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Running Head: Acute physical exercise and overt attention.

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Abstract

The abrupt onset of a visual stimulus typically results in overt attentional capture, which can be quantified by saccadic eye movements. Here, we tested whether attentional capture following onset of task-irrelevant visual stimuli (new object) is reduced after a bout of intense physical exercise. A group of participants performed a visual search task in two different activity conditions: Rest - without any prior effort; Effort - immediately after an acute bout of intense exercise. The results showed that participants exhibited: 1) slower reaction time of the first saccade toward the target when a new object was simultaneously presented in the visual field, but only in the rest activity condition; 2) more saccades to the new object in the rest activity condition than in the effort activity condition. We suggest that immediately after an acute bout of effort, participants improved their ability to inhibit irrelevant (distracting) stimuli.

Key words: Acute exercise, effort, eye movements, attention, exogenous attention, physical activity.

Introduction

Humans have developed the ability to select relevant information in the environment guided by their goals and expectations: the so-called top-down or goal-driven attention. Crucially, we are also sensitive to the sudden and unexpected onset of stimuli, which triggers stimulus-driven or bottom-up mechanisms of attentional selection (for a review see Ruz & Lupiañez, 2002). Indeed, research has revealed that even when task-irrelevant, the abrupt onset of a visual stimulus captures attention, typically resulting in saccadic eye movements toward it (overt attentional capture; e.g., Fuchs, Theeuwes, & Ansorge, 2013; Theeuwes, Kramer, Hahn, & Irwin, 1998). As a consequence, goal-directed eye movement to a target stimulus and an associated perceptual decision are disrupted by the appearance of a new irrelevant stimulus (Theeuwes et al., 1998).

Inhibition of irrelevant information in order to select and respond to task relevant stimuli is improved following an acute bout of exercise (e.g., Hogervorst, Riedel, Jeukendrup y Jolles, 1996; Tomporowski, 2003; Tomporowski et al., 2005). In line with the outcome of that research, Llorens et al. (Llorens, Sanabria & Huertas, 2014) showed, for the first time, that the influence of a task-irrelevant spatial cue on target processing was reduced after an acute bout of exercise with respect to a baseline condition. Importantly, Llorens et al. (2014) investigated covert stimulus-driven attention (without eye movements), thus leaving open the question of whether acute exercise would also reduce overt attentional capture. This is not a trivial issue, since in daily life people are often under the effect of previous exercise when they are exposed to sudden and unexpected appearance of task-irrelevant stimuli. For example, a cyclist's overt attention might be captured by the onset of any unexpected visual or auditory stimulus when stopping at a pedestrian crossing, potentially leading to a fall or to a failure to detect a relevant stimulus like a child running through the street.

Here, then, we aimed at extending the findings of Llorens et al. (2014) to the case of overt attention, and specifically the impact of acute intense exercise on goal-directed eye movements. To this end, participants completed a well-known visual search task (see Theeuwes et al., 1998) in two different activity conditions: at rest, with no prior effort (rest session) and immediately after a short bout of intense effort (effort session).

Method

Participants

Fourteen graduates (7 males and 7 females; Age range = 23-31 years old; Mean age = 26 ± 3) from Liverpool John Moore University who volunteered to participate in this study. This sample size was based on Theeuwes et al. (1998) research and on an analysis using the G POWER software (Faul, Erdfelder, Lang, & Buchner, 2007) that indicated that 12 participants would provide a statistical power of .80, with alpha of 0.05, for an effect size of .80 in a one-tailed t-test. Due to unexpected technical issues during the experiment we had to discard data from five participants (1 male and 4 females) from the analyses. Non-parametric statistical analyses were performed to deal with the final low sample size (see below).

Participants gave written informed consent prior to participation and reported to be physically active less than 1 hr per week. Their low physical fitness level (see American College of Sport Medicine, 2005) was further confirmed by the results of an effort test (oxygen uptake [VO_2] at anaerobic threshold [AT], Mean = 19.95 ml.min-1.kg^{-1}) (Table 1). All participants had normal or corrected-to-normal vision, and self-reported not to have any neuromuscular or medical conditions that would preclude participation. The experiment was compliant with the procedures of the local ethics committee.

Apparatus and Materials

An electrically-braked cycle ergometer (Monark 817E, Stokholm, Sweden), FT1 Polar HR monitor (Polar Electro Oy, Kemple, Finland) and an online gas analysis system (MetaMax 3B gas analysis system, Cortex, Biophysik, Leipzig, Germany) were used to determine the AT. A host PC was used to present the stimuli in the visual search task. Visual stimuli were generated using the COGENT toolbox implemented through MATLAB (Mathworks Inc.). The host PC also recorded participant's behavioural response and provide a TTL signal to synchronise recording of left eye movement using an EyeLink 1000 (SR Research, Ottawa, Ontario, Canada), operating at 250Hz.

The visual search task was divided in 4 blocks of 40 trials and consisted of the presentation of six grey circles, each containing a small grey figure-eight pre-mask. After 1000 ms, all circles but one change to red and at the same time the small pre-masks inside the circles change to letters. Participants were instructed to quickly make a saccade, as soon as the colour of the circles changed, directly to the only grey circle left and to determine whether the letter inside the grey circle was a "C" or a reverse "C". They were required to press the right arrow on a keyboard (RAZR, Lycosa; 1000-Hz polling) for "C" and the left arrow for reverse "C". The letters inside the red circles were distractors letters. Crucially, on half of the trials, an additional red circle (new object) was added to the display at the same time that the colour singleton was revealed.

The new object was presented at one of six possible positions between two distractors or a distractor and the target (see Figure 1). This additional new object was presented with the intention to capture exogenous spatial attention.

Procedure and Design

Participants completed three sessions in three separate days (with 1 to 5 days between sessions; Mean = 3 ± 1 day). In the first session, participants performed a submaximal exercise test to obtain their AT by analyzing the gas exchange (following Myers & Ashley, 1997). The submaximal exercise test started at 25 W and the power was increased 25 W every 2 min until participants reached their AT. Following the effort test they completed one block of the visual search task (i.e., 40 trials) for the purpose of familiarization.

In the other two sessions, participants performed the visual search task either at rest without any prior effort (rest) or immediately after cycling 15 min at 100% of HR and power output determined during the AT test (effort). In the effort session, the power load was gradually increased following the same protocol described above until the participant reached AT. The mean elapsed time from the beginning of the effort (i.e., warm-up) until the participants reached their AT was 9 ± 3 minutes. In the rest session, participants were not subject to any physical effort prior to performing the visual search task, and instead were seated on the cycle ergometer without pedalling for about 25 minutes (Mean = 22 ± 4 minutes). This rest period was determined for each individual by adding 15 minutes (i.e., the duration of the effort session) to the time the participant took to reach his AT during the submaximal effort test. Immediately after the bout of effort or the rest condition, the participant dismounted from the cycloergometer and sat in front of the monitor with the forehead and chin resting on height-adjustable support. In this positon, the eyes were located 60 cm from the monitor and were clearly visible to the EyeLink 1000 remote camera. They completed the task in a silent and dimly illuminated room. The order in which the rest and effort sessions were performed was counterbalanced across participants.

Design and Statistical Analysis

Three dependent variables (DV) were evaluated in this study: (1) *Manual RT* - RT of the motor response to the target; (2) *First saccade to the target* - RT of the first target-directed saccade (note that the participant could have made other saccades before this); and (3) *Saccades to new object* - number of saccades toward the new object. For the first two DVs, we had a within-groups 2 Session (effort, rest) x 2 New object (present, absent) design. For the third DV, however, the new object always had to be present, so these data were analysed using 1-way within-groups design. Note that previous research has shown that the relative position of the new object does not affect the results in the visual search task used here (Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin, & Zeliinsky, 1999). Moreover, including that factor would have resulted in an insufficient number of trials in order to perform reliable statistical analyses.

All analyses were completed using statistical nonparametric permutation tests. These tests do not make any assumption of the underlying distribution of the data, which make them appropriate for small sample sizes. Also, permutation tests are exact, unbiased and almost as efficient as their parametric counterparts (Pesarin & Salmaso, 2010). Finally, the independence of the permutation test from the underlying distribution gives freedom to choose any test statistic we consider appropriate.

A permutation test requires constructing the histogram by doing all possible label exchanges. However, this is not feasible in practice, so a Monte Carlo approximation is generally used, in which the exchange procedure repeats a very high number of times. A key concept in permutation analyses is that of exchangeability, which refers to the fact that, under the null hypothesis, the labels can be exchanged without changing the underlying joint probability of the sample. Therefore, in a complex factorial design with repeated measures variables, the labels exchanges should be performed taking the exchangeability concept into account. In this study, we followed a general label exchange procedure for multifactor designs with paired samples described in Good (2005).

Results

Manual RT[1] results showed significant main effects of Session (p < .001), with slower RTs in the rest session than in the effort session, and New object (p < .001), with slower RTs when the new object was present than when it was absent. The interaction between Session and New object was not significant (p = .202; see Figure 2). *First saccade to the target* results showed a significant interaction between Session and New object (p < .001). Pairwise comparisons for the factor New object in each Session showed no statistical effect for the effort session (p = .728) but a significant effect for the rest session (p < .001; see Figure 2), with slower RTs when the new object was present. Finally, results on *Saccades to new object* data showed a significant main effect of Session (p = .014; see Figure 3), with a higher number of saccades to the new object in the rest session than in the effort session (see Table 2).

Discussion

We examined whether attentional capture following onset of task-irrelevant visual stimuli (new object) was reduced after a bout of intense physical exercise. To this end, participants completed a visual search and object-identification task at rest without any prior effort and immediately after an acute bout of intense physical exercise. The results in the rest session replicated those reported by Theeuwes et al. (1998), with both a longer manual RT and slower first saccade to the target in the presence than the absence of a new object. In addition, we found that manual RTs were sensitive to the

[1] Incorrect manual responses (0.48%) were eliminated from the analyses.

bout of effort, with overall faster RTs after exercise than in the rest session. A close look to Figure 2 reveals that the difference between trials (object absent vs. object present) in manual RT was higher in the rest session than in the effort session. However, the analyses did not show a significant interaction. Crucially, the gaze data were more sensitive to the effort manipulation than the manual RT data.

No effect of the new object on the first saccade to the target was observed in the effort session. Moreover, fewer saccades to new object were shown in the effort session than in the rest session. It would seem, therefore, that after intense exercise reflexive saccades, and thus overt attentional capture, were inhibited resulting in more efficient goal-directed saccades.

Tasks requiring inhibition of irrelevant information (like our visual search task) activate the prefrontal cortex (PFC) (McMorris & Hale, 2012; Sänger, Bechtold, Schoofs, Blaszkewicz, & Wascher, 2014), which is thought to be part of the neural network responsible of executive processing (McMorris, 2008). Research has shown increased availability of noradrenaline and dopamine, which are involved in the activation the PFC (see McMorris, 2008 and McMorris & Hale, 2012 for a review), during and following physical exercise. We would argue, then, that following exercise, and due to the enhanced activity of the PFC, our participants improved their ability to inhibit eye movements to the distractor and instead focus on the target stimulus. In other words, exercise can facilitate the activation of top-down mechanisms that, in turn, modulate attentional capture. While we cannot comment on how long such effects might persist after cessation of exercise, or how they might be influenced by more graded levels exercise intensity, our findings are relevant since they show that overt attentional capture is not mandatory under conditions that are experienced when exercising in daily life or playing sport.

In sum, the outcome of the present study showed that our eyes do not always go toward new objects appearing in the visual field when under the effect of a prior bout of intense physical effort. We believe that these results open new interesting avenues for future research.

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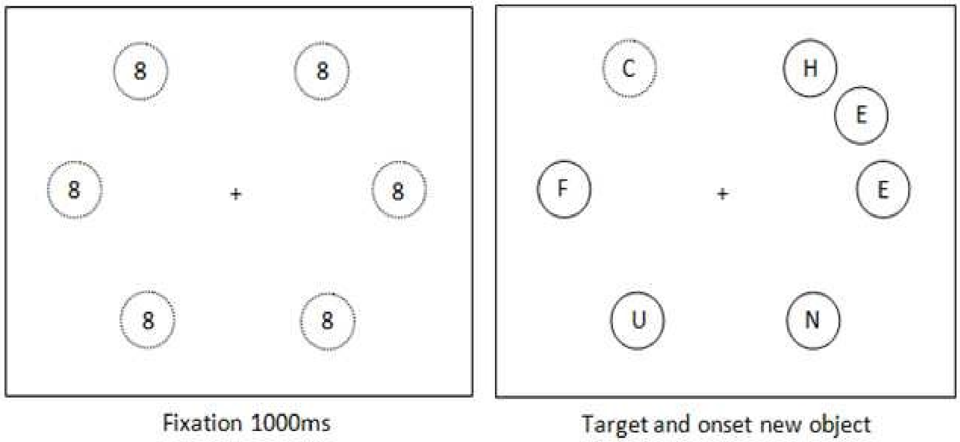

Figure 1.

Schematic view of the visual search task. Note that the target was presented simultaneously with the appearance of the distracting new object. The grey circles are indicated by the dotted lines and the red circles indicated by the solid lines.

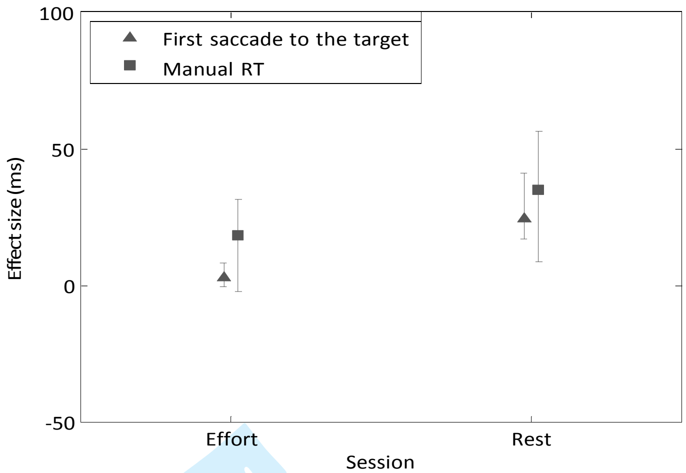

Figure 2.

Effect size (differences RT between new object present and new object absent trials) ±95% confidence intervals for Manual RT and First saccade to the target between sessions (effort, rest).

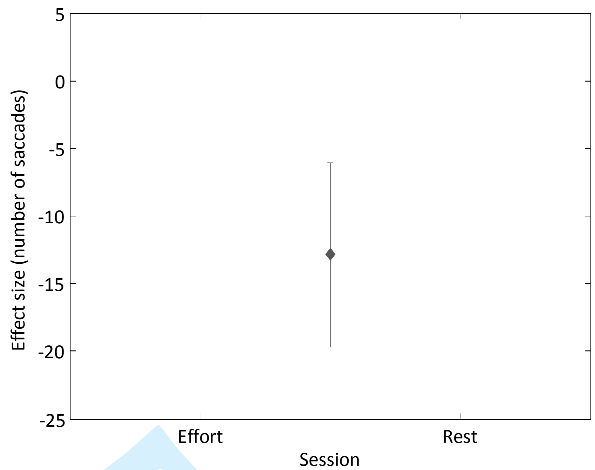

Figure 3.

Effect size (differences RT between new object present and new object absent trials) ±95% confidence intervals for Number of saccades between sessions (effort, rest).

Table 1.

*Mean [±95% confidence interval] of the physiological data from the submaximal effort test and the two experimental sessions. The Mean HR (bpm) corresponds to the participants' HR just before starting the attentional task. * HR_{max} = 208 – 0.7 x Age (Tanaka, Monahan, & Seals, 2001).*

			% AT
Physiological Parameters from the submaximal exercise test	VO_2 at AT (ml.min-1.kg^{-1})	20.08 [24.34, 15.56]	--
	Power output at AT (W)	130 [151, 109]	--
	Relative Power output at AT (W•Kg^{-1})	1.78 [1.94, 1.63]	--
	Mean HR at AT (bpm)	155 [158, 152]	--
	HR max.*	189 [191, 188]	82
Rest	Mean HR (bpm)	75 [82, 70]	48
Post-effort	Power output (W)	133 [157, 110]	102
	Relative power output (W*Kg^{-1})	1.82 [2.03, 1.62]	101
	Mean HR (bpm)	149 [153, 145]	97

Table 2.

Mean (ms) and 95% confidence interval for Manual RT, First saccade to the target and Number of saccades in each session.

	Effort session		Rest session	
	New object present	**New object absent**	**New object present**	**New object absent**
Manual RT	M = 852.23 ms, 95% CI [840.69, 864.46]	M = 811.73 ms, 95% CI [801.78, 822.76]	M = 887.33 ms, 95% CI [873.24, 902.26]	M = 843.97 ms, 95% CI [830.91, 858.09]
First saccade to the target	M = 652.49 ms, 95% CI [641.12, 662.92]	M = 649.52 ms, 95% CI [639.81, 657.98]	M = 696.21 ms, 95% CI [686.91, 704.95]	M = 639.88 ms, 95% CI [629.75, 648.28]
Number of saccades	M = 18.22, 95% CI [10.94, 27.27]		M = 31.11, 95% CI [22.44, 41.22]	