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Original Article

Acute effects of physical education, structured play, and unstructured play in children's executive functions in primary school

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Abstract:
Purpose: Research continuously reports a close connection between Physical Activity (PA) and its effect on pupils' Executive Functions (EF). Thus, the purpose of the present study was to expand previous knowledge and examine the acute effects on the EF – working memory and inhibition – in two primary level class cohorts (4th class: n = 20 students, mean age 9.95 ± .39 years; 6th class: n = 23 students, mean age 12.00 ± .30 years; 22 boys, 21 girls) of a school-based PA policy in a four-week design intervention programme. **Methods:** The PA policy included Physical Education (PE), Structured Play (SP) and Unstructured Play (UP). Testing of EF was carried out with a Working Memory Test and an Animal Stroop Test, before and after each session of each PA policy component. To determine whether each component of the PA intervention had an effect on working memory and inhibition, two separate repeated measures multivariate analysis of variance, controlling for gender and class as between-subject factors. **Results:** Results showed that the PE intervention improved more students' working memory (3.49% increase), comparing to SP ($p = .002$, $\eta^2 = .057$) and UP ($p < .001$, $\eta^2 = .077$) interventions. Furthermore, the PE intervention improved more students' inhibition (3.57% increase), comparing to SP ($p = .001$, $\eta^2 = .074$) and UP ($p < .001$, $\eta^2 = .105$) interventions. No gender and class differences were observed. **Discussion:** While whole school PA policies need to focus on all PA components and provide school-based opportunities to meet PA recommendations to benefit health in general, PE appears to be more beneficial for improving most students' EF. Based on this finding, it is suggested that structured PE to be prioritised when developing PA policy in schools. Potential causes on the differences direct the conclusion towards school-based PA policy recommendations.
Keywords: Working Memory, Inhibition, Whole-School Physical Activity, Exercise, Cognition, Intervention.

Introduction

Research continuously reports a close connection between Physical Activity (PA) and its effect on pupils' Executive Functions (EF) (Ludyga, Gerber, Pühse, Looser, & Kamijo, 2020; Nazlieva,Mavilidi, Baars, & Paas, 2020). Despite this research, many schools are attempting to increase instructional time for mathematics, English, and science in an effort to improve standards-based test scores (Wilkins et al., 2003) neglecting the importance of EF for those purposes and how it can benefit from PA. Furthermore, schools across the world face increasing challenges in allocating time for physical education and other physical activity opportunities during the school day (Hardman, 2006, 2008; Morgan & Hansen, 2008). Also, break time has been reduced to allow for increased instructional time so that schools can meet the ongoing demands of raising their standard-based scores for literacy and numeracy (Blatchford & Sumpner, 1998; Dills, Morgan, & Rotthoff, 2011). Pellegrini and colleagues (2005) rebate such decisions, arguing that school policy should be based on theory and the best empirical evidence available that supports the significance of play and PA. Those authors stress that break times are beneficial and have the potential to influence the child's social and emotional development.

Increased regular PA has been associated with small and measurable improvements in neuropsychological tests of EF (Jackson, Davis, Sands, Whittington, & Sun, 2016), although Singh et al. (2019) conclude on inconclusive evidence on the effects from PA on cognitive and overall academic performance and strong evidence for beneficial effects of PA on maths performance in children. Specifically, the inhibitory control and working memory enhancement seems more responsive to cognitively-engaging activities (Jackson et al., 2016). Vazou and colleagues (2019), in a review of school-PA interventions, concluded that curricular PE lessons seem to be the most appropriate framework for promoting the development of children's cognitive functions, likely for providing a medium for cognitively-engaging PA.

Effects of physical activity on executive functions

According to Salimpoor and Desrocher (2006) 'EF are a group of interrelated complex mental abilities that are involved in planning and initiating goals and carrying them through despite interruptions' (p. 15). The

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most prominent theoretical framework suggests that EF has three basic components: inhibition, working memory and shifting (Diamond, 2006). The component of inhibition refers to the deliberate, controlled suppression of prepotent responses (Miyake et al., 2000) and is usually tested with children aged 13-16 years old with the Animal Stroop test (Wright, Waterman, Prescott, & Murdoch-Eaton, 2003). Working memory is referred to as a system for temporarily holding and manipulating information as part of a wide range of essential cognitive tasks such as learning, reasoning and comprehending (Baddeley, 1997). This can be assessed by using the Working Memory Test Battery for Children (WMTB-C) which includes the Listening Recall test which is suitable for children in an age range of 5-15 years (Gathercole & Pickering, 2001). The third component, shifting, while not explored in this study, is often defined as the ability to adapt mental set when required, including the ability to change a strategy in a responsive manner, or abandon a strategy in response to negative feedback (Henry & Bettenay, 2010).

PA programmes and their effects on EF can be divided into two fields of research. One being the evidence resulting from experiments using chronic aerobic exercise (exercise over a long period of time showing long term effects) and the other using acute bouts of aerobic exercise (once off periods of exercise and showing immediate effect on EF). We will predominantly focus on the effects of acute aerobic exercise as this empirical research is based on an acute PA programme in a school.

Using an experimental design, Pesce and colleagues (2009) compared two forms of acute aerobic exercise of equivalent aerobic intensity. A group of preadolescent children aged eleven to twelve completed one hour of individual circuit training and in another session completed an hour of aerobic group games. To test the effect on EF, after each session the group completed a list-learning procedure to assess the immediate and delayed word recall. The findings showed that the acute bout of group aerobic games enhanced their immediate word recall and for delayed recall both groups enhanced their memory performance. In both situations the samples' EF were positively affected. Caterino and Polak's (1999) study investigated the effect of an acute bout of stretching and aerobic walking, which was grade appropriate. It was assessed by the Woodcock-Johnson Test of Concentration and it found that the EF selective attention had improved for 4th graders but not with 2nd and 3rd graders. The development time point of the sample is significant here. During late childhood, inhibition (Hillman et al., 2009) may be more sensitive than shifting (Tomporowski, Davis, Miller, & Naglieri, 2007) to the effects of acute exercise. The acute aerobic study by Caterino and Polak (1999) addressed this issue but gave little explanation as to why 4th graders scored differently to 2nd and 3rd.

Ludyga and colleagues (2020) findings from a meta-analysis investigating moderators of long-term effects of exercise on cognition suggested a general effect of exercise on cognition, which was influenced by sex, exercise type and reciprocal relationships between dose parameters. Regarding sex, Quan and colleagues (2018) found that specific cognitive functions (i.e. Verbal Intelligence Quotient, Performance Intelligence Quotient, and Full Intelligence Quotient) were associated with light PA, only in boys. Furthermore, the combination of high physical exertion and high cognitive engagement in a classroom-based PA setting (i.e. inclusion of cognitively engaging PA breaks) was mostly beneficial for students' enhanced shifting and mathematic performance (Egger, Benzing, Conzelmann, & Schmidt, 2019).

Few studies have addressed a related question regarding the potential influence of the pubertal status of participants. It may be possible that the hormone levels could alter the effect of PA on EF. Chu et al. (2015) argues that acute exercise has a selective effect on cognitive function, specifically effecting the motor response inhibition aspect of EF. Furthermore, the same authors have stated that acute exercise predominately impacts later stages of information processing during motor response inhibition, which may lead to an increase in attentional resource allocation and confer the ability to successfully withhold a response to achieve motor response inhibition.

For the most part, these findings are concurrent with the thesis that acute aerobic exercise in schools has a positive effect on children's EF, however the effects of numerous elements of PA on cognition remain to be explored (e.g. type, amount, frequency, timing), and many questions remain regarding how to best incorporate PA within schools, such as activity breaks versus active lessons (Donnelly et al., 2016). Also, most research approaches are externally driven and less has been documented "real-world settings" (Jäger, Schmidt, Conzelmann, & Roebers, 2015) on internally designed and driven approaches from the school staff, which is the focus of this study to address the following research question: What are the acute effects of three different components of a Whole-School PE Policy (PE sessions, Unstructured Recess, Structured Recess) in the Executive Functions of Inhibition and Working Memory (verbal and visual) of Primary level children?

Material & methods

This research employed a quasi-experimental approach. A pilot-study was initially conducted with a 5th class students' cohort (n = 17) for reliability purposes. Considering Diamond's (2006) EF framework, the choice of EF testing for this study was essentially sourced from Henry and Bettenay's (2010) design.

Sample and procedures

The study cohort consisted of two classes from an Irish primary school (4th class: n = 20 students, mean age 9.95 ± .39 years; 6th class: n = 23 students, mean age 12.00 ± .30 years), with an overall split of 22 boys and 21 girls. The multi-component PA intervention included three distinct components: PE, Structured Play (SP), and Unstructured Play (UP). After a one-week baseline assessment of the students' EF, the programme was implemented during official school-time for four weeks (12 sessions in total). All sessions occurred at the same time and day of each week, in the same sequence, testing the EF 10 mins before and 10 mins after each session. Children's working memory was measured with a verbal visual memory test using curriculum-based vocabulary, while their inhibition was assessed through the Animal Stroop-like test.

Ethics

The host institution provided ethical consent to the study and the research team guaranteed to follow all ethical requirements. Prior to participation, all students, as well as their parents or guardians, got the opportunity to read the information sheet and agreed to participate in the study. The informed consent ensured confidentiality and anonymity with the appropriate use of coding to track each student with the results of their testing in the database.

It is important to acknowledge that the main researcher was the school principal where the study was conducted. This element was not used to place pressure on the participation from teachers and students and any concerns with the first researcher's school role were thoughtfully considered and supported by the rest of the research team. The main advantage was the facilitated access to the setting and enhanced engagement from the teachers as an element of protocol fidelity. It was made clear to the school community that the researcher was playing a facilitating role and there was no leveraging undertaken on their behalf as manager. This was made explicit for teachers, students and guardians in the sense that no prejudice on educational and relational aspects were implied for any unwillingness or withdrawal of participation from the study, without negative implications on the participation in the whole-school PA policy.

Protocol Implementation

During the four-weeks of the study, the working memory and inhibition testing were administered immediately before and after each separate component (i.e. PE, SP and UP), without changes to weekdays, time of day and sequence in the week. This was part of the whole-school PA policy as a structured timetable for different PA opportunities. As such, pre and post testing of EF was carried out for PE lesson each Monday, for UP each Wednesday at lunch break, and for SP each Friday at lunch break.

Independent Variables - Whole-School Physical Activity Policy as Intervention

The three PA policy components, framed as independent variables, contributed to an overall commitment of 60 minutes of daily school-based PA following international PA guidelines (Organisation, 2010).

Physical Education Lesson: The PE lessons were based on the Games strand as per the Primary School Curriculum (Assessment, 1999) and the lessons were sourced from the Primary Schools Sports Initiative PE lesson pack (Teachers, 2002). It was agreed that the class teacher would carry out the formal PE lesson to allow for minimum disruption during the normal classes' timetable on Mondays. As part of the lesson, Fundamental Movement Skills were also taught based on the 'Move Well, Move Often' resource pack (Teachers, 2016), differentiated by class level. The duration of the PE lesson was a 30-minute session and it took place at 11.30am until 12.00 for a four-week period.

Unstructured Play: In line with Pellegrini and Bohn (2005), UP involved students participating in more leisurely PA such as 'tip the can', 'basketball shoots', 'catch' and 'den to den' during break-time from formal instruction. Students had to choose in which PA they would participate. These activities took place four days a week, twice a day, although for research purposes only one day per week was considered for EF testing for the duration of four weeks. This activity took place as a 20-minute recess session at lunch break, each Wednesday between 12.40pm and 1.00pm.

Structured Play: As part of the PA policy, SP was introduced as a 20-minute recess session, every Friday between 12.40pm and 1.00pm, labelled 'Fun Friday'. A plan for eight PA stations was drawn up by the PE coordination team which included students from the Active School Committee. A team of students would participate at a particular PA station each Friday during the lunchtime break for a 20-minute session, for the duration of four weeks. The groups rotated each Friday so that the activities varied. The students were fully engaged for the duration of the activity and the stations included activities such as ladders and hurdles, soccer, basketball, hula-hoops, skipping, handball, game of the week and beanbag toss.

Dependent Variables - Testing of Working Memory and Inhibition

It was intended to test all three main components of EF, i.e. inhibition, working memory and shifting (Diamond, 2006). However, after careful consideration, the Modified Wisconsin Card Sorting Test by Nelson (1976) that tested the EF shifting was not carried out as it had to be administered individually by student and there was insufficient time and personnel. The two remaining components of EF testing - inhibition and working memory - were considered as dependent variables. Both tests were randomized with a different sequence for each pre and post-test procedure aiming at ensuring enhanced internal validity and reliability by reducing learning and memory effects from previous trials over the intervention period.

Inhibition Test: The new Stroop-like measure, Animal Stroop task assesses young children's inhibition (Wright et al., 2003). In the present study, children were initially asked to identify pictures of familiar animals, e.g. congruent images of a cow, pig, duck and sheep. In the Animal-Stroop task children were asked to look at pictures where the head of the animal had been swapped with the head of another animal, i.e. non-congruent images. The students were then asked to identify the 'body' of the animal for both the congruent and the non-congruent images. With the face of the animal pictures so prominent, the students were challenged to ignore it. Each test was marked out of 36 (three sequences of 12 pictures) and the number of correct answers was aggregated and used for the statistical analysis.

Working Memory Test: A verbal memory test is often used by researchers to test subjects to memorise spoken or written lists of words or phrases, as prescribed in the Working Memory Test for Children (Gathercole & Pickering, 2001). The lists of words for the test were selected from the curriculum spelling lists for the students' relevant classes, which ensured that these were appropriate to their age and language development level. The test was introduced on each occasion with a list of 12 new words presented visually. Both cohorts attempted to memorise these words and continued the following three trials to record whether each word was 'new' or 'repeated'. Each test was marked out of 36 (three sequences of 12 words) and the number of correct answers was aggregated and used for the statistical analysis.

Statistical analysis

All students were assessed in both tests (i.e. Inhibition and Working memory) twice (pre- and post-PA lesson) for every single session (4 weeks x 3 sessions per week), throughout the 4-week programme. The everyday accumulated data for every PA component (pre-PE, post-PE; pre-SP, post-SP; pre-UP, post-UP) were included in the statistical analysis, as evidence of the programmes' acute effects.

Data analysis was conducted with the use of the statistical package SPSS Version 23.0 (IBM Corp., Armonk, NY, USA). Before analysis, variables were screened for accuracy of data entry, missing values, distribution (skewness and kurtosis), and potential outliers. No missing values and univariate outliers were observed. Descriptive data were initially presented [means (*M*), standard deviations (*SD*) and percentages (%)]. To determine whether each component of the PA intervention had an effect on working memory and inhibition, two separate repeated measures multivariate analysis of variance (MANOVA) were employed [2 times (pre- and post-intervention) x 3 components (PE, SP, UP)], controlling for gender and class as between-subject factors. When significant differences across conditions or time were identified based on the statistical significance of MANOVA, univariate follow-up pairwise comparisons with Bonferroni adjustments were conducted. For all analyses, a *p*-value below 0.05 ($p < 0.05$) was considered statistically significant. Lastly, the partial η^2 was presented as a measure of effect size for *F*-tests. A partial η^2 value between 0.01 and 0.06 was associated with a small effect, between 0.06 and 0.14 with a medium effect, and 0.14 or greater with a large effect (Warner, 2012).

Results

Descriptive results from working memory and inhibition pre- and post-testing, per gender and class, are presented in Tables 1 and 2.

Table 1. Descriptive statistics (M, SD) for working memory and inhibition by gender

	Boys (n=22)		Girls (n=21)		Total (n=43)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Intervention	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Working memory (max score = 36)						
PE	30.98 (4.80)	32.01 (2.62)	30.97 (4.73)	32.11 (3.01)	30.98 (4.75)	32.06 (2.81)
SP	31.42 (3.25)	31.34 (3.80)	31.95 (3.09)	31.25 (3.77)	31.67 (3.18)	31.30 (3.78)
UP	32.96 (2.59)	32.15 (3.07)	33.01 (2.70)	32.61 (2.45)	32.99 (2.63)	32.37 (2.79)
Inhibition (max score = 36)						
PE	33.93 (3.40)	35.48 (1.54)	34.50 (3.61)	35.34 (2.56)	34.20 (3.05)	35.42 (2.08)
SP	35.00 (3.02)	35.11 (3.28)	35.74 (.92)	35.83 (1.16)	35.35 (2.30)	35.45 (2.54)
UP	35.46 (1.96)	35.48 (1.74)	35.78 (1.12)	35.68 (1.30)	35.61 (1.62)	35.58 (1.55)

Note. *PE* = Physical Education; *SP* = Structured Play; *UP* = Unstructured Play.

Table 2. Descriptive statistics (*M, SD*) for working memory and inhibition by class

	4th class (n=20)		6th class (n=23)		Total (n=43)	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Intervention	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Working memory (max score = 36)						
PE	30.76 (5.67)	31.93 (2.62)	31.16 (3.80)	32.16 (2.97)	30.98 (4.75)	32.06 (2.81)
SP	32.17 (2.93)	31.56 (3.62)	31.23 (3.34)	31.07 (3.91)	31.67 (3.18)	31.30 (3.78)
UP	33.37 (2.03)	32.93 (2.52)	32.65 (3.04)	31.87 (2.94)	32.99 (2.63)	32.37 (2.79)
Inhibition (max score = 36)						
PE	34.37 (3.36)	35.01 (2.90)	34.06 (3.62)	35.75 (.85)	34.20 (3.05)	35.42 (2.08)
SP	35.74 (.76)	35.79 (.94)	35.02 (3.01)	35.16 (3.30)	35.35 (2.30)	35.45 (2.54)
UP	35.70 (1.16)	35.51 (1.52)	35.53 (1.92)	35.64 (1.58)	35.61 (1.62)	35.58 (1.55)

Note. *PE* = Physical Education; *SP* = Structured Play; *UP* = Unstructured Play.

For working memory, the repeated measures MANOVA analysis, with Greenhouse-Geisser correction due to violations of sphericity (Mauchly's $W = .81$, $p < .001$), revealed non-significant interaction effect for both Intervention x Time x Gender [$F(2,265) = .823$, $p = .422$, $\eta^2 = .005$], and Intervention x Time x Class [$F(2,265) =$

0.584, $p = .530$, $\eta^2 = .004$] with small effect sizes. The interaction effect for Intervention x Time was statistically significant [$F(2,265) = 9.211$, $p < .001$, $\eta^2 = .055$], with a small effect size. All remaining interaction effects were not statistically significant ($p > .05$). The main effect of Time was not statistically significant [$F(1,157) = .010$, $p = .919$, $\eta^2 < .001$], however the main effect of Intervention was statistically significant [$F(2,305) = 15.530$, $p < .001$, $\eta^2 = .090$], with a medium effect size.

The univariate follow-up pairwise comparisons with Bonferroni adjustments indicated that, for all children, the PE intervention improved more students' working memory, comparing to SP [$F(1,157) = 9.539$, $p = .002$, $\eta^2 = .057$] and UP [$F(1,157) = 13.187$, $p < .001$, $\eta^2 = .077$] interventions. PE intervention improved all students' working memory by 3.49% (pre-test $M = 30.98$, $SD = 4.75$; post-test $M = 32.06$, $SD = 2.81$), while during SP (pre-test $M = 31.67$, $SD = 3.18$; post-test $M = 31.30$, $SD = 3.78$) and UP (pre-test $M = 32.99$, $SD = 2.63$; post-test $M = 32.37$, $SD = 2.79$) working memory levels declined by 1.17% and 1.88% respectively. No gender or class differences were observed ($p > .05$).

For inhibition, the repeated measures MANOVA analysis, with Greenhouse-Geisser correction due to violations of sphericity (Mauchly's $W = .83$, $p < .001$), revealed non-significant interaction effects for both Intervention x Time x Gender [$F(2,269) = 1.190$, $p = .301$, $\eta^2 = .008$] and Intervention x Time x Class [$F(2,269) = 2.017$, $p = .142$, $\eta^2 = .013$]. The interaction effect for Intervention x Time [$F(2,269) = 12.332$, $p < .001$, $\eta^2 = .073$] was statistically significant, with medium effect size. All remaining interaction effects were not statistically significant ($p > .05$). The main effects of Time [$F(1,157) = 12.180$, $p = .001$, $\eta^2 = .072$] and Intervention [$F(2,295) = 9.978$, $p < .001$, $\eta^2 = .060$] were also statistically significant, with medium effect sizes.

The univariate follow-up pairwise comparisons with Bonferroni adjustments indicated that, for all children, the PE intervention improved more students' inhibition, comparing to SP [$F(1,157) = 12.633$, $p = .001$, $\eta^2 = .074$] and UP [$F(1,157) = 18.349$, $p < .001$, $\eta^2 = .105$] interventions. PE intervention improved all students' inhibition by 3.57% (pre-test $M = 34.20$, $SD = 3.05$; post-test $M = 35.42$, $SD = 2.08$), while UP improved it by .28% (pre-test $M = 35.35$, $SD = 2.30$; post-test $M = 35.45$, $SD = 2.54$), and during SP inhibition levels declined by .08% (pre-test $M = 35.61$, $SD = 1.62$; post-test $M = 35.58$, $SD = 1.55$). No gender or class differences were observed ($p > .05$).

Discussion

The aim of the present study was to investigate the acute effects on students' EF (working memory and inhibition) from the PE lesson, UP recess session and SP recess session as multiple components of a whole-school PA policy. The findings suggest that students' EF benefited more from PE sessions comparing to SP and UP recess sessions. Regarding both components of EF measured, no gender and class differences were observed.

Our findings further reinforce the cognitive value of PE for both dimensions of EF here assessed, compared to less cognitively demanding PA, currently provided through SP and UP (Jackson et al., 2016; Vazou et al., 2019). PE higher effect sizes might be explained by the fact that it intentionally addresses the cognitive dimension (among others) that might benefit children's EF more than the other components. Nonetheless, from a PA recommendation perspective (WHO, 2010), all PA components are worthwhile (Jäger et al., 2015; Tomporowski et al., 2011).

The combined effects have not been explored in this study and the timeframe was short, thus it was not possible to extrapolate an overall effect of the whole-school policy. Still, the fact that EF came out benefited following each session (despite the slight and non-significant decreases from UP), supports the research on the positive outcomes and advances the conclusions from Jäger et al. (2015) on the unexpected missing differences from different PA components on EF. As the findings refer to the effects immediately before and after the intervention, PA, and particularly PE, might create a window of opportunity where children's academic performance can benefit of enhanced EF and can be considered particularly beneficial for primary classroom-related learning (Cortés Pascual, Moyano Muñoz, & Quílez Robres, 2019). This is a valuable argument against the increase of instructional time for different subjects by sacrificing diverse PA opportunities (Wilkins et al., 2003).

Despite the regular findings on differences between boys and girls in their movement skills (Junaid & Fellowes, 2006), our findings suggest that whole-school PA programmes benefit both boys and girls in their EF. No differences between gender and class means that, at least at the middle and end stages of Primary education, every child might benefit from PA with regards to EF and, by extension, academic performance and achievement.

In presenting these results, it is important to consider key limitations. As the sample size refers to a single school the generalisation power is limited. Moreover, the results may not fully reflect the effect the PA policy has on all classes within the school or indeed on other classes in other schools. Also, it would be interesting to explore the differences and effect sizes in the EF if more time was available to carry out the research, and to include shifting for a fuller view on EF. While the focus of the research was on the acute effects in EF, with a longer timeframe it would have been possible to analyse the relationship with the pupils' academic achievement.

A core strength of this study is that it was carried out in "real-world settings" (Jäger et al., 2015), building evidence on a whole-school PA policy incorporating multiple PA components as a needed research design, especially given the inconclusiveness of findings in this topic (Singh et al., 2019). By integrating previous reviews' recommendations (Jackson et al., 2016; Singh et al., 2019; Tomporowski, Lambourne, & Okumura, 2011; Vazou et al., 2019) into natural settings, and working with school stakeholders to develop intentional PA policies that contribute to PA and EF (Pellegrini & Bohn, 2005), the research-base on this relation can be renovated for more robust and ecologically valid conclusions and interventions.

Whole school PA policies need to focus on all PA components and provide school-based opportunities to meet PA recommendations to benefit health in general (Tomporowski et al., 2011), and focus on structured PA (namely PE) when EF and academic achievement are a priority for the school/children (Vazou et al., 2019).

Conclusions

Our findings suggest PA has a significant and positive association with cognitive function, especially PE. As such, the programme shows potential to support the children academic performance considering the importance of EF (Hinkle et al., 1993; Tuckman and Hinkle, 1986) but also the potential to enhance their wellbeing through PA adding to the recommended 60 min/day of PA (WHO, 2010). Moreover, it cannot be disregarded the importance of SP and UP in whole-school PA programmes by providing opportunities for developing other brain functions through exploration and self-regulated and self-directed behaviour (Pellegrini and Bohn, 2005).

Our findings have implications for future intervention strategies. A longitudinal study on the impact of the PA intervention could be conducted over the length of the Irish primary school cycle (eight years in total) considering both academic performance (EF) and achievement (scores). This would provide more definitive evidence in relation to the long-term impact of the PA intervention on academic performance and its links with academic achievement as chronic and combined effects in other developmental outcomes. The outcomes of that research could support the content of the Junior Cycle Wellbeing programme and the Leaving Certificate PE Programme to inform a progressive spiral curriculum providing the best possible learning opportunities for the students. In summary, we suggest structured PE should be prioritised when developing PA policy in school towards the specific aim of promoting EF and the developmental stage of the pupils may be relevant when considering the effects of a PA intervention in EF as mediators of academic performance. Further research is warranted on longitudinal studies towards the chronic and combined effects, in different EF and in other developmental outcomes. Additionally, policy level implications are drawn from the research considering the current national curriculum developments in PE.

Conflicts of interest - The authors have no conflict of interest to declare.

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