

The Effects of Acute Exercise and Virtual Reality Tasks on Children's Memory Function and Exercise Preference

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ABSTRACT

Background: It is well established that regular participation in exercise and virtual reality (VR) environments are important tools for improving or maintaining human health and cognitive function. **Objectives:** This study examined the effects of acute exercise and VR environments on children's memory function and exercise preference (i.e. cycling with or without the use of VR technology). **Methods:** A 2×3 factorial design was adopted with two measures (pre, post) and three study groups. Forty-five healthy children aged 9 to 13 years ($M_{age} = 10.91 \pm 1.24$ years) voluntarily participated in the study. Participants were randomly assigned into three groups receiving different treatment: (1) an exercise+VR group that cycled for 15 min in a VR environment (forest path) combined with basic mathematical problem-solving tasks, (2) an exercise group that cycled for 15 min, and (3) a no-exercise group that sat in a specific place in a lab for 15 min (the control group). Before and after the acute exercise, all the groups completed the Sternberg Memory Task. Upon completion of the intervention, the two exercise groups completed measures of enjoyment, intention and attitudes towards cycling. The exercise+VR group also completed a scale capturing the VR's usability. **Results:** The results show that the exercise group scored higher on Sternberg's Memory Task ($p < .05$) after the acute exercise treatment (post) than before it (pre). Similarly, the exercise+VR participants scored higher on the post-intervention memory task than did the exercise and control groups ($p < .05$). Moreover, the exercise+VR group reported higher scores on enjoyment, intention and attitude towards cycling than the exercise group, but this difference was not statistically significant ($p > .05$). Finally, the exercise+VR participants recorded high scores on the usability of the VR system during the acute exercise programme. **Conclusions:** These findings are in line with those of previous studies, underlining the important roles of exercise and VR environments on youths' cognitive function.

Key words: Children, Exercise, Virtual Reality, Pleasure, Memory, Technology, Exergame

INTRODUCTION

It is well documented that systematic participation in exercise significantly improves and maintains human cognitive function and memory (e.g. Doherty & Forés Miravalles, 2019; Etnier & Chang, 2009, 2019; Ploughman, 2008). As Ploughman (2008, p. 236) rightly noted a few years ago, "Exercise is brain food". But what about acute exercise or a single bout of exercise? The recent literature cites growing evidence that acute exercise or single exercise bouts have a small but positive effect on human cognitive function, mood and memory (e.g. Basso & Suzuki, 2017; Chang et al., 2012a; Loprinzi & Edwards, 2018; Loprinzi et al., 2018). This small effect of acute exercise on human cognitive function may result from the multiple variations in the experimental designs of these studies. More specifically, the diverse samples (male or female, youths or adults and elderly people, healthy

or unhealthy), sample sizes, types of exercise (e.g. walking, cycling, running, resistance training), exercise intensities (low, moderate, vigorous), exercise durations (from 10 to 60 min) and cognitive evaluation tasks (e.g. attention, information processing, memory recall tasks, reaction time) used in previous studies could adequately explain why the effect of acute exercise on the participants' cognitive function remained small (e.g. Basso & Suzuki, 2017; Chang et al., 2012a; Mrakic-Sposta et al., 2018). Moreover, the majority of these studies focused mainly on adults or elderly people, but there is still only limited evidence-based research on the cognitive function of children and adolescents (Chang et al., 2012a).

In the past decades, virtual reality (VR), which allows humans to interact in a simulated environment produced by information technologies, has attracted the attention of many researchers in various scientific disciplines. As has been

repeatedly noted (e.g. McMillan et al., 2017; Mol, 2019; Stavroulia & Lanitis, 2017), VR is defined by the Oxford English Dictionary as “the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors”. According to the extant literature (e.g. Guixeres et al., 2013; Rizzo et al., 2011), two main types of VR exist: (1) *immersive VR*, in which participants can be immersed or move in a simulated environment with real-time graphics using sophisticated and complex computer devices, such as head-mounted displays or body-tracking sensors, and (2) *non-immersive VR*, in which participants can navigate or interact in a simulated environment using innovative computer and console game systems on a display screen.

Previous studies have used VR to teach pedestrian safety to children (McComas et al., 2002), to educate teachers (Stavroulia & Lanitis, 2017), to treat social phobia (e.g. Anderson et al., 2003) and eating disorders (Clus et al., 2018), to reduce acute or chronic pain (e.g. Botella et al., 2008; Jones et al., 2016; Wiederhold et al., 2014), to improve the physical fitness of individuals with intellectual and developmental disabilities (Lotan et al., 2009), to improve motor control in children with cerebral palsy (Bryanton et al., 2006) and to improve mood in combination with exercise (Plante et al., 2003). Importantly, the participants were more motivated when exposed to VR environments (Harris & Reid, 2005) and experienced greater fun and enjoyment when they combined exercise with VR (e.g. Bryanton et al., 2006; Plante et al., 2003).

In conclusion, the vast majority of studies using VR have been in the fields of health and rehabilitation, but only a few studies using VR have been conducted among children with intellectual and developmental disabilities, and even fewer have examined the participants’ motivation and enjoyment during or immediately after the implementation of an exercise programme combined with VR. In addition to the benefits of exercise and VR on youths’ cognitive function, it is well established that mathematical problem-solving tasks activate specific areas of children’s brains (e.g. Arsalidou et al., 2018).

Furthermore, the dual-task training design of the present study may represent a methodological advance, as one of its experimental groups engaged in simultaneous exercise and cognitive training through VR (Cooke et al., 2020). According to Wollesen et al.’s (2022) scoping review, “Dual task training interventions may improve physical and/or cognitive functions in children and adolescents” (p. 1). Also, Wollesen et al. (2022) found that there is still only a small number (seven) of dual-task training interventions that examined their impact on healthy youths’ cognitive and physical performance.

Summarizing the above, research has demonstrated the effects of exercise on cognitive function, but there is limited evidence for the population of children; in addition, VR environments seem to strengthen individuals’ interest and motivation to exercise, but this has not been combined with

acute cognitive outcomes. Based on the above, this study examined the effects of acute exercise and a VR environment combined with basic, simple mathematical problem-solving tasks on children’s memory function and preference of exercise type (i.e. cycling with or without the use of VR technology). To our knowledge, this would be the first study to combine acute exercise and a VR environment with basic mathematical problem-solving tasks in children to examine whether their cognitive function is improved through a dual-task training design. Accordingly, the present study extends the literature pertaining to the acute exercise and VR environments, but also provides useful insights for its impact on children’s memory function. The hypotheses were as follows: (1) the exercise+VR group (cycling in a VR forest combined with basic mathematical problem-solving tasks, such as addition, subtraction and multiplication) will score better in memory function (correct answers, reaction time) than the exercise group (only cycling) and control group (no exercise); (2) the exercise+VR group will record higher scores of acute exercise enjoyment, intention to cycle and attitude towards cycling than the exercise group; (3) the exercise+VR participants will achieve similar scores to the exercise group for average cycling speed (SP), heart rate (HR) and rating of perceived exertion (RPE) prior, during (only for SP and HR) and immediately after the acute exercise programme (no significant differences); and (4) the exercise+VR group will give high scores to VR usability during the acute exercise programme (cycling), and there will be significant correlations among the examined variables of exercise enjoyment, intention to cycle, attitude towards cycling and VR usability in the exercise+VR group.

METHODS

Study Design and Ethics

A 2×3 factorial design was adopted with two measures (pre, post) and three study groups (*exercise+VR*: cycling and VR; *exercise*: only cycling; *control*: no exercise). Using a lottery method, an independent researcher randomly assigned the participants to three groups: (1) an exercise+VR group that completed 15 min of cycling in a VR environment combined with basic mathematical problem-solving tasks ($n = 15$), (2) an exercise-only group that completed 15 min of cycling ($n = 15$) and (3) a control group that did not exercise but sat in a predetermined place in the lab for 15 min ($n = 15$). The study was first approved by the Bioethics Committee of the School of Physical Education and Sport Science, University of Thessaly. The participants and their parents signed a consent form, completed a medical history questionnaire and were thoroughly informed about the whole experimental design by a researcher.

Sample Size Calculation

An experimental study was conducted. According to an a priori power analysis for F test (ANOVA with between and within subjects analysis) using the G*Power program version 3.1 (Faul et al., 2007), the desired sample size for the

present study was 42 participants. Specifically, with an expected medium effect size of .25, a power to .80 and a p -value of less than .05 (e.g. Cohen, 1992; Uttley, 2019), this offered an acceptable power of .81. Similarly, an a priori power analysis for t test (i.e. paired samples t -test) with the G*Power program 3.1 (Faul et al., 2007) revealed that the desired sample size for an actual power of .81 was 27 participants, giving an expected medium effect size of .5, a power to .80 and a p -value of less than .05 (e.g. Cohen, 1992; Uttley, 2019). It is important to mention that the above medium effect sizes were chosen based on previous studies with similar experimental designs and samples (e.g. Chang et al., 2012b; Drollette et al., 2014) or on existing meta-analyses examining the effects of acute exercise on cognitive performance (e.g. Chang et al., 2012a). For example, Drollette et al. (2014) found an exercise effect size on children's cognitive function ranging from .14 to .76 measured by the Eriksen flanker task (Eriksen & Eriksen, 1974). Based on the aforementioned, the sample size of the present study ($N = 45$) clearly surpassed the number of volunteers required to achieve acceptable statistical power.

Participants

Sixty healthy children, with no medical contradictions for exercise participation and no learning difficulties, from a children's private creative learning centre and a soccer club in central Greece were eligible to participate in the study. Based on the power calculation, 45 children were randomly selected to participate in the study. Figure 1 presents details regarding participants' recruitment and allocation to the three experimental groups.

Procedures

The participants were randomly assigned into three groups: (1) experimental group 1 (exercise+VR) cycled for 15 min in a VR environment (forest path) combined with too easy mathematical problem-solving tasks ($N=15$; 9 boys, 6 girls),

(2) experimental group 2 (exercise) only cycled for 15 min ($N=15$; 12 boys, 3 girls) and (3) experimental group 3 (control/no exercise) sat in a specified place in the lab for 15 min ($N=15$; 11 boys, 4 girls). Participants were first introduced to the requirements and the procedures of the study and were encouraged to ask any questions they may had. Subsequently, all participants completed the cognitive function test (Sternberg, 1966).

Participants of the exercise groups underwent the cycling task. A BRX R 300 stationary cycle-ergometer was used for the acute exercise protocol (TOORX Chrono Line, Garlando S.p.A., Via Regione Piemonte 32, Italy; voltage: 220 VAC; frequency: 50 Hz; power: 11.7 VA; maximum user weight: 150 kg). According to Hassandra et al. (2021, p. 4), this stationary bike has been shown to "reduce the risk of users falling, facilitate accurate control of training conditions, and also meets the requirements of Bluetooth connectivity capability with VR device". At 3-min intervals, the SP was recorded by a trained researcher, and then the average SP of each participant was calculated.

Participants of the exercise+VR group were in addition presented and explained the VR device. The VRADA VR app system (Hassandra et al., 2021) was used to create a dynamically generated forest path as a relaxing, enjoyable VR scenery for the study's acute exercise protocol (Picture 1). The forest's 3D scenery changed constantly as the user cycled along the path. While cycling, each volunteer used a mobile controller to do 21 basic, simple mathematical calculations (addition, subtraction and multiplication), which appeared on the digital screen at regular intervals. The VRADA VR app consists of the Oculus Go mobile head-mounted display equipped with the ORamaVR M.A.G.E.S. platform (Papagiannakis et al., 2018) supporting interactive VR learning environments as well as a mobile hand controller. More details on the VRADA VR's features can be found in Hassandra et al. (2021).

Immediately after the experimental treatment (exercise and control conditions) all participants completed again the cognitive function test (Sternberg, 1966). Participants of the

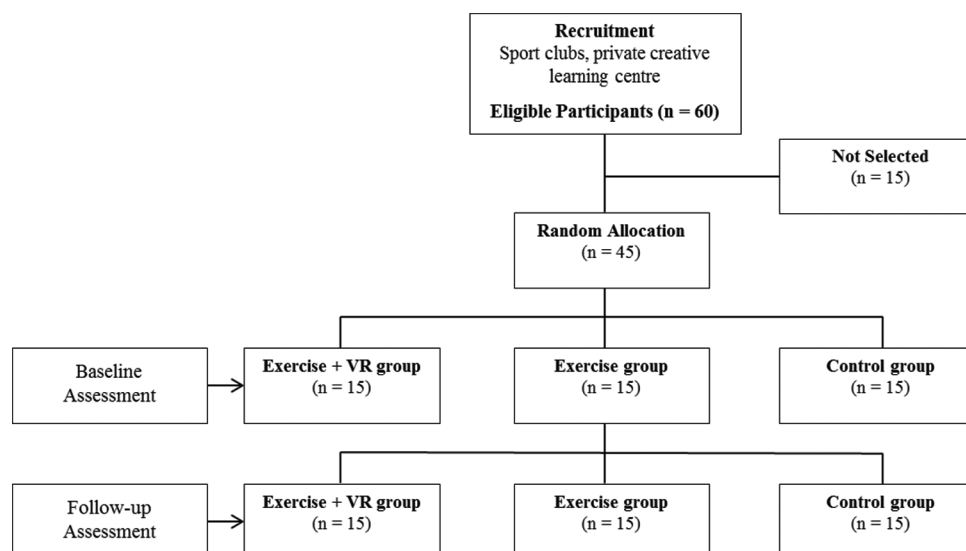
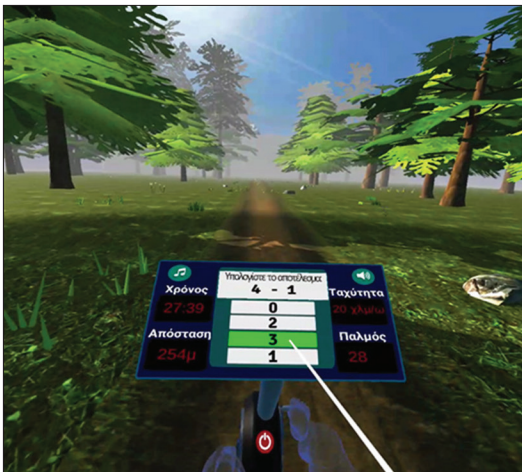


Figure 1. Flow diagram portraying the allocation of participants



Picture 1. VR environment

exercise groups completed in addition the enjoyment, intention to participate in an exercise programme, and attitude towards exercise scales. The exercise+VR group also completed the scale for usability of the VR during acute exercise.

All the measures were taken in the Psychology of Exercise and Quality of Life Laboratory at the School of Physical Education and Sport Science, University of Thessaly under controlled room conditions (25°C constant temperature). The experimental procedures took place in single sessions that lasted approximately 45 min for each participant.

Primary Outcome Measure

Cognitive function. Cognitive function was the primary outcome measure of the study. In particular, volunteers' memory function was tested by the Sternberg Memory Task (1966), a venerable and widely used measure of both short-term and working memory (e.g. Jensen & Tesche, 2002; Vinkhuyzen et al., 2010). In it, participants are asked to watch a series of random numbers on a digital touch screen (iPad). At some point, a number with a different colour (yellow) appears, and they are asked whether this digit is part of the previous sequence (by selecting Yes or No). The answer must be given as soon as possible without making errors. Correct answers (the number was part of the set) as well as reaction times (RTs) (in milliseconds) are recorded and evaluated. In the present study, after three unrecorded pilot trials to get familiarised with the task, each volunteer in the three experimental groups performed a block of 24 consecutive trials before and after the intervention treatment (exercise+VR: cycling with VR; exercise: only cycling; control: no acute exercise).

Other Measures

RPE. The participants' subjective RPE, effort and fatigue during the exercise protocol was assessed with the Children's OMNI Scale of Perceived Exertion (Robertson et al., 2000). They were asked to rate their exertion-fatigue while cycling on a scale from 0 (not tired at all) to 10 (very, very tired). During the exercise protocol, a researcher recorded their RPE prior to and immediately after the acute exercise.

HR. HR was assessed with a Polar HR monitor watch (Model FT1; Polar Electro Oy, Kempele, Finland) that was connected to a Polar T31 coded transmitter chest strap throughout the exercise protocol. A researcher recorded the participants' HR data at 3-min intervals. HR before (HR pre), average HR during exercise (avg-HR during) and HR after the exercise protocol (HR post) were used as indicators of HR. Regarding the HR and RPE measures, a similar procedure was followed by Chang et al. (2012b) in examining acute exercise's effect on the cognitive function of children with attention deficit hyperactivity disorder.

Enjoyment. The Greek version of the enjoyment subscale (Papacharisis & Goudas, 2003) of the Intrinsic Motivation Inventory (McAuley et al., 1989) was used to capture the participants' enjoyment while cycling with or without VR. This subscale comprises five items (e.g. "I enjoyed cycling/cycling with VR very much", "Cycling/cycling with VR was fun", and "While cycling/cycling with VR, I was thinking about how much I enjoyed it"), which the participants answered on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). A reliability analysis of the enjoyment scale showed acceptable internal consistency ($\alpha = .74$).

Intention. Intention to cycle or cycle with VR was measured by three items created on the basis of Ajzen's (2005) recommendations (e.g. "If I gain access, I intend to use a stationary cycle for exercise" and "I intend to use a stationary cycle with VR for exercise"). Similar items have been used in previous studies in Greece that measured individuals' intentions to exercise (e.g. Bebetos et al., 2003; Hassandra et al., 2021; Theodorakis, 1994). The participants responded on a 7-point Likert scale from 1 (very unlikely) to 7 (very likely). This scale exhibited acceptable internal consistency ($\alpha = .76$).

Attitude. Attitude towards cycling or cycling with VR was captured with five items also based on Ajzen's (2005) recommendations. Similar items have been used by previous researchers in Greece to measure attitudes towards exercise (e.g. Hassandra et al., 2021; Theodorakis, 1994; Theodorakis et al., 2003). All responses were given on a 7-point Likert scale from 1 ("I find cycling or cycling with VR ... very bad or very useless or very unpleasant") to 7 ("I find cycling or cycling with VR ... very good or very useful or very pleasant"). The attitude towards exercise scale also showed high internal consistency ($\alpha = .78$).

Usability. The VR's usability during acute exercise (cycling) was measured by seven items (e.g. "I found the VR app very complex" and "I thought that this VR app was easy to use") based on the previous work of Brooke (1996). This scale had already been translated and used in the Greek language (Hassandra et al., 2021; Touloudi et al., 2022). Individuals answered on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The Cronbach's α index exhibited acceptable reliability ($\alpha = .72$).

It should be noted that the scales for enjoyment, intention to participate in an exercise programme and attitude towards exercise were administered to both the exercise

and exercise+VR groups while the scale for usability of VR during acute exercise (cycling) was given only to the latter group.

Intervention

Exercise groups. After a 5 min warm-up (low intensity cycling), each participant in the exercise+VR and exercise groups cycled for 15 min. Exercise intensity was set at 50%–60% of the maximum HR of each participant (American College of Sports Medicine, 2010), calculated on the basis of the age-predicted value. Similar exercise intensity has been used in previous studies measuring the effect of acute exercise on children's brain function (e.g. Chang et al., 2012b; Drollette et al., 2014; Mrakic-Sposta et al., 2018). Notably, during the exercise session, the participants were instructed to keep their cycling speed between 21 and 24 km/h, which was particularly suited to the targeted exercise intensity (50%-60% of maximum HR) as the researchers had observed in previous pilot tasks that they had conducted with volunteers of similar age. Before, at 3 min intervals during and immediately after the exercise session, the participants' HR (as determined by the Polar) was measured by a trained researcher and their RPE (OMNI scale; Robertson et al., 1982) was also measured by the trained researcher before and immediately after the acute exercise. As necessary to maintain the target HR, a researcher instructed the participants to increase or decrease their pedal speed; a similar procedure was followed by ElleMBERG and St-Louis Descènes (2010) in their study measuring the effect of acute exercise on children's cognitive function. Furthermore, a trained researcher recorded the speed every 3 min and subsequently calculated the average speed of each participant. Finally, the participants did a 5-min recovery programme of low intensity cycling (until their HR fell to around 100 beats per min).

Control group. The control group spent 15 min resting.

A summary of the intervention protocol is presented in Table 1.

Adherence and Attrition

All participants completed successfully the study protocol.

Statistical Analysis

The Kolmogorov-Smirnov test was first used to test the data's normal distribution, and then the means and standard deviations were calculated for all the examined variables. Reliability analysis was also conducted to examine the internal consistency of the aforementioned scales. Two-way ANCOVA with repeated measures was used to assess possible differences in the participants' cognitive function (correct answers, RT) within groups (pre, post) and between groups (exercise+VR, exercise and control) as well as to test for interactions within and between groups after controlling for age, gender and correct answers (Memory T1: pre-intervention correct answers; Memory T2: post-intervention correct answers) or RT (RT1: pre-intervention RT in milliseconds; RT2: post-intervention RT in milliseconds). Then, to examine within-group differences (pre, post) in the participants' memory function (only for the correct answers), paired samples t-tests were conducted separately for each intervention group. Furthermore, one-way ANCOVA was conducted to examine possible differences in the volunteers' post-intervention cognitive function (only Memory T2) between groups (exercise+VR, exercise, control) after controlling for age, gender, and Memory T1 and RT (pre, post). Similarly, a separate one-way ANCOVA was used to assess possible differences between groups (exercise+VR, exercise) in HR (HR pre; avg HR during; HR post), SP and RPE (RPE pre; RPE post) during the acute exercise protocol after controlling for age and gender. A separate one-way ANCOVA was also used to explore possible differences in enjoyment, intention and attitude towards cycling with VR or only cycling between groups (exercise+VR, exercise) after controlling for age and gender. Finally, Spearman correlation nonparametric analysis was implemented only on the exercise+VR group ($n = 15$) to examine whether any significant relationship emerged between the VR's system usability and the participants' enjoyment, intentions and attitudes towards

Table 1. Summary of the acute exercise intervention protocol

Group	Pre Measures	Exercise Intervention	Post Measures
Exercise+VR: Cycling and VR combined with basic mathematical problem-solving tasks ($n = 15$)	<ul style="list-style-type: none"> • Sternberg Memory Task • Three min cycling warm-up • RPE (OMNI) scale • HR monitoring (Polar) 	<ul style="list-style-type: none"> • 15 min cycling at 50%-60% of maximum HR • HR monitoring every 3 min (Polar) 	<ul style="list-style-type: none"> • RPE scale • HR monitoring (Polar) • 2-3 min recovery until HR returns to 100 • Sternberg Memory Task • Enjoyment, intention to cycle with VR, attitude towards cycling with VR and VR system usability
Exercise: Only cycling ($n = 15$)	<ul style="list-style-type: none"> • Sternberg Memory Task • Three min cycling warm-up • RPE (OMNI) scale • HR monitoring (Polar) 	<ul style="list-style-type: none"> • 15 min cycling at 50%-60% of maximum HR • HR monitoring every 3 min (Polar) 	<ul style="list-style-type: none"> • RPE scale • HR monitoring (Polar) • 2-3 min recovery until HR returns to 100 • Sternberg Memory Task • Enjoyment, intention to cycle and attitude towards cycling
Control: No exercise ($n = 15$)	<ul style="list-style-type: none"> • Sternberg Memory Task 	<ul style="list-style-type: none"> • 15 min sitting at a designated point in the lab 	<ul style="list-style-type: none"> • Sternberg Memory Task

cycling in a VR environment. The data analyses were conducted with PASW Statistics software version 26.0, with the level of significance set at $p < .05$.

RESULTS

Participants' Characteristics, Attrition and Adherence Rates

Participants were 45 children (13 girls and 32 boys) aged ranged from 9 to 13 years ($M_{\text{age}} = 10.91 \pm 1.24$ years). All randomized children completed the original experimental protocol. Thus, no attrition was recorded and the adherence rate for all the experimental groups was 100%.

Normality Test, Descriptive Statistics and Reliability Analysis

The Kolmogorov-Smirnov test, descriptive statistics (means, standard deviations) and reliability analysis of all the examined scales at the pre- and post-intervention measurements are presented in Table 2. All the variables were normally distributed ($p > .05$).

Primary Outcome - Memory Function

A 2×3 ANCOVA with repeated measures revealed no significant interaction ($F_{2,38} = 2.212, p = .123, \eta_p^2 = .104$) on Sternberg Memory Task correct answers (Memory) between time (pre, post) and groups (exercise+VR, exercise, control) after controlling for age, gender, RT1 and RT2. Significant differences emerged in the participants' memory function between times ($F_{1,38} = 6.238, p < .05, \eta_p^2 = .141$). A separate paired samples t-test for only the exercise+VR group revealed no significant differences in memory function between the pre and post measures ($t_{14} = -1.181, p = .257$). Similarly, no significant differences emerged in memory function between the pre and post measures ($t_{14} = -1.058, p = .308$) for the participants in the control group. By contrast, a paired samples t-test for only the exercise group revealed significant differences in memory between the pre and post measures ($t_{14} = -3.407, p < .01$). The exercise-only participants had

higher scores on Memory T2 than on Memory T1 (Table 3). Furthermore, one-way ANCOVA revealed significant differences ($F_{1,37} = 3.405, p < .05, \eta_p^2 = .155$) in volunteers' Memory T2 between groups (exercise+VR, exercise, control) after controlling for age, gender, Memory T1 and RT (pre, post). More specifically, the exercise+VR group had higher scores in post-intervention memory function than the exercise and control groups (Table 3).

Furthermore, a 2×3 ANCOVA with repeated measures revealed no significant interaction ($F_{2,38} = 2.606, p = .087, \eta_p^2 = .121$) on the Sternberg Task RT between time and groups after controlling for age, gender, Memory T1 and Memory T2. Similarly, no significant differences emerged in the participants' RT between times ($F_{1,38} = 1.029, p = .317, \eta_p^2 = .026$). Nevertheless, it is important to mention that a slight but nonsignificant decrease was observed in the participants' RT2 at the post-intervention measure compared to RT1 in all groups (Table 3).

Other Measures

Regarding the participants' HR (pre, during, post cycling), SP (during cycling) and RPE (pre, post cycling), a separate one-way ANCOVA revealed no significant differences in HR pre ($F_{1,26} = 2.568, p = .121, \eta_p^2 = .090$), avg-HR during ($F_{1,26} = 1.524, p = .228, \eta_p^2 = .055$), HR post ($F_{1,26} = .213, p = .649, \eta_p^2 = .008$), SP ($F_{1,26} = 2.848, p = .103, \eta_p^2 = .099$), RPE pre ($F_{1,26} = 1.846, p = .186, \eta_p^2 = .066$) or RPE post ($F_{1,26} = .027, p = .872, \eta_p^2 = .001$) between the exercise+VR and exercise groups after controlling for age and gender (Table 3).

Regarding the self-reported questionnaires, a separate one-way ANCOVA revealed no significant differences in participants' enjoyment ($F_{1,26} = 1.181, p = .287, \eta_p^2 = .043$), intentions ($F_{1,26} = .770, p = .388, \eta_p^2 = .029$) or attitudes towards cycling ($F_{1,26} = 1.401, p = .247, \eta_p^2 = .051$) between the exercise+VR and exercise groups after controlling for age and gender. Nevertheless, the exercise+VR group reported higher scores on enjoyment, intention and attitude towards cycling than the exercise group, although this difference was not statistically significant (Table 3).

Table 2. Descriptive statistics, kolmogorov-smirnov test and reliability analysis of all the examined variables at the pre- and post-intervention measurements in the total sample

Variables	Pre-intervention		During intervention		α	Post-intervention	
	M \pm SD	K-S	M \pm SD	K-S		M \pm SD	K-S
Correct answers (Memory)	20.31 \pm 3.06	1.331	-	-	-	21.51 \pm 2.46	1.200
Reaction time (RT)	1615.13 \pm 543.85	1.309	-	-	-	1384.94 \pm 385.53	.797
Heart rate (HR)	109 \pm 14.15	.512	112.12 \pm 8.23	0.604	-	112.83 \pm 8.09	.506
Speed (SP)	-	-	22.01 \pm 1.95	0.786	-	-	-
Perceived exertion (RPE)	1.27 \pm 1.14	1.236	-	-	-	3.13 \pm 1.76	1.135
Enjoyment	-	-	-	-	.74	4.34 \pm 0.50	.653
Intention	-	-	-	-	.76	5.82 \pm 1.19	.882
Attitude	-	-	-	-	.78	6.42 \pm 0.61	.951
VR's usability	-	-	-	-	.72	4.13 \pm 0.54	.764

M = mean; SD = standard deviation; K-S = Kolmogorov-Smirnov test; α = Cronbach's α reliability index

Table 3. Descriptive statistics (mean, standard deviation) and significant differences in the examined variables between and within groups

Variables	Exercise+VR group (cycling + VR) M±SD		Exercise group (only cycling) M±SD		Control group (no exercise) M±SD			
	Pre	During	Pre	During	Pre	Post		
Correct answers	21.40±1.88	-	22.13±1.46 ^b	-	19.67±4.30 ^b	21.93±3.39 ^{ab}	19.87±2.33	20.47±1.89 ^b
RT	1517.35±285.48	-	1404.62±274.04	-	1540.43±532.57	1332.92±534.65	1787.60±718.57	1417.29±318.98
HR	113.53±15.17	114.42±8.59	114.40±9.17	109.82±7.43	104.47±11.86	111.27±6.80	-	-
SP	-	21.56±2.06	-	22.56±1.72	-	-	-	-
RPE	1.53±1.19	-	3.27±1.75	-	1.0±1.07	3.0±1.81	-	-
Enjoyment	-	-	4.45±0.49	-	-	4.23±0.51	-	-
Intention	-	-	6.02±1.20	-	-	5.62±1.18	-	-
Attitudes	-	-	6.57±0.44	-	-	6.27±0.73	-	-
Usability	-	-	4.13±0.54	-	-	-	-	-

M = mean; SD = standard deviation; Pre = pre-intervention measurements; Post = post-intervention measurements; RT = reaction time; HR = heart rate; SP = speed; RPE = rating of perceived exertion; ^a = within group (exercise) significant differences in COR; ^b = between groups (exercise+VR, exercise, control) significant differences in memory function

Finally, it is notable that the exercise+VR participants gave high scores on the usability of the VRADA VR app system during the acute exercise programme ($M = 4.13 \pm .54$). Moreover, a Spearman’s correlation nonparametric analysis showed that the VR’s usability (for only the exercise+VR group) was positively related with enjoyment ($r = .548, p < .05$) and attitude towards cycling ($r = .561, p < .05$) but not with intention to cycle ($r = .215, p = .442$).

DISCUSSION

The main purpose of the present study was to examine the effects of acute exercise and a VR environment on children’s memory function. Thus, an experimental study was designed with three groups: (1) exercise+VR (cycling + VR), (2) exercise (only cycling) and (3) control (no exercise). The results show that the exercise group yielded higher scores (correct answers) on memory function after the acute exercise treatment (Memory T2) than prior to it (Memory T1). Similarly, the exercise+VR group scored higher on Memory T2 than did the exercise and control groups. By contrast, there were no significant differences in RT between the three groups. The above findings partially support the study’s first hypothesis, that the combination of moderately intense acute exercise (cycling) and VR would better improve the volunteers’ cognitive function than acute exercise (only cycling) or lack of exercise (control). These results may be affected by the dual-task training design. Only a small number of dual-task training intervention studies have examined their impact on healthy youths’ cognitive and physical performance, yet research has shown that this kind of experimental design (dual-task training) is quite effective in improving children and adolescents’ physical and cognitive function (Wollesen et al., 2020).

Furthermore, the findings confirm that acute exercise alone (without VR) improved the participants’ cognitive function. These results align with the vast majority of previous studies suggesting that acute exercise (e.g. Basso & Suzuki, 2017; Chang et al., 2012a; Loprinzi & Edwards, 2018; Ploughman, 2008) and/or VR environments (e.g. Plante et al., 2003) improve individuals’ cognitive function and mood. As described by Ploughman (2008, p. 237), there are three possible mechanisms through which exercise affects human brain function: (1) “Increase of oxygen saturation and angiogenesis”, (2) “increase of brain neurotransmitters, such as serotonin and norepinephrine” and (3) “upregulation of neurotrophins such as brain-derived neurotrophic factor (BDNF), insulin-like growth factor (IGF-I) and basic fibroblast growth factor (bFGF)”.

A second goal of this study was to explore whether exercise with VR yielded higher scores on enjoyment during acute exercise, intention to cycle and attitude towards cycling than exercise alone. The results show that exercise+VR group yielded higher scores on enjoyment, intention and attitude towards cycling than the exercise only group, but this difference was not statistically significant. This finding provides partial support for second hypothesis of the study, that the combined acute exercise with VR environment would yield higher scores of exercise enjoyment, intention to cycle

and attitude towards cycling than acute exercise alone. This result is partially in line with previous studies finding that participants were more motivated when exposed to VR environments (Harris & Reid, 2005) and experienced greater fun and enjoyment when they combined exercise with VR (e.g. Bryanton et al., 2006; Plante et al., 2003). Perhaps, the existence of a more adventurous VR environment, or the existence of a more demanding virtual route in nature would further increase participants' fun and intention to exercise with VR systems.

A third purpose of this study was to examine the fidelity of the intervention protocol (manipulation check) and, more specifically, to determine whether there were significant differences in the volunteers' SP, HR and RPE between the two exercise groups (exercise+VR, exercise). The results revealed no significant differences in SP (during), HR (pre, during, post) or RPE (pre, post) between the exercise+VR and exercise groups, indicating that both groups followed the same exercise treatment protocol. These findings support the third hypothesis, that the exercise+VR group would yield similar scores to the exercise group (only cycling) on SP, HR and RPE prior, during (only for SP and HR) and immediately after the acute exercise programme. As part of the manipulation check, the above results are in line with previous studies in this research area that have also explored the differences in the examined variables (e.g., HR, RPE) between experimental groups and found no significant differences (e.g., Chang et al., 2012b).

A final goal of the present study was to assess the VR system's usability and relationship to the other scales (enjoyment, intention, attitudes). The results show that exercise+VR participants gave high scores to the VR system's usability during the acute exercise programme. Furthermore, the VR's usability was positively related with enjoyment and attitude towards cycling. This result is in line with previous work by Hassandra et al. (2021), who also that found high scores on the VR system's usability in a sample of older people with mild cognitive impairment. This finding provides partial support for the fourth hypothesis of the study, that the exercise+VR group would give high scores on the VR's usability during cycling (acute exercise) and that there would be significant correlations between the VR's usability and the examined variables of enjoyment, intention (where no correlation emerged) and attitude towards cycling.

Limitations and Future Studies

The small number of participants ($N = 45$) and of girls (only 13) may represent limitations of the present study. A larger number of participants with more girls and perhaps different age groups (e.g. adolescents) might yield different or more promising results regarding the effect of acute exercise with VR or only acute exercise on children's memory function. Another limitation of this study was the use of only one test to measure cognitive function (Sternberg's Memory Task). In future studies, it is recommended to use more than one test to check individuals' brain function (e.g. a combination of two or more tasks). For example, Calvert et al.

(2019) used four distinct memory tests to examine the effects of acute physical activity on children's cognitive function. Other researchers should consider using more sophisticated tests, such as the Stroop Test (Stroop, 1935), Wisconsin Card Sorting Test (Greve et al., 2005) or Eriksen flanker task (Eriksen & Eriksen, 1974), or more accurate, in-depth ways of determining brain function, such as electroencephalographic (EEG) control (e.g. McFarland et al., 2010). Also, future studies might explore the impact of various exercise intensities (low, moderate and vigorous) on children's cognitive function or the use of diverse types of exercise (e.g. running, skiing) or different VR environments to motivate the participants to continue exercising (e.g. exercise trails in the mountains or near the sea).

CONCLUSIONS

Overall, the findings align with those of previous studies and underline the important roles of exercise and VR on youths' cognitive function. The results indicate that the combination of acute exercise (cycling) and a VR environment (forest path) can improve children's cognitive function and affect their preference of exercise type (i.e. cycling with or without the use of VR technology). Among the strengths of the present study were the dual-task training design and the combined use of acute exercise, VR environment and problem-solving tasks. Based on the above findings, it is recommended to exercise professionals coaching children and adolescents to combine bouts of exercise with VR environments, if and as long as they have this technological support, or at least to combine bouts of exercise with easy mathematical problem-solving tasks as this might increase their children's memory function.

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