster RT and higher accuracy), and especially a benefit in cognitive control functioning (i.e., reduced interference), after an acute bout of light- intensity than in baseline condition or after an acute-bout of vigorous- intensity exercise.

Materials and methods

Participants

Sample size was a priori estimated using G* power 3.1[41], based on the effect size *($\eta^p_2 = 0.18$)* of exercise for overall RT in the ANTI sub-task of Sanchis et al.[9]. We estimated that at least 14 participants would be needed to replicate the above-mentioned effect with a power of $1\text{-}\beta = 0.95$ and a significance criterion of $\alpha = 0.05$ through a repeated-measures ANOVA with the design of the present study, that is, one within-participant factor (exercise intensity) of three levels (baseline/light- intensity/vigorous- intensity). We decided to double the a-priori estimated sample size, given that in this study we had other measures of interest, for which we aimed at collecting data from 30 participants, similar to the sample size of Sanchis et al. with the ANTI-Vea task[9]. Furthermore, anticipating possible dropouts, and noncompliance with inclusion criteria, we decided to collect data form 36 participants for this experimental and crossover study.

However, 6 participants were discarded from data analysis due to the following reasons: 4 because they withdraw from the study without completing all the sessions, 1 due to exclusion criteria (sleep deprivation the night before data collection), and another one because of technical issues with data collected with the online ANTI-Vea task. Therefore, 30 young physical active participants (21 men and 9 women), with an average age of 20.93 years *($SD = 1.51$)*, participated in the study. They were undergraduate university students who did not follow a structured or supervised training plan, did not compete at federative level, and did not practice cycling or spinning more than 2 h per week. The objective was to observe the effects of two different intensities in physical active young people who were not high-performance athletes. Indeed, confirming this, their average absolute MMP was of 225 W *($SD = 51$)* and their average of relative MMP was of 3.34 W^*Kg^{-1}*($SD = 0.58$)*.

Participation in this study was voluntary, although some participants received course credits for their participation according to the regulations of Catholic University of Valencia. All participants were properly informed regarding the potential risks and benefits of the study and signed an informed consent document prior to participation. The study was conducted according to the ethical standards of the 1964 Declaration of Helsinki (last update: Fortaleza, 2013) and approved by the Ethical Committee of the Universidad Católica de Valencia "San Vicente Martir" (project code UCV/2020–2021/173).

Material

An indoor cycling trainer Cardgirus W3+ (G&G Innovation, Sabadell, Spain) was used to measure the MMP and for controlling exercise intensity during the experimental sessions. HR was monitored with a chest band by Garmin (Garmin HRM-Dual™, USA). The online ANTI-Vea[42,43] was run in a desktop computer from the ANTI-Vea-UGR platform (https://anti-vea.ugr.es*)*.

Procedure

Participants were cited at the laboratory in 3 sessions at different days, separated by at least 72 h (average days between sessions = 8.2; *SD* = 4.6). In addition, 48 h prior to the first session, aiming to familiarize the participants with the task, they completed at home the standard practice blocks of the ANTI-Vea task (i.e., three progressive practice blocks with visual feedback and half of an experimental block without visual feedback) plus one experimental block. These results were analysed with the aim to guarantee a minimum level of comprehension of the task, but these were not included in the planned statistical analyses. In the first session, the ANTI-Vea was completed as baseline before an incremental cycling physical fitness test. During the following two sessions, the ANTI-Vea was performed after a vigorous or a light- intensity exercise in a counterbalanced order across participants. To avoid any residual fatigue, participants were asked to refrain strenuous exercise at least 72 h before each experimental session.

First session: baseline and incremental test

Participants completed three experimental blocks of the ANTI-Vea task[7] that were considered as baseline (i.e., attentional functioning under rest condition). Subsequently, an incremental cycling test with an initial power of 20 W was carried out, which was increased progressively and automatically by 5 W every 15 s, until the participant was unable to maintain a cadence above 60 rpm for more than 5 s, or when the participant's HR reached 95% of its theoretical maximum from Karvonen's formula[44]. The aim of this test was to establish the individual MMP, which was used to define the exercise workload for the following sessions. MMP was calculated as the average of maximum power during 30 s.

Acute bout of exercise sessions: vigorous vs. light- intensity exercise

The vigorous- intensity session included an incremental exercise until the participant´s exhaustion or when the participant was unable to maintain a cadence above 60 rpm for more than 5 s. When participant's MMP value was between 200 W and 230 W, the workload was increased by 5 W every 40 s. In case the participant's MMP value was between 230 and 260 W, the workload was increased by 5 W every 35 s and so on, i.e. for every 30 W interval, the time needed to increase the power by 5 W was reduced by 5 s. This manipulation was done to maintain the duration of the exercise between participants. The average time for participants to reach exhaustion was 23 min 9 s (SD = 3,1).

The light- intensity session consisted of 21 min exercise, structured in a 2 min warm up cycling at 20% of participant's MMP, following 18 min at 30% MMP, and a final cool down of 1 min at 20% MMP.

HR, power output and the Rate of Perceived Exertion (RPE) were recorded during both exercise sessions to check that the manipulation of exercise intensity modulates the external and internal load. RPE scale was based on a range between 6, being the least amount of exertion, and 20 being the maximum level of exertion[45]. RPE was asked each minute during the vigorous- intensity exercise and every five minutes during light- intensity exercise. The timing of RPE measurement differed for the two exercise intensity conditions because light- intensity maintains a constant intensity, while vigorous exercise increases progressively. Immediately after ending the vigorous or light- intensity exercise in each session, participants sat in front of the computer to complete three experimental blocks of the ANTI-Vea task.

Behavioral task: ANTI-Vea

The online version of the ANTI-Vea task was used (https://anti-vea.ugr.es/*)*. The ANTI-Vea[7] is a behavioral task suitable to assess the independence and interactions of the attentional functions measured by the ANT for Interactions task[46] (i.e., phasic alertness, orienting and cognitive control), and two vigilance components (i.e., EV and AV). The ANTI-Vea task combines three different types of trials, which are randomly presented: ANTI (60%), EV (20%) and AV (20%). Participants completed only three experimental blocks without breaks (duration of task: 16 min and 24 s), to avoid excessively lengthening the duration of each visit and as vigilance decrement was not an effect of interest in the present study, we decided to use three blocks of trials in the ANTI-Vea, as this size of trials has been shown to be enough to estimate the main indexes measured in the task[47].

In the ANTI trials, a string of five arrows is presented and participants had to respond according to the direction pointed by the target, i.e., the central arrow, while ignoring the direction of the surrounding flanking arrows (see Fig. 1 panel a). The target could be anticipated by an auditory warning signal and a visual spatial cue. Cognitive control was measured as a function of the interference between the flanking and target arrows, i.e., the difference between congruent trials (50% of ANTI trials) and incongruent trials (50% of ANTI trials) (see Fig. 1 panel d). Orienting was measured as a function of the location of the visual cue regarding the target position (see Fig. 1, panel c), i.e., valid cue (33,33% of ANTI trials), invalid cue (33,33% of ANTI trials), and no cue (33,33% of ANTI trials) (see Fig. 1 panel c). Phasic alertness was measured as a function of the presence (tone condition, 50% of ANTI trials) or absence (no tone condition, 50% of ANTI trials) of the auditory warning signal presented before target onset (see Fig. 1 panel a).

EV trials had the same procedure than the ANTI ones, except that the target was vertically displaced from its central position. Participants had to detect the infrequent vertical displacement of the target by pressing the space bar key, while ignoring the direction pointed by the target (see Fig. 1, panel d). For measuring EV, hits were computed as the percentage of correct responses in EV trials And false alarms (FA) as the percentage of

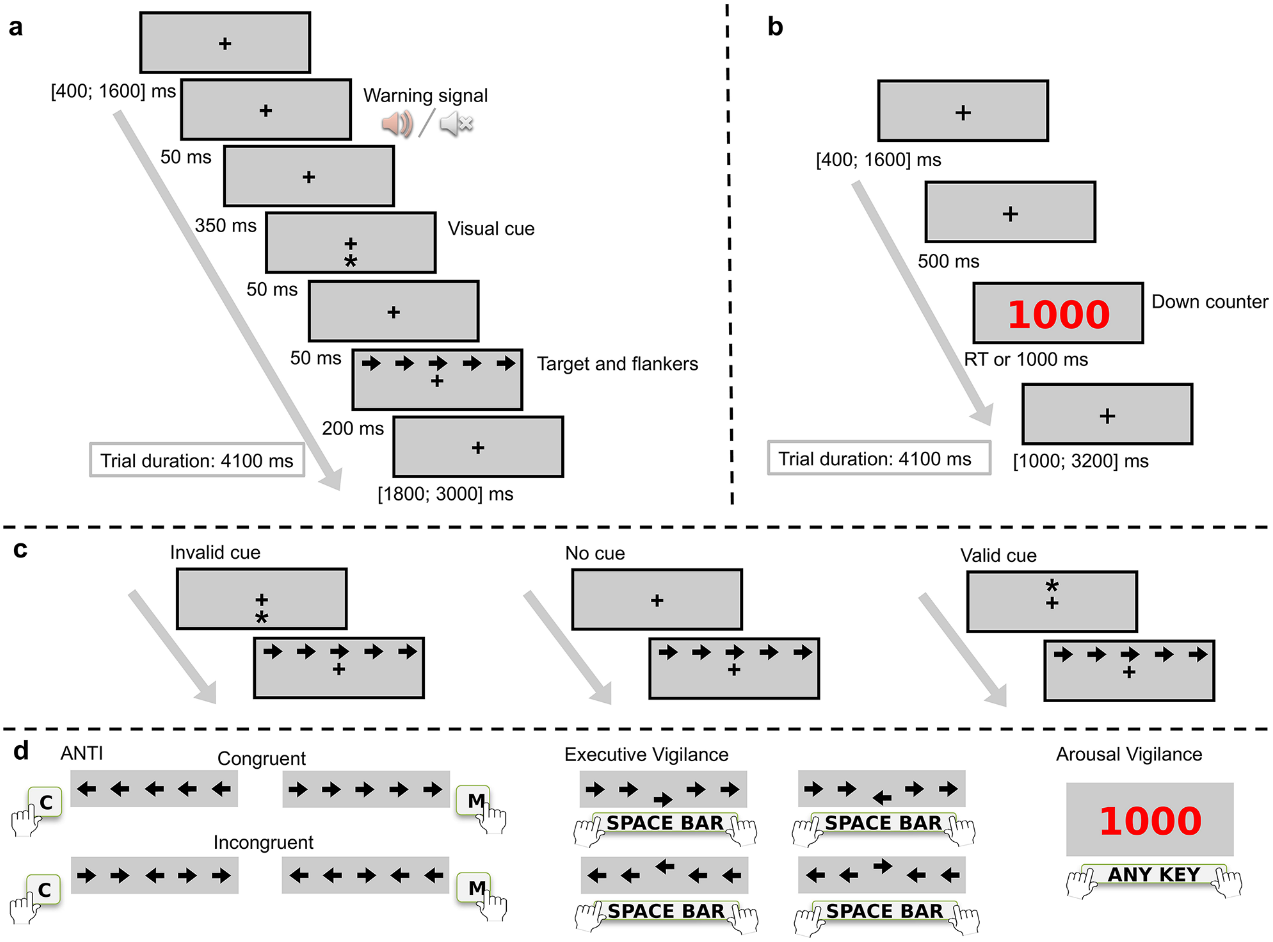

Fig. 1. ANTI-Vea design. Experimental procedure and stimuli sequence of (**a**) both ANTI and executive vigilance trials and (**b**) arousal vigilance trials. (**c**) Example of visual cue conditions. (**d**) Correct responses for each type of trial. Figure modified from Cásedas et al.[49].

space bar responses in ANTI trials, that is, when the target was not largely displaced, following the procedure by Luna et al.[48].

Lastly, in AV trials, no tone, visual cue, or arrows were presented, and instead a red millisecond counter appeared in the centre of the screen, starting at 1000 and going down to zero (see Fig. 1, panel b). Participants were asked to stop the counter as fast as they could by pressing any key of the keyboard (see Fig. 1, panel d). For measuring AV, mean RT, SD of RT, and the percentage of lapses (i.e., responses slower than 600 ms) were computed as dependent variables in AV trials.

Statistical analyses

All statistical analyses were performed using JASP software (Version 0.14.1.0, JASP Team, The Netherlands)[50]. Paired *t*-tests were used to analyze the effect of exercise conditions (light vs. vigorous- intensity) on the internal and external load (mean power output, RPE and HR). In the ANTI trials, for RT analyses, trials with incorrect responses (5.48%) and those with RT below 200 ms or above 1500 ms (0.83%) were excluded, as in Luna et al.[42]. Then, different repeated-measures ANOVAs were conducted including, as within-participant factors, exercise condition (baseline, vigorous- intensity, light- intensity), and a different variable for the analysis of each attentional network: tone (no tone, tone) for phasic alertness, cue (invalid, no cue, valid) for orienting, and congruency (incongruent, congruent) for cognitive control. Different ANOVASs were conducted with mean correct RT and the percentage of correct responses as dependent variables. Pairwise comparisons were conducted to further explore significant main effects and interactions.

For EV trials, separated repeated-measures ANOVAs were conducted, with exercise (baseline, vigorous-intensity, light-intensity) as within-participant factor and the percentage of hits, FA, or mean RT on hits (1.29% of trials with RT below 200 ms or above 1500 ms excluded) as dependent variable. Finally, for AV trials, three repeated-measures ANOVAs were performed with mean RT, SD of RT, or the percentage of lapses as dependent variable, and including exercise (baseline, vigorous- intensity, light- intensity) as a within-participant factor.

Then, to determine the available evidence in favour or against our hypotheses, Bayesian analyses for each attentional effect and vigilance measure of interest were conducted as a function of exercise conditions.

Physiological variables	Light- intensity	Vigorous- intensity
Power Output (W)*	66.87 (15.08)	109.90 (32.79)
Relative Power Output (W.kg^{-1})*	1.00 (0.25)	1.63 (0.45)
HR (bpm)*	119.53 (15.31)	155.48 (18.87)
% HRmax (%)	60.00 (7.70)	78.07 (9,48)
RPE *	10.06 (2.25)	17.67 (10.06)

Table 1. Mean and standard deviation (between parentheses) of physiological variables measured at different exercising conditions. *HR* Heart Rate, *BPM* Beats per minute, $\%HR_{max}$ Percentage of maximal Heart Rate, *RPE*Rate of Perceived Exertion. *$p < .001$ between exercise conditions

Attentional measures		Baseline		Light- Intensity		Vigorous- Intensity	
Factor	**Levels**	**RT**	**Accuracy**	**RT**	**Accuracy**	**RT**	**Accuracy**
Alertness *	Tone	656111)	94.10(5.80)	635(85)	96.70(4.90)	632(93)	95.10(6.80)
	No tone	678(107)	94.40(6.80)	673(87)	95.10(6.00)	672(97)	93.70(6.00)
	Index	22(33)	-0.30(6.00)	39(39)	1.60(5.10)	41(37)	1.40(4.30)
Orienting	Valid cue	653(110)	92.20(6.00)	641(93)	95.70(5.20)	641(101)	92.90(6.00)
	No cue	667(107)	94.20(5.60)	654(84)	95.90(4.90)	652(93)	94.40(6.10)
	Invalid	691(11)	94.30(5.50)	675(99)	96.50(4.50)	671(99)	94.20(5.30)
	Index	38(37)	2.10(4.70)	33(21)	0.80(3.60)	30(28)	1.30(4.70)
Cognitive control	Congruent	662(111)	92.60(6.30)	648(93)	95.40(5.60)	651(99)	92.70(7.00)
	Incongruent	679(110)	94.50(5.60)	665(91)	96.70(3.50)	659(97)	95.00(4.10)
	Index	16(25)	1.90(4.30)	16(22)	1.30(3.20)	8(26)	2.30 (4.90)

Table 2. Table 2, Mean and SD (between parentheses) of attentional networks functions for mean correct RT (ms) and Accuracy (%) as a function of exercise condition. RT Phasic alertness Index = No tone - Tone; RT Orienting index = Invalid – Valid ; RT Cognitive control index = Incongruent – Congruent ; Accuracy Phasic alertness Index = Tone – No Tone; Accuracy Orienting index = Valid – Invalid; Accuracy Cognitive control index = Congruent - Incongruent. *$p < .05$ between exercise conditions.

For Null Hypothesis Significance Testing (NHST) analyses, the alpha level was set at $p < .05$ for paired *t*-test and repeated-measures ANOVAs. The partial eta squared (η^2_p) effect size is reported in ANOVAs, which indicates small ($\eta^2_p > 0.01$), moderate ($\eta^2_p > 0.06$), or strong ($\eta^2_p > 0.14$) effect sizes. The Cohen's *d* effect size is reported in *t*-tests, which indicates small ($d > 0.2$), medium ($d > 0.5$), and large effect sizes ($d > 0.8$)[51–53]. Bayesian's results revealed whether data provide evidence supporting the alternative hypothesis with Bayes Factors (BF) as BF_{10} larger than 3 (the larger the BF the larger the supporting evidence), or supporting the null hypothesis, when the value of BF_{01} is larger than 3[54,55].

Results

Exercise effect on physiological variables

As expected, the load adjustment showed differences in the physiological dependent variables, evidenced by higher values in Power Output, $t(29) = 10.99$, $p < .001$, $d = 2.04$; Relative Power Output, $t(29) = 12.395$, $p < .001$, $d = 2.263$; HR, $t(29) = 15.24$, $p < .001$, $d = 2.19$; and RPE, $t(29) = 17.48$, $p < .001$, $d = 3.25$, for the vigorous than for the light- intensity condition (see Table 1).

Attentional functioning

Table 2 and Fig. 2 show the descriptive results across all attentional networks and effort conditions. RT analyses showed the typical main effects usually observed with the ANTI-Vea[7], supporting the effectiveness of the task in assessing the classic attentional functions in the current study. A significant main effect of tone was observed, $F(1, 29) = 51.14$, $p < .001$,$\eta^2_p = .64$, with faster responses in the tone than in the no tone condition. The main effect of orienting was also significant, $F(2, 58) = 52.05$, $p < .001$, $\eta^2_p = .64$, with faster responses in the valid than in no cue, $t(29) = 3.76$ $p < .001$, $d = 0{,}686$ and invalid trials, $t(29) = 10.09$ $p < .001$, $d = 1{,}84$, and faster responses in the no cue than in the invalid trials $t(29) = 6.36$ $p < .001$, $d = 1{,}16$. Lastly, the main effect of congruency was also significant, $F\ (1, 29) = 20.12$, $p < .001$, $\eta^2_p = 0.41$, with faster responses in the congruent than in the incongruent condition.

Regarding accuracy, the main effect of visual cue was significant $F(2, 58) = 4.84$, $p = .011$, $\eta^2_p = .14$, with higher accuracy in invalid than valid trials, $t(29) = 2.84$ $p = .019$, $d = 0{,}58$, and with higher accuracy in no cue than in valid trials, $t(29) = 2.53$ $p = .028$, $d = 0{,}462$, being not significant the difference between invalid and no cue trials, $t(29) = 0.31$ $p = .762$, $d = 0{,}06$. The main effect of congruency was also significant, $F(1, 29) = 10.65$, $p = .003$, $\eta^2_p = .26$, showing a reversed pattern of outcomes, with higher accuracy in incongruent than congruent trials. Lastly, response accuracy was not modulated by tone, $F(1, 29) = 1.82$, $p = .188$, $\eta^2_p = .01$ (see table 2).

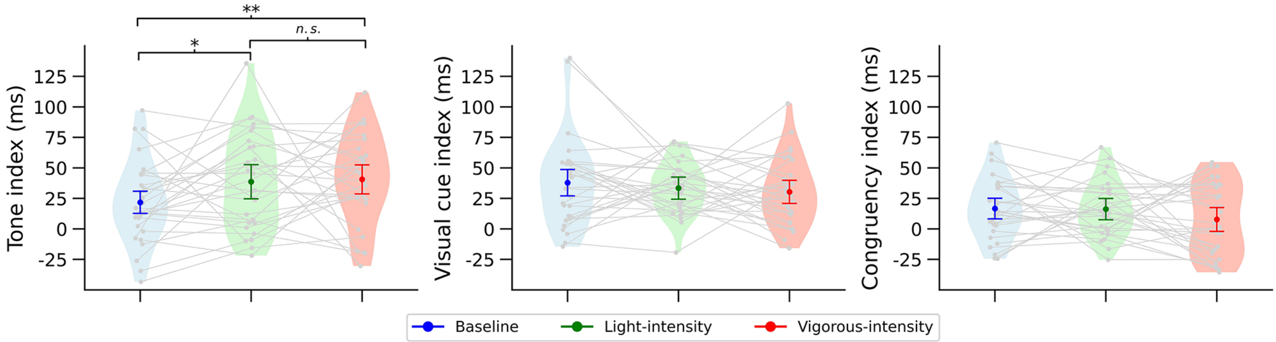

Fig. 2. Attentional RT index. Color dots represents the mean and bars the 95% confidence intervals of the mean computed by the Cousineau method, corrected by Morey (2008)[56]. Gray dots represent each participant' score on each exercise condition, linked to each other through gray lines. * $p < .05$ and ** = $p < .01$.

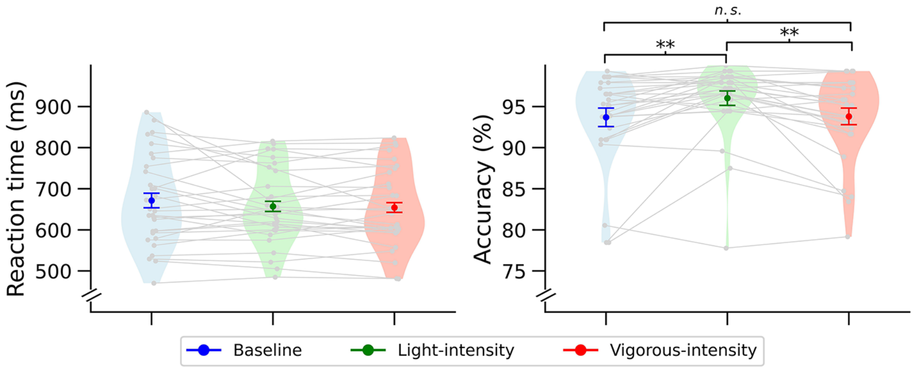

Fig. 3. Overall performance in ANTI trials. Color dots represents the mean and bars the 95% confidence intervals of the mean computed by the Cousineau method, corrected by Morey (2008)[56]. Gray dots represent each participant' score on each exercise condition, linked to each other through gray lines. ** = $p < .01$.

Attentional functioning and exercising condition

Overall performance in ANTI trials

Exercise condition did not modulate the overall mean RT, $F(2, 58) = 1.52$, $p = .227$, $\eta^2_p = 0.05$. However, the overall response accuracy was influenced by exercise, $F(2, 58) = 7.49$, $p = .001$, $\eta^2_p = 0.205$, showing higher accuracy in the light *(M = 96,00%; SD = 4.40%)* than in the vigorous- intensity condition ($M = 93.80\%$; SD = 5.60), $t(29) = 3.16$, $p = .005$, $d = 0.58$, and the baseline condition, (M = 93.80%; SD = 5.20), $t(29) = 3.52$, $p = .003$, $d = 0.64$, with no statistical differences between vigorous- intensity and baseline, $t(29) = 0.34$, $p = .718$, $d = 0.07$ (see Fig. 3).

The Bayesian analysis showed strong evidence for larger accuracy after the light- intensity exercise than after vigorous- intensity exercise ($BF_{10} = 29.82$) and during the baseline- resting condition ($BF_{10} = 23.11$). In other words, the presence of a beneficial effect of light- intensity exercise was 23 times more likely than its absence, in comparison to baseline (almost 30 times more likely in comparison with vigorous- intensity). In contrast, Bayesian analysis rather showed evidence supporting the absence of any effect of exercise for overall RT ($BF_{01} = 5.05$).

Phasic alertness

Exercise had a significant, albeit small, modulatory effect on phasic alertness in the RT score, $F(2, 58) = 3.20$, $p = .048$, $\eta^2_p = 0.01$. The two exercise- intensity conditions did not significantly differ from each other, $t(29) = 0.20$, $p = .842$, $d = 0.04$. However, a larger phasic alertness effect was observed in the vigorous- intensity condition compared to the baseline, $t(29) = 2.97$, $p = .006$, $d = 0.54$, and in the light- intensity condition compared to the baseline, $t(29) = 2.07$, $p = .047$, $d = 0.38$. Concerning accuracy, the analysis did not reveal any significant modulation of exercise on phasic alertness $F(2, 58) = 1.44$, $p = .246$, $\eta^2_p = 0.05$.

The Bayesian analysis of the modulation of exercise on phasic alertness for RT showed moderate evidence for the presence of a beneficial effect of light- intensity in comparison to baseline ($BF_{10} = 4.10$), whereas evidence was inconsistent regarding the difference of vigorous- intensity against baseline ($BF_{10} = 1.25$). In contrast, for accuracy, evidence analyzed supported the absence of any type of exercise effect ($BF_{01} = 5.10$).

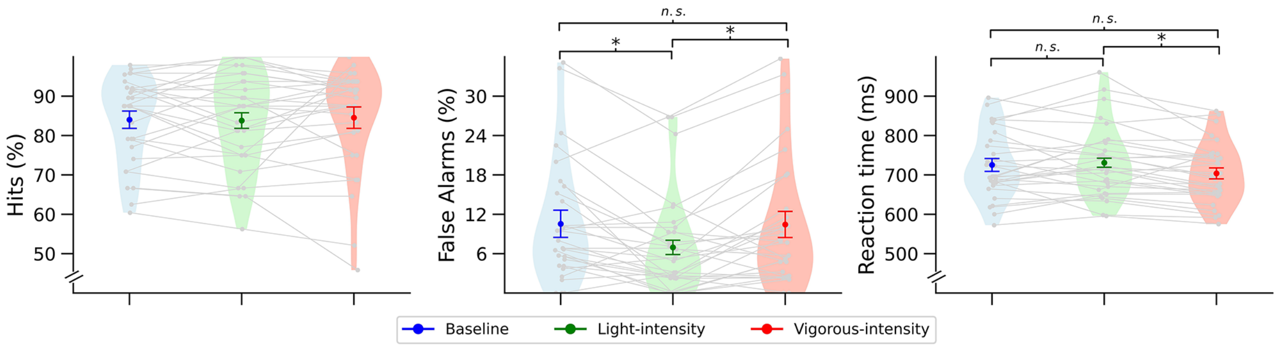

Fig. 4. Overall performance in EV. Color dots represents the mean and bars the 95% confidence intervals of the mean computed by the Cousineau method, corrected by Morey (2008)[56]. Gray dots represent each participant' score on each exercise condition, linked to each other through gray lines * = $p < .05$.

EV	Baseline	Light- Intensity	Vigorous- Intensity
FAs (%)	10.80 (9.20)	7.00 (7.60)	10.50 (10.00)
Hits (%)	84,10 (11.)	83,80 (12.30)	84.40(13.20)
Mean RT (ms)	725 (84)	731 (91)	706 (78)

Table 3. Mean and SD (between parentheses) for executive vigilance (EV) scores as a function of exercise condition.

Orienting

Exercise did not significantly influence orienting for RT, $F(4, 116) = 0.34$, $p = .854$, $\eta^2_p = 0.01$, nor response accuracy, $F(4, 116) = 0.87$, $p = .482$, $\eta^2_p = 0.03$.

The Bayesian analysis showed evidence supporting the absence of a modulation of exercise on orienting for both RT ($\text{BF}_{01} = 4.57$) and accuracy ($\text{BF}_{01} = 4.27$).

Cognitive control

Cognitive control was not modulated by exercise condition neither for RT, $F(2, 58) = 1.31$, $p = .277$, $\eta^2_p = 0.04$, nor for accuracy, $F(2, 58) = 0.63$, $p = .537$, $\eta^2_p = 0.02$.

The results of Bayesian analysis provided evidence rather supporting the absence of modulation of exercise intensity on cognitive control, both for RT ($\text{BF}_{01} = 2.42$) and accuracy ($\text{BF}_{01} = 2.60$).

Executive vigilance (EV)

Exercise condition modulated the percentage of FAs, $F(2, 58) = 5.97$, $p = .004$, $\eta^2_p = 0.17$. As depicted in Fig. 4, participants showed lower percentage of FAs after the light than the vigorous- intensity exercise, $t(29) = 2.9$, $p = .011$, $d = 0.53$, and after the light than the baseline condition $t(29) = 3.08$, $p = .010$, $d = 0.56$. FAs were not significantly different between the vigorous- intensity and the baseline condition $t(29) = 0.18$, $p = .860$, $d = 0.03$. Exercise did not significantly modulate the percentage of hits, $F(2, 58) = 0.07$, $p = .931$, $\eta^2_p < .01$ (see Table 3; Fig. 4).

Furthermore, although mean RT in hits is not typically analyzed for EV in the ANTI-Vea, we nevertheless analyzed it in an exploratory way, motivated by previous findings of effect of exercise intensity on RT of EV[9]. Our results showed a significant main effect of exercise for mean RT in hits, $F(2, 58) = 3.59$, $p = .034$, $\eta^2_p = 0.11$. Responses were faster after the vigorous compared to the light- intensity condition, $t(29) = 2.55$, $p = .040$, $d = 0.47$, while no significant differences were found between vigorous- intensity and baseline, $t(29) = 1.98$, $p = .104$, $d = 0.36$, nor between light- intensity and baseline conditions, $t(29) = 0.57$, $p = .570$, $d = 0.19$ (see Table 3; Fig. 4).

The Bayesian analysis showed strong evidence for fewer FAs after the light- intensity exercise than after vigorous- intensity exercise ($\text{BF}_{10} = 26.47$) and in the baseline ($\text{BF}_{10} = 25.71$). In other words, the presence of a beneficial effect of light- intensity exercise was 26 times more likely than its absence, in comparison to vigorous-intensity (26 times more likely in comparison with baseline). In contrast, the analysis showed, that the evidence did not support any difference in FAs between vigorous- intensity and baseline ($\text{BF}_{01} = 5.09$). The analysis of RT in hits also showed substantial evidence supporting faster responses after vigorous- intensity than after light-intensity ($\text{BF}_{10} = 10.27$), with evidence supporting the lack of differences between baseline and light- intensity exercise ($\text{BF}_{01} = 4.44$) and between vigorous- intensity and baseline ($\text{BF}_{01} = 1.39$). In other words, the presence of a beneficial effect of vigorous- intensity exercise was 10 times more likely in comparison to light- intensity. In contrast, the Bayesian analysis showed evidence supporting the absence of an effect of exercise intensity on hits ($\text{BF}_{01} = 4.60$).

AV score	Baseline	Light- intensity	Vigorous- intensity
Mean RT (ms)	490.03 (67.62)	484.83 (73.78)	483.16 (71.88)
SD of RT (ms)	65.95 (15)	65.61 (20.94)	64.18 (22.88)
Lapses	11.40 (24.60)	10.80 (22.10)	11.00 (22.90)

Table 4. Mean and SD (between parentheses) for arousal vigilance scores as a function of exercise condition.

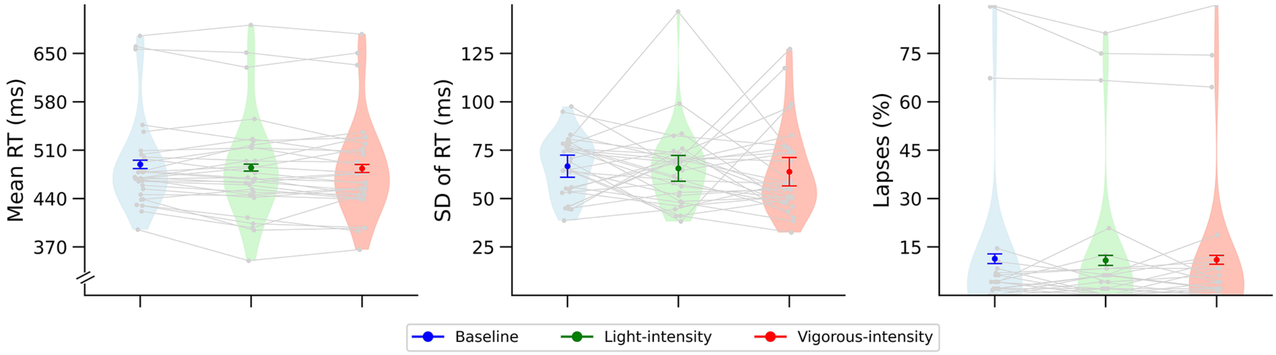

Fig. 5. Overall performance in AV. Color dots represents the mean and bars the 95% confidence intervals of the mean computed by the Cousineau method, corrected by Morey (2008)[56]. Gray dots represent each participant' score on each exercise condition, linked to each other through gray lines.

Arousal Vigilance (AV)

Exercise condition did not modulate mean RT, $F(2, 58) = 1.86$, $p = .172$, $\eta^2_p = 0.06$, nor SD of RT, $F(2, 58) = 0.08$, $p = .919$, $\eta^2_p < 0.01$, nor the percentage of lapses, $F(2, 58) = 0.18$, $p = .834$, $\eta^2_p = < .01$ (see Table 4; Fig. 5).

Discussion

The present study aimed to analyze the effects of an acute bout of light- vs. vigorous-intensity exercise on several attentional and vigilance components. To do so, an experimental and crossover study was conducted. Participants completed three sessions to compare attentional functioning during a baseline- resting situation with two exercise conditions (after light- vs. after vigorous-intensity cycling) using the ANTI-Vea task.

To the best of our knowledge, this study represents the first attempt to investigate the effects of an acute bout of different physical exercise intensities on phasic alertness, orienting, cognitive control, as well as EV and AV. Previous studies analyzed the effects of acute exercise performed at different intensities on the different attentional networks[11,27], although using behavioral tasks measuring a single attentional function. However, measuring several attentional functions under the same participant state can contribute to dissociate modulatory effects of internal or external factors on one or several attentional components[5]. Therefore, the significance of analysing multiple effects measured in a task like the ANTI-Vea, as in the present study, is the possibility to determine beneficial or detrimental modulations by other factors on specific attentional networks' functions. It is worth noting that Chang et al. examined the effect of acute exercise on phasic alertness, orienting and cognitive control by using the ANT[57], which did not measure the EV and AV[37]. Additionally, the study by Chang et al.[37] did not compare different exercise intensities.

As expected, our manipulation of exercise condition on the physiological response was confirmed by the overall values of power output, relative power output, HR, and RPE. According to ACSM[26], the exercise intensity used in this study is considered light- intensity since the average HR is 60% of HR_{max}, based on the formula of Tanaka et al.[58]. On the other hand, the condition of exercise to exhaustion corresponds to vigorous- intensity, as an average of 78.07% of HRmax was observed. However, as mentioned above, the ACSM[26] classification presents a challenge, as different studies utilize different measures and/or labels of exercise intensity, as observed in the studies cited in this manuscript. It is recommended that future research adopt the ACSM[26] classification to standardize exercise intensity measures across studies.

In addition, the typical main effects usually observed by the ANTI-Vea were observed in RT analyses, supporting the effectiveness of the task in measuring attentional functioning in the present study. More importantly, and regarding the effect of the exercise on attentional functioning, our results showed that, while an acute bout of light-intensity of exercise improved overall accuracy, reduced false alarms, and increased the RT score of phasic alertness, a vigorous-intensity exercise seemed to reduce RT in the EV sub-task.

In line with our predictions, overall response accuracy improved after a light-intensity exercise in comparison to both the baseline condition and after a vigorous- intensity exercise in the attentional networks sub-task. These results are consistent with previous research in which participants performed physical exercise before attentional tasks[11,20]. This beneficial effect of light-intensity exercise on response accuracy could be attributed to the fact that moderate-intensity exercise optimally increases the concentration of cortisol and catecholamines in the brain. On the other hand, exercising at higher intensity results in an excessive increase in this hormone and neurotransmitter concentration, which may not have a beneficial effect and could even be detrimental to the speed and accuracy of motor responses[59–61] according with the inverted U theory and the RAH model[20,32,33]. As mentioned earlier, light- intensity could almost be considered as moderate- intensity. Therefore, this intensity could increase the concentration of neurotransmitters (catecholamines and cortisol). Nevertheless, it is important to note, as a limitation of the current study, such that these blood or salivary measures were not included in our design. Future research could try to replicate our findings adding the analyses of cortisol and catecholamines concentration to test whether our interpretation of the observed data pattern is correct.

On the other hand, and contrary to our hypothesis and previous studies in the field[9], exercise condition did not modulate the overall RT. It is noticeable that the difference between our study and the previous one by Sanchis et al. remains in the fact that they compared the online effects of light- vs. moderate- intensity during exercise[9] whereas we analysed post- exercise effects. These controversy between findings obtained in the above-mentioned study (cycling + manual response to stimuli during exercise)[9] and our study (response after ending the exercise) could be explained by the different cognitive and motor resources needed in the previous one[9]. In Sanchis et al., participants had to perform the complex ANTI-Vea task while pedalling at a certain intensity level[9], in contrast to the present study in which participants performed the ANTI-Vea after, not while pedalling. Additionally, and although exercise can increase dopamine, norepinephrine, cortisol and catecholamine concentrations during and after physical activity[20,59–61], this unexpected result might be attributed to the fact that activating effects on RT, related with motor response, disappear more quickly than on accuracy, more related with perception and decision making, after exercise cessation[62]. In any case, differences in the effect of exercise on response depending on the contextual demands (single vs. dual task) should be further replicated in future studies in which participants could be tested in all the exercise and contextual conditions in a counterbalanced order.

Regarding the effect of exercise condition on attentional functioning, and also contrary to our hypothesis based on previous studies[11,17,25,27], our results showed that cognitive control was not modulated by exercise. However, it is important to note that our descriptive results revealed a reduced congruency effect of 13.7 ms on average with respect to other previous studies using the ANTI-Vea (e.g., 44 ms in Luna et al.[42] and 35 ms in Sanchis et al.[9]). This reduced congruency effect, evidenced even in the baseline condition (17 ms), raises questions about the discrepancy between our study and the trend generally observed in the ANTI-Vea task, which seems to be due to different reasons. One possibility might be that participants only performed three blocks of trials in our study, while 6 blocks are typically performed, and the congruency effect has been shown to increase across blocks of trials in the ANTI-Vea[63]. It could also be plausible that this pattern is specific to the sample of participants in the present study, although this cannot be confirmed. In any case, it is worth noting that such small congruency effect may complicate the detection of significant changes due to the exercise conditions in the present study. Therefore, we consider crucial to replicate these findings in future studies, especially those that include task familiarisation, baseline, and exercise sessions conditions, to gain a more complete and accurate understanding of the modulation of online/offline exercise intensities on cognitive control.

Concerning phasic alertness, our results showed that both exercise conditions led to a significant larger phasic alertness effect compared to the baseline level. Hence, our study's results align with previous studies in terms of observing faster RT after exercise, which only occurred when taking advantage of the alerting tone. Note that overall RT seems to be more similar across exercise conditions, and compared to baseline, in the no tone trials, but not in the tone trials, in which the light and vigorous conditions showed faster RT than the baseline (see descriptive statistics in Table 2). Our pattern of results is contradictory to that observed by Huertas et al.[39], showing faster RT during moderate aerobic than in rest condition, although contrary to our findings, the exercise effect was larger in no tone trials than in tone ones. The discrepancy in results between our study and that of Huertas et al.[39] could be attributed to several methodological differences. In our study, the task is performed immediately after exercise, whereas in Huertas et al.[39], it was conducted during exercise. This difference might explain why no significant variations between the three exercise conditions are found in the no tone trials in our study, likely due to the recovery phase, while differences are observed in the tone trials, possibly due to increased reactivity following post-exercise activation. Additionally, this difference in results might also be related to the nature and intensity of the exercises used in each study. In Huertas et al.'s study, differences are observed in the moderate- intensity condition, whereas in our study, the intensity is lower (light). Regarding the vigorous exercise condition, our study employs an incremental test to exhaustion, while Huertas et al.'s study uses a continuous and steady exercise. These differences in exercise protocols could contribute to the variation in the results observed between the two studies. Furthermore, these results are in line with the interpretation of Córdova et al., in which there is an increase in post-exercise phasic alertness[28].

However, note that Bayesian analysis showed that evidence was inconsistent regarding the difference between vigorous- intensity and baseline, as $BF_{10} < 3$. The fact that NHST showed significant differences between vigorous- /light- intensity against baseline, but Bayesian analysis showed only moderate evidence supporting a beneficial effect of light-intensity exercise on RT, while providing inconsistent evidence regarding the beneficial effect of vigorous- intensity on RT, might limits further interpretations about phasic alertness modulation by exercise intensities. Noting the discrepancy between NHST and Bayesian analysis, it seems necessary to collect further evidence on this modulatory effect in future studies, by testing larger sample sizes and/or conducting replication studies.

With regards to the functioning of the orienting network, and according to previous studies[29,30,37,38], our results did not show any modulation of exercise on the visual cue effect. Only Llorens et al. revealed that, after the bout of vigorous- intensity exercise, only low-fit participants showed a reduced orienting (exogeneous spatial attention) effects compared to rest conditions, whereas fit participants showed similar performance in both experiment conditions[30]. It might be the case that participants of the present study (which most of them were students of Sport Sciences) were enough fit to not show any effect of exercise on orienting. Divergences among the present study also emerged with findings by Sanabria et al., showing that spatial orienting was modulated both during and after exercise in comparison with rest condition[31]. Interestingly, the differences between our results and those obtained by Sanabria et al. could be related to the different measure of the orienting function. Our study employed the ANTI-Vea, which measures facilitation of attentional orienting, whereas Sanabria et al. used a paradigm suitable to measure facilitation and inhibition of return respectively in the long and large SOA conditions. Indeed, Sanabria et al. found no effect of exercise at the short SOA, where facilitation was observed, as in our study. The modulation of exercise was exclusively observed at the long SOAs where an IOR effect was only observed in the baseline condition. Therefore, our results are coherent with those of Sanabria et al. (short SOA) and the work by Sanchis et al. using the same task as in our study, although comparing the online effects of light vs. moderate exercise, showing no modulation of orienting during exercise[9]. Future studies examining the impact of acute exercise on attention might include groups with different fitness level using different exercise intensities and baseline, and investigate different aspects of exogenous and endogenous orienting, to gain a more accurate understanding of these effects and interactions.

Regarding the effect of acute exercise affects over Executive Vigilance (EV), our results showed a lower percentage of FAs after the light-intensity exercise, although without influence of exercise on hits. These results are in line with those reported by Mehren et al. who investigated the effects of acute exercise at moderate and vigorous intensities on executive function, including functional MRI. Results showed a tendency towards improved behavioural performance in the Go/No-go task, interpreted as improved ability to inhibit a prepotent response and to sustain attention, and increased brain activation, as changes in BOLD response, in frontal areas following light- intensity exercise compared to vigorous- intensity[26]. Nevertheless, our results revealed no difference between rest and vigorous- intensity condition. It is worth mentioning that mean RT on hits was also dependent on exercise intensity showing that participants were faster after performing the vigorous than the light- intensity condition. In a study aiming to investigate the acute effect of cycling at different intensities, results showed better selective attention especially for congruent stimuli[17] after the most vigorous- intensity (95% of the MMP) and in the shortest duration (~ 3 min) compared to the baseline. It is noteworthy that the vigorous-intensity exercise in our study has an average duration of 23 min, significantly longer than the 3 min duration of the above-mentioned study, which could explain the different results. Our vigorous- intensity condition involves an incremental effort until exhaustion. However, finding by Sudo et al.[60] investigating the effects of an incremental exercise to exhaustion revealed no modulation in RT within a cognitive task combining a Spatial Delayed-Response task and a Go/No-Go task. Additionally, another study showed that after 25 min of vigorous-intensity interval training (20 s sprint and 40 s recovery) the speed score increase compared to the control group in the revised d2-test of attention[25]. Furthermore, the controversial difference between our results and previous ones could be explained based on the different complexity of the task used to measure selective attention and the different attentional set ups required in the ANTI-Vea task. To deep into the influence of the time course on this effect, we explored whether there was a decrement in percentage of hits during our longer 3 blocks of ANTI-Vea task (i.e. more than 16 min) confirming no vigilance decrement in neither of the three activity conditions. Future research could extend the task to 6 blocks in order to see how performance evolves over longer times and whether vigilance decrement across time on task is modulated or not by exercise.

With respect to Arousal Vigilance (AV), we observe no modulation of exercise intensities on AV scores. These results are similar to those reported by previous studies comparing the immediate and short-term effects of 35 min of aerobic (55% of MMP) cycling exercise[62], or the meta-analysis by Chang et al.[13]. This well-known pattern of results suggests that effects of exercise on simple RT task disappear very quickly after exercise cessation. Notably, there are scarce studies as ours analysing AV specifically along with other attentional networks in a complex task, being a factor that influences vigilance performance[9,35]. Our work could complement the findings by Sanchis et al.[9] suggesting that exercise may not significantly modulate AV when assessed using a complex task performed both during and after exercise. It is interesting that after vigorous- intensity exercise, or during exercise in Sanchis et al., responses were faster in EV, but not in AV trials, adding more evidence in favour of task demands and cognitive resources assigned to the task as modulators of the effect of exercise on responses.

Before concluding, it is important to note that the present study is not exempted from some limitations. The fact that the baseline session was not counterbalanced could constraint the interpretation of the differences between the rest and both exercise conditions due to practice effects. This decision was made based on the difficulties to include four experimental sessions, and trying to reduce the risk of participants dropping out of the study given its duration. We tried to mitigate this problem by including a previous familiarization session at home with ANTI-Vea before the baseline session. Nevertheless, a proper counterbalancing of all conditions would have allowed us to more confidently compare the three activity conditions. In any case, it is important to consider that no large practice effects have been observed with the ANTI-Vea even across 10 sessions ([64], see project pre-registration at https://osf.io/vh2g9). Similarly, a previous study examining the efficacy of the ANT and ANT for Interactions tasks over ten sessions found no evidence of an increase in phasic alertness effect between the second and third sessions[65]. Therefore, considering that our participants performed the task immediately after physical exercise, which was their third or fourth time completing it, it could be argued that the observed larger alertness effect observed with RT after the exercise, compared to baseline, cannot be fully explained as a practice effect.

Conclusions

To conclude, our results reveal that an acute bout of exercise modulates different attentional and vigilance scores but depending on the exercise intensity. First, while vigorous- intensity exercise does not modulate overall performance, light- intensity exercise improves the overall accuracy in the attentional networks sub-task but does not accelerate the overall RT. Regarding the attentional functioning, a modulation of exercise over phasic alertness was observed, accelerating the response to the acoustic stimuli, without affecting accuracy in the phasic alertness. The functioning of the orienting and cognitive control networks was not affected. For the vigilance components, executive vigilance (EV) was improved by vigorous- intensity exercise, showing faster responses in hits, while light- intensity exercise improved accuracy by reducing the false alarm rate compared to the other two conditions. However, exercise did not significantly modulate the percentage of hits. Arousal vigilance (AV) was not modulated by the activity condition.

To further clear the existing controversy in the literature, future research should compare the effect of exercise at different intensities on the attentional networks, EV and AV including participant of diverse fitness level to check the modulatory effect of fitness level and task demands on attentional functioning.

Data availability

The dataset generated during the current study is available in the OSF repository, https://osf.io/mpkej/.

Received: 20 February 2024; Accepted: 21 October 2024

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Author contributions

E. S-N. and F.H developed the study idea and methodology. E.S-N. collected and compiled subject's data. E.S-N., F.L., F.H. and J.L wrote the whole paper as a team. E.S-N., F.H., F.L., and J.L completed the statistical analysis. F.L elaborated the figures.

Funding

Juan Lupiáñez was funded by the Spanish MCIN/AEI/https://doi.org/10.13039/501100011033/, through grant number PID2020-114790GB-I00 nd PID2023-148421NB-I00, and ESF+, CEX2023-001312-M, and UCE-PP2023-11 by University of Granada. Article processing charge (APC) has been covered by internal funds from the Catholic University of Valencia “San Vicente Mártir.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to F.H.

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