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Original Article

24 sessions of monitored cooperative high-intensity interval training improves attention-concentration and mathematical calculation in secondary school

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Abstract
The aim was to analyse the effect of monitored cooperative high-intensity interval training (monitored C-HIIT) on memory, selective attention, concentration, mathematical calculation, and linguistic reasoning in adolescents. A randomized controlled trial was used with a control group (CG, n = 94), and an experimental group (EG, n = 90) that performed monitored C-HIIT at the beginning of physical education (PE) classes, during 12 weeks (24 sessions). The EG increased 14.2% in selective attention, 8.41% in concentration, and 15.5% in mathematical calculation relative to the CG after the monitored C-HIIT programme (all $p < 0.001$). These improvements are especially significant in inactive students (all $p < 0.001$), but there were no differences in memory or linguistic reasoning variables ($p > 0.05$). It is concluded that a 16-minute monitored C-HIIT programme applied at the beginning of PE classes improves some cognitive variables, especially in physically inactive adolescents.
Keywords: Cognitive performance, HIIT, physical activity, physical education, secondary education

Introduction

Currently, physical fitness has been shown to have a potential improvement effect on cognitive capacities beyond the traditional physiological health effects (Etnier et al., 1997; Ruiz-Ariza, Grao-Cruces, Loureiro, & Martínez-López, 2017a; Schmidt, Jäger, Egger, Roebers, & Conzelmann, 2015). More concretely, fitness is related to better memory (Chaddock-Heyman et al., 2014; Sibley & Beilock, 2007), selective attention and concentration (Vanhelst et al., 2016), arithmetic skills (Moore, Drollette, Scudder, Bharij, & Hillman, 2014), and linguistic reasoning (Raine et al., 2017). The combined improvements in these cognitive variables could be fundamental in improving mental skills responsible for planning, task switching, problem solving, organization, strategy generation to achieve a particular objective, and behaviour control (Ruiz-Ariza et al., 2017a).

In spite of the above, four out of five adolescents do not reach the minimum daily amount of PA recommended by international institutions (Cheung, 2017). Thus, there is an imperative need to find new motivants and efficient methods targeted to enhance the effects of PA in the shortest time possible (Ruiz-Ariza, Suárez-Manzano, López-Serrano, & Martínez-López, 2017b). The majority of current studies about PA and CP are focused on moderate-intensity PA, as well as including acute interventions and a wide variety of different exercises and durations of the sessions, from 4 to 55 minutes (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008; Cooper, Bandelow, Nute, Morris, & Nevill, 2012). However, little evidence exists on the most favourable intensity, activity type, and long-term duration for improving CP (Ardoy et al., 2014; Costigan, Eather, Plotnikoff, Hillman, & Lubans, 2016; Ruiz-Ariza et al., 2017b; Zervas, Danis, & Klissouras, 1991).

In recent years, high-intensity interval training (HIIT) has appeared as a method that allows for maximizing the effects during a short time available for PA practice and increasing key fitness components for CP, such as cardiorespiratory fitness [CRF] (Batacan, Duncan, Dalbo, Tucker, & Fenning, 2017; Eddolls, McNarry, Stratton, Winn, & Mackintosh, 2017). This method includes short intervals of vigorous activity (from ≤ 45 seconds to 2–4 minutes at > 85% HRmax) and short break periods between them (Costigan et al., 2016). However, very few studies have highlighted the potential of incorporating high intensity within the secondary-school context. Ardoy et al. (2014), demonstrated a positive chronic effect on cognitive and academic performance after 4 sessions/week of PE at high intensity over 4 months. Another study showed a positive chronic impact effect on physical self-concept (especially appearance), executive functions, and psychological well-being among adolescents after a programme of 8–10 minutes of HIIT, with a work-to-rest ratio of 30:30 seconds, 3 sessions/week, during 2 months (Costigan et al., 2016).

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Based on the above, recently a new didactic method has been proposed to enhance the emotional and creative potential of PE classes (Ruiz-Ariza et al., 2017b). This method adds individualized and centralized monitoring to control heart rate at high intensity, and a cooperative dynamic within the HIIT programme, termed monitored cooperative high-intensity interval training [monitored C-HIIT] (Ruiz-Ariza et al., 2017b). PA controlled and motivated with groupal heart rate monitoring, and performed in a cooperative way – physical exercises in pairs or in small groups – has been shown to provide increases in motivation, promotion of continued play and playful entertainment, group decision-making in cooperative exercises, and increases in self-efficacy and pro-social behaviors (Ruiz-Ariza et al., 2017b). In fact, according the the American College of Sports Medicine, HIIT, group training and wearable technology as pulsomtry, are forecast as the top 3 fitness trends for 2018 (Thompson, 2017). In the C-HIIT study by Ruiz-Ariza et al. (2017b), a monitored intervention during 12 weeks at the beginning of PE classes showed positive effects on creativity, well-being, and sociability, above all in inactive adolescents. Nevertheless, the evidence regarding whether monitored C-HIIT improves key CP variables for school performance is yet unknown. In this sense, monitored C-HIIT could be a novel educational strategy to enhance specific cognitive benefits of PA. In addition, there is evidence that these effects do not influence all students in the same way (Costigan et al., 2016; Ruiz-Ariza, De la Torre-Cruz, Latorre-Román, & Martínez-López, 2016). Physically inactive students could show different results because these individuals could have a higher margin of improvement due to the dose-response effect (Ruiz-Ariza et al., 2017b). Thus, the aim of this study was to analyse the effect of 16 minutes of monitored C-HIIT at the beginning of PE classes for 12 weeks on CP variables such as memory, selective attention and concentration, mathematical calculation, and linguistic reasoning in adolescents aged 12–16 years old. In addition, results were analysed to determine whether they differed according to the weekly PA level.

Materials and Methods

The study used a quantitative randomized controlled and blind trial with control group (CG; n = 94) that performed static stretching and an experimental group (EG; n = 90) that carried out 16 minutes of monitored C-HIIT within PE classes (2 days/week). This short C-HIIT time would make it possible to prove the hypothesis, confirming that its application is compatible with the development of the daily programmes provided for each PE teacher session.

Participants

A total sample of 184 adolescents from 4 secondary schools in the south of Spain participated in this study. Participants were 13.73 ± 1.34 years old, with a body mass index (BMI) of 21.34 ± 3.61 kg/m^2. Participants had an average of 2.76 ± 1.59 computers at home, performed 2.80 ± 1.58 days/week of MVPA, and studied 115.76 ± 47.39 minutes/day. Only 3.3% had no Internet access. With regard to maternal educational level, an important factor of socioeducational family status (Ruiz-Ariza, Casuso, Suarez-Manzano, and Martínez-López, 2018), only 1.1% of mothers did not have studies, and 25% did not have a job. No initial differences between the CG and the EG were found in any of the variables analysed except for BMI (p = .034) [see Table 1].

Table 1 Anthropometric and sociodemographic characteristics of participants. Values are presented as mean and standard deviation or percentage.

		All (n=184)	CG (n =94)	EG (n =90)	P-value
Age (years)		13.73±1.34	13.67±1.29	13.79±1.38	.549
Sex (%)	Girl	86 (46.7)	42 (47.7)	44 (48.9)	.567
	Boy	98 (53.3)	52 (53.3)	46 (51.1)	
Weight (Kg)		56.87±12.571	55.47±10.13	58.27±14.52	.136
Hight (m)		1.62±.093	1.63±.099	1.62±.086	.530
BMI (Kg/m^2)		21.34±3.61	20.76±2.97	21.92±4.11	.034
Computers at home (n)		2.76±1.59	2.72±1.63	2.81±1.54	.716
Daily time studying (min/day)		115.76±47.39	120.72±43.78	110.63±50.60	.160
MVPA (days/week)		2.80±1.58	2.98±1.58	2.62±1.57	.117
MVPA	Inactive students	132 (71.7)	64 (68.1)	68 (75.6)	.261
	Active students	52 (28.3)	30 (31.9)	22 (24.4)	
Internet access (%)	No	6 (3.3)	3 (3.2)	3 (3.3)	.957
	Yes	178 (96.7)	91 (96.8)	87 (96.7)	
Maternal studies	No studies	2 (1.1)	1 (1.1)	1 (1.1)	.879
	Primary	21 (11.4)	9 (9.6)	12 (13.3)	
	Secondary	70 (38)	36 (38.3)	34 (37.8)	
	University	91 (49.5)	48 (51.1)	43 (47.8)	
Maternal work	No work	46 (25)	24 (25.5)	22 (24.4)	.865
	Work	138 (75)	70 (74.5)	68 (75.6)	

Note. CG = Control group; EG = Experimental group; BMI = Body mass index; MVPA = Moderate-to-vigorous physical activity.

Adolescents with some physical pathology or medical contraindication to perform PA were excluded from this study. Youth diagnosed with learning disabilities (e.g., ADHD) were not included among the eligible students. Despite this, they performed the activities corresponding to their groups; however, these data were not included in the analysis. The final sample was formed by youth who completed all CP data and carried out the total intervention period correctly. Each participant had to maintain high intensity of over 85% of their HRmax (range ≈ 165–185 beats per minute [bpm]) during at least 80% of the 16 minutes of each session within the monitored C-HIIT programme (Ruiz-Ariza et al., 2017b). From an initial sample of 214 volunteers with parental informed consent, finally took part in the study a final sample of 184 participants (12 did not complete CP data, 6 abandoned during the intervention and 16 did not compliance the required intensity).

Measures

Memory. To assess memory, an ad hoc test of 1 minute was used, from the memory test included in the Spanish adaptation of the RIAS test (Santamaría-Fernández & Fernández-Pinto, 2013). A poster of 15 Spanish playing cards, randomly selected, was projected for 20 seconds on a 3 x 2-metre screen. Immediately afterwards, the participants had 40 seconds to record on a standardized sheet all of the cards they could remember. This memory test has been previously used by Ruiz-Ariza et al. (2018). The reliability test–retest (48 hours, n = 24) was 0.921.

Selective attention and concentration. These variables were assessed under stress induced by a completion time by using Brickenkamp's d2 Test in the Spanish version (Seisdedos, 2012). Selective attention capacity was calculated by using the following formula: [number of processed elements – (omissions + mistakes)]. In addition, concentration was calculated with the following formula: (number of hits – number of mistakes). The reliability test–retest (48 hours, n = 24) was 0.878.

Mathematical calculation. To analyse mathematical calculation, an ad hoc test was used (Ruiz-Ariza et al., 2018). This test included 2 groups of addition and subtraction with 6 digits (e.g., 8 – 6 + 5 + 8 – 6 = 9). Participants had 1 minute to perform as many operations as possible, and the total number of hits was counted. Test–retest reliability (48 hours, n = 24) was 0.887.

Linguistic reasoning. To evaluate the reading speed and semantic comprehension of participants (linguistic reasoning), an ad hoc test was developed (Ruiz-Ariza et al. (2018) The test showed 30 rows of 4 words each. In each row of words, 3 belonged to the same semantic field, while a fourth had no relation to the others (e.g., *car, dog, motorbike, lorry*). The order of these was randomly established. The reliability test–retest (48 hours, n = 23) was 0.811.

Monitored Cooperative high-intensity interval training (monitored C-HIIT). The sample was randomly selected to ensure the equality of sexes between the two groups. The CG carried out static stretching, because this is the fitness component least associated with cognitive variables (Ruiz-Ariza et al., 2017a). The EG performed monitored C-HIIT, whose sessions started with a short warm-up activity of 4 minutes including running and dynamic stretching at medium intensity. The programme was composed of sessions of 16 minutes of monitored C-HIIT, 2 sessions per week, for 12 weeks (24 sessions in total). Previous studies had checked the cognitive effect of HIIT after different periods of daily practice in school; for example, 4 minutes (Ma, Mare, & Gurd, 2015), 8–10 minutes (Costigan et al., 2016), or one complete PE session (Ardoy et al., 2014). The present study considered that 16 minutes/day –approximately one-third of a PE session – could be enough to obtain significant physical and cognitive effects, allowing the teacher to dedicate the rest of the time to the usual development of the programmed PE class – two-thirds of the PE session.
Following the base of previous studies with HIIT (Costigan et al., 2016), each session had 4 series of each proposed exercise, with a work-to-rest ratio varying from 20:40 seconds to 40:20 seconds in the last 2 weeks (weeks 1 and 2 = ratio 20:40 seconds; weeks 3 and 4 = ratio 25:35 seconds; weeks 5 through 8 = 30:30 seconds; weeks 9 and 10 = 35:25 seconds; weeks 11 and 12 = 40:20 seconds). The monitored C-HIIT included a combination of cardiorespiratory, speed/agility (S/A), and coordinative training exercises because these are the fitness components that mostly enhance cognitive capacity in adolescents (Ruiz-Ariza et al., 2017a). In addition, all activities were carried out in pairs that rotated after each series to promote the cooperative context. Participants wore heart rate monitors (Seego Realtracksystems, Spain, http://seego.realtracksystems.com/) to encourage maintenance of the appropriate exercise intensity and to motivate the individual effort (Figure 1b). They could see their hear rate percentages projected with a slide projector on a 6 x 3-metre screen. Each participant from the EG had to be in an intensity ≥ 85% of HRmax (Costigan et al., 2016). Figure 1 shows a graphical example of a session of the monitored C-HIIT programme (figure 1a), an example of Seego screen (figure 1b), and the intensity of effort (figure 1c).

Figure captions

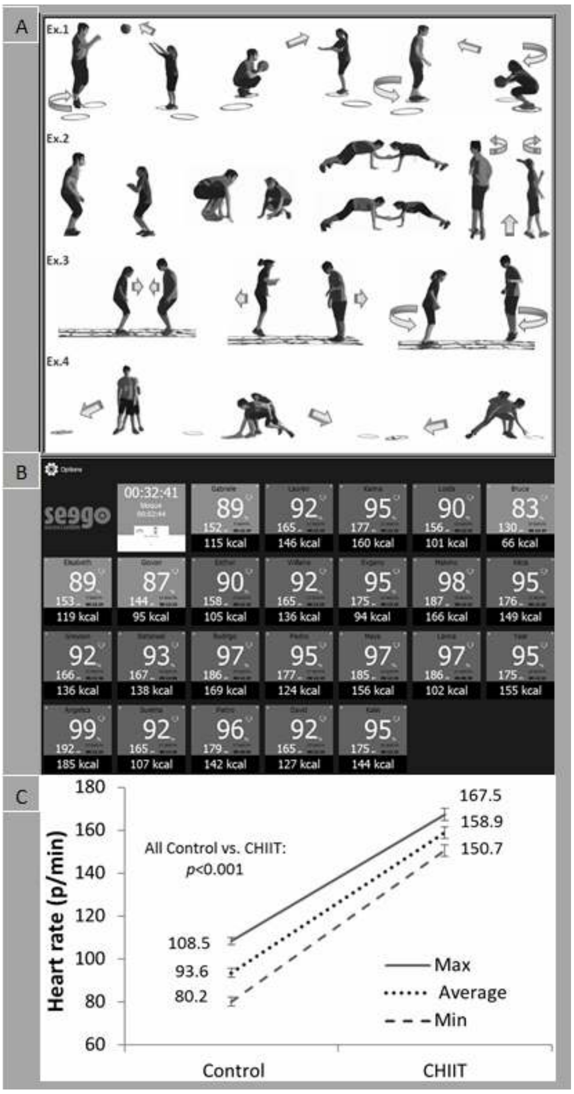

Figure 1: Graphical description of an example session of the 12-week monitored C-HIIT programme. Figure 1a: C-HIIT activities: **Ex. 1.** At 4 metres of distance between participants, lateral jump in hoops with legs together, passing a ball in pairs in each jump, crouching when receiving the ball, as many times as possible during the work time. **Ex. 2.** Burpees in pairs, clasping hands in the push-up position and turning during the jump, repeated as many times as possible during the work time. **Ex. 3.** Coordination ladder, one in front of the other, imitating the partner during the work time. When one series is completed, the roles are rotated. **Ex. 4.** Lateral running back and forth between hoops at 5 metres. The two members must be one behind the other, holding by the waist. They must pick up a sponge on the ground and change it to the other hoop. The pair must add up the number of sponges changed from one hoop to the other. Figure 1b: Example of visual control of the heart rate. Figure 1c: Minimum, maximum and average intensity values in the class group.***Weekly practice of MVPA.*** The participants were classified based on the baseline level of PA according to Prochaska, Sallis, and Long's (2001) MVPA questionnaire. Of the students, 131 (71.7%) were included as inactive (< 5 days/week of at least 1 hour of MVPA), and 53 (28.3%) were classified as active (≥ 5 days/week). Similar to other studies (Ruiz-Ariza et al., 2018), internal consistency of PA items was high (Cronbach's alpha = 0.809).

Confounders. Age and BMI [weight/height (m^2)] were used as confounders (Ruiz-Ariza et al., 2016, 2017a). An ASIMED B-type-class III (Spain) and a portable height meter, the SECA 214 (SECA Ltd., Germany), were used to measure weight and height. Both measurements were carried out on barefoot participants dressed in light clothes.

Other measurements (physical fitness assessment). Fitness was measured with the ALPHA-Fitness battery. The reliability of these tests for young people has been previously published (Ruiz et al., 2011). CRF was measured with the 20-metre shuttle run test. S/A was measured with the 4 x 10-metre shuttle run test of speed, agility, and coordination. Muscular strength (MS) was measured with the standing long jump test. The S/A and MS tests were performed twice in each measure (pre and post), and the better record was registered. They showed an excellent intraclass correlation (ICC = .921, 95% CI = .874–9.520, and ICC = .911, 95% CI = .872–.935, respectively).

Procedure

Parents signed a written consent before the study commenced. The participants' fitness level and CP were measured at 2 time points during the first school hours in the morning in both groups: at baseline and after 12 weeks. The students underwent a full assessment of their responses to the effort, and each family received an individual report. The monitored C-HIIT design allowed all participants to reach the intensity range required without limitation resulting from their level of ability or coordination. The CG performed static stretching exercises during the same time (Mayorga-Vega, Merino-Marban, Real, & Viciana, 2015). None of the participants carried out extracurricular high-intensity PA during the 12 weeks of the study. This study was approved by the Bioethics Committee of the University of Jaén (Spain). The design complies with the Spanish regulations for clinical research in humans (Law 14/2007, July 3rd, Biomedical Research), and with the principles of the Declaration of Helsinki (2013 version, Brazil).

Data analysis

The comparison of the continuous and categorical variables according to participation in the study (CG vs. EG) was carried out through student's t-tests and χ^2, respectively. Tests of normal distribution and homogeneity (Kolmogorov-Smirnov and Levene's) were conducted before analysis. The repeated measures analysis of covariance (ANCOVA), 2 times (pre, post) x 2 groups (CG, EG) x 2 PA levels (inactive, active students), was used to analyse the chronic effect of 16 minutes of monitored C-HIIT. Memory, attention, concentration, mathematical calculation, and linguistic reasoning tests were used as dependent variables; the group and MVPA were used as fixed factors; and age, BMI, and baseline values of the dependent variables were studied as covariates. Post-hoc analysis was adjusted by Bonferroni. The effect size was computed and reported as a partial η^2 value for the analysis of variance (ANOVA) evaluations. To quantify the magnitude of changes between and within groups in the dependent variables, the effect sizes were calculated by Cohen's *d*. A Cohen's *d* value $\geq .8$ indicates a large effect size, a Cohen's *d* value $\geq .5$ and $< .8$ indicates a medium effect size, and a Cohen's *d* value $\geq .2$ and $< .5$ indicates a small effect size (Cohen, 1998). These analyses were carried out separately for each dependent variable. Partial correlations between changes in fitness and changes in study outcomes were performed for all the participants together, after adjusting for age, BMI, and baseline values of the outcomes studied (these variables were included in the partial correlation models as covariates). The percentage of change between groups after the monitored C-HIIT programme was calculated as follows: [(GE post-measurement – GC post-measurement) / GC post-measurement] x 100. For all the analyses, a 95% confidence level was used ($p < .05$). The analyses were completed by using SPSS (v.22 for Windows).

Results

Analysis of intensity of monitored C-HIIT

Values of heart rate were similar between the two study groups at the beginning of the study (CG = 81.68 ± 19.9 vs. EG = 81.12 ± 23.2 bpm, $p > .05$). However, during the monitored C-HIIT programme, the mean of heart rate in CG (X = 102.3 ± 14.6 bpm) was lower than in the monitored C-HIIT group (X = 148.7 ± 16.2 bpm, range: X_{max} = 176.11 ± 16.7 and X_{min} = 81.12 ± 23.2 bpm, all $p < .001$) [Figure 1c].

ANCOVA analysis of 12 weeks of monitored C-HIIT on CP

ANCOVA 2 times x 2 groups x 2 PA levels carried out on memory showed neither main nor interaction effects (all $p > .05$). Group x PA level was the interaction effect closer to significance ($p = .322$). See Figure 2.

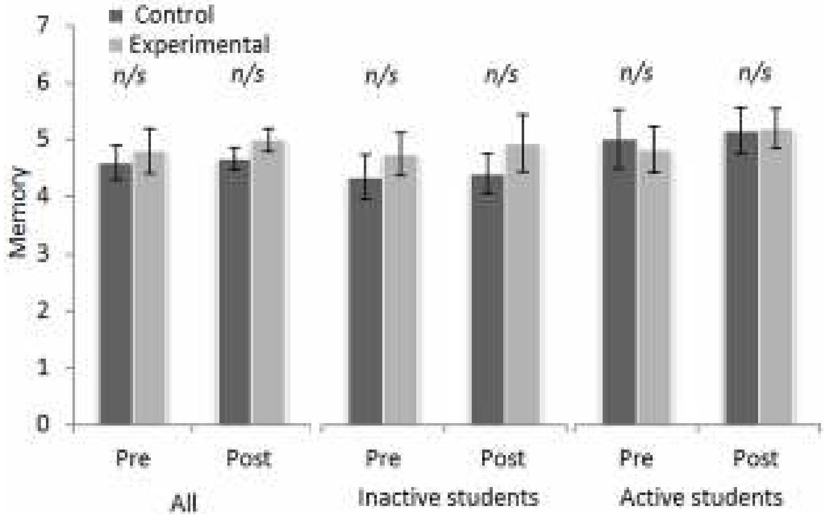

Figure 2: Results of memory in adolescents after 12 weeks (16 minutes for 2 days/week) of monitored C-HIIT. Inactive students exercised < 5 days/week, and active students exercised ≥ 5 days/week with at least 1 hour of MVPA. Data expressed in mean and SD. n/s denotes no significant differences between groups in the same measure.

Data regarding selective attention showed a main group effect F(1,170) = 15.017, $p < .001$, partial $\eta^2 = .081$, $1 - \beta = .971$; a group x PA level interaction on the verge of significance F(1,170) = 3.149, $p = .078$, partial $\eta^2 = .018$, $1 - \beta = .423$; and a time x group x PA level interaction F(1,70) = 4.015, $p = .047$, partial, $\eta^2 = .023$, $1 - \beta = .513$. After 12 weeks, selective attention in the EG increased relative to the pre measure within the same group (165.07 ± 45.68 vs. 147.443690 ± 40.49, $p = 0.018$, Cohen's $d = 0.404$). However, a more detailed analysis showed that only inactive students increased in selective attention after the monitored C-HIIT programme, in comparison to the initial measure (170.62 ± 40.68 vs. 144.31 ± 35.55, $p < .001$, Cohen's $d = .779$). Analysis between groups revealed that in post measure, selective attention in the EG increased 14.20% relative to the CG (165.07 ± 45.68 vs. 144.48 ± 39.16, respectively, $p < .001$, Cohen's $d = .498$). In the inactive group, the EG also improved 18.05% relative to the CG in the post measure (170.62 ± 40.68 vs. 144.90 ± 42.777, $p < .001$, Cohen's $d = .621$). See Figure 3a.

Concentration analysis found a group main effect F(1,170) = 4.398, $p < .037$, partial $\eta^2 = .025$, $1 - \beta = .550$; an interaction group x PA level F(1,170) = 5.628, $p = .019$, partial $\eta^2 = .032$, $1 - \beta = .655$; and an interaction time x group x PA level near to significance F(1,70) = 2.868, $p = .067$, partial $\eta^2 = .017$, $1 - \beta = .391$. After 12 weeks of monitored C-HIIT, concentration increased in EG relative to pre measure within the same group (150.33 ± 31.03 vs. 138.3 ± 30.42, $p = .041$, Cohen's $d = .404$). Similar results were observed in inactive students (158.53 ± 36.40 vs. 137.68 ± 38.93, $p = .009$, Cohen's $d = .551$). Analysis between groups showed that concentration increased 8.41% in EG relative to CG after 12 weeks of monitored C-HIIT (150.33 ± 31.03 vs. 138.36 ± 37.70, respectively, $p = .033$, Cohen's $d = .315$). In the inactive group, the EG also improved 17% relative to the CG in the post measure (158.53 ± 36.40 vs. 134.17 ± 42.89, respectively, $p = .002$, Cohen's $d = .626$). See Figure 3b.

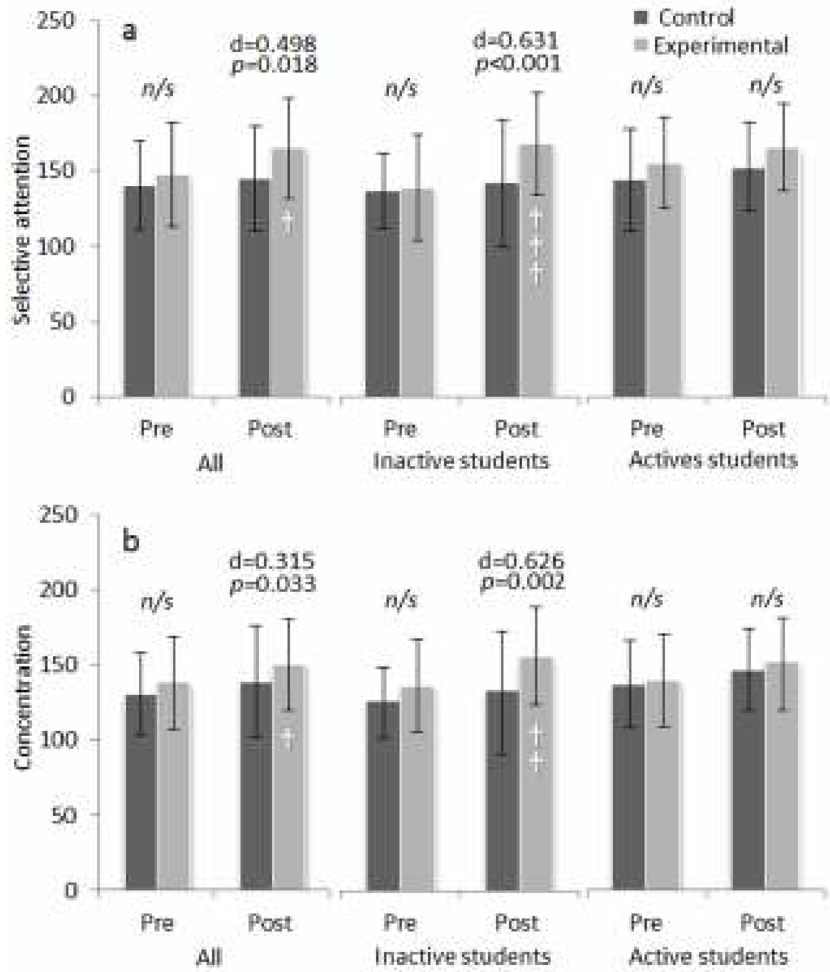

Figure 3: Results for attention and concentration in adolescents after 12 weeks (16 minutes, 2 days/week) of monitored C-HIIT. Inactive students exercised < 5 days/week, and active students exercised ≥ 5 days/week for at least 1 hour of MVPA. Data expressed in mean and SD. ††† denotes $p < .001$ relative to pre measure in the same group. n/s denotes no significant differences between groups in the same measure.Mathematical calculation analysis found a group main effect F(1,170) = 3.776, $p = .054$, partial $\eta^2 =$

.022, $1 - \beta = .489$; a group x PA level interaction $F(1,170) = 9.799$, $p = .002$, partial $\eta^2 = .055$, $1 - \beta = .875$; and a time x group x PA level interaction $F(1,170) = 25.166$, $p = .012$, partial $\eta^2 = .037$, $1 - \beta = .715$. The post analysis of interest showed that the EG increased mathematical calculation 15.5% relative to CG (6.70 ± 2.10 vs. 5.83 ± 2.42 exercises correctly solved, $p = .012$, Cohen's $d = 0.383$). More specifically, inactive students improved relative to the pre measure (7.06 ± 2.32 vs. 5.93 ± 2.36, $p < .001$, Cohen's $d = 0.487$) and increased 16.6% relative to CG (7.06 ± 2.32 vs. 6.01 ± 2.12 exercises correctly solved, $p = .002$, Cohen's $d = .472$). Active students also increased their mathematical calculation relative to CG, but the differences were not significant ($p = .274$). See Figure 4a.

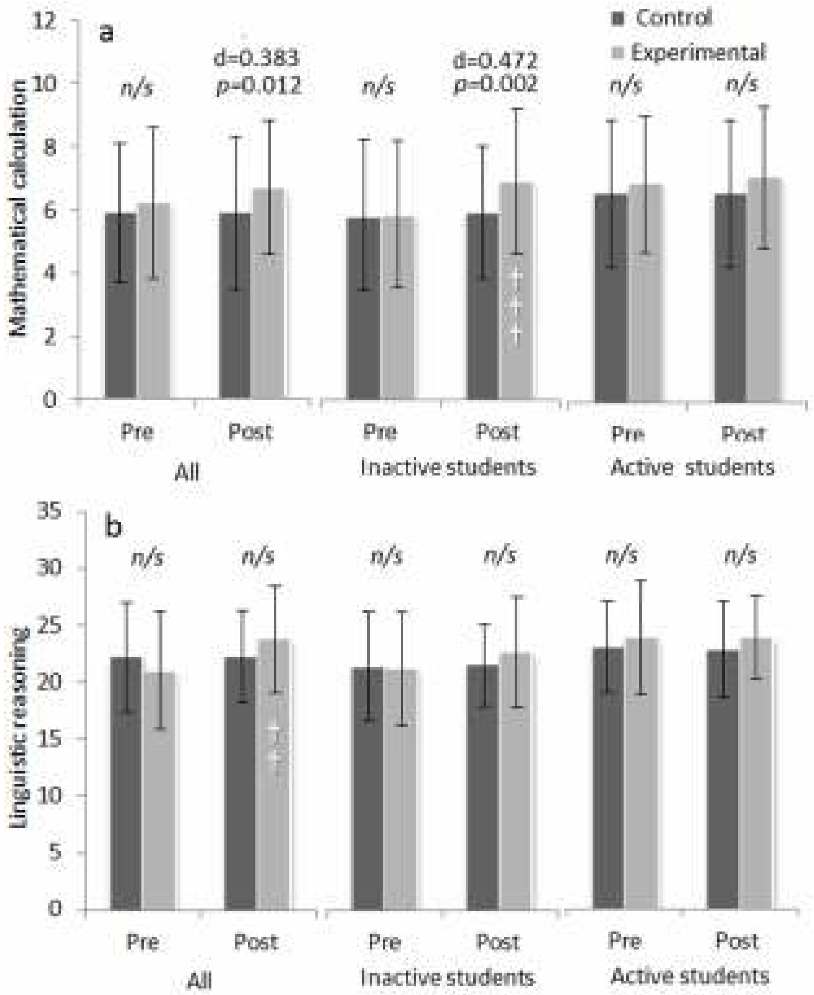

Figure 4: Results for mathematical calculation and linguistic reasoning in adolescents after 12 weeks (16 minutes, 2 days/week) of monitored C-HIIT. Inactive students exercised < 5 days/week, and active students exercised ≥ 5 days/week for at least 1 hour of MVPA. Data expressed in mean and SD. †† denotes $p < .01$, and ††† denotes $p < .001$ relative to pre measure in the same group. n/s denotes no significant differences between groups in the same measure.

Results in linguistic reasoning showed a time x group interaction near significance $F(1,170) = 3.706$, $p = .056$, partial $\eta^2 = .021$, $1 - \beta = .482$. The EG increased linguistic reasoning scores relative to the pre measure after 12 weeks of monitored C-HIIT (23.64 ± 4.79 vs. 21.83 ± 5.28 linguistic test score, $p = .009$, Cohen's $d = .359$). See Figure 4b. Differences were not found between groups (all together) nor within the inactive and active student groups (all $p > .05$).

Additional analyses

Additional analyses consisted of partial correlation analysis in the full sample (data not shown), adjusted for age, BMI, and baseline values of the study outcomes. These showed that higher values of improvements in CRF were positively correlated with selective attention, concentration, and mathematical calculation ($r = .262$, $p = .021$; $r = .202$, $p = .042$; and $r = .311$, $p = .002$, respectively). Higher values of improvements in S/A were correlated with higher mathematical calculation ($r = -.203$, $p = .023$; lower values in the S/A test mean higher performance). No associations were observed between fitness and other cognitive variables. Overall, the results did not differ when sex was used in the models instead of age and BMI.

Discussion

The aim was to analyse the effects of monitored C-HIIT at the beginning of PE classes on cognitive variables in adolescents between 12 and 16 years, as well as monitored C-HIIT's effects according to the usual weekly PA level. Results showed that 2 days of 16 minutes of PA at high intensity, performed in a cooperative and continuous way for 12 weeks, improves selective attention, concentration, and mathematical calculation levels in adolescents. In addition, improvements are especially significant among physically inactive students. Positive modifications in memory and linguistic reasoning have not been sufficiently proved. No negative effects of monitored C-HIIT were observed, and no injury occurred during the programme.

Some of the main cognitive results of this study show that a monitored C-HIIT programme improves selective attention and concentration levels relative to CG by 14.2% and 8.4%, respectively. These findings confirm, in part, the authors' previous hypothesis and are similar to those obtained by Costigan et al. (2016), who showed a positive effect of 8 weeks of HIIT on executive functions and psychological well-being in adolescents. A recent study showed improvements in overall cognitive variables after an intervention of 4 months, with 4 PE classes/week of 55 minutes, at a mean intensity of 147 bpm (Ardoy et al., 2014). Vanhelst et al. (2016) concluded that it would be necessary to reach a threshold of > 12 minutes/day of high-intensity exercise to improve attentional capacity in adolescents 12–17 years old. This study showed that 2 weekly stimuli of 16 minutes of C-HIIT at the beginning of PE classes is sufficient. However, contrary to the above-mentioned, Zervas et al. (1991) demonstrated no significant cognitive effects after individual running training at high intensity on a treadmill for 3 days/week for 25 weeks in PE classes (warm-up: 15 minutes, intervention: 60 ± 15 minutes).

With regard to mathematical calculation, EG increased 15.5% relative to CG after 12 weeks of C-HIIT. Several studies have showed that a higher CRF level, S/A, coordination, motor skill, organized leisure-time sport participation and bicycling, and active commuting to school are related with better success in maths (Castelli, Hillman, Buck, & Erwin, 2007; Correa-Burrows, Burrows, Orellana, & Ivanovic, 2014; Raine et al., 2017; Sævarsson et al., 2017). Another recent study of association conducted by Ruiz-Ariza et al. (2016) showed that enjoyment of vigorous PA is related to higher grades in maths among adolescent girls. More specifically, Moore et al. (2014) suggest that higher CRF is associated with better mathematical calculation skills and resolution of arithmetic problems. Nevertheless, the results from the current study and the above differ from pioneer cross-sectional studies performed by McNaughten and Gabbard (1993) and Daley and Ryan (2000), who did not find an association of PA with a timed test of mathematical calculation, nor of time of daily moderate PA with performance in maths, respectively.

Because data regarding chronic effects is scarce, this study also reviewed evidence from acute studies to search for possible explanations of effects of monitored C-HIIT in attention-concentration and mathematical calculation in young people. Two educational interventions found significant acute improvements in attention-concentration (Budde et al., 2008; Zervas et al., 1991). In addition, Travlos (2010), in a study with adolescents, found that maths ability was enhanced after a high-intensity (> 85% HRmax) running exercise, but only when it was performed early in the school day. Similarly, a single vigorous bout of PA in PE at 70–85% HRmax improved the results of a standardized maths test at 30 minutes post intervention by 11–22% (Phillips, Hannon, & Castelli, 2015). All of these studies agree that low-to-moderate-intensity activity does not show effects on selective attention and mathematical calculation. However, the studies using a higher PA intensity have shown more satisfying results.

Although the results of the present study did not find an effect of monitored C-HIIT on memory or linguistic reasoning, the majority of studies show that memory increases after short-term exercise (Budde et al., 2008; Cooper et al., 2012; Samuel et al., 2017), and a current chronic study shows that 6 weeks of a high-intensity training regimen resulted in improvements in working memory (Moreau, Kirk, & Waldie, 2017). Sjöwallm, Hertz, and Klingberg (2017) found in a 2-year school-based intervention in preadolescent children (ages 6–13) that the increase of weekly PE classes (aimed at increasing CRF) from 2 to 5 days a week did not affect working memory. Therefore, the above disagreement shows the need to continue studying acute and chronic effects of monitored C-HIIT in memory factors, as well as the chronic physio-psychological mechanisms that could act in this relationship and the intensity, duration, and kind of exercise that is more adequate to affect memory. With regard to linguistic reasoning, in agreement with the present study's data, Ardoy et al. (2014) and Samuel et al. (2017) did not find an effect on the verbal reasoning factor. However, a current systematic review representing 414 participants from 5 different countries shows that 60% of studies found beneficial effects on the language domain (Carson et al., 2016). In this line, Raine et al. (2017) concluded that changes in aerobic fitness were positively related to changes in reading between sixth and eighth grade. Physical activity even enhances the learning of a second non-maternal language (Liu et al., 2017). This disagreement among research could be caused by the specific neuromechanisms for these cognitive functions, the variability of linguistic tests, or the inherent characteristics of each study sample. It is necessary to continue studying to determine what could be the best physical and mental stimuli to achieve significant effects on important academic variables such as memory and linguistic reasoning.

On the other hand, one of the most important results of this study is the effect on CP when the sample was separated into inactive and active students. The data showed that higher values of change in CRF were positively correlated with selective attention, concentration, and mathematical calculation, and higher values of change in S/A were correlated with higher mathematical calculation scores. While in the inactive group the EG improved selective attention, concentration, and mathematical calculation by 18.05%, 17%, and 16.6%, respectively, relative to the CG after the monitored C-HIIT programme, differences were not found in active adolescents. A recent pioneer study concluded that performing 16 minutes of monitored C-HIIT at the beginning of PE classes improves creativity, well-being, and sociability in physically inactive youth, and it did not find effects in active students (Ruiz-Ariza et al., 2017b). Contrary to these findings, some studies have showed that adolescents aged 15 years with the highest allocation of time to regular PA performed better in maths than inactive students (Correa-Burrows et al., 2014). Sævarsson et al. (2017), in a further analysis, showed that a less active group (≤ MVPA once a week) had significantly lower improvements in maths compared to the most active group (≥ MVPA 4 times/week or more 2-3 times/week). These varied results could be due to the characteristics of each CP test or to the type and duration of activity; however, the greatest evidence indicates that the most important variable is the intensity of the programme. The causes of the different effects on CP in inactive and active young people cannot be explained from the present study. However, the differences could be mainly due to the dose-response effect. In this later case, the inactive group perceived a higher stimulus for PA practice than the active group, and the margin for improvement is greater (Ruiz-Ariza et al., 2017b). Monitored C-HIIT may act as an arousal stimulus for lower levels of inactivity, and it may promote greater improvements in the microstructure of the white matter of the brain, improving neuronal efficiency, decision speed, and information-processing capacity (Chaddock-Heyman et al., 2014).

Despite all of the above, the results shown here must be taken with caution, because this study has some limitations. During monitored C-HIIT, it was noticed that it was rather difficult for some participants to be continuously active for 16 minutes at high intensity. In some cases, the intensity of the PA bouts may not have been at the targeted level during the full 20 minutes, although the heart rate monitors encouraged the adolescents to maintain the correct intensity. Also, although it was indicated that none of the participants carried out extracurricular high-intensity PA during the weeks of the study, this was measured with the MVPA questionnaire, a self-report measurement (Prochaska, Sallis, & Long, 2001).

It is concluded that a programme of 12 weeks of 16 minutes of monitored C-HIIT, twice a week at the beginning of PE classes (24 sessions in total), improves attention, concentration level, and mathematical calculation skill in adolescents, but it does not produce differences in memory or linguistic reasoning variables. In addition, improvements are especially significant among physically inactive students. It is suggested that PE classes involve cooperative high-intensity interval exercises to promote physical, cognitive, and academic success, and that educative institutions promote the inclusion of daily monitored C-HIIT during secondary school. Further intervention studies are required to learn more details of the acute effects of monitored C-HIIT, including its influence on other important academic performance variables, such as behaviour for learning, technological stress, and teamwork skills.

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