The effects of different protocols of physical exercise and rest on long-term memory

Wesley Pyke[1*], Fadi Ifram[1*], Laura Coventry[1], Yee Sung[1], Isabelle Champion[1], Amir-Homayoun Javadi[1,2,3]

[1] School of Psychology, University of Kent, Canterbury, United Kingdom
[2] Institute of Behavioural Neuroscience, Department of Experimental Psychology, University College London, London, United Kingdom
[3] School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[*] These authors contributed equally.

Corresponding Author:
Amir-Homayoun Javadi
a.h.javadi@gmail.com
+44 1227 82 7770
Address:
School of Psychology
Keynes College
University of Kent
Canterbury, CT2 7NP
United Kingdom

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Abstract

Objectives Many studies have looked at the effects of physical exercise on long-term memory. However, to date, no study has compared the effect of different intensities and protocols of physical exercise and different rest conditions on long-term memory.

Methods In three studies (N=59) we measured the extent that physical exercise (in its varying intensities) and wakeful rest (active-rest; in which participants were cognitively engaged while seated and passive-rest; no cognitive engagement while seated) could influence long-term memory. Across all three studies, nearly identical procedures were employed, using the same old/new recognition memory test in order to establish the most effective protocol for cognitive enhancement. In Study 1, the effects of continuous moderate intensity exercise, uninterrupted wakeful rest (passive) and rest with an engagement task (active) were explored. In Study 2, continuous moderate intensity exercise was compared to high-intensity interval training (HIIT) and passive rest. Study 3 observed the effects of low-, moderate- and high-intensity continuous exercise.

Results Across the three studies moderate intensity exercise had the greatest positive impact on memory performance. Passive rest was more effective than active rest, however, less than high-intensity interval-training (HIIT).

Conclusion Our findings suggest that it is not necessary to physically overexert oneself in order to achieve observable improvements to long-term memory. By also investigating uninterrupted wakeful rest, it reaffirmed the importance of the consolidation period for the formation of long-term memories.

Introduction

Due to advancements in medical technologies and medicine, it is thought that global life expectancy will increase substantially within the coming decades. With age being a significant risk factor for neurodegenerative diseases, such as Alzheimer's Disease (AD), it is of vital importance that research into preserving cognition in older age is not ignored. This research should provide methods that are affordable and easily accessible for both the state and the individual. There is much evidence to support the notion that aerobic physical exercise (PE) has beneficial effects on cognition as a whole(1,2) for a model, see(3). Current research observes positive effects of PE on various aspects of memory at different age groups, from young to older adults(4). The growing body of research hopes to encourage the population to partake in frequent exercise as a protective measure against neurodegenerative diseases(5). Another method shown to benefit cognition, somewhat markedly different to PE, is wakeful rest. Short periods of uninterrupted wakeful rest have been shown to increase performance in a wide range of memory domains(6–9). It would therefore be of interest to investigate whether PE promotes greater memory performances than wakeful rest and if so, what the most beneficial protocol of PE is. In this research, we investigate this question using two types of PE (namely continuous and interval-training), differing intensities of PE and wakeful rest.

When observing the current research on PE, much has focused on the effect that continuous, moderate-intensity has on cognition, with strong evidence in support(4,10–12). When measuring the impact of different intensities of PE on cognition, mixed results have been found. A study testing associative memory found moderate intensity exercise to yield greater results compared to high-intensity, both 2 hours after the exercise intervention and 3 months later(13). Conversely, Hötting and colleagues(14) found a continuous higher intensity exercise condition to yield better performance than moderate and rest conditions on a word recall task. Relatively unexplored in its relation to cognition is high-intensity interval training (HIIT). HIIT can be defined as anaerobic, short, repeated bursts of high-intensity exercise, typically between 15 seconds and 4 minutes, separated by periods of rest of a similar time. Research has shown HIIT can provide cardiovascular improvements similar to continuous exercise training, with far less time needed(15–17), giving hope for those with busy schedules and little time for typical exercise regimens. One study by Winter and colleagues(18) found a bout of HIIT to speed up vocabulary learning by 20%. HIIT protocols have also been shown to improve both motor learning memory and high-interference memory(19,20).

It is important not to overlook the importance of rest in studies of memory, with evidence suggesting wakeful rest to be beneficial for memory performance(7,8). Alber, Sala, & Dewar(6) showed that wakeful rest with minimal sensory stimulation led to 73% more amnesic participants recalling >30% of a prose, compared to those who completed a cognitive task during wakeful rest. Many other studies have found similar conditions of wakeful rest to improve recall even when tested 7 days later. It is suggested that a period of cognitive disengagement is vital for the consolidation of newly learned stimuli and interruption of this process can cause new memory traces to be overlooked in favour of another task(6,9,21).

To measure whether PE and wakeful rest were beneficial to memory performance, we conducted three studies, each employing similar methods throughout, to provide a standardised evidence base for the most effective protocol. In the first study, memory performance is measured for continuous moderate intensity exercise against both active (cognitive engagement task) and passive (no task employed) rest, with results on a recall task recorded. Following this, the second study compares continuous, moderate-intensity exercise with a HIIT protocol and a passive rest condition. In the third study, the cognitive benefits of low, moderate and high-intensity continuous exercise are compared. It was hypothesised that across the three studies, moderate intensity exercise would yield the most positive results with the passive rest condition performing better than active-rest.

Methods

Participants

A total of 59 participants took part in three studies: Study 1 comparing different types of rest conditions with moderate continuous exercise (N=17, 10 females, age mean[SD]= 9.77[1.27]), Study 2 comparing moderate continuous exercise with high intensity interval training (N=23, 20 females, age mean[SD]=19.62[1.51]), and Study 3 comparing different intensities of continuous exercise (N=19, 11 females, age mean[SD]=21.85[2.43]). All participants were naive to the aim of the study, spoke fluent English, and had normal or corrected-to-normal vision. Participants were screened to exclude those with a history of neurological or psychiatric disorders, and no participant was taking centrally-acting medication. All participants gave their written informed consent, and the study was given ethical approval by the Psychology Research Ethical Committee, University of Kent.

Study Design

All studies followed a within subject design with three conditions. Figure 1 summarises the conditions for the three studies. Each experimental session, consisted of an encoding phase, an intervention phase, a retention interval and a retrieval phase. During the encoding phase, participants memorised 80 image-word pairs of the same object. Participants watched episodes of the American sitcom "Friends" during the retention interval. In the retrieval phase, participants were asked to perform an old/new recognition task on 160 image-word pairs (80 old and 80 new). Table 1 summarises the protocols for each condition of each study.

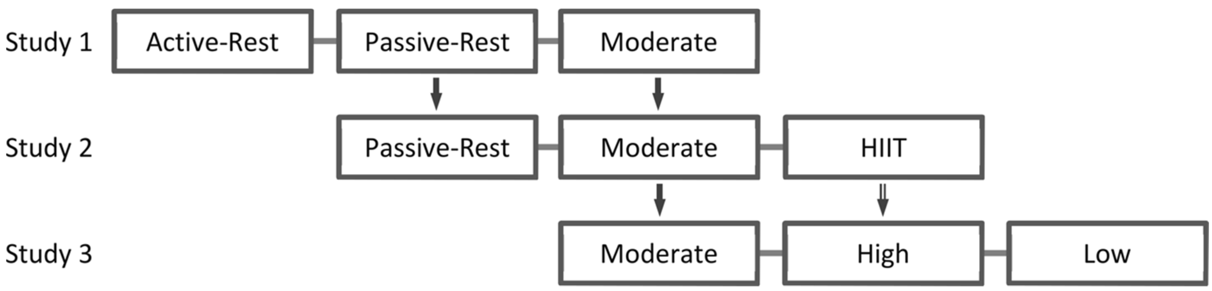

Figure 1. Summary of different intervention conditions for the three studies. The top panel shows the procedure of each session. Low, Moderate and High indicate low-, moderate- and high-continuous exercise, respectively. HIIT refers to high-intensity interval training.

Table 1. A chronological summary of the procedures used across the three studies. Please refer to the behavioural section for the details of the interventions.

Study	Condition	Intervention	Retention Interval
Study 1	Active-Rest	30’ cognitive engagement task	60’
	Passive-Rest	30’ resting with no task	60’
	Moderate	6 × 4’ continuous moderate-intensity cycling	60’
Study 2	Passive-Rest	30’ passively resting	60’
	Moderate	2 × 3’ continuous moderate-intensity cycling	80’
	HIIT	4 × 0.5’ maximum speed cycling	80’
Study 3	Moderate	6 × 4’ continuous high-intensity cycling	50’
	High	6 × 4’ continuous moderate-intensity cycling	50’
	Low	6 × 4’ continuous low-intensity cycling	50’

Note: in all studies, the duration between the encoding and retrieval was the same across different conditions. Durations are indicated in minutes.

Materials

A collection of 480 image-word pairs of common objects were created. A set of 160 pairs was randomly selected for each experimental session. The experiment was run on a desktop computer with a 17-inch monitor. Stimulus presentation and the recording of response time were achieved using MATLAB (v2015b; MathWorks Company, Natick, MA) and the Psychtoolbox v3 (22).

Behavioural Tasks

The encoding phase consisted of presentation of 80 image-word pairs. Participants were asked to memorise the objects for a later old/new recognition task. They were instructed to memorise the concept of the image rather than the actual image, as a different images of the same concept were presented in the encoding and recognition phases. In each trial image-word pairs were presented for 1 second followed by a 2 second fixation cross.

In the retrieval phase, 160 image-word pairs were presented in random order. The pairs consisted of the 80 image-word pairs presented in the encoding phase (Old stimuli) and 80 new image-word pairs (New stimuli). The image-word pair was presented on the screen until participant’s response. Participants’ task was to indicate which stimulus is Old and which stimulus is New. Participants were asked to respond as accurately and as fast as possible. Each experimental session contained a new set of 160 image-word pairs to avoid interference between sessions.

Interventions

Throughout the studies four interventions were administered: continuous exercise with different intensities, high-intensity interval training (HIIT), active-rest and passive-rest. *Continuous exercise* consisted of six blocks of 4-min cycling on an ergonomic exercise bike (Stages SC3 Indoor Cycle, Stages Cycling, US), and 1-min of rest. Participants were given a speed range (60-70rpm, 65-75rpm, 70-80rpm) at the beginning of each block and were asked to keep their speed within that speed range. The resistance of the bike was adjusted manually based on the participant's maximum heart rate (HR_{max}): low-intensity 55-65% HR_{max}, moderate-intensity between 65-75% HR_{max}, and high-intensity between 75-85% HR_{max}. HR_{max} was calculated based on participant's age using the following formula (23):

$$HR_{max}=208 - (0.7 \times age)$$

Heart rate was monitored using a Mio Fuse Heart Rate Monitor (Mio Global, US). Participants were given two minutes to warm up and cool down with their desired speed and intensity.

The *HIIT* condition consisted of four blocks of 30s cycling and 1-min rest. Participants were instructed to cycle as fast as possible throughout the cycling period. The four blocks of 30s cycling were decided based on a pilot study in which participants in two separate sessions (n=21) were asked to cycle for six blocks of 30s as fast as possible or cycle for two blocks of 3 minutes with moderate-intensity. Two blocks of 3 minutes of moderate-intensity exercise was calculated based on our previous data from Study 1. Four blocks of 30s HIIT resulted in a similar total energy expenditure as the two blocks of 3 minutes moderate-intensity exercise (mean[SD] HIIT=25.476[8.829], moderate-intensity=27.666[9.355], $t(20)=1.182$, $p=0.251$).

The *Active-rest* condition contained a cognitive task simulating the speed thresholds on the continuous exercise condition. Participants were required to monitor and maintain a fluctuating number displayed on the monitor within a certain range. This fluctuating number was equal to the speed range participants maintained during continuous exercise. Similar to the continuous exercise condition, this condition consisted of six blocks of 4-minute task and 1-minute rest. At the beginning of each block a range (60-70, 65-75, 70-80) was given to the participant. Participant's task was to monitor and keep the fluctuating number displayed on the monitor within that range: press down or up arrow-key when the number went above or below the range, respectively.

In the *passive-rest* condition participants were asked to sit quietly and comfortably on a chair for 30 minutes and do nothing. Participants were regularly monitored so as to ensure they did not fall asleep. At the end of the session (after the retrieval phase) they were asked what they did during the rest period to identify whether they rehearsed the stimuli or not. Participants who rehearsed (N=3 for Study 1 and N=1 for Study 2) were excluded from the analysis.

Statistical Analysis

Data analyses were performed using SPSS (v19; LEAD Technologies, Inc, Charlotte, NC). Accuracy for the recognition of the old and new words were analysed separately. One-way repeated measures of analysis of variance (rANOVA) was used to investigate the main effect of condition with percentage accuracy in recognition of the old and new words, as well as reaction time for the old and new words. Following significant main effect of condition, post-hoc paired-sample t-tests were run to investigate the difference between groups.

Results

Table 2 summarises the descriptives for the three studies. Four separate rANOVA were run. Table 3 summarises the rANOVAs run for each study. Table 4 and Figure 2 summarise post-hoc comparison between different intervention condition. Our results showed that different interventions modulated accuracy for the old words, but not the new words. They did not have any effect on the reaction time. The post-hoc comparison between different conditions in the three studies showed significant improving effect of moderate PE.

Table 2. Summary of the descriptives of the three studies (mean[SD]) split over old and new words, and the three conditions in each study.

	Measure	Condition	Old Words	New Words
Study 1	Accuracy	Moderate	81.985[2.874]	88.824[3.063]
		Active-Rest	75.294[3.287]	84.926[3.102]
		Passive-Rest	77.794[3.614]	90.074[2.553]
	RT	Moderate	1.344[0.089]	1.628[0.109]
		Active-Rest	1.530[0.138]	2.069[0.422]
		Passive-Rest	1.407[0.164]	1.694[0.191]
Study 2	Accuracy	Moderate	77.337[2.630]	83.859[3.011]
		HIIT	74.348[2.485]	84.620[2.363]
		Passive-Rest	71.467[2.076]	82.717[2.614]
	RT	Moderate	1.219[0.063]	1.400[0.075]
		HIIT	1.354[0.100]	1.428[0.085]
		Passive-Rest	1.317[0.100]	1.393[0.103]
Study 3	Accuracy	Moderate	88.496[1.596]	92.782[1.512]
		High	82.105[3.032]	92.030[1.383]
		Low	82.481[2.498]	92.932[1.611]
	RT	Moderate	1.390[0.077]	1.738[0.124]
		High	1.427[0.090]	1.784[0.147]
		Low	1.561[0.107]	1.938[0.179]

Notes: RT stands for reaction time. Low, Moderate and High indicate low-, moderate- and high-continuous exercise, respectively. HIIT refers to high-intensity interval training.

Table 3. Summary of the rANOVA for each study separated for old and new words, and performance accuracy (Acc) and reaction time (RT).

		Old Words	New Words
Study 1	Acc	$F(2,32)=4.621$, $p=0.017$, $\eta_p^2=0.224$*	$F(2,32)=2.540$, $p=0.095$, $\eta_p^2=0.137$
	RT	$F(2,32)=1.206$, $p=0.313$, $\eta_p^2=0.070$	$F(2,32)=1.111$, $p=0.341$, $\eta_p^2=0.065$
Study 2	Acc	$F(2,44)=3.991$, $p=0.026$, $\eta_p^2=0.154$*	$F(2,44)=0.560$, $p=0.575$, $\eta_p^2=0.025$
	RT	$F(2,44)=0.889$, $p=0.418$, $\eta_p^2=0.039$	$F(2,44)=0.114$, $p=0.892$, $\eta_p^2=0.005$
Study 3	Acc	$F(2,36)=4.503$, $p=0.018$, $\eta_p^2=0.200$*	$F(2,36)=0.299$, $p=0.743$, $\eta_p^2=0.016$
	RT	$F(2,36)=1.732$, $p=0.191$, $\eta_p^2=0.088$	$F(2,36)=1.266$, $p=0.294$, $\eta_p^2=0.066$

Notes: RT stands for reaction time. Low, Moderate and High indicate low-, moderate- and high- continuous exercise, respectively. HIIT refers to high-intensity interval training. *p<0.05

Table 4. Summary of the post-hoc paired-sample t-tests for the performance on the old words for each study.

		t	***p***	**Cohen's d**
Study 1	Moderate vs Active-Rest	$t(16)=3.190$	$p=0.006^{**}$	$d=0.774$
	Moderate vs Passive-Rest	$t(16)=2.073$	$p=0.055^{\dagger}$	$d=0.503$
	Active-Rest vs Passive-Rest	$t(16)=0.992$	$p=0.336$	$d=0.241$
Study 2	Moderate vs HIIT	$t(22)=1.573$	$p=0.130$	$d=0.328$
	Moderate vs Passive-Rest	$t(22)=2.775$	$p=0.011^{*}$	$d=0.579$
	HIIT vs Passive-Rest	$t(22)=1.306$	$p=0.205$	$d=0.272$
Study 3	Moderate vs High	$t(18)=2.256$	$p=0.037^{*}$	$d=0.518$
	Moderate vs Low	$t(18)=3.691$	$p=0.002^{**}$	$d=0.847$
	High vs Low	$t(18)=0.148$	$p=0.884$	$d=0.034$

Notes: *p<0.05, **p<0.01, †marginally significant. Low, Moderate and High indicate low-, moderate- and high- continuous exercise, respectively. HIIT refers to high-intensity interval training.

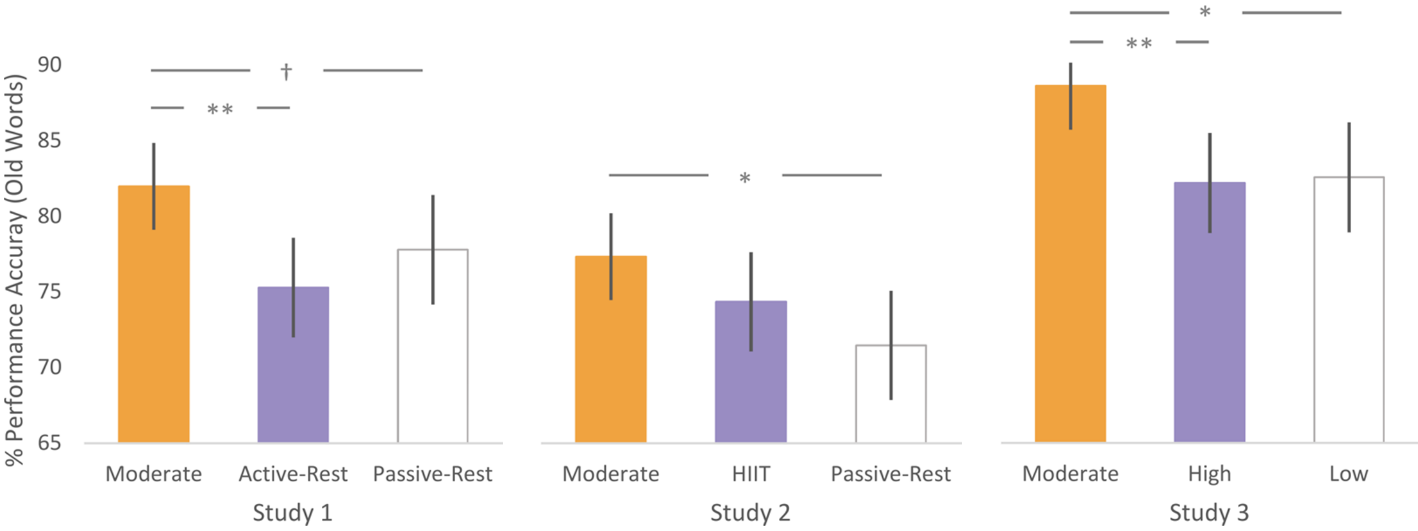

Figure 2. Performance accuracy for the three studies split over different conditions. *p<0.05, **p<0.01, †p=0.055. Error bars represent one standard error of the mean.

Discussion

The aim of this investigation was to observe whether varying intensities of exercise or different types of rest could directly affect scores on a recognition memory test. Results from all three studies suggest that moderate exercise has the greatest influence on an old/new recognition task compared to other protocols (continuous, low- and high-intensity/HIIT/passive and active rest). In Study 1, post-hoc comparisons between the conditions revealed that when participants took part in the moderate exercise condition, accuracy on the old/new recognition task was significantly greater than active rest, with marginal significance compared to the passive rest. Although not significant, the passive rest condition recalled images with greater accuracy than the active rest condition. In Study 2, moderate-intensity exercise again yielded the greatest recall accuracy, with significantly better performance than the passive rest condition. The HIIT condition also performed better than the passive rest condition, although this did not reach a level of significance. In Study 3, moderate exercise again had a significantly greater recall accuracy than both low- and high-intensity conditions, with little difference between low and high conditions.

Cognitive Improvement

It has been shown that hippocampal replay, the process of strengthening previously experienced stimuli, is most effective during an awakened, relatively immobile state(24). This process occurs immediately following presentation of stimuli with previous research showing 0 - 10 minutes to be the most crucial time period for optimum consolidation(6–9,25). By using non-recallable, fabricated words, Dewar et al.,(25) showed that during wakeful uninterrupted rest, increases in memory performances could not be attributed to intentional learning or recall, therefore consolidation must be the focal process. This suggests that the cognitive engagement task presented in the active rest condition likely inhibited consolidation of the recently learnt stimuli(9,21,25).

The results obtained from this study provide an interesting addition to the current literature on the impact that HIIT has on cognition. Previous research looking at higher intensity or HIIT conditions with similar procedures to the current study have found HIIT to be detrimental to memory performance. Here, although non-significant, we found that HIIT performs better than a passive rest condition. Hötting et al.,(14) found that those who participated in a high-intensity exercise condition (80% HR_{max}) recalled more words than those in other conditions (low intensity; rest), but only after 24 hours. Initially, when tested 20 minutes after the exercise intervention, those in the control group (rest) achieved better results than those in the two experimental conditions (low; high intensity). A study conducted by Roig et al.,(20) provides further evidence for this. They split participants into three groups, either practising a visuomotor accuracy-tracking task before or after HIIT, with a control rest condition included. Findings showed that the differences between both exercise groups in motor skill acquisition was non-significant. However, an increase in motor skill retention was only shown 24 hours and 7 days after practice, not after 1 hour, where negative results were displayed. A meta-analysis by Chang, Labban, Gapin, & Etnier(26) showed that effects of exercise had a negative impact on results in a memory test, compared to rest groups, if tested within 20 minutes of ceasing physical exercise. It appears that with high-intensity exercise, the longer the delay (>20 minutes) between exercise and testing, the greater the results achieved on the recall task. In many cases, scores obtained immediately after high-intensity exercise have been lower than those in the control/rest conditions. This suggests that time in which the recall task is executed following exercise is key, as consolidation of stimuli is highly sensitive to external influences, whether physiological (exercise), or psychological (engagement tasks).

Cognitive Impairment

Potential reasons for this short-term decline in cognitive abilities following high-intensity exercise may be attributed to the endocrine system. Increased levels of cortisol are released in to the brain by the adrenal glands in response to stressful situations in this instance, high-intensity exercise (physical stress;(11,27). High levels of cortisol are associated with a short-term decline in cognitive abilities(28,29). It has been shown that levels of cortisol are higher following intense exercise, but not moderate exercise(27,30). Evidence suggests that any exercise exerting >70% $VO2_{max}$ will facilitate secretion of cortisol in humans(31). After cessation of intense exercise, cortisol levels can take between 2 and 4 hours to return to the baseline level(31). This evidence suggests that following high-intensity exercise, as cortisol levels are higher, memory is impaired until cortisol levels return to baseline. This notion falls in line with the current study's findings as the retrieval task was conducted after only 1 hour of completion of exercise.

Conversely, there is much evidence in support of moderate continuous exercise as a beneficial method of cognitive enhancement. This has a well-documented neurophysiological explanation(3). It has been shown that physical exercise initiates the release of brain-derived neurotrophic factor (BDNF;(14,32,33), which has been shown to be vital for neurogenesis, the maturation and protection of neurons(34) and neural plasticity(13,35). Higher concentration of BDNF is positively associated with increased hippocampal volume, which is in turn, associated with improved spatial memory(4). Further evidence for this is provided in a review by Stimpson et al.,(3) in which they propose a model containing several other short-term effects of PE on cognition. Increased serum BDNF, serum vascular endothelial growth factor (VEGF), neuronal insulin-like growth factor 1 (IGF-1) uptake and hippocampal VEGF expression all make a cumulative contribution to brain plasticity, which, in turn, produces cognitive benefits. Serum BDNF has also been shown to increase significantly following a short bout of high-intensity exercise, although levels drop considerably faster after ceasing (6 minutes) than a longer bout of continuous exercise(11). The evidence suggests that exercise performed at a moderate intensity lies between two thresholds. Firstly, enough exertion is performed to initiate the release of BDNF to aid neurogenesis, thus improving learning and memory, and secondly, it does not reach the threshold at which physical stress becomes an inhibitor to retention and consolidation.

Considerations

By using a pilot study (n=21), the total energy expenditure achieved from moderate-intensity exercise and HIIT conditions was equated. This is an important procedure as differences between short bouts of high intensity exercise and longer, continuous moderate exercise have considerably different neurophysiological effects. By matching the energy output, any observable differences in scores between the two conditions (moderate and HIIT), were less likely to be attributed to a difference in energy expenditure.

Between the studies, memory performance scores showed some degree of variability. Reasons for this variance may be due to differences in the implemented protocols, individual reactions to exercise in general, as well as differences in baseline cognitive abilities and motivation to complete the tasks(36). This perhaps highlights the need for an initial cognitive test to measure baseline performance, so comparisons between the conditions can be made.

This study, like many others measuring long-term memory, used cycling as an intervention. Whilst we have shown cycling, a form of continuous aerobic exercise, to be an effective intervention to improve long-term memory, it is important not to discount other forms of exercise such as resistance training and yoga, of which all are comparable to aerobic exercise for increasing cognitive functions in general(37) . Exploring how resistance programs can influence long-term memory directly may provide benefits to those who may not necessarily be able partake in aerobic exercise, perhaps due to disabilities or older age.

It would also be useful to record physiological differences such as saliva or serum samples to provide information on BDNF, VEGF, IGF -1 and cortisol levels at various time points following exercise. This way, one could speculate with greater accuracy as to why the exercise dependant conditions achieved the results they did.

Conclusion

Our research has shown that moderate-intensity exercise has the most beneficial effect on memory performance. This indicates that it is not necessary to overexert oneself in order to achieve observable cognitive improvements. It has also shown that short periods of uninterrupted wakeful rest after learning can increase the likelihood of remembering at a later date. This may have practical implications for those who require immediate benefits to memory performances, such as those sitting exams.

Competing interests

Authors declare no conflict of interest.

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