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DOI 10.1016/j.actpsy.2021.103363
ISSN 0001-6918

Publisher: Elsevier

Acta Psychologica 218 (2021) 103363

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

The acute effects of continuous and intermittent cycling on executive function in children

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ARTICLE INFO

Keywords:
Physical activity
Cognitive function
Inhibition
Working memory
Exercise
Children

ABSTRACT

This study assessed the effect of acute continuous and intermittent physical activity (PA) on children's executive function (EF). Twenty-four participants (14 boys M = 10.32 ± 0.48 years), using a within-subjects design, performed a continuous (70% HRmax) and an intermittent (≥85%HRmax; 12 bouts: 30 s work, 45 s rest) PA bout of cycling, both lasting 15 min. Executive function was assessed using the Stroop task, Digit Span and Corsi Blocks tests and these were administered before and 1 min and 30 min post PA. Comparing both conditions, performance at the Stroop task (i.e., reaction time) improved in the continuous condition after 1 min and after 30 min (congruent stimuli) (mean diff = 126 ms ± 59; p = 0.047 and mean diff = 89 ms ± 38; p = 0.031, respectively). The intermittent condition improved at 30 min post (congruent and incongruent) (mean diff = 116 ms ± 46; p = 0.021 and mean diff = 111 ms ± 49; p = 0.039, respectively) showing a delayed benefit from the PA bout and greater improvements compared to the continuous condition. Verbal memory was improved for the continuous condition 1 min post only and no effects on visual memory were observed for both experimental conditions. The results demonstrated that both acute PA bouts might be a time-efficient approach for enhancing EF, with intermittent PA having a delayed and greater benefit.

1. Introduction

Executive functions (EF) can be described as a variety of control processes, characterised by inhibition, cognitive flexibility and working memory (WM) (Diamond, 2013). These EF domains play an important role in educational settings where academic achievement is of high importance (Howie & Pate, 2012). According to Tomporowski et al. (2015), physical activity (PA) can modify children's cognition (e.g. executive function, attention, memory, and intelligence) and metacognition processes (e.g. strategies, procedural and declarative knowledge) leading to changes on academic performance. Therefore, the investigation of the immediate and sustained effects of this relationship in educational settings for younger ages is essential, and ways to optimise EF through PA, remains of interest to researchers and teachers alike.

A single bout of PA, longer than 10 min, has been associated with better EF performance in adults (aged >18 years), adolescents (aged 12–18 years) and children (aged 6–11 years), with effects observed from 20 to 30 min post (Chang et al., 2012; Etnier et al., 1997; Hsieh et al., 2020; Lambourne & Tomporowski, 2010; Ludyga et al., 2016; Williams et al., 2019). However, the reviews mentioned suggest only small to moderate effect sizes, which may mediated by physical activity intensity, time for EF test administration and type of physical activity. The intensity of acute PA has been a main focus in prior work in adults and children, where light-moderate intensities seem more effective immediately on cessation of PA, but when performed after 1 min of delay (or longer), high-intensity PA results in larger effects (Chang et al., 2012). Yet, another recent review from Ai et al. (2021) has suggested that when considering intermittent PA, both submaximal and maximal intensities might benefit EF when these assessments are conducted within 30 min post PA, but only a small number of studies conducted in children was considered. Another important factor is that it seems that children benefit more from moderate intensities compared to other age groups when reaction time (inhibition) is considered as variable (Ludyga et al., 2016), but the effects of intermittent PA and its different intensities and types are not well understood yet, leading to a situation where research in children requires more evidence to elucidate the effects of different intensities and type of PA.

In studies specifically examining the acute PA effects on EF in children, moderate intensities (e.g. 60–76% HR of the maximal heart rate) (Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009a; Lambrick

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https://doi.org/10.1016/j.actpsy.2021.103363
Received 15 October 2020; Received in revised form 23 June 2021; Accepted 29 June 2021
Available online 1 July 2021

et al., 2016) and maximal intensities (Cooper et al., 2016) have shown to improve EF immediately post PA and these effects seem to subside up to 45 min (Chen et al., 2014; Cooper et al., 2016; Jäger et al., 2014; Lambrick et al., 2016). However, it is essential to note that these studies measured EF using different tools (e.g. modified EFT, more odd task, 2-back, backward recall, trail making and Stroop test), types (e.g. intermittent, continuous and game-based approaches), research designs (e.g. between or within-subjects), age groups, time of assessment and durations. Although the above evidence provides some understanding on the effects of PA for EF enhancement, little is known about the optimal dose for EF enhancement, duration of effects, how children perceive these optimal doses and the mechanisms underpinning these improvements.

When considering optimal dose, different types of PA may influence PA (Lubans et al., 2016) Lambourne and Tomporowski (2010) reported that, for young adults, cycling has greater benefits post-PA than running. To date, only four studies in children included cycling as part of their protocols (Berse et al., 2015; Ellemberg & St-Louis-Deschênes, 2010; Hogan et al., 2013; Stroth et al., 2009). All of these aforementioned studies focused on the pre-post effect with no follow-up after PA cessation. Understanding if any effects of PA persists after exercise cessation in children following cycling is a key question which remains unanswered.

Of further consideration on the effects of cycling, is how the cycling is completed (e.g. continuous or intermittent cycling). To our knowledge, only one study has compared continuous and intermittent PA bouts in children (aged 8–10 years) (Lambrick et al., 2016) suggesting that both PA modes (treadmill at moderate intensity) improved the inhibitory aspect of EF as assessed by reaction time at 1 min, 15 min and 30 min post-PA, with larger benefits for the intermittent condition. Lambrick et al. (2016) work compared intermittent and continuous PA bouts at the same intensity where the intermittent condition was designed to reflect children's typical activity patterns (45 s at a heavy intensity, 33 s at a moderate intensity, 10s at a severe intensity, and 62 s at a low intensity) and only reaction time was measured. As EF comprises more than just inhibition, it would be of benefit to investigate the effects of these type of activities on other aspects of EF. Given that many children are not active enough to achieve the associated benefits (Aubert et al., 2018) and that any intervention is likely to be ineffective unless adhered to, gaining insight into children perceptions of types and intensities of activities in imperative in finding the optimal dose and mechanisms associated with these changes.

It has been hypothesised that due to the PA demands, high-intensity PA has the capacity to elicit higher values of arousal than continuous at moderate intensity (Oliveira et al., 2013) and consequently higher levels of arousal lead to enhanced cognitive performance (Lambourne & Tomporowski, 2010), but this relation is still unclear for children. The current study addresses several key gaps in the literature, given the lack of experimental evidence particularly relating to the nature of PA (intermittent vs continuous), the time course effect (pre-post vs pre-post and thereafter), intensity and how children perceive these activities on the cycle ergometer. The purpose of this study was to assess the effect of an acute continuous and intermittent cycling PA bout on EF (inhibition, verbal and visual memory) and considering scales of affect to understand participants' enjoyment and arousal in children.

2. Methods

2.1. Participants

Following institutional ethics approval (no: P79858), informed parental consent and child assent, twenty-four participants (14 boys M = 10.32 ± 0.48 years) were recruited (convenience sampling), from two primary schools in West Midlands, UK. The minimum number of participants required (24–63) was determined by apriori power calculation, using G-power software (Power = 0.8 and $\alpha = 0.05$; ES (f) = 0.14–0.25 or $\eta^2 p = 0.02$–0.06) (Faul et al., 2007) considering the cognitive outcomes for a repeated measures ANOVA and previous literature that suggests small to moderate effects of PA on executive function in children (Chang et al., 2012; de Greeff et al., 2018; Hillman et al., 2019; Ludyga et al., 2016). Participants with musculoskeletal, cognitive impairments (including special needs), mental health disorders, cardiovascular contraindication to PA or taking any medication were excluded (informed by participant information/parents' consent, physical activity readiness questionnaire and class teacher).

2.2. Anthropometric measures

Height, sitting-height and mass were measured to predict age at peak height velocity (PHV) determined by the Mirwald et al. (2002) equation. By using the age of PHV as the maturational benchmark, each measurement occasion was described as years from PHV by subtracting the age of PHV from the chronological age at each measurement occasion. The difference in years was defined as a value of maturity offset (Mirwald et al., 2002). All these measures were taken considering the nearest mm and body mass to the nearest 0.1 kg. Two measurements were taken for each anthropometric variable. A third measurement was required if the first two differed by more than 4 mm for height and sitting height and 0.4 kg for weight. The two measurements for each anthropometric measure were averaged. If three measures were taken, the median value was used (Bailey, 1997). Body mass index (BMI) was calculated as body mass (kg) divided by stature (m) squared. Age and sex-specific BMI cut points for overweight and obese status were determined by Cole et al. (2000).

2.3. Cognitive assessments

EF was assessed before, 1 min post and 30 min post PA using an open-source software: the software Psychology Experiment Building Language (PEBL; (Mueller, 2011)) to perform Corsi Blocks, Digit Span Forwards and Colour Stroop Tasks. All the participants received the same instructions (see appendix for instructions) provided automatically by this software and if participants had vision limitations, they were instructed to wear glasses or contact lenses accordingly. The average time to complete the tests battery was 15 min and the tests were always administered by the following order: Stroop Test, Digit Span and Corsi Blocks. Although some studies have used Digit Span Forwards and Corsi Blocks tests as a measure of short term memory, the cognitive tasks were conceptualised as measures of EF in the current study, in line and consistent with prior work (Cooper et al., 2016; Pontifex et al., 2018).

2.3.1. The colour Stroop task

The Stroop task is a classic measure of selective attention and inhibition/interference (Lucas et al., 2012) that has been widely used to assess the effects of acute PA on EF (Chang et al., 2012; Cooper et al., 2016; Lambrick et al., 2016). Participants completed the Stroop interference task with four colours (blue, yellow, green, red). The colour in which each word is presented could be congruent (green word-written in green) involving well-learned reading processes to produce fast and accurate responding, incongruent (green word-written in blue) giving use of cognitive control mechanisms to dampen word reading and activate colour-naming processes or neutral (neutral word-written in any colour). Participants were asked to identify the colour of each word being presented as quickly as possible, responding by clicking on the respective answer button on the keyboard (1,2,3,4) (blue, yellow, green, red). All participants were presented 30 stimuli of each trial (congruent, incongruent and neutral) with 1000 ms fixation time and 3000 ms to answer, if their reaction time was longer than 3000 ms the stimuli would be considered "too slow" and if faster than 200 ms would be excluded from analyses (Hedge et al., 2019). Participants were also instructed to answer as quick and accurate as possible, stay in absolute silence, keep their hands close to the keyboard to avoid any delay in their reaction and prior to all measurements all participants completed 5 practice rounds until a 0.75 accuracy was reached. The total average time per response (reaction time), and the number of correct answers (response accuracy) were recorded as measures of performance. Previous research suggests that this test has a good reliability ($r > 0.80$) and is valid for children (Homack & Riccio, 2004).

2.3.2. Digit span test

The Digit Span is classic verbal WM test adapted from Wechsler (1949) that requires the participant to recall a sequence of numbers. The sequence of numbers was presented for forward recall at one-second rate and two trials were presented at each increasing list length (starting with two). Testing ended when the participants failed to accurately report both sequences for one length or when the maximal list length was reached (10 digits). The total number of correct sequences, and the memory span score were recorded as a standard outcome of this software using the keyboard as input. Digit span has been reported on test-retest as having moderately high reliability of 0.83–0.89 for children 6–12 years old (Alloway et al., 2008; Flanagan et al., 2010). It is also worth to consider that computerised versions of digit span can significantly enhance the reliability and precision (avoid rate, intensity, emphasis, digit enunciations and inter-individual variations) of digit span assessments of verbal memory (Jahanshahi et al., 2008; Woods et al., 2011).

2.3.3. Corsi block test

The Corsi test is a classic visuo-spatial WM test used as a visuo-spatial version of digit span based on Corsi test (Corsi, 1972; Kessels et al., 2000). This task consisted of a computer screen containing nine blocks at fixed and pseudorandom positions. The participants were asked to tap the block sequence presented (starting with three to a maximum of nine pattern sequences) in the same order as presented before. The block sequences were gradually increasing in length (intervals of 1000 ms), and the scores obtained were the general number of correctly remembered sequences or the length of the longest sequence that was remembered correctly (i.e., block span), total correct trials (the number of trials total that were correctly recalled) and memory span (the minimum list length, adds the total number correct, and divides by the number of lists at each length).

The advantage of a computerised Corsi version is that automatic scoring can have higher accuracy than manual scoring and it also allows the examiner to observe other important characteristics that might help to explain their performance (e.g., distractibility, physical movements and mental fatigue).

2.4. Affect scales and rating of perceived exertion

Participants also reported measures of affect using the Feeling Scale (FS) (Hardy & Rejeski, 1989), Felt Arousal Scale (FAS) (Svebak & Murgatroyd, 1985) and Rating of Perceived Exertion (RPE) using the 1–10 Pictorial Children's OMNI scale (Utter et al., 2002). For the FS, participants rated their current feelings on an 11-point bipolar scale ranging from +5 to −5, with verbal anchors of very good (+5), good (+3), fairly good (+1), neutral (0), fairly bad (−1), bad (−3), and very bad (−5). For the FAS, participants rating themselves on a 6-point scale ranging from 1 to 6, with anchors at 1′ low arousal' and 6′ high arousal.

RPE was assessed using the 1–10 Pictorial Children's OMNI scale (Utter et al., 2002). The OMNI has a range of numbers familiar to youth (1 to 10) and uses age-appropriate verbal expressions as descriptors of PA effort. Anchors range from, not tired at all" (0) to "very, very tired" (10) and has been previously validated for children between 6 and 13 years old with correlations of RPE and %VO2max ($r = 0.41$–0.60, $P < 0.001$) and HR ($r = 0.26$–0.52, $P < 0.01$) (Utter et al., 2002).

All participants were measured before, for every minute of the continuous condition and for the intermittent condition at the end of each active bout, 1 min post and 30 min post, similar to the protocols applied by Malik et al. (2017). However, due to the different nature of the conditions, the measurements computed and a median was used for before, during 1 (average of the first 7.5 min), during 2 (average of the second 7.5 min), 1 min post and 30 min post. Participants in their first day were given standardised instructions on how to use the scales and had time to practice during the familiarisation stage and the same researcher administered the scales to all participants.

Similar to the study by Malik et al. (2019), the FS and FAS scales were represented by the circumplex model (Russell et al., 1989). The circumplex is divided into 4 quadrants, each characteristic of different affective states: 1) unactivated/pleasant affect (e.g. calmness and relaxation); 2) unactivated/unpleasant affect (e.g. boredom or fatigue); 3) activated/unpleasant affect (e.g. tension or nervousness); and 4) activated/pleasant affect (e.g. excitement or happiness). FS and FAS exhibited correlations ranging from 0.41 to 0.59 and 0.47 to 0.65, respectively, with the Affect Grid (Russell et al., 1989) indicative of convergent validity with similar established measures (Van Landuyt et al., 2000).

2.5. Procedures

The study employed a within-subjects crossover design where participants were randomly allocated to a sequence involving control, continuous or intermittent PA (experimental protocols described below and Fig. 1) in different orders, using a research randomiser (https://www.randomizer.org). Similar to the study by Benzing et al. (2016), the control condition sat and watched a neutral video (One breath around the world (https://www.youtube.com/watch?v=OnvQggy3Ezw)) for the same duration as the experimental conditions, which did not require greater arousal levels than resting.

Cognitive tests were performed in a quiet area/classroom in the school setting and data were collected at the beginning of each afternoon, when the schools were more receptive to our research. All participants were required to be in a well-rested and hydrated state and a washout period of at least 48 h–72 h was implemented in line with Lambrick et al. (2016). As this data was collected in the afternoon, all participants engaged in the same lessons (Maths, English and Sciences) in the morning, with no PE or any vigorous PA in the day before. To avoid learning effects (e.g. improvement due to the practice) participants were familiarised in their first day, performing at least 2–3 full trials of each cognitive test. These effects have been investigated and learning effects can be diminished by repeated exposures to the task, with no significant differences found between the 2nd-4th administration (Bartels et al., 2010; Calamia et al., 2012; Collie et al., 2003).

Resting heart rate was obtained following 10 min seated rest during the familiarisation trial (Polar FT1 Heart Rate Monitor, Polar Electro, Finland) by using the 208–0.7(age) equation to predict the mean HRmax (Tanaka et al., 2001) which has been shown to closely predict mean HRmax for 7–17 years old children (Mahon et al., 2010). Resting heart rate was also taken before every condition. To understand cardiorespiratory fitness of the group, a 550-m distance run/walk was conducted, and this test has shown to be valid for 8–13-year-old children (Hamlin et al., 2014).

2.6. Cycling protocol

All participants completed two experimental conditions using a cycle ergometer (Monark 824E). Prior to each protocol, ergonomic adjustments were made following the recommendations from Monark 824E User's manual (https://sport-medical.monarkexercise.se/support-downloads/). Distance (m), work done (J), mean power (W), maximum power (W), mean pedal Rate (rpm) were recorded using the Lab Chart Reader (v.8) and analysed with Monark cycle ergometer analysis software adapted and based on Lakomy (1986).

The Intermittent condition consisted of 12 bouts of 30s at ≥85% HRmax with resting periods of 45 s (recovery time), the participants did not pedal in the recovery periods. This protocol was 15 min long

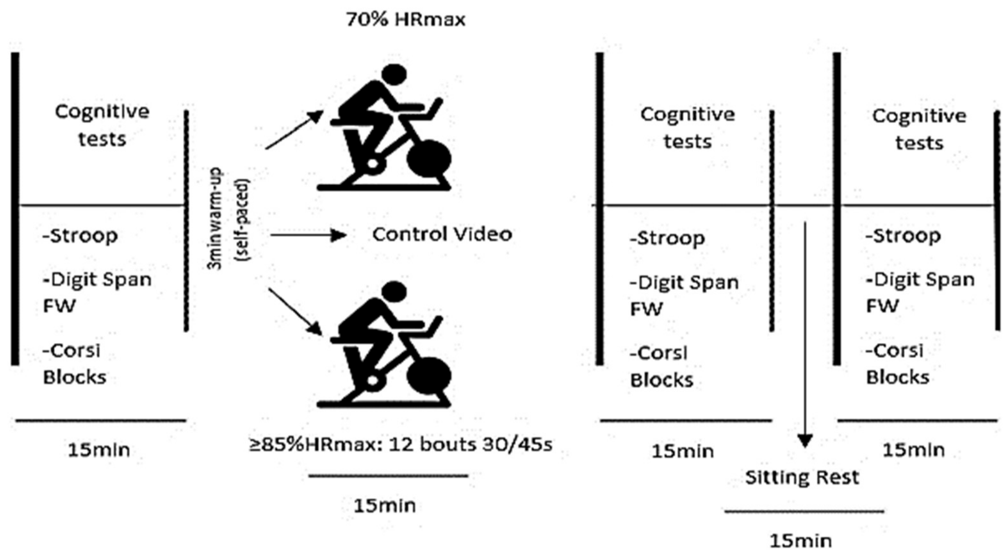

Fig. 1. The time course and procedure for the continuous, control and intermittent conditions.

(Active+Rest) and based on the literature, intermittent/high-intensity PA protocols have been designed with intensities between 50 and 90% HRmax (Budde et al., 2008; Niemann et al., 2013). The continuous condition involved participants cycling continuously for 15 min at 70% HRmax, in line with previous literature moderate continuous activities have been designed between 50 and 80%HRmax (Hillman et al., 2009a, Ishihara et al., 2017, Jäger et al., 2014, Pontifex et al., 2013).

Although the experimental PA conditions were not intensity matched, given the difficulty of achieving this in a pragmatic manner that could be practically used in schools, both protocols were designed to be equal to 15 min as it is representative of the UK school break-time.

Participants were informed of their HRmax and instructed how to keep the expected pace at the familiarisation stage. The same researcher monitored the participants' HR throughout all data collection to assure homogeneity. Affect scales, Rating of perceived exertion and HR were measured before, for every minute of the continuous condition and for the intermittent condition at the end of each active bout, 1 min post and 30 min.

2.7. Statistical procedures

All the cognitive outcomes were analysed using SPSS Statistics (v.26.0, SPSS Inc. USA) performing a series of 3 (Condition: CON, INT and Control) by 3 (Time: before, 1 min post, 30 min post) repeated-measures ANOVA. Where sphericity was violated, Greenhouse-Geisser was used to adjust the degrees of freedom, and these are reported. In the event of significant effects ($p < 0.05$), follow-up post hoc tests, with Bonferroni adjustments where applicable, were conducted to examine the location of mean differences, if not appropriate, LSD post hoc testes were applied as this test suits our sample size and allows comparisons between 3 condition means. The magnitude of mean differences were interpreted using effect sizes determined as 0.01 (small), 0.06 (medium), and 0.14 (large) using partial eta-squared η^2p (Cohen, 1992). All cognitive data were tested for normality with histograms and Q–Q values, where the values showed to be within the recommended range plots for skewness (−2,+2) and kurtosis (−7,+7) (Byrne, 2013; Hair et al., 2010). Also, a preliminary analysis was conducted to examine the experiment session order (the order in which the continuous, intermittent and control conditions were presented to participants) to ensure that observed effects are not due to specific experimental orders the cognitive outcomes. These were computed and summed by variable-condition and analysed employing a one-way ANOVA using the condition order as a factor.

The affect scales were analysed using a non-parametric repeated measures ANOVA (Friedman) on Jamovi (V.1.2.17). Pairwise comparisons were conducted using Durbin Conover equations to enable differences to be discerned across time-points (before, during 1, during 2, 1 min and 30 min post), and the results were provided by medians (Med) and interquartile ranges (IQR).

3. Results

3.1. Cognitive outcomes

Descriptive statistics of the cognitive outcomes are displayed in Table 2 and Fig. 2. The session order had no effect on this study $F(5, 15) = 1.0, p = 0.477$. Two participants were excluded from the Stroop task analyses as the criteria defined for reaction time in the cognitive tests was not met (see Section 2.3.1 The Colour Stroop task).

3.1.1. Stroop task

There was a large statistically significant effect of time $F(2,30) = 4.9, p = 0.018, \eta^2p = 0.224$) (before vs 1 min post $p = 0.007$ mean diff = 60 ms ± 20) and a large statistically significant condition by time interaction for the Stroop Congruent $F(4, 68) = 3.0, p = 0.023, \eta^2p = 0.15$). A condition by time post hoc analysis demonstrated that participants had a significantly quicker reaction time on the Congruent Stimuli of the Stroop task for the continuous condition 1 min and 30 min post compared to the control condition (mean diff = 126 ms ± 59; $p = 0.047$ and mean diff = 89 ms ± 38; $p = 0.031$). The intermittent condition showed a delayed effect and significantly improved reaction time compared to the control condition at 30 min post (mean diff = 116 ms ± 46; $p = 0.021$).

For the Incongruent Stimuli of the Stroop task a significant effect of time $F(2, 34) = 6.2, p = 0.005, \eta^2p = 0.268$) (before vs 1 min post $p = 0.003$ mean diff = 61 ms ± 17 and 1 min post vs 30 min post $p = 0.010$; mean diff = 52 ms ± 18) and a condition by time interaction $F(3, 44) = 3.0, p = 0.047, \eta^2p = 0.150$) were found with large effects reported. The post hoc analysis demonstrated that the intermittent condition significantly improved their reaction time at 30 min post compared to the control condition (mean diff = 111 ms ± 49; $p = 0.039$), whereas the continuous condition did not significantly change compared to control (all $p > 0.05$).

The Neutral stimuli from the Stroop task did not show any significant changes across condition, time, or condition by time (all $p > 0.05$; main

Table 2
Cognitive performance scores for the Stroop task, Digit Span and Corsi for the Control, Intermittent and Continuous conditions, represented by milliseconds (ms), accuracy (range 0–1) and memory span.

	Control (95% CI)			Intermittent (95% CI)			Continuous (95% CI)		
	Before	1 min post	30 min post	Before	1 min post	30 min post	Before	1 min post	30 min post
Stroop task									
Congruent	905	933	970	953	●837	*854	900	*,●807	*881
	(791–1018)	(785–1080)	(833–1108)	(800–1106)	(725–948)	(731–988)	(778–1021)	(706–908)	(771–992)
Accuracy	0.93	0.92	0.91	0.94	0.93	0.94	0.93	0.93	0.92
	(0.91–0.96)	(0.88–0.97)	(0.87–0.96)	(0.92–0.96)	(0.90–0.96)	(0.91–0.96)	(0.91–0.95)	(0.90–0.96)	(0.90–0.95)
Incongruent	1013	995	1068	1072	●986	*958	989	●910	1020
	(875–1151)	(869–1121)	(920–1217)	(882–1261)	(831–1142)	(817–1098)	(849–1130)	(804–1017)	(880–1161)
Accuracy	0.90	0.88	0.86	0.89	0.89	0.91	0.91	0.90	0.90
	(0.86–0.94)	(0.84–0.91)	(0.81–0.91)	(0.84–0.93)	(0.84–0.93)	(0.85–0.97)	(0.89–0.94)	(0.86–0.94)	(0.86–0.93)
Neutral	941	995	961	966	901	930	940	896	945
	(834–1048)	(853–1137)	(842–1081)	(818–1115)	(765–1038)	(790–1069)	(818–1061)	(790–1002)	(807–1083)
Accuracy	0.90	0.90	0.90	0.91	0.91	0.91	0.92	0.93	0.93
	(0.86–0.93)	(0.87–0.93)	(0.86–0.94)	(0.88–0.94)	(0.88–0.95)	(0.88–0.95)	(0.89–0.95)	(0.91–0.96)	(0.91–0.95)
Digit Span									
Correct	7.32	6.6	7.3	7.5	6.7	6.7	7.0	7.5	7.4
sequences	(6.3–8.3)	(5.3–7.9)	(6.3–8.3)	(6.5–8.5)	(5.8–7.6)	(5.5–7.8)	(6.1–7.7)	(6.4–8.6)	(6.4–8.4)
Memory span	6.4	5.8	6.2	6.2	5.9	5.9	5.8	*,●6.4	6.2
	(5.7–7.0)	(5.1–6.5)	(5.6–6.7)	(5.6–6.8)	(5.4–6.5)	(5.2–6.63)	(5.4–6.3)	(5.8-7.0)	(5.6–6.8)
Corsi									
Block span	5.7	5.8	5.5	5.4	5.5	5.8	5.8	5.9	5.9
	(5.1–6.3)	(5.2–6.3)	(5.2–5.8)	(4.9–6.0)	(5.0–6.0)	(5.2–6.5)	(5.3–6.4)	(5.3–6.5)	(5.3–6.5)
Correct trials	7.9	7.8	8.2	7.8	7.8	8.2	7.9	8.3	8.2
	(7.1–8.8)	(7.1–8.6)	(7.6–8.6)	(7.0–8.7)	(7.3–8.4)	(7.4–9.1	(7.3–8.5)	(7.4–9.1)	(7.4–9.0)
Memory span	4.9	5.0	5.0	4.9	4.9	5.1	4.9	5.1	5.1
	(4.5–5.3)	(4.6–5.4)	(4.7–5.3)	(4.5–5.3)	(4.6–5.2)	(4.6–5.5)	(4.6–5.3)	(4.7–5.5)	(4.7–5.5)

[*] Significant at $P < 0.05$, based on 95% CI (compared to control condition).
● Significant at $P < 0.05$, based on 95% CI (within groups compared to before).

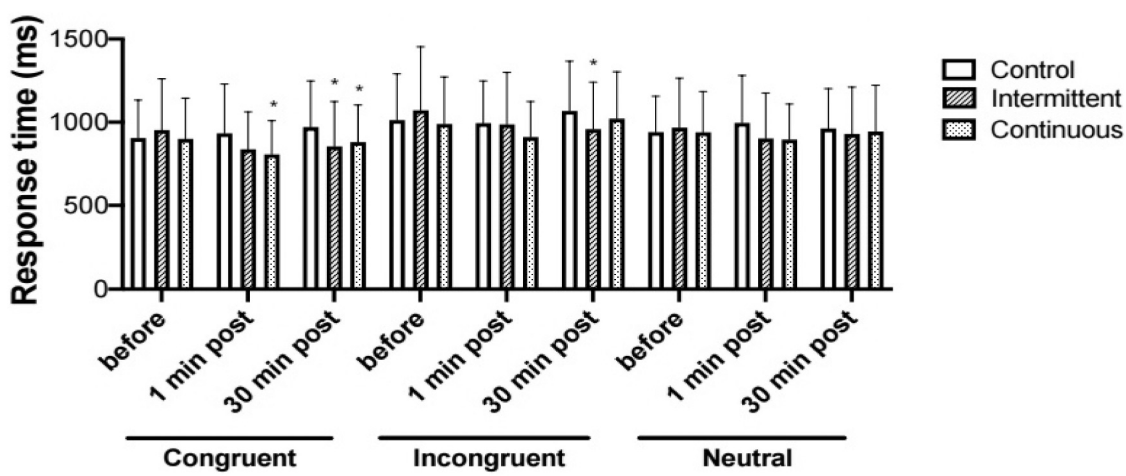

Fig. 2. Stroop test reaction time score in means (SD) for the Control, Intermittent and Continuous. *Significant at $P < 0.05$ compared to control condition.

effect: $F(4, 68) = 1.9, p = 0.116, \eta^2p = 0.102$) and the accuracy for Congruent, Incongruent and Neutral did not statistically change (condition by time: $F(4, 68) = 0.3, p = 0.882, \eta^2p = 0.017$, $F(4, 68) = 1.1, p = 0.357, \eta^2p = 0.061$ and $F(4, 68) = 1.9, p = 0.116, \eta^2p = 0.102$).

3.1.2. *Digit span*

The number of correct words did not change across the time, condition or condition by time (main effect: $F (4, 72) = 2.3, p = 0.066, \eta^2p = 0.114$). For the memory span there was a condition by time interaction $F (4, 72) = 2.7, p = 0.037, \eta^2p = 0.131$) with a medium effect reported. The post hoc tests showed a significant improvement for the continuous condition 1 min post compared to the control condition (mean diff = 0.6 ms ± 0.3; $p = 0.045$). However, the number of correct sequences did not significantly change (condition by time; $F(4, 72) = 2.3, p = 0.066, \eta^2p = 0.114$).

3.1.3. *Corsi block test*

The visual WM test did not change significantly for condition, time or condition by time (all $p > 0.05$). The main effects (condition by time): Block Span $F(4, 72) = 0.7, p = 0.604, \eta^2p = 0.037$), correct trials $F(4, 72) = 0.3, p = 0.858, \eta^2p = 0.018$) and memory span $F(4, 72) = 0.2, p = 0.944, \eta^2p = 0.010$).

3.2. *Affect scales*

Descriptive statistics of the affect scales are displayed in the Table 3 and the circumplex model is represented in the Fig. 3 to illustrate these changes.

Table 3
The affect scales (Feeling Scale (FS) and Felt Arousal Scale (FAS)) and RPE for Control, Intermittent and Continuous represented by medians and 25 and 75 quartile ranges. *Significant at $P < 0.05$. During 1 = average of the first 7.5 min, and during 2 = average of the second 7.5 min.

		Before	During 1	During 2	1 min Post	30 min Post
FS	Control	4 (3–5)	3 (3–5)	3 (3–5)	3 (3–5)	3 (3–5)
	Continuous	5 (3–5)	1.5 (0–3)*	1.5 (−1–3)*	2.5 (−1–3)*	4 (3–5)
	Intermittent	3 (3–5)	1.5 (0–3)*	−0.5 (−3–2)*	−1 (−5–1)*	3.5 (3–5)
FAS	Control	3 (1–4)	2 (1–3)	2 (1–3)	2 (1–3)	2 (1–2)
	Continuous	3 (2–3)	4 (4–5)*	4.75 (4–5)*	4.5 (4–5)*	2 (1–3)
	Intermittent	3 (2–4)	4.20 (4–5)*	5 (4–6)*	5 (3–6)*	3 (2–4)*
OMNI	Control	0 (0–2)	0 (0–1)	0 (0–1)	0 (0–2)	0 (0–2)
	Continuous	0 (0–0)	4.5 (3–6)	7 (4–7)	6.5 (4–7)	0 (0–2)
	Intermittent	0 (0–1)	4 (4–7)	7.5 (67–10)	9 (8–10)	2 (1–3)

3.2.1. *Feeling scale*

Statistically significant differences were reported for the FS across the conditions $\chi^2(14) = 126, p = 0.001$. The control condition did not statistically change across the different time points (all $p > 0.05$). However, the intermittent and continuous conditions did significantly change throughout the PA bout with decreased reported values (less pleasure) at during 1, during 2 and 1 min post compared to before (all $p = 0.001$). The control condition at during 1, during 2 and 1 min post were statistically significantly higher (more pleasurable) compared to both experimental conditions (all $p = 0.001$). However, across all conditions, there were no significant changes when comparing before to 30 min post (all $p > 0.05$).

A further consideration is that the intermittent condition had significantly lower values at during 2 compared to during 1. However, this did not happen in the continuous condition where the during 1 and during 2 were not statistically different ($p > 0.05$). There was also a statistically significant increase for the experimental conditions at 30 min post compared to 1 min post (all $p = 0.001$) showing an increase of pleasure following the cessation of the PA bout. When comparing all conditions at the time before a statistically significant difference for the intermittent and continuous conditions were observed ($p = 0.031$).

3.2.2. *Felt arousal scale*

Statistically significant differences were found for the FAS across the conditions $\chi^2(14) = 127$, $p = 0.001$. Although the time before remained constant across all of the three conditions (all $p > 0.05$), statistically significant differences were found for the different time points for the control condition, the participants reported higher values of arousal (activation) at before and during 1 (not statistically significant from another $p = 0.102$) and significantly lower values at during 2, 1 min post ($p = 0.010$) and 30 min post ($p = 0.004$) when compared to before.

The experimental conditions did significantly increase the reported values during 1, during 2 and 1 min post compared to before and a decrease in the values at 30 min post when comparing to during 1 and during 2 (all $p = 0.001$). The 30 min post did not statistically change between control and continuous conditions ($p = 0.126$), but the intermittent condition reported significantly higher values for this time point when compared to the control condition ($p = 0.007$). However, not significantly higher when comparing to the intermittent and continuous conditions ($p = 0.230$).

3.3. *Rating of perceived exertion*

Statistically significant differences were found for the OMNI scale across the conditions $\chi^2(14) = 218$, $p = 0.001$. The control condition

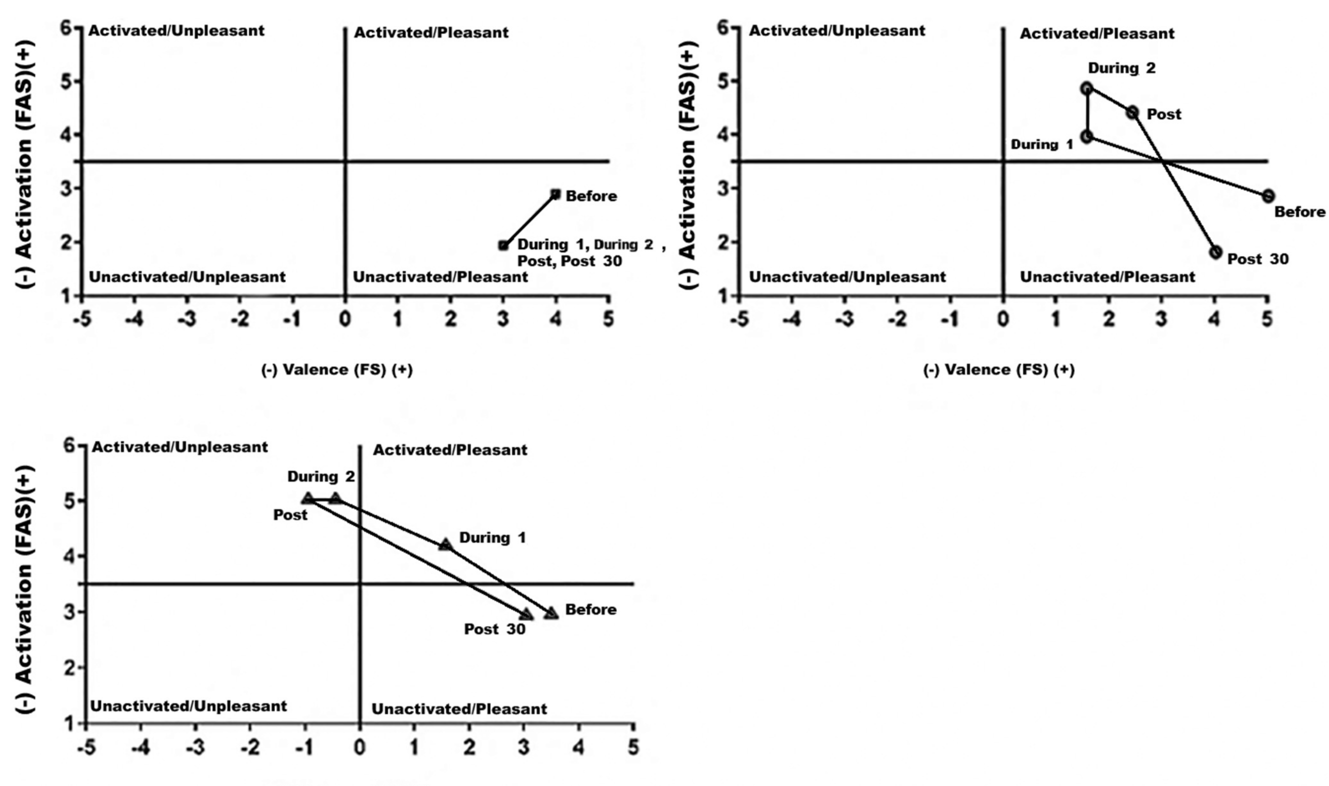

Fig. 3. FS and FAS scales were analysed using the circumplex model (Russell et al., 1989).

did not significantly change throughout the different time points (all $p > 0.05$) and considering all the conditions none of them were statistically significant at the time before (all $p > 0.05$). However, both experimental conditions have reported higher values at during 1, during 2, 1 min and 30 min post compared to the control condition (all $p = 0.001$, Table 3). The intermittent condition reported significantly higher values at during 2, 1 min and 30 min post, when compared to the continuous and control conditions (all $p = 0.001$). Yet, the continuous condition had significantly higher values at during 1 when compared to intermittent ($p = 0.041$).

4. Discussion

This study investigated the effects of acute intermittent and continuous PA bouts on children's EF 1 min and 30 min post PA. Findings suggest that both continuous and intermittent PA can enhance EF. More specifically, the continuous condition had an improved reaction time (inhibition) for the congruent stimuli at 1 min post and 30 min post, confirming prior research that low to moderate intensity seems to have higher effect shortly after the PA bout and these effects are maintained for up to 15–30 min (Chang et al., 2012; Lambrick et al., 2016; Williams et al., 2019). However, the intermittent condition did not have statistically significant improvements 1 min post PA compared to the control condition for the congruent stimuli, and, similarly to previous research, a delay is observed and expected when the intermittent PA is applied (Chang et al., 2012; Williams et al., 2019). Comparing the time 30 min post, an increase of 13.7% is observed when compared to the control condition (mean diff = 116 ms) while the continuous condition improved significantly 10.1% (mean diff = 89 ms). Similarly to the congruent stimuli, when considering the effects on the incongruent domain of the stroop task, which requires a higher inhibitory response, compared to the control condition, only the intermittent condition had a significantly quicker reaction time at 30 min post and a delay is observed with no accuracy decline, showing that the only experimental condition having effect is the intermittent PA.

The improvements on the Stroop task observed in the current study are consistent with the literature, with improvements on EF following a PA bout of at least 10 min (Chen et al., 2014; Cooper et al., 2016; Ishihara et al., 2017; Jäger et al., 2015; Lambrick et al., 2016; Niemann et al., 2013). However, Chang et al. (2012) suggested that the demands of high-intensity/intermittent PA can worsen EF immediately after PA and that these effects can be diminished following a 1 min delay. Our results confirm that the intermittent condition has delayed positive effects, however, the results 1 min post did not significantly improve compared to the control condition, contradicting the 1 min delay suggested by Chang et al. (2012). This review also suggested that the most significant positive effects occur 11–20 min following PA and these effects can subside after a long delay (>20 min). Our study did not specifically assess EF between 11 and 20 min, but it was clear that 30 min post, the intermittent condition had a significant improvement in their reaction time, confirming the evidence found in adults (only a small portion of children included in this study) that high-intensity PA might elicit more prolonged effects (Chang et al., 2012).

Lambrick et al. (2016) investigated the acute effects of continuous vs intermittent PA, and similarly to the present study, both conditions were specifically designed to equal 15 min to match the typical period of school recess. The results from Lambrick et al. (2016) suggested that both conditions had significantly improved EF, with the intermittent condition having more significant improvements following PA and these were maintained up to 30 min. However, as the intensities were differently measured (GET, delta and self-paced) and also both conditions were performed at moderate intensity (running), it is not possible to directly compare it to our study. Despite this our study confirms that intermittent PA may have a greater significant impact on EF compared to continuous at moderate intensity for a similar age range, but on the other hand participants from the intermittent condition did not have improvements 1 min post PA, showing a delayed effect and this might be explained by the delayed effect expected following higher intensities reported by Chang et al. (2012).

On the other hand, Stroth et al. (2009) have found that adolescents (13–14 years of age) following a 20 min cycling bout at 60% of their HRmax did not significantly change the event-related brain potentials (N2 and P3) responsible for the executive processes and allocation of attentional and memory control when performing an executive functioning test (Erikson flanker). Although this study is innovative due to its neuroelectric measurements, it is not directly comparable to our study due to the different intensity and durations and more research is needed as previous literature have suggested a positive effect of aerobic PA (Chen et al., 2014; Drollette et al., 2014; Hillman et al., 2009; Ishihara et al., 2017; Jäger et al., 2015; Lambrick et al., 2016; Pontifex et al., 2013; Vazou & Smiley-Oyen, 2014).

A further consideration is that WM (verbal component only) had a significant increase 1 min post for the continuous condition compared to control, and this is contradictory to Chang et al. (2012) that suggested nonsignificant effects for verbal WM digit span (forward) and Williams et al. (2019) that stated that benefits in WM usually happen between 25 and 30 min following PA. The Corsi blocks (visual component) test results did not significantly change following PA, and this might be due to its lower sensitivity, and similar results were obtained in adolescents with no effects immediately after or 45 min post (Niemann et al., 2013; Pesce et al., 2009; Williams et al., 2019). Although our results suggest a benefit following continuous PA, these effects might be associated with the dose and arousal state post PA associated with the specific timing of assessment, which could be differently associated with the intermittent PA. However, more studies are required to understand this relation as it has not been previously studied.

There are some mechanisms that might be responsible for these changes (e.g. increases in lactate, arousal, neurofunctional adaptations, the effect of catecholamines on brain function and BDNF) (Hillman et al., 2019,Pontifex et al., 2018) due to the impossibility of pragmatically measure all these moderators. It seems plausible to assume that these results might be mode and intensity dependent. The continuous condition performed a longer distance compared to the intermittent condition and had a workload superior to intermittent (Table 1), but the physiological demands caused by the higher intensity of the intermittent PA have elicited higher values of arousal and these changes are associated in the literature with better cognitive performance (Lambourne & Tomporowski, 2010).

Considering the arousal levels, both experimental conditions increased significantly the FAS values reported compared to the control condition. Contrary to the continuous condition, the intermittent condition had significantly higher values at 30 min post, showing a higher level of activation and this might have elicited a higher performance for the Stroop task 30 min post, which is highly susceptible to changes in arousal. It is known that acute PA induces an increase on arousal, and this is responsible for enhanced performance on tasks that involve rapid decisions, problem-solving and goal-oriented tasks (Lambourne & Tomporowski, 2010). Oliveira et al. (2013) confirmed that Intermittent PA elicits higher responses on the FAS, and consequently improving Stroop task performance that is highly susceptible to these changes (Arnsten, 2011), but improvements in EF due to increased state of arousal, are typically associated with moderate-intensity PA in preschoolers, school-age children and adolescents (Best, 2010; Verburgh et al., 2014). Our study shows that both experimental protocols can increase arousal levels, but the intermittent condition had statistically significant higher values of arousal 30 min post compared to control, and it might be linked to the delayed effect observed on the Stroop task. However, intermittent PA may elicit greater improvements on fast decisions and for incongruent stimuli and therefore the intermittent protocol might also be more appropriated and adapted to children's behaviours providing an optimal 'format' for eliciting EF benefits. To our knowledge, the acute relation between PA, EF and arousal is yet to

Table 1
Demographic sample description, distances performed and HR measures in means (SD).

Variables	Mean and SD	Variables	Control	Intermittent	Continuous
Age	10 ± 0.48	Distance	–	3405 ± 591	5185 ± 801
Height	145 ± 7.04	Work done (J)		52,477 ± 13,119	61,482 ± 15,441
Weight (kg)	39 ± 10.5*	HR before	94 ± 9	97 ± 12	92 ± 9
Sitting height	73 ± 3.98	HR during	97 ± 6	–	168 ± 4**
PHV	2 ± 1.03	HR active bouts	–	189 ± 8***	–
BMI	19 ± 3.73	HR rest bouts	–	170 ± 10	–
550 m Run	2.57 ± 0.45	HR 30 min post	99 ± 7	108 ± 12	105 ± 7
550 m Score	0 ± 0.99	Mean power (w)	–	–	66 ± 16
Resting HR	88 ± 5	Mean pedal rate (w)	–	–	55 ± 9

Distances are represented in meters, age in years, heights in centimeters and HR in bpm. * 29.17% overweight. **100% and ***91.77% of the participants achieved their predicted intensity. PHV = peak height velocity.

be explored in children, and additional studies are needed investigating the different mechanisms meditating this relation and measuring arousal more consistently post-PA.

The present study has a number of strengths such as, a comparison between continuous and intermittent PA, the first investigation considering these two PA bouts on a cycle ergometer in children and also the consideration of scales of affect that have not been investigated before in studies involving PA and EF in children. Despite the aforementioned strengths, there are several limitations that should be considered. The experimental protocols were not specifically work matched, the energy expenditure, estimated VO_2 peak longer follow up should have been considered to understand the length of the effects for the intermittent condition. As this study was conducted in the afternoon, the lunch might be a confounder, and this should have been controlled. The sample size is relatively small and the results should be interpreted carefully.

In conclusion, the present study suggests that EF can be enhanced following both PA protocols. Although both conditions were beneficial, the intermittent condition has improvements 30 min post and the continuous does not, suggesting that an intermittent protocol might have the potential to fit into break time in schools and inform future research, where an intermittent protocol can be applied and effects will be of a greater magnitude, last longer and should be considered in core moments of the day to elicit higher values of arousal and consequently improve children's cognitive performance. Given this, it is essential that future research focus on the development of ecological valid activities that can be easily implemented in schools are enjoyable for the participants and consider larger sample sizes.

The authors report no conflict of interest.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Instructions from the open-source software PEBL: the psychology experiment building language (Mueller, 2011)

Corsi blocks

"You are about to take part in a test that measures your ability to remember a sequence of locations on the screen. You will see nine blue squares on the screen. On each trial, the squares will be lit up one at a time in sequence. Remember the sequence. When the sequence is finished, you need to click on each square IN THE SAME ORDER THEY WERE GIVEN. When you are done, click the button labelled DONE. If you cannot remember the order of squares, click them in as close the original order as you can. You will start with a sequence of two squares, and you will get two tries for each sequence length. The sequence will increase by one whenever you get at least one of the two sequences correct. If you are correct, your next list will be one longer; Click the mouse button when you are ready to begin."

Digit span forwards

"You are about to take part in a memory test. You will be presented with a sequence of digits, one at a time on the screen. Each digit will occur only once during a list. You will then be asked to type the list of digits EXACTLY THE ORDER YOU SAW THEM IN. If you do not know what digit comes next, you can skip over it by typing the key. Try to put the numbers you saw in the original list positions. If you make a mistake, you can use the backspace key to make a correction. You will start with a list of three items and will get three different lists at each length. If you are able to recall two out of three lists completely correctly, you will move on to the next longest list length."

Stroop task

"You are about to take part in one study in which you will be asked to determine the colour that written words appear in. Sometimes, the words will be actual colour names. When this happens, try not to respond with the written colour name, but only with the colour of the word. You will need to respond with the 1-2-3-4 keys on the top of the keyboard."

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