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The role of chronic physical exercise and selective attention at encoding on implicit and explicit memory

Concepción Padilla[123], Julia Mayas[4], Soledad Ballesteros[4] and Pilar Andrés[12]

[1] Neuropsychology and Cognition Research Group, Department of Psychology and Research Institute of Health Sciences, University of the Balearic Islands, Palma de Mallorca, Spain

[2] Instituto de Investigación Sanitaria de Palma, Palma de Mallorca, Spain

[3] Cambridge Intellectual and Developmental Disabilities Research Group, Department of Psychiatry, University of Cambridge, Cambridge, UK

[4] Studies on Aging and Neurodegenerative Diseases Research Group, Departmento de Psicología Básica II, Universidad Nacional de Educación a Distancia, Madrid, Spain

* Request for reprints should be addressed to Concepción Padilla, Douglas House, 18b, Trumpington Road, Cambridge, United Kingdom, CB2 8AH, email: cfp31@medschl.cam.ac.uk.

Abstract

Despite the evidence revealing benefits of chronic cardiovascular exercise on executive functions, little research has been conducted on long-term memory. We aimed to investigate the effect of physical exercise on implicit and explicit memory when attention was modulated at encoding in two groups of active and sedentary participants. With this purpose, attention was manipulated in a similar way in the implicit and explicit memory tasks by presenting picture outlines of two familiar objects, one in blue and the other in green, and participants were asked to pay attention only to one of them. Implicit memory was assessed through conceptual priming and explicit memory through a free recall task followed by recognition. The results did not reveal significant differences between groups in conceptual priming or free recall. However, in recognition, while both groups had similar discrimination for attended stimuli, active participants showed lower discrimination between unattended and new stimuli. These results suggested that exercise may have effects on specific cognitive processes, i.e., that active participants may suppress non-relevant information better than sedentary participants, making the discrimination between unattended and new items more difficult.

Keywords: cardiovascular, implicit, explicit, inhibition, suppression, memory

Introduction

Chronic cardiovascular exercise stands as a way to enhance cognitive functions, especially when they involve executive control (Colcombe & Kramer, 2003). This type of exercise refers to the regular practice of physical activity maintained over time, leading to more permanent changes in the brain and cognition (Kenney, Wilmore, & Costill, 2015) than acute exercise, which is the momentary practice of exercise and it is related to immediate and reversible changes in the brain (Kenney et al., 2015). In this manner, it was recently shown that participants who have practiced cardiovascular exercise regularly for at least ten years performed better on motor inhibition (Padilla, Pérez, Parmentier, & Andrés, 2013), interference control (Pérez, Padilla, Parmentier, & Andrés, 2014), speeded perception, visuospatial attention and dynamic visual acuity (Muiños & Ballesteros, 2014; 2015). There is also evidence that these improvements in physically active individuals are accompanied by greater working memory capacity (Padilla, Pérez, & Andrés, 2014). Guiney and Machado (2013) recently summarised the existing literature by showing that regular aerobic exercise improves executive processes such as task switching, selective attention, inhibition and working memory.

Moreover, cardiovascular exercise may trigger neurobiological and neurological changes that may enhance long-term memory performance. Some physical exercise intervention studies have revealed an increase in brain-derived neurotrophic factor (Vaynman, Ying, & Gomez-Pinilla, 2004) as well as in the brain volume of memory-related areas such as the hippocampus, frontal and superior temporal cortex, cuneus and basal ganglia (Chaddock et al., 2010; Colcombe et al., 2006; Holzschneider, Wolbers, Roder, & Hotting, 2012; Maass et al., 2015; Pereira et al., 2007). However, despite the evidence of these neurobiological and neurological changes, it is remarkable that research on physical exercise and long-term memory using experimentally controlled tasks has been rather limited, and has found no differences in memory scores between the pre- and post- interventions (for example, Erickson et al., 2009; 2011).

Among the few recent studies that have investigated the role of chronic exercise on long-term memory, Déry et al. (2013) compared the performance of a group of sedentary participants before and after a 6-week exercise intervention on two memory tasks that differed in their sensitivity to estimate neurogenesis. The first was a memory task that generated high levels of interference between previously learned and subsequently tested stimuli, the "pattern separation task" (Kirwan & Stark, 2007). This is a visual recognition memory task in which participants have to respond if the objects presented on the screen are new, equal or similar to the previous ones. Participants must avoid the interference generated by similar items, which are related but not identical to previous items. The second task was the "paired associate learning task" (PAL, from CANTAB®), a well-established visuospatial associative learning that is sensitive to hippocampal pathology (Beddington et al., 2008; Blackwell et al., 2004; Jager et al., 2008; Rover et al., 2011). In this task, participants have to remember the position in which different objects appeared on the screen previously. A feature that differentiates these tasks is the greater executive control required by the first compared with the second task. The results revealed that exercise, measured by improvement in VO_2 peak, specifically improved the ability to distinguish similar lures from previously studied targets, an ability that strongly depends on executive control (control of interference). However, exercise did not improve memory *per se,* since it did not affect old-new discrimination in the first task or items localisation recall in the second task.

Ballesteros, Mayas, and Reales (2013) also studied the effect of self-reported chronic cardiovascular exercise on long-term memory using a perceptual priming task in two groups of older adults, one group who practised regular exercise and another who did not. The results, however, showed similar levels of repetition priming for both groups. For their part, Maas et al. (2015) carried out a 3-month cardiovascular exercise intervention in which they observed a relationship between exercise-related changes in perfusion (hippocampal blood flow and volume) and early recall for configural spatial object memory, but not for verbal memory nor delayed recall.

Finally, recent reviews and meta-analyses investigating the effects of cardiovascular exercise on human memory suggested that chronic cardiovascular exercise either does not lead to better long-term memory (Roig et al., 2013), or it is related to a modest improvement, being larger only in those participants showing memory deficits previous to the physical exercise intervention (Smith et al., 2010).

As can be seen, there is some contradiction between the changes observed at the neural level (e.g., in the hippocampus) and the empirical evidence for a behavioural long-term memory improvement induced by chronic cardiovascular exercise. As previous research has shown greater effects of chronic cardiovascular exercise on executive processes (Colcombe & Kramer, 2003; Guiney & Machado, 2013), one could expect that exercise would be related to explicit but not to implicit memory. Implicit memory refers to previous experience with stimuli that does not require intentional, conscious retrieval of previously encountered stimuli (Reber, 2013). However, explicit memory involves the conscious or intentional recollection of previous experience, being more dependent on executive control, and requiring the correct functioning of the hippocampus and medial temporal lobe (Reber, 2013).

For this reason, we aimed at investigating the extent to which the relationship between cardiovascular exercise and implicit and explicit long-term memory might be modulated by executive functions through a task that explicitly controls selective attention, a function that has proven to be sensitive to physical exercise (Padilla, Andrés, & Bajo, 2016).

To this purpose, participants in the present study performed the same long-term memory tasks used by Ballesteros and Mayas (2015) to investigate the role of selective attention at encoding on implicit and explicit memory. Conceptual *priming* (a measure of implicit memory) was assessed with a speeded conceptual object priming task and explicit memory with a free recall task and an “old-new” recognition task. In all memory tasks, participants had to focus their attention on just one stimulus at encoding, not attending the other stimulus that was presented simultaneously. Ballesteros and Mayas found that conceptual *priming* required some degree of attention at encoding, showing that implicit memory is not an automatic process (Ballesteros et al., 2008; Ballesteros et al., 2013; Spataro, Cestari, & Rossi-Arnaud, 2011). As expected, they also found that explicit memory required attention at encoding to obtain significant recall and recognition.

Thereby, we predicted that, since explicit memory relies on encoding and retrieval strategies that depend on executive control processes (such as selective attention), it might be affected to a greater extent by chronic cardiovascular exercise than implicit memory. Since previous results with young adults have revealed better motor inhibition and interference control in physically active participants (Padilla et al., 2013; 2014; 2016; Guiney & Machado, 2013), we also considered the possibility that active participants would filter or suppress better the pictures that were unattended at encoding, making them more difficult to be differentiated from the new (not presented pictures at encoding), giving, therefore, rise to differences in discrimination scores.

Method

Participants

Thirty-seven active and 37 sedentary undergraduate students participated in this study (see Table 1 for demographic details). The same participants performed the two long-term memory procedures in the same session, accomplishing the implicit memory procedure first, followed after a short delay by the explicit memory procedure.

Participants were recruited through advertisements placed across the university campus and its sports centre, as well as from other sports facilities throughout the city. The inclusion criteria to recruit the active participants were inspired by Padilla et al.'s (2013; 2014) studies: they should have been doing cardiovascular exercise (running, football, swimming, etc.) for at least ten years, with a minimum of six hours per week, distributed in at least three different days. Sedentary participants could not have been exercising for the last 4 years more than 1 h per week, being that little exercise non-cardiovascular (i.e. yoga, Pilates, etc.). Besides, they could not have been practising more than 6 h per week of cardiovascular exercise during their childhood (from 0 to 14 years old, taking into account that it is mandatory to have at least 3 hours per week of physical education at primary and secondary school). They were categorised as physically active or sedentary by completing a questionnaire (see Padilla et al., 2013; 2014; Pérez et al., 2014) exploring the frequency, intensity and type of physical activity carried out along their life. This self-reported exercise was corroborated by the results from the Rockport 1-mile Fitness Walking Test (Kline et al., 1987), a VO_2max estimated measure.

A history of neurological disease, psychiatric illness, head injury, stroke, substance abuse (excluding nicotine), learning disabilities, or any difficulty that could interfere with cognitive testing were considered exclusion criteria. All participants reported normal or corrected-to-normal vision. They gave their informed consent and were paid in exchange for their participation. Implicit and explicit procedures were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Insert here Table 1

Design, apparatus, stimuli and procedure

An LG computer with a 19 inches Phillips screen was used to run the tasks, which were programmed using SuperLab 4.0 software (Cedrus Corporation). Before participants came to the lab, an experimented psychologist interviewed them by phone to administer the physical activity questionnaire. Once participants were selected, they came to the university facilities and completed the Vocabulary subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III, Wechsler, 1999), a questionnaire to assess their educational level, health status and medication history before they carried out the implicit and explicit memory tasks. Finally, the participants performed the Rockport 1-mile Fitness Walking Test (Kline et al., 1987) to assess cardiovascular fitness. This sub-maximum cardiovascular stress test provides an accurate estimate of the maximum level of oxygen consumption (VO_2max), with a correlation coefficient of .88 between VO_2max estimated based on performances during the test and a direct measure of VO_2max during an increment test on a treadmill (Kline et al., 1987; Weiglein, Herrick, Kirk, & Kirk, 2011). Higher values of VO_{2max} are considered to reflect higher aerobic capacity since it means greater oxygen consumption. The Rockport Test was performed within the University campus surroundings. The whole evaluation procedure lasted for approximately two hours.

The stimuli used in both procedures were 240 standardised outline pictures of natural or artificial objects, 120 selected from the Snodgrass and Vanderwart's (1980) stimuli set, and 120 selected from Bonin, Peereman, Malardier, Méot, and Chalard's (2003). The total set of 240 stimuli was divided randomly into two sets of 120 stimuli to be used one in the implicit and the other in the explicit memory task. The stimuli were prepared in three different colours, blue, green, and black. Blue and green outlines were used at the encoding phase and the black ones were used at the test phase of the implicit and explicit procedures. Half of the stimuli depicted natural objects and the other half artificial objects. Each 120-stimuli set was subdivided in 36 attended, 36 unattended and 48 new items. Two different combinations were created in each 120-stimuli set, so four different stimuli sets were obtained (A, B, C, D) to counterbalance stimuli presentation and attended colour (see Table 2). All versions had 50% of artificial and 50% of natural objects in the attended, unattended and new conditions.

Insert here Table 2

Before the study phase of each memory task began, there were 10 practice trials for which 20 additional pictures were used. In both study phases, just the attended and unattended items were displayed, while in the test phases, the previous attended and unattended stimuli along with the new ones were presented in black.

The experimental design of the implicit and explicit tasks was similar. In the study phase, every trial consisted of two stimuli, one blue and one green (see Figure 1a), displayed 1 cm apart inside a rectangular box of 9.5 x 22.6 cm. This box was used to focus attention. One stimulus appeared on the left and the other on the right of the fixation cross. Visual stimuli set subtended a visual angle of 8.5º x 16.5º, measuring ~ 4.3º x 4.9º each visual stimulus. At encoding, half of the participants were instructed to attend to the green picture and the other half to the blue picture.

Insert here Figure 1

In the test phase, single black picture outlines were displayed, one after another (see Figure 1b). The visual stimulus was placed in the centre of the screen and subtended a visual angle of ~ 4.3º x 4.9º.

Implicit memory procedure

The experiment was a 2 (Group: active versus sedentary) x 3 (Study condition: attended, unattended, and new) mixed factorial design. Group was the between-subjects factor and study condition the within-subjects factor. This procedure lasted about 35 minutes and had a study and a test phase.

Study phase. As described above, participants performed a speeded conceptual classification task with 36 trials. They were asked to respond as fast and accurately as possible. This procedure began with 10 practice trials followed by the study phase. Only experimental trials were recorded. In all trials, a fixation cross appeared for 20 seconds and later was substituted by the box with the two pictures inside. Participants had to look at the picture drawn in the colour that they had been told to attend to (see Figure 1a) and respond as accurately and quickly as possible whether the object was artificial or natural by pressing the keys (”m” and ”n”). The two keys had a sticker showing the initial of the category (A and N respectively). The stimuli were presented for 1000 ms in random order, plus a variable inter-stimuli interval (ISI) of 2000, 4000, 6000 or 10000 ms, which averaged 6500 ms among attended, unattended and new conditions[1]. The stimulus disappeared after the first 1000 ms and was replaced by a fixation cross during ISI. After that, a new trial started. The study phase included 1 run of 36 trials. Those trials contained 36 attended and 36 unattended stimuli consisting of artificial and natural objects that had the same probability to appear. When it finished, participants performed a 3-min distraction task consisting of producing words starting by the letter “b”.

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[1] This variable ISI was included to increase signal sensitivity in an fMRI study, for which this task was originally designed. However, participants from this study did not take part in any neuroimaging experiment.

Test Phase. When the distraction task was over, participants had to classify again as quickly as possible the object that appeared in black on a white screen (Figure 1b) as natural or artificial pressing the keys “m” and “n”. In this phase 36 attended (previously outlined in the colour that should be attended to), 36 unattended (previously outlined in the colour that did not have to be attended to) and 48 new pictures were presented in three runs of 40 trials each. The order of presentation of the 120 stimuli (36 attended, 36 unattended and 48 new) was randomised for each participant.

A fixation cross was displayed for 20 seconds and replaced by an outlined picture in black that remained on the screen for 1000 ms. A fixation cross then appeared for a variable ISI that could be of 2000, 4000, 6000 or 10000 milliseconds with an average of 6500 ms for attended, unattended and new stimuli. After that, another trial started.

Reaction times (RTs) were measured from the time the picture appeared on the screen until the participant’s response (see Figure 1b). Performance in conceptual priming was assessed by the RT at which the stimuli were correctly classified.

Explicit memory procedure

Following a short break after the previous implicit memory procedure, the same participants performed the explicit memory procedure, which also consisted of a study and a test phase.

Study Phase. It had exactly the same structure as the study phase from the implicit memory task, having participants to categorise the picture drawn in the same attended colour than before (green or blue) into natural or artificial as fast and accurately as possible. However, in this task, the instructions required participants to try to remember the attended stimuli because they would be asked for them later. After 10 practice trials, the explicit recognition task started. Only experimental trials were recorded. The stimuli set was different from the one used in the previous implicit procedure (see Table 2). After the study phase, a 3-minute distraction task consisting of counting from 1000 to 0 by twos was carried out.

Test Phase. Participants performed two explicit memory tests to evaluate explicit memory when the distraction task finished. First, they were required to recall in writing as many objects as possible from the latest study phase. They were asked to recall both attended and unattended items. When this task was over, participants performed an "old-new" recognition test. The procedure was similar to the test phase of the implicit task, however, this time, participants had to classify the single outlined picture presented in black as old or new as quickly and accurately as possible. Participants were told to classify as old the items that had been attended and unattended in the previous study phase. Different keys from the keyboard were used ("x" for new and "z" for old; also labelled with the initials of the categories "new" or "old") to categorise the presented stimulus.

Results

Implicit Memory

To investigate whether both groups of participants were similarly accurate in the classification task at the test phase, we calculated accuracy proportions for both groups (see Table 3). The ANOVA revealed that there were no significant differences between conditions, F (1, 72) = 0.69, MSE = 0.00, p = .41, η^2_p = .01, or groups, F (1, 72) = 0.07, MSE = 0.00, p = .79, η^2_p = .00. The group x condition was not significant either, F (1, 72) = 0.02, MSE = 0.00, p = .88, η^2_p = .00.

Insert here Table 3

Extreme RTs were removed before the results were analysed, following a method that takes into account the median, since most of the RT distributions have a negative asymmetry and contain extreme values, which would distort the average. The limit to consider an atypical value was calculated adding or subtracting 1.5 times the interquartile range to the third or first interquartile (q3+ or q1 - 1.5 x (q3 - q1); Perea & Algarabel González, 1999; Laurikkala, Juhola, & Kentala, 2000). RTs higher or lower than these limits were removed (less than 6%), not finding significant differences between active and sedentary participants in the number of removed outliers, F (1, 72) = 1.14, MSE = 5.83, p = .29, η^2_p = .02. After that, averages were calculated for each condition (attended, unattended and new conditions).

Mean RTs in attended, unattended and new conditions before and after removing outliers are presented on Table 3. The 2 (Group: active and sedentary) x 3 (Condition: attended, unattended, new) repeated measures ANOVA conducted on mean RTs after removing outliers revealed a significant effect of condition, F (1, 72) = 38.28, MSE = 883.45, p < .001 η^2_p = .35, but not of group, F (1, 72) = 1.85, MSE = 45,307.43, p = .18, η^2_p = .03, or group x condition interaction[2], F (1, 72) = 0.00, MSE = 883.45, p = .99, η^2_p = .00.

We compared conditions (attended, unattended, and new) using pairwise comparisons to investigate the priming and selective attention effects. Pairwise comparisons apply Bonferroni correction for multiple comparisons. The priming or facilitation effect is measured as the difference in RTs between the attended or unattended and new trials. The difference between attended and new condition was significant, p < .001 revealing facilitation by having previously seen the attended stimuli compared to a condition where the stimuli were new. Moreover, this effect was statistically equivalent for active and sedentary participants, as

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[2] Similar results were obtained when repeated ANOVA was calculated on raw mean RTs, indicating a significant effect of condition, F (1, 72) = 29.56, MSE = 1012.54, p < .001 η^2_p = .29, but not of group, F (1, 72) = 1.89, MSE = 51071.03, p = .17, η^2_p = .03, or group x condition interaction, F (1, 72) = .00, MSE = 1012.54, p = .99, η^2_p = .00.

shown by the non-significant group x condition interaction, $p > .05$, in the previous ANOVA. Priming for unattended stimuli (unattended – new) was not significant, $p = 1$. Finally, RTs in attended and unattended conditions were significantly different, $p < .001$, indicating a significant selective attention effect.

Explicit Memory

Free recall

A 2 (Group: active versus sedentary) x 2 (Study condition: attended and unattended) repeated measures ANOVA demonstrated that recall in the test phase was different among conditions, F (1, 67) = 54.32, MSE = 0.01, $p < .001$, $\eta^2_p = .00$, being the attended items better recalled than the unattended stimuli (see Table 4). However, neither the effect of group, F (1, 67) = 0.41, MSE = 0.01, $p = .52$, $\eta^2_p = .01$, nor the interaction group by study condition was statistically significant, F (1, 67) = 0.17, MSE = 0.01, $p = .89$, $\eta^2_p = .00$.

Recognition

Accuracy levels in explicit memory were analysed within the context of signal detection theory of recognition (Green & Swets, 1966). This theory quantifies the participant´s ability to discriminate between stimulus and noise using a confusion matrix including ‘hits’ (old items recognized as “old”), ‘misses’ (old items recognized as “new”), ‘false alarms’ (new items recognized as “old”) and ‘correct rejections’ (new items recognized as “new”).

Within this context, *sensitivity or discrimination index d’* is the difference between hits and false alarms, previously converted to z scores. The higher the index, the better the discrimination between old and new items is. In the current procedure, both the attended and unattended items were considered ‘old’ items, so *d*’ was calculated for attended items and for unattended items independently in each group, taking into account the same number of new items recognised as old (false alarms). Table 4 presents *d’* for active and sedentary participants. Unsurprisingly, a 2 (Group: active versus sedentary) x 2 (Study condition: attended and unattended) ANOVA for repeated measures revealed a significant difference between attended and unattended conditions, F (1, 72) = 61.23, MSE = .72, $p < .001$, $\eta^2_p = .46$, with the attended items (M = 1.80, SD = 1.27) being better recognized than the unattended (M = 0.70, SD = 0.74). The group effect was marginally significant, F (1, 72) = 3.88, MSE = 1.41, $p = .05$, $\eta^2_p = .05$, but no significant group x condition interaction was observed, F (1, 72) = 0.06, MSE = .72, $p = .80$, $\eta^2_p = .00$.

Insert Table 4

Exploratory analyses. To explore further the trend suggesting that groups might differ in their discrimination performance, pairwise comparisons, which apply Bonferroni correction for multiple comparisons, were calculated. The results revealed a significantly lower discrimination in the unattended condition for the active (see Table 4) than for the sedentary participants, $p < .05$. However, no significant differences between groups were found in discrimination for the attended condition, $p = .16$.

Decisional criterion (*c*), an index that describes how flexible or conservative a participant is, independent of discrimination (see Green & Swets, 1966), was also estimated. The higher the criterion, the more conservative the participant is. A repeated measures 2 (Group: active versus sedentary) x 2 (Study condition: attended and unattended) ANOVA revealed a significant effect of condition, F (1, 72) = 17.92, MSE = .19, $p < .001$, $\eta^2_p = .19$, while the group, F (1, 72) = 2.45, MSE = 0.32, $p = .12$, $\eta^2_p = .03$, or interaction, F (1, 72) = 0.00, MSE = 0.19, $p = .96$, $\eta^2_p = .00$, effects were not significant. These results reveal that participants from both groups were generally more conservative when they responded to unattended than attended items (see Table 4).

Discussion

The aim of this study was to explore the extent to which chronic aerobic exercise could be related to long-term memory capacities through the modulation of selective attention. Two procedures were conducted to assess implicit and explicit memory, expecting a significant association of physical activity with recognition and recall but not on repetition priming after manipulating selective attention at encoding. The modulation of selective attention in the task was aimed at increasing the likelihood to detect a relationship between exercise and memory since aerobic chronic exercise has been frequently shown to enhance executive control (Guiney & Machado, 2013).

In the implicit memory procedure, our results revealed differences between conditions, with participants being faster responding to repeated attended stimuli, but not to repeated unattended ones, showing conceptual priming only for the attended stimuli. This finding suggests a significant role of selective attention at encoding for priming to occur, supporting previous research (Ballesteros & Mayas, 2015; Ballesteros et al., 2008). Moreover, as anticipated, sedentary and active participants did not differ in conceptual object priming, revealing equivalent performance in the implicit memory task. Thus, chronic exercise does not seem to be related to implicit memory.

In the explicit memory procedure active and sedentary participants performed at the same level in the free recall task, revealing that both groups recalled better attended than unattended items. However, although both groups discriminated better attended than unattended items in the recognition task, a marginally significant difference between active and sedentary participants was observed, suggesting that sedentary participants might discriminate old items (attended plus unattended) from new items better than active participants. As this trend contradicted our hypothesis, we conducted further exploratory analyses in order to investigate the pattern of recognition in each group per condition. These analyses revealed that active participants discriminate fewer unattended items than sedentary participants, showing that for active participants it is more difficult to discriminate between unattended (but presented) and new (never presented at encoding) items than for sedentary participants. However, both groups equally discriminate between attended and new items.

This exploratory analysis must be interpreted cautiously, since there is still not a clear consensus about the concept of “marginal significance”, despite the fact that it has been increasingly and widely used in psychology journals for the past twenty years (see Pritschet, Powell, & Horne, 2016). There is a possibility that a marginally significant result might lead to a false positive. However, such a tendency also indicates that it should be explored conducting further studies or controlling selective attention in subsequent experiments involving aerobic exercise and explicit memory.

Thereby, we first found that conceptual object priming was only observed for attended stimuli, replicating the effect of selective attention on conceptual implicit memory observed by Ballesteros and Mayas (2015). Consistent with previous results obtained with perceptual priming tasks (see also Ballesteros et al., 2008; 2013; Ballesteros, Reales, García, & Carrasco, 2006), conceptual object priming as explicit long-term memory is not attention free and requires selective attention at encoding. The finding suggests that the unattended stimuli were filtered out by the attentional system and not deeply encoded, confirming that implicit memory, although incidentally built, needs at least some attention to be created (Ballesteros et al., 2006; Ballesteros et al., 2008). Second, as expected, we found that the attended items were recalled and recognised better than the unattended by both groups. Participants successfully filtered out the unattended pictures.

Regarding the association between cardiovascular exercise and conceptual object priming, no group effects were observed for neither of the comparisons made (attended versus unattended, attended versus new and unattended versus new), confirming previous studies looking at the association of chronic exercise with perceptual priming in older adults (Ballesteros et al., 2013). Therefore, the current study looking at conceptual priming, which requires more elaborate processing than perceptual priming (Gong et al., 2015), shows that there is, at least so far, no evidence of an association between chronic exercise and priming.

Concerning explicit memory, a marginally significant difference between groups indicating that sedentary participants might discriminate better old from new items led us to conduct exploratory analyses. Such analyses suggested that active participants would discriminate unattended items from new items worse than sedentary participants. If this were the case, it would mean that for active participants the strength of the memory traces of the unattended and new items would be closer together than for the sedentary participants. It may be suggested that the weaker memory traces for unattended items for active participants resulted from suppression strategies. According to Lustig, Hasher, and Zacks (2007), inhibition can be involved in any of the three stages of processing: access (perceptual filtering), deletion (non-relevant-memory traces suppression) or restraint (automatic responses inhibition). Since there was no evidence of differential perceptual filtering of unattended pictures at encoding in the implicit task (no group effect or interaction were observed), where no encoding strategies are applied, it is likely that perceptual filtering was similar in both groups at the access stage. However, when participants were explicitly asked to encode the information at the same time as they ignored unattended pictures, it is likely that they applied strategies in order to retrieve the to-be-remembered information later. Active participants might have applied strategies to encode attended stimuli, but also to suppress the unattended material accessing the cognitive system in order not to interfere with the to be attended and remembered pictures, reducing their activation levels and making them more similar to the new item memory traces. This is consistent with recent findings from our laboratory showing better inhibitory strategies in memory using the retrieval induced forgetting (R.I.F.) paradigm

(Padilla, Andrés & Bajo, 2016). It is also consistent with Déry et al.'s (2013) results showing that, despite not improving memory *per se,* exercise specifically improved the ability to distinguish lures from similar previously studied targets, an ability that also depends on executive control (control of interference).

In terms of the possible limitations of our study, it is worth noting that interventional (as opposed to cross-sectional) studies are better suited to investigate the effect of exercise on cognition. We should underline, however, that in the present study significant differences in an objective measure of cardiovascular fitness as well as in frequency of aerobic exercise performed along life support the characterization of the sedentary and active groups as distinct groups with different cardiovascular levels. Future research might look at the effect of selective attention modulation on memory functioning before and after an exercise intervention to confirm the results obtained in our study using a cross-sectional design. Additionally, as noted above, it would be necessary to carry out additional studies to explore the modulation of the relationship between cardiovascular exercise and recognition by selective attention.

To conclude, physically active and sedentary participants performed at the same level in conceptual priming and recall. However, the results in recognition showed a marginally significant difference between groups suggesting that sedentary participants discriminate better old from new items. Further analyses to investigate this trend suggested that, although active and sedentary participants discriminated attended items similarly, active participants discriminated fewer unattended items probably owing to their better ability to suppress the non-relevant memory traces once they had accessed memory. This finding is consistent with previous results revealing better inhibitory control on active participants (Padilla et al., 2013, 2014; 2016; Pérez et al., 2014), and provides additional support to the hypothesis that regular cardiovascular exercise taps executive control.

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Table 1

Sample demographic variables averages and standard deviations in brackets.

	N	Age	TAM*	Rockport*	WAIS	Education
Active	37	23.7 (3.5)	200.6 (77.8)	56.0 (7.9)	44.0 (6.6)	12.5 (0.9)
Sedentary	37	23.7 (3.7)	81.6 (75.4)	46.8 (8.5)	43.9 (6.1)	12.4 (0.8)

Note: Age, total activity months of exercise along the whole life (TAM), scores on the Rockport fitness walking level test, scores on vocabulary test (WAIS), and years of education. * = $p < .05$

Table 2.

Experimental stimuli sets

Green-1: subjects must look at the green picture *Implicit Memory* Study Phase: Set A (37 A + 37 U = 74 pictures) Test Phase: Set A (74 A & U) +B (48 N pictures) *Explicit Memory* Study Phase: Set C (37 A + 37 U = 74 pictures) Test Phase: Set C (74 A & U) +D (48 N pictures)	Blue-1: subjects must look at the blue picture *Implicit Memory* Study Phase: Set A (37 A + 37 U = 74 pictures) Test Phase: Set A (74 A & U) +B (48 N pictures) *Explicit Memory* Study Phase: Set C (37 A + 37 U = 74 pictures) Test Phase: Set C (74 A & U) +D (48 N pictures)
Green-2: subjects must look at the green picture *Implicit Memory* Study Phase: Set B (48 + 26 from A, divided in A & U) Test Phase: Set B (74 A & U) +A (48 N) *Explicit Memory* Study Phase: Set D (48 + 26 from A, divided in A & U) Test Phase: Set D (74 A & U) +C (48 N)	Blue-2: subjects must look at the blue picture *Implicit Memory* Study Phase: Set B (48 + 26 from A, divided in A & U) Test Phase: Set B (74 A & U) +A (48 N) *Explicit Memory* Study Phase: Set D (48 + 26 from A, divided in A & U) Test Phase: Set D (74 A & U) +C (48 N)

Note. A = Attended; U = Unattended; N = New.

Table 3

Implicit memory: accuracy and reaction times (RT) before and after removing outliers measured on correct responses proportions in the test phase

	Attended			Unattended			New		
	Accuracy	Raw RT	No Outliers RT	Accuracy	Raw RT	No Outliers RT	Accuracy	Raw RT	No Outliers RT
Active	.95	722.79	705.34	.93	743.70	724.18	.95	751.13	735.55
	(.03)	(116.72)	(102.86)	(.05)	(103.08)	(97.67)	(.05)	(117.05)	(101.49)
Sedentary	.96	759.29	737.40	.94	795.75	776.43	.95	787.83	767.66
	(.04)	(147.05)	(138.43)	(.05)	(160.56)	(160.47)	(.04)	(148.28)	(140.77)

Note: averages and standard deviations in brackets are provided.

Table 4

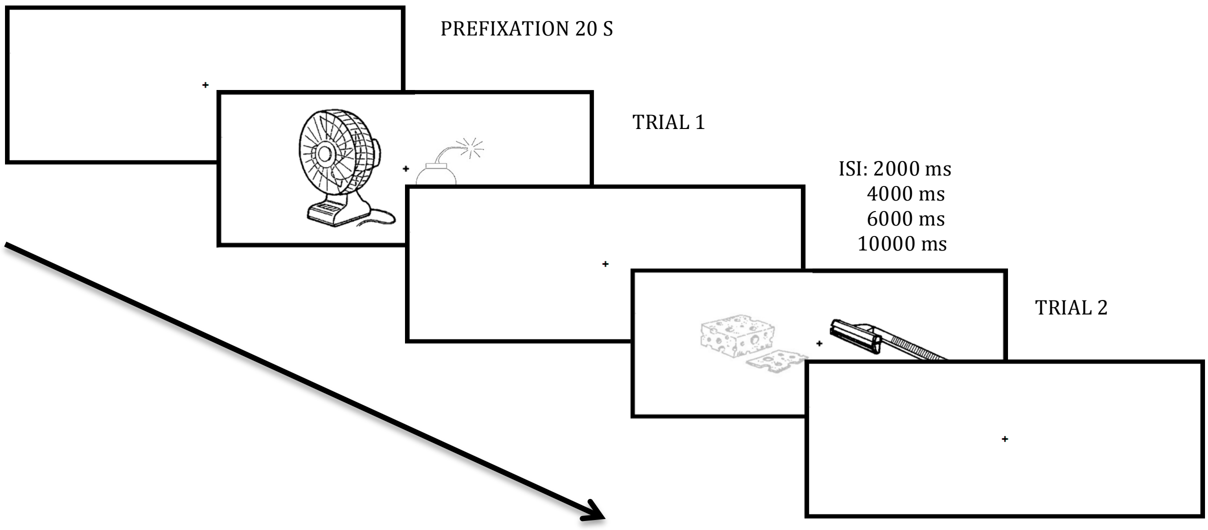
Mean d', criterion and free recall proportion of items in attended and unattended conditions in the test phase

	Active	Sedentary
	M (SD)	M (SD)
Free recall attended	0.21 (0.11)	0.20 (0.15)
Free recall unattended	0.08 (0.07)	0.07 (0.07)
d' attended	1.59 (1.47)	2.01 (1.02)
d' unattended	0.53 (0.62)	0.88 (0.81)
Criterion attended	-0.06 (0.27)	0.09 (0.49)
Criterion unattended	0.25 (0.66)	0.39 (0.52)

Note: Standard deviations are shown in brackets.

Figure 1. Details of the experimental procedure. a) Study phase: after a pre-fixation cross of 20 s, two picture outlines drawn on blue (light grey) or green (black) were presented inside a box, on each side of the fixation point, for 1000 ms. After that, a fixation cross appeared for a variable stimulus interval and a new trial started again. Participants had to categorise the attended picture outline (just one colour during the whole task) as natural or artificial as fast and precisely as they could. b) Test phase: a fixation cross appeared for 20 s, after that a picture outline in black appeared in the centre of a box for 1000 ms. Later, it was replaced by a fixation cross remaining on the screen for a variable stimulus interval. Participants had to categorise the items as artificial or natural in the implicit procedure, but as old or new in the explicit procedure.

a. Study Phase



b. Test Phase