Current Psychology
https://doi.org/10.1007/s12144-019-00454-z

Acute physical exercise intensity, cognitive inhibition and psychological well-being in adolescent physical education students

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Abstract
Cognitive function and psychological well-being are two variables related to mental health. Several studies have shown that these variables are sensitive to acute physical exercise, but it is not known which doses of exercise are the most adaptive. To explore this issue, 35 adolescents performed three sessions of physical education with different intensities: no-exercise, light/moderate exercise, and moderate/vigorous exercise, controlling intensities with accelerometers. Stroop test and well-being questionnaires were used before and after each session. The repeated measures design showed that cognitive inhibition was significantly higher after physical exercise sessions than in the non-exercise session, with no differences between the exercise intensity conditions. Vitality increased only in the non-exercise session and positive affect increased and negative affect decreased after the light/moderate physical exercise session only. These results show that including physical exercise prior to performing tasks that require high cognitive inhibition may be a useful strategy to improve cognitive performance.

Keywords Adolescence · Cognitive inhibition · Well-being · Acute physical exercise

Introduction

There is growing interest in the scientific community to extend our knowledge about the factors that are related to mental health in adolescence (Lubans et al. 2016). Mental health is considered how "…*a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community*" (WHO 2005, p. 12).

One domain of the mental health is a correct cognitive function. Cognitive function can be conceptualized as a set of processes that allow one to plan, coordinate, sequence, and monitor cognitive operations (Boucard et al. 2012; Stuss 1992), and are very relevant to improve mental health (Gale et al. 2012). As a dimension of the cognitive function, Diamond (2013, 2015) describes the cognitive control capacity, and differentiates three latent variables related to cognitive control: *inhibition or inhibitory control, involves the control of attention, behavior, thoughts and/or emotions*, and includes selective attention, control of distractions, and focal attention (which in turn implies the capacity to resist distractions), *working memory,* and *cognitive flexibility.*

Inhibition is related to the capacity to delete irrelevant information and one's response tendency. However, there is no agreement on the concept of inhibition. Some authors distinguish different components of inhibition as a function of the response selection in different situations of conflict (Miyake et al. 2000). One of these components is called response suppression or *non-selective inhibition,* which serves to suppress the execution of actions that are habitual or that were previously planned. It is called non-selective because it does not compete with another possible response but instead it detects

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Published online: 12 September 2019

that, in a particular situation, the response is incorrect, so it suppresses it (Kramer et al. 2011). Another component of inhibition refers to what is known as *control of interference* or *selective inhibition*. This concept is based on the hypothesis of activation-suppression (Ridderinkhof 2002). This type of control of interference is related with inhibitory control of attention (Diamond 2013), and is considered selective because it must reduce the activation of one of several responses that compete in a certain situation that requires a unique (and correct) response (Ridderinkhof 2002).

In that sense, control of interference has been shown to be very relevant in the prediction of academic performance of different tasks but it has been studied primarily in the process of lexical selection (Shao et al. 2015).

Regarding well-being, some works show that students' perception of well-being in the school environment is a very relevant indicator of the quality of the educational process (Holopainen et al. 2012; Huang et al. 2017) and is at the core of the mental health (Lubans et al. 2016) and their school engagement (Rodríguez-Fernández et al. 2016). Nowadays well-being is becoming an European priority (Miret et al. 2015), however, as indicated by Korhonen et al. (2014) there is no consensus on the definition or operationalization of well-being. Positive or negative indicators of well-being (such as self-esteem, subjective well-being, quality of life, and psychological resilience or stress) are usually used as indicators of adolescents' well-being.

Ryan et al. (2013) consider two perspectives to study well-being: the hedonic perspective, which considers well-being as the presence of positive affect and the absence of negative affect; and the eudaimonic perspective, which associates well-being with the possibility of performing or expressing the most valued human potentials, related to optimal psychological functioning (Ryan et al. 2013). In general, the works carried out in the academic with youth and adolescents setting show a clear positive relation between well-being and the establishment of behavioral patterns that may enhance or diminish mental health (Sawyer et al. 2012). Knowledge of the variables that can have an impact both on the improvement of cognitive functions and on well-being in the educational setting is of interest to researchers and educators.

One of the variables that is providing promising results in the improvement of well-being and cognitive functions is physical exercise (Cervelló et al. 2014; Garcia et al. 2015; Li et al. 2017). In general, studies show that there is a positive relation between the practice of physical exercise, executive cognitive functions (Li et al. 2017), and psychological well-being (McMahon et al. 2017; Trainor et al. 2010). These benefits have been found both in the continuous performance of physical activity over time ('chronic' activity) and in the acute performance of a single session of physical exercise (Cervelló et al. 2014; Li et al. 2017).

However, in view of a recent revision (Li et al. 2017) there are several issues that require in-depth study, such as, for example, the most adaptive dose of exercise to achieve improvements both in cognitive functions and well-being.

In this regard, there is evidence that the effects of acute physical exercise on cognitive functions and well-being are maintained immediately after exercise but there are few works about this in adolescent populations (Cervelló et al. 2014; Koutsandreou et al. 2016; Park and Etnier 2019; Peruyero et al. 2017). Some recent articles study the effect of exercise on Stroop response (Park and Etnier 2019), likewise, the possible differential effects of different intensities of exercise in adolescent populations should be analyzed. It has been proposed that moderate intensity is the most beneficial for cognitive performance (Chang et al., 2015, b). However, it has been shown that in adult populations increases in intensity have been associated with increases in cognitive functioning, as long as a state of exhaustion is not reached (Schmit et al., 2015), and a recent article shows similar results in adolescents (Peruyero et al., 2017). Applying this to younger people, performing physical exercise on regular school days (either in physical education classes or in recesses between classes) may be a tool to consider for the improvement of selective inhibitory control and well-being and, therefore, indirectly for mental health. If exercise performed before complex cognitive tasks can lead to benefits in cognition and well-being, the order of physical exercise in the school day may have an important impact. Moreover, the magnitude of improvement in learning may be regulated by the intensity of exercise (Schmit et al., 2015).

In view of the results of the research reviewed, the main goal of this paper is to analyze, in a sample of adolescents, whether different intensities of exercise (no exercise, light/moderate exercise, or moderate/vigorous exercise) lead to changes in post-session selective inhibitory control and well-being, also analyzing which exercise intensity leads to the greatest changes in these variables.

Our hypothesis is that there will be an improvement in the rate of control of interference and of well-being after the sessions in which physical exercise is performed, with better results when higher intensities are applied.

Method

Participants

The initial sample comprised 35 students from 2nd grade of high school (19 boys and 16 girls), aged between 16 and 18 years ($M = 16.49$, $SD = .79$). The students belonged to a public school of a large city in Spain.

Measures

Measure of Interference Index (Stroop Test) The interference index was calculated from the scores obtained by the participants in the Spanish adaptation of the Stroop test (Martin et al., 2012) using a pencil-and-paper version.

The test consists of three pages of words and drawings printed in colors that combine in different ways. The first set or page, called Word (W), is made up of the words *blue*, *green,* and *red*, written in black ink on a white background. The second page, called Color (C), presents groups of four Xs (XXXX), printed in one of the above-mentioned colors (blue, red or green). The participants are requested to name the color of the four Xs presented. The last page, called Word-Color (WC) is made up of the names of the colors that appear on page 1, but in ink colors that are incongruent with the printed word. Participants are requested to name the color while inhibiting the reading of the word.

All the pages have 100 items, and each test lasts 45 s. The number of hits are added. For this study, we calculated the interference index with the formula, Interference Index = WC – ((WxC)/(W + C)). As indicated by Martin et al. (2012), this index represents the difference between the real performance on page 3 and the expected performance as a function of the hits on pages 1 and 2. Higher values indicate better control of interference.

Measure of Psychological Well-Being

Subjective Vitality To measure the students' perception of vitality before and after the three sessions, we used the Subjective Vitality Questionnaire (Ryan & Frederick, 1997), adapted to Spanish by Molina-García et al. (2007). This questionnaire can be considered as a eudaimonic measure of psychological well-being (Ryan et al., 2013). The questionnaire is made up of 7 items that indicate how the person feels at that moment (e.g., "I am full of energy"). The responses are rated on an 8-point Likert-type scale ranging from 0 (*not at all)* to 7 (*very true*). Cronbach's alpha in the different experimental situations ranged from .74 to .82.

Affect The Spanish version (Cervelló et al., 2014) of the short form of the Positive and Negative Affect Schedule (Mackinnon et al., 1999) was used to measure positive and negative feelings before and after the sessions of physical education. This questionnaire is considered a hedonic measure of well-being. The scale is made up of 9 adjectives, which are grouped into two factors in response to the item "Indicate how you feel right now…". Four of the items represent feelings associated with Positive Affect (glad, happy, content, amused), and five of them represent Negative Affect (depressed, worried, frustrated, angry, unhappy). The responses are rated on an 8-point Likert-type scale ranging from 1 (*not at all)* to 7 (*extremely*). Cronbach's alpha ranged between .76 and. 90 for the two factors in the present study.

Procedure

Only the participants who handed in an informed consent signed by themselves, their parents, and the school could participate. They were informed of the confidentiality and anonymity of the results obtained. Although all the adolescents of the three classes that participated in the study underwent all the experimental sessions (as a part of their physical education curriculum), we only measured the students who had handed in the signed informed consent. The final sample ($N = 35$) was made up of those who participated in all the pre and post experimental sessions. We counterbalanced the three experimental sessions in the three classes. The participants carried out four sessions (one pre-experimental session and three experimental sessions). For each group, every session was done at the same hour every week, with only one weekly session. The experiments were done in October 2016.

The experiment was approved by the Ethics Committee of the authors' university and approved by the corresponding academic authority of the high school. All participants signed an informed consent by themselves and their parents. All methods were performed in accordance with the relevant guidelines and regulations. The Clinical Trial was registered in ClinicalTrials.gov as ID:NCT03441386. CONSORT flowchart is included as Fig. 1, and CONSORT checklist and TREND checklist are included as supporting information.

Pre-Experimental Session In the first session, the participants completed the socio-demographic data and then carried out a Stroop test training session, before receiving a physical education class, in order to prevent a possible "learning effect" in test performance. The participants performed a minimum of 2 attempts of each page. When the participants made two attempts with variability of intra-page hits below 5% with regard to the previous attempt, the training session ended. Thus, we respected individual variability in learning the test. Prior studies have also used this percentage of intra-variability as an indication of stable performance in cognitive inhibition tests (Schmit et al., 2015). Nevertheless, recent studies have shown that the intra-class correlation coefficient of the test in the paper-and-pencil version in Spanish is high when comparing different temporal measures in the same population (Rodríguez Barreto et al., 2016).

Experimental Sessions The other three sessions consisted of: (a) a 20-min theoretical physical education session, without a physical component, in which the students answered questions about theoretical concepts of training; (b) a session of physical exercise of light and moderate intensity, structured as follows: a 5-min warm-up, 20 min of predominantly light and

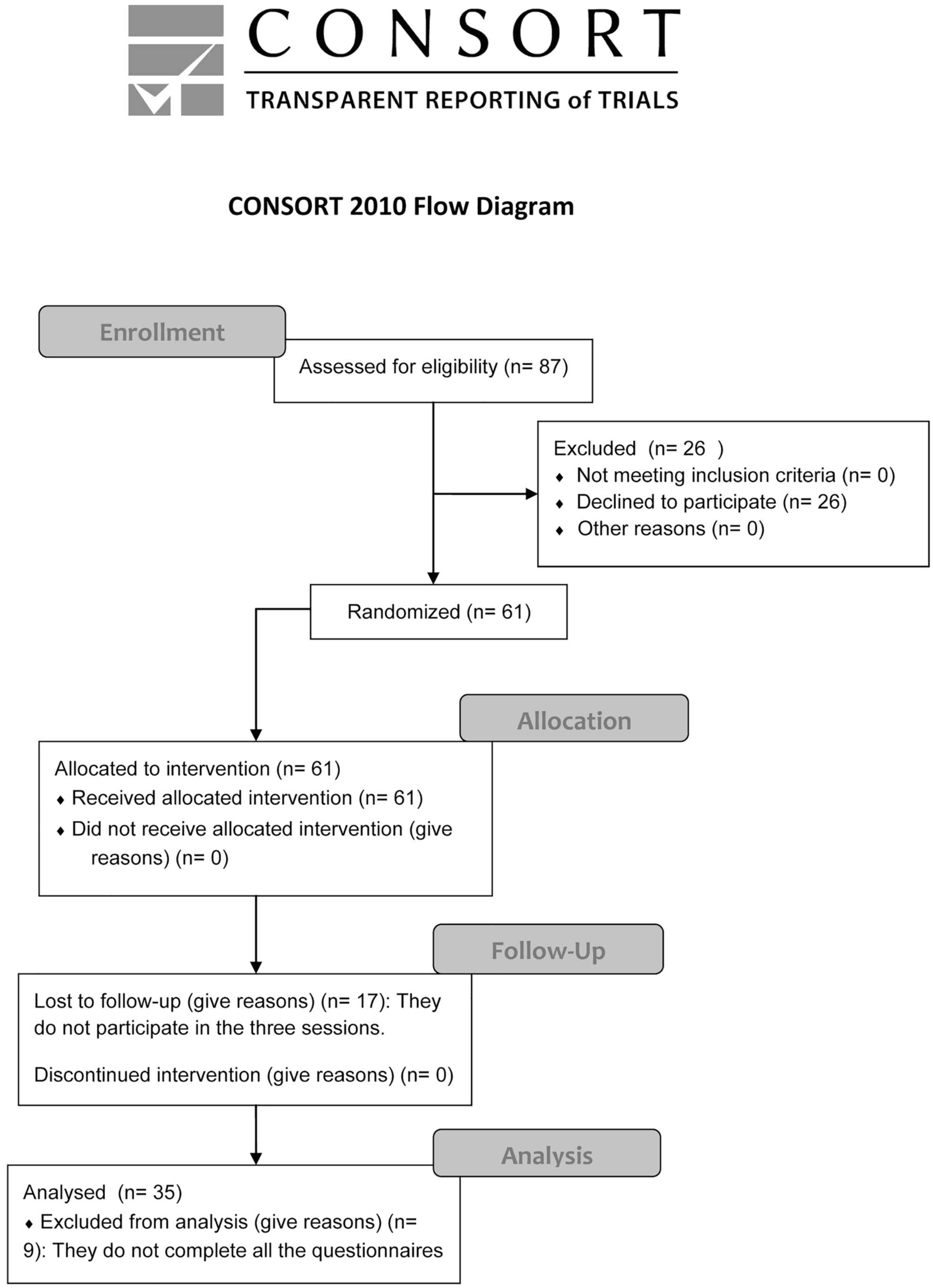

Fig. 1 CONSORT flowchart

moderate physical exercise, and a 5-min cool-off; and (c) a session of physical exercise of predominantly moderate and vigorous intensity, with the same structure as before. There was a one-week interval between the sessions. The physical exercise sessions was based on aerobics class directed by an instructor.

The duration of the main part of the sessions was established from the recommendations of (Chang et al., 2015, b), which indicate that, for acute sessions of physical exercise, the greatest cognitive benefits are obtained with durations of about 20 min.

Before and after each session, the adolescents completed the instruments that measured psychological well-being and cognitive interference. The questionnaires are also counterbalanced. The data were collected 5 min before and 15 min after the end of each session. Fifteen minutes after session was decided to make the measure as is the period with higher benefits for cognitive evaluation (Chang et al. 2015, b).

Control of the Intensity of the Exercise To control the intensity of the sessions, in addition to measures with accelerometry in each session, we performed a pilot study with 5 adolescents in which we adjusted the intensity of the exercises and the recovery times to ensure that they fulfilled the goals of the session. For this purpose, we used simple aerobic exercises that do not pose any coordination difficulties, and the students followed a monitor's instructions. After adapting the sessions, they were performed in the experimental situation.

We calculated the intensity of the sessions with accelerometry. We used tri-axial GT3X accelerometers that each of the participants wore while performing sessions "b" and "c". The students were shown how to put on and use the accelerometer before beginning the sessions (Santos-Lozano et al., 2013). The frequency of time storage was a 1-s *"epoch"*. We ignored periods of use of less than 15 epochs, and periods of no activity of longer than 1 min were eliminated from the analysis. The software used for data treatment was ActiLife 6 (Actigraph, Actilife version 6.11.5) and to define the type of activity (light moderate and vigorous), we used the cutpoints defined by (Troiano et al., 2008). We chose this author because he clearly and concisely defines the cutpoints as a function of concrete ages (Troiano et al., 2008).

Figure 2 presents the percentages in each of the intensities, showing that, while retaining the percentage of moderate physical exercise of the session, the times of light and vigorous physical exercise were modified, such that we classified the sessions as light/moderate and moderate/vigorous, although all three intensities were present in the session. The goal was to determine whether cognitive interference and well-being were different as a function of predominance of a lighter or more vigorous activity, maintaining a similar moderate intensity, which is the most similar to real classrooms of physical education, where intensity is not constant and activities are changing during the classroom.

Statistical Analysis

2 × 3 repeated measures ANOVA was used to analyze data using IBM SPSS software. d of Cohen was calculated to measure the effect size. Description is included in results.

Results

To achieve the goals of the work, we conducted a 2 × 3 repeated measures *ANOVA*, taking into account the time when we measured these variables (pre and post), and the three treatments concerning the levels of intensity (no exercise, light/moderate exercise, and moderate/vigorous exercise). The dependent variables analyzed were the index of interference, perceived vitality and perceived affect (positive and negative). The descriptive statistics are presented as means ± standard deviations (Table 1).

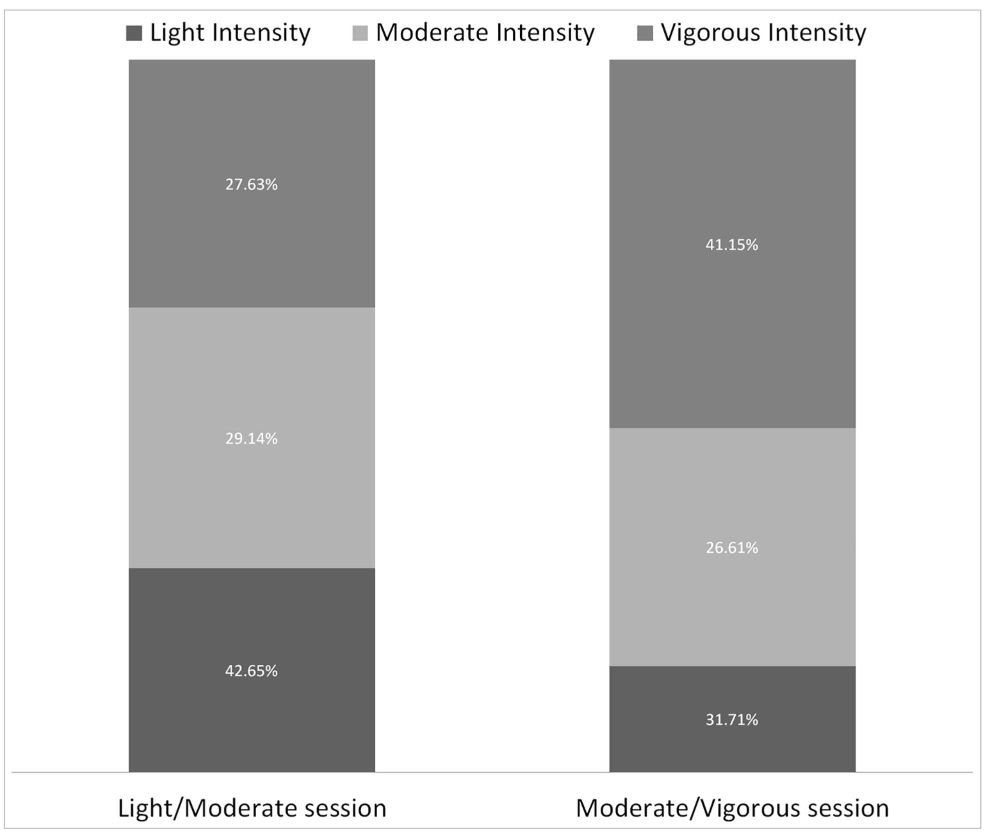

Fig. 2 Percentages of time in the different intensities of exercise in Sessions 2 and 3

Table 1 Pre and post sessions Descriptive Statistics for different intensities

	Intensity					
	Light/Moderate		No Exercise		Moderate/Vigorous	
Variables	Pre	Post	Pre	Post	Pre	Post
Interference Index	38.79 ± 8.14	44.06 ± 8.07	32.73 ± 9.25	33.77 ± 9.20	40.90 ± 7.04	46.47 ± 4.48
Vitality	4.73 ± 1.23	4.92 ± 1.15	4.26 ± 1.78	4.75 ± 1.49	4.63 ± 1.27	4.72 ± 1.51
Positive affective state	4.22 ± 0.82	4.48 ± 0.70	3.85 ± 1.01	3.89 ± 1.01	4.30 ± 0.77	4.40 ± 0.88
Negative affective state	1.39 ± 0.53	1.16 ± 0.33	1.66 ± 0.75	1.77 ± 0.90	1.30 ± .50	1.16 ± 0.33

We performed post-hoc *t*-tests with Bonferroni adjustments for multiple comparisons of the significant effects. The effect sizes are expressed as partial eta-squared (η_p^2), and we used an alpha of .05 for the level of significance. Eta-squared effect sizes are grouped as small (≤ .01), medium (≤ .06) and large (≤ .14) as Cohen describes (Cohen, 1988).

Firstly, we examined the sphericity of the repeated measures statistical test, which showed that Mauchly's *W* was significant both in the case of treatment and in the Time x Treatment interaction for positive and negative affect. In the case of the index of interference and vitality, in the conditions of treatment and Time x Treatment interaction, the value of Mauchly's *W* was nonsignificant, so we assumed sphericity of the test for these variables. In the variables for which we could not assume sphericity, we selected the test with a higher observed power (in our case, the Greenhouse-Geisser test) to explore the significance of *F*.

The results showed a main effect of time in the index of interference with a large effect size ($F_{(1, 34)} = 13.73$; $p < .002$; $\eta_p^2 = .28$), and in subjective vitality ($F_{(1, 34)} = 4.38$, $p < .05$; $\eta_p^2 = .12$), with a moderate effect size. There were no significant differences either in positive ($F_{(1, 34)} = 3.22$, $p < .09$; $\eta_p^2 = .08$) or negative affect ($F_{(1, 34)} = 1.59$, $p < .22$; $\eta_p^2 = .04$).

However, the effects of time were affected by the session, with no physical activity, and no significant changes were observed in the pre-post measures in any variable except for subjective vitality, which did show an effect of time in the no-exercise session ($p < .014$). Interestingly, vitality showed no pre-post differences either in the light/moderate ($p < .264$) or moderate/vigorous sessions ($p < .669$) (see Figs. 2 and 3).

In order to interpret more clearly the effects of time on the variables of interest, we examined the pre-post data of the sessions in which there was physical exercise and the effect size (d of Cohen) and confidence interval (CI) were calculated. Effect sizes (d) are reported as small (≤ 0.20), medium (≤ 0.50) and large (≤ 0.80) (Cohen, 1992). Regarding the different intensities, the results revealed significant differences with higher post-treatment measures in the index of interference for light/moderate ($p < .005$; d = .65, CI [0.16–1.12]) and moderate/vigorous ($p < .001$; d = .94, CI [0.41–1.43]) physical exerecise. We found significant post-treatment increases of positive affect only in the session of light/moderate physical exercise ($p < .005$; d = .34, CI [−0.13–0.81]). Lastly, we found a significant post-treatment decrease of negative affect in the case of the light/moderate session ($p < .013$, d = 0.52, CI [0.04–0.99]). In the case of the moderate/vigorous session, there was a similar decrease of negative affect, but without reaching statistical significance ($p < .075$, d = 0.33, CI [−0.14–0.80]) (see Figs. 2 and 3).

With regard to the effect of the different intensities of exercise on the variables of interest, the results revealed a main effect for treatment and with a large effect size on the index of interference ($F_{(2, 68)} = 40.70$; $p < .001$; $\eta p^2 = .54$), positive affect ($F_{(1.43, 61.03)} = 12.88$; $p < .001$; $\eta p^2 = .27$), and negative affect ($F_{(1.20, 41.02)} = 18.49$; $p < .001$; $\eta p^2 = .35$). In the case of positive affect, we found differences between the no-exercise session and the light/moderate session (favoring the light/moderate session, $p < .001$), and also with the moderate/vigorous session (favoring the moderate/vigorous session, $p < .002$). We also found significant decreases in negative affect when comparing the no-exercise session with the light/moderate exercise session ($p < .001$) and the non-exercise session with the moderate/vigorous exercise session ($p < .002$). No significant differences were found in subjective vitality ($F_{(2, 68)} = 1.46$; $p < .24$; $\eta p^2 = .04$). Lastly, we found an effect of the Time x Treatment interaction only for the index of interference, with a small effect size ($F_{(2, 68)} = 3.11$; $p < .05$; $\eta p^2 = .09$) (Fig. 2).

In this regard, inspection of the pre-post effect sizes showed that the moderate/vigorous ($p < .001$; d = .94) and light/moderate intensity condition ($p < .005$; d = .65) were more effective in improving the index of interference than the no-exercise condition (d = 0.11, not significant pre-post analysis) as they obtained higher effect sizes and significant pre-post differences (Fig. 2), with a higher effect size for moderate/vigorous session than for light/moderate session (Fig. 4).

Discussion

The main goal of this work was to determine whether the performance of three physical education classes with different

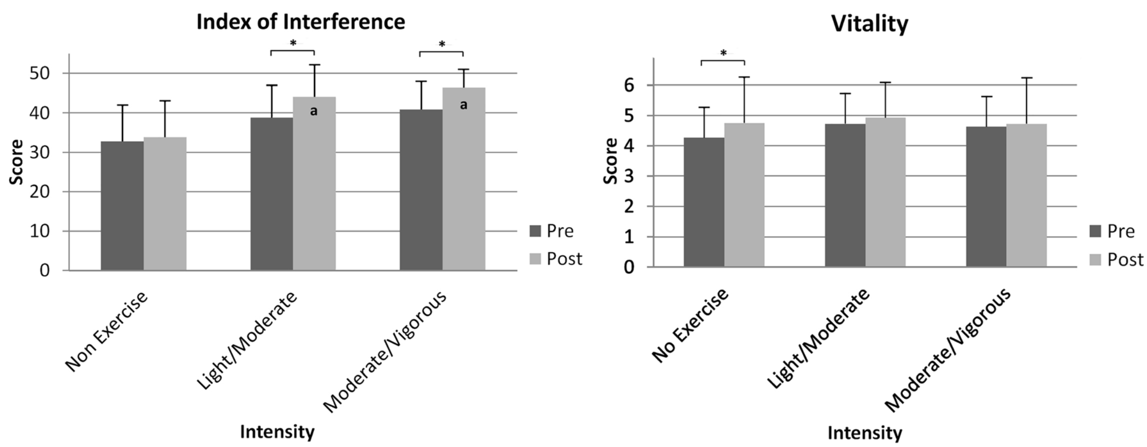

Fig. 3 Comparison of the means of the index of interference and vitality in the different sessions. The results of the pairwise Bonferroni comparisons are presented: [a] indicates significant differences ($p < .05$) in the post-treatment scores obtained in the index of interference in the no-exercise session

intensities of exercise (no-exercise, light/moderate, and moderate/vigorous) affects adolescent students' cognitive functioning (through the assessment of the index of interference) and psychological well-being and, if so, to what extent.

Our working hypothesis was that the practice of physical exercise, compared to a no-exercise session, would lead to significant improvements in the students' index of interference and well-being, and that the higher the intensity of the exercise, the greater these improvements would be. The results corroborated these hypotheses only partially.

With regard to the effect of the different intensities on the index of interference, the results showed that it was significantly higher in the post measures of the two sessions in which exercise was performed (light/moderate and moderate/vigorous), and these differences were not found in the no-exercise session.

In addition, the interaction effect showed that the post-treatment measures of the two sessions with physical exercise presented a significant improvement in the index of interference when compared to the post-treatment measure of the no-exercise session. A high effect size was obtained in the analysis of the effect of the treatment on the index of interference, underlining the importance of performing exercise to modify this variable.

These results show that performance of acute physical exercise is a good way to influence executive function, and specifically the control of interference. Our results are also consistent with the results of other studies on the effect on cognitive functions of acute practice of exercise (Li et al., 2017; Park & Etnier, 2019). This result can be produced by the exercise-induced arousal as was described by Lambourne and Tomporowski (2010), this arousal modification by exercise can produce an improvement in speeded mental processes. Our results also support the results from studies carried out in school settings, which propose the performance of acute

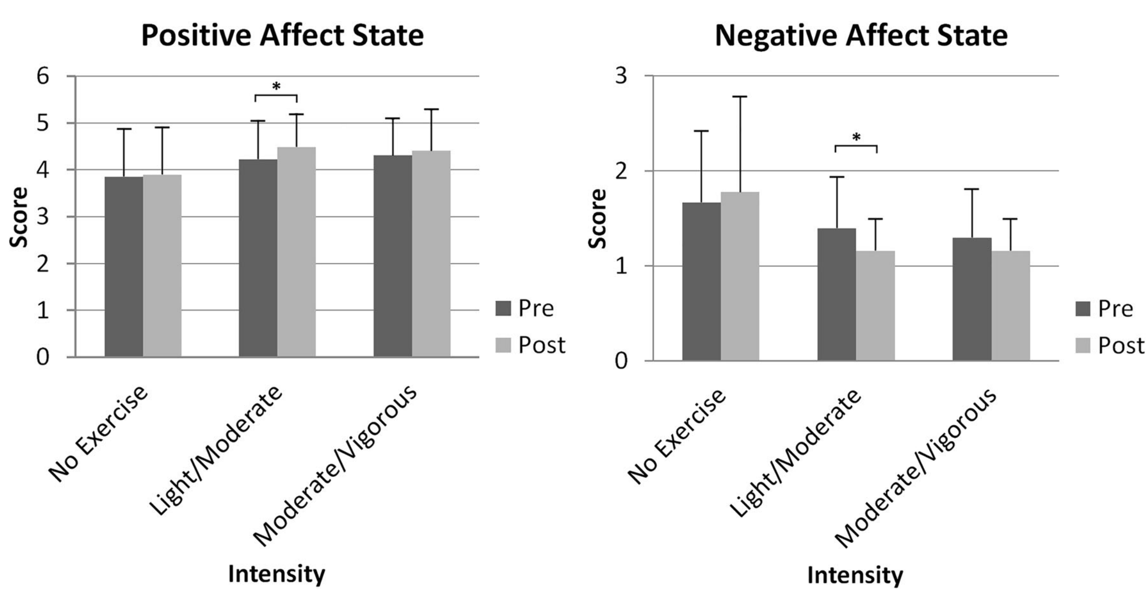

Fig. 4 Comparison of the means of positive and negative affect in the different sessions. The results of the Bonferroni pairwise comparisons are presented

physical exercise to improve students' functional capacity during the day, thereby improving their predisposition to learn (Howie et al., 2015).

Our results revealed no differences in the index of interference when comparing the light/moderate with the moderate/vigorous intensities, but the effect sizes in the pre-post analysis showed a higher effect for moderate/vigorous intensity. Maybe intensity does not matter, or simply light/moderate intensity is sufficient to increase cognitive function, as shown by some works (Rojas Vega et al., 2006), maybe this higher effect size implies that intensity, in fact, does matter, in accord with Schmit et al. (2015).

Drawing on the results obtained in our work, future research should try to determine the most adequate dose of physical exercise to obtain the highest improvement of the index of interference and cognitive function in general. Issues such as the minimum duration of the sessions and verification of the duration of the effects on the improvement of adolescents' cognitive function are areas that should be examined.

Regarding the measures of well-being, the results were mixed. In the case of vitality, we did not observe any positive effect on this variable through the practice of physical exercise. In fact, only in the no-exercise class were there any differences between the pre and post measures, in favor of the post and in contrast to our hypothesis. However, in the case of affect (positive and negative), we found pre-post differences in the light/moderate session, increasing positive affect and decreasing negative affect. In the moderate/vigorous session, we found the same tendency, although it did not reach statistical significance. We also found a significant treatment effect on positive and negative affect, indicating that performing either light/moderate or moderate/vigorous physical exercise modifies affect in the expected direction, increasing positive affect and decreasing negative affect.

These results are consistent with those found by Cervelló et al. (2014), in which affect improved after performing an acute session of physical exercise independently of the intensity although, as we have seen, vitality did not follow this pattern. This may be due to the fact that vitality is affected by fatigue caused by the acute physical exercise, and more recovery time may be needed before observing an increase of vitality after performing exercise. In fact, recent work has shown an inverse relation between exhaustion and vitality in the practice of acute physical exercise (Amador et al., 2017).

It should also be noted that, with regard to affect and exercise, other variables may be influential for improving students' affect. The study by McMahon et al. (2017), for example, with more than 11,000 adolescents, showed a clear relation between the frequency of exercise and subjective well-being.

To conclude, the results of our work have several practical implications. Performing sessions of physical exercise before tasks that involve complex cognitive operations can lead to great benefits, not only for cognitive function but also for some dimensions of well-being. It is necessary to continue to examine the adequate dose of exercise to obtain the greatest benefits. Obviously, this study is not exempt from limitations. The sample of the study was not very large because only the students who handed in the informed consent participated. Another possible bias is the intensity structure of the sessions, as we look for analyze a total ecologic environment, the exercise intensity in both sessions have similar moderate intensity and both sessions have, in a different degree, low and high intensity. We know this is lesser clear than the all-time in low or high intensity, but in a real environment, not all adolescence can endure 20 min of high intensity exercise, and this kind of continuous intensity is not normal in physical education classrooms. As we know that physical education classrooms usually develop a combination of intensities, and we wanted to study real adolescences with their individual endurance differences, we select this combination of intensities, with predominantly moderate intensity, and we assume this is a probably bias of the study. But to analyze the effect of non-ecological intensities there are other laboratory studies which shows these data, and our objective was to study how we can interfere in a real ecological environment changing intensity in a moderate manner that can be assume by all the students and can be structures as a common physical education classroom. Moreover, recent study from Park and Etnier (2019) speaks about a possible bias produces by order of the sessions, that maybe is not corrected by counterbalance design, and this bias has been not analyzed in this study. Future works should control these variables and introduce new cognitive functions (attention, memory, concentration) to offer a more precise view of cognitive functions when performing acute physical exercise.

Funding Information Spanish Government: Ministerio de Economía y Empresa. Convocatoria Retos. RTI2018–098335-B-I00.

Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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