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The Acute Effects of Multiple Components in a Whole-School Physical Activity Policy on Executive Functions of Primary Level Students

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Resumen

Un creciente cuerpo de literatura examina la relación entre la actividad física (AF) con las funciones ejecutivas (FE) y el rendimiento académico en niños y adolescentes. El presente estudio tuvo como objetivo examinar cómo componentes múltiplos de una intervención de política de AF en un entorno de escuela primaria afectó el FE (i.e. la memoria de trabajo y la inhibición) de los estudiantes. La política de AF tenía tres componentes, Educación física (EF), Juego estructurado (JE) y Juego no estructurado (JNE). Las pruebas de FE para la memoria de trabajo y la inhibición se llevaron a cabo con una muestra de 43 estudiantes de las clases 4 y 6 antes y después de cada componente de la política de AF, una vez a la semana durante cuatro semanas, después de una semana piloto. La memoria de trabajo de los niños se midió con una prueba de memoria visual verbal utilizando vocabulario basado en el currículo, mientras que su inhibición se evaluó mediante la prueba similar a Animal Stroop. El efecto de cada componente de la intervención de AF en la memoria de trabajo y la inhibición se analizó con dos MANOVA de medidas repetidas separadas, controlando el género y la clase como factores entre sujetos. Tanto para la memoria de trabajo como para la inhibición, la EF fue más beneficiosa para todos los estudiantes en comparación con JE y JNE ($p < .001$). Respecto a la inhibición, no se observaron diferencias de género y clase. Sin embargo, para la memoria de trabajo, hubo mejoras más altas para la 4ta clase en comparación con los estudiantes de 6ta clase ($p < .05$). La EF parece ser más beneficiosa para mejorar el FE de los estudiantes y se sugiere que se le dé prioridad al desarrollar políticas de AF en las escuelas. Se requiere investigación adicional con estudios longitudinales.

Palabras clave: rendimiento académico, funciones ejecutivas, inhibición, memoria de trabajo, actividad física, política de toda la escuela.

Introduction

In the Irish post-primary education context, the students' wellbeing was recently established as core to the Junior Cycle Profile of Achievement (NCCA, 2017), positioned within a whole-school culture, strongly supported by physical activity (PA) and Physical Education (PE) as determinant to students' academic performance and achievement. Additionally, PE is being piloted as a Leaving Certificate subject to be fully introduced from 2020. Consequently, in primary education, students are expected to benefit from a solid foundation in wellbeing.

A growing body of literature examines the relationship between PA with cognitive functions, academic performance and achievement in children and adolescents (Donnelly et al., 2016). Centrally to this study, research supports models conceiving the executive functions (EF) as mediator of the relationship between children's PA and academic performance and achievement (Schmidt et al., 2017). For clarity, we take academic performance as process-related aspects (e.g. attention and engagement), differing from academic achievement as product-related (e.g. scores and grades). Given the paucity of research on the relationship between PA and EF through whole-school PA programmes, we aimed at examining the effects of multiple components in a PA policy intervention in a primary school on students' EF.

Considering the socio-educational change in the Irish educational landscape, increasing research provides significant evidence on the connection between PA and academic performance and academic achievement among schoolchildren (Donnelly et al., 2016; Rasberry et al., 2011), notwithstanding concurrent important health-related benefits such as wellbeing. Among the Trois-Rivieres regional project's (Shephard and Trudeau, 2013) most significant findings was the positive effect on academic performance of the experimental group, despite the reduction of 14% academic teaching time and the introduction of one-hour daily PE. In the Sports, Play and Active Recreation for Kids programme (SPARK; Sallis, Mc Kenzie, Kolody, Lewis, Marshall, and Rosengard, 1999), while doubling the amount of weekly PE time in comparison to the control condition, there was no interference with the student's academic performance. Such led to the question if PA programmes can enhance the latest while providing health-related benefits such as improved wellbeing. A recent review on the association between school-based PA and academic performance (Rasberry et al., 2011) concluded that "The pattern of having positive relationships or no relationships, along with the lack of negative relationships, is consistent throughout and suggests that adding PA to the school day may

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enhance and does not detract from academic performance" (p. 19). Furthermore, Vazou, Pesce, Lakes and Smiley-Oyen (2016), in a review of school PA interventions, concluded that curricular PE seems to provide the most appropriate framework for promoting the development of children's cognitive functions, otherwise known as EF.

According to Salimpoor and Desrocher (2006) the 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). Considering the focus on academic performance, EF were deemed to be essential for the students effective and sustained cognitive engagement towards higher academic achievements. The most prominent theoretical framework suggests that EF has three basic components: inhibition, working memory, and shifting (Diamond, 2006). While these components are briefly presented, inhibition and working memory were primarily targeted in this study. The component of inhibition refers to the deliberate, controlled suppression of prepotent responses (Miyake et al., 2000). The Animal Stroop test is often used when testing younger children, aged 3-16-year old (Wright, Waterman, Prescott, and Murdoch-Eaton, 2003) with the purpose of providing conflicting information in a given image and requesting the participant to correctly identify one of the requested elements. 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 with the Working Memory Test Battery for Children (WMTB-C) suitable for children between 5 and 15 years (Pickering and Gathercole, 2001). Shifting, not addressed in this study, is explained as the ability to adapt the 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 and Bettenay, 2010).

The effects of PA programmes through acute bouts of aerobic exercise (i.e. once-off periods of exercise and showing immediate effect on EF) are the focus for this study. Caterino and Polak (1999), investigating the effect on concentration from an acute bout of stretching and aerobic walking, found that selective attention had improved for 4th graders but not with 2nd and 3rd graders, although with little exploring explanations. Pesce and colleagues (2009), through an experimental design, compared two forms of acute aerobic exercise of equivalent intensity regarding its effects in working memory of a group of preadolescent children (11-12 years old). The findings showed that the bout of group aerobic games enhanced their immediate word recall and for delayed recall, and both groups enhanced their memory performance. Similarly, during late childhood, inhibition may be more sensitive than shifting to the effects of acute exercise (Hillman et al., 2009; Tomporowski, Davis, Miller, and Nagkieri, 2008). However, this may alter during adolescence, when there is less effect and sensitivity (Stroth et al., 2009). Few studies have addressed a related question regarding the potential influence of the pubertal status of the participants, where it may be possible that the hormone levels could alter the effect of PA on EF.

Essentially, research findings concur in that external interventions providing acute aerobic exercise in schools have a positive effect on children's EF. As less is known on the effects from whole-school PA policies in EF this study sought to answer the following research question: What are the acute effects of multiple components in a whole-school PA policy on executive functions of primary level students, considering gender and class level?

Methods

This research employed a post-positivist perspective considering the reality and ecological validity of the research site. To ensure reliability, each test and the protocol were rehearsed through a pilot-study in the same school but with a 5th class students' cohort (n=17).

Sample and procedures

The study cohort from an Irish primary school included 20 4th class (Mage = 9.95 years, SDage = .39 years) and 23 6th class students (Mage = 12.00 years, SDage = .30 years) (22 boys - 21 girls in total). The multiple component PA intervention comprised three distinct components: PE lesson, Structured Play (SP) recess, and Unstructured Play (UP) recess. It started after a one-week baseline assessment and was conducted during official school-time for one month (adding to 12 sessions, with four PE lessons, four SP recess sessions, and four UP recess sessions) with each component ran at the same time and day of each week. 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, read the information sheet and signed an informed consent document approved by the School of Education Research Ethics Committee, guaranteeing confidentiality and anonymity with the appropriate use of coding to track each student with the results of their testing in the database.

As the main researcher was the school principal, this facilitated access to the field and ensured maximum engagement from the teachers as an element of protocol fidelity although no pressure on teachers and students' participation was placed and any concerns with the first researcher's school role were thoughtfully considered. 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 of participation.

Implementation of the Protocol

Over the course of the study, the working memory and inhibition testing were administered immediately before and after each separate component (i.e. PE, SP, UP), during a four-week period for the 4th and 6th class participants. The sequence and time of components was stable for the entire duration of the protocol, reflecting the current school policy in place, i.e. pre and post testing was carried out for PE lesson each Monday, for UP recess each Wednesday at lunch break, and for SP recess each Friday at lunch break.

Independent Variables: Whole-School Physical Activity Policy as Intervention

According to national and international guidelines (e.g. WHO, 2010), the school PA policy included at least 60 minutes of daily-PA with the three mentioned components as independent variables described below.

Physical Education Lesson.

The PE lessons were based on the Games strand as per the Primary School Curriculum (NCCA, 1999) and the lessons were sourced from the Primary Schools Sports Initiative PE lesson pack (PDST, 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 (PDST, 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 (Figure 2).

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 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 (Pickering and Gathercole, 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 data analyses were completed using SPSS Version 23.0 (IBM Corp., Armonk, NY, USA). Descriptive data were initially presented [means (M) and standard deviations (SD)]. For the inferential statistical analysis, in order to test for possible differences between means, M, standard errors (SE) and percentages (%) were preferred. SE was preferred in this

occasion over SD because we were interested in the precision, rather than the variability, of the M. To determine whether each component of the PA intervention had an effect on working memory and inhibition, two separate repeated measures 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 the multivariate analysis of variance test, univariate follow-up pairwise comparisons with Bonferroni adjustments were conducted. For all analyses, a p-value below .05 ($p < .05$) was considered statistically significant. Lastly, the partial η2 was presented as a measure of effect size for F-tests. A partial η2 value between .01 and .06 was associated with a small effect, between .06 and .14 with a medium effect, and .14 or greater with a large effect (Warner, 2012).

Results

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

Table 1

Descriptive statistics for working memory and inhibition by gender

	Boys (n = 22)		Girls (n = 21)	
	Pre-test	Post-test	Pre-test	Post-test
Intervention	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Working memory (max score = 36)				
PE	26.19 (6.13)	31.62 (3.28)	25.28 (5.73)	31.33 (3.71)
SP	29.29 (2.92)	31.90 (3.82)	29.89 (3.10)	33.78 (1.73)
UP	33.10 (2.34)	32.29 (3.29)	32.94 (2.58)	33.50 (2.26)
Inhibition (max score = 36)				
PE	32.86 (3.18)	35.32 (1.91)	33.12 (5.61)	35.65 (1.00)
SP	35.68 (1.29)	33.32 (5.94)	35.35 (1.62)	35.41 (2.43)
UP	35.73 (.77)	35.36 (2.13)	35.41(2.19)	35.76 (.75)

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

Table 2

Descriptive statistics for working memory and inhibition by class

	4th class (n = 20)		6th class (n = 23)	
	Pre-test	Post-test	Pre-test	Post-test
Intervention	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Working memory (max score = 36)				
PE	23.06 (6.15)	31.72 (2.95)	28.10 (4.66)	31.29 (3.88)
SP	29.61 (3.03)	33.44 (1.85)	29.52 (3.01)	32.19 (3.89)
UP	33.17 (1.92)	32.56 (3.19)	32.90 (2.83)	33.10 (2.66)
Inhibition (max score = 36)				
PE	30.44 (5.32)	35.19 (1.94)	34.74 (2.03)	35.65 (1.27)
SP	35.75 (.78)	35.31 (1.89)	35.39 (1.75)	33.48 (6.00)
UP	35.38 (2.25)	35.56 (.81)	35.74 (.75)	35.52 (2.09)

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 $W = .66$, $p = .001$), revealed a non-significant interaction effect for Intervention x Time x Gender [$F(2,52) = .013$, $p = .987$, $\eta^2 < .001$]. A statistically significant interaction effect was observed for Intervention x Time x Class [$F(2,52) = 5.045$, $p = .017$, $\eta^2 = .126$] with a medium effect size, and for Intervention x Time [$F(2,52) = 18.035$, $p < .001$, $\eta^2 = .340$] with a large effect size. All remaining interaction effects were not statistically significant ($p > .05$). The main effects of Time [$F(1,52) = 45.051$, $p < .001$, $\eta^2 = .563$] and Intervention [$F(2,52) = 43.173$, $p < .001$, $\eta^2 = .555$] were also statistically significant with large effect sizes.

The univariate follow-up pairwise comparisons with Bonferroni adjustments indicated that PE improved more students' working memory, comparing to SP [$F(1,35) = 6.903$, $p = .013$, $\eta^2 = .165$] and UP [$F(1,35) = 24.338$, $p < .001$, $\eta^2 = .410$]. PE improved students' working memory by 24.05% (pre-test $M = 25.41$, $SE = .88$; post-test $M = 31.52$, $SE = .58$), while SP improved it by 11.15% (pre-test $M = 29.50$, $SE = .49$; post-test $M = 32.79$, $SE = .47$) and, during UP, working memory levels declined by .58% (pre-test $M = 33.02$, $SE = .41$; post-test $M = 32.83$, $SE = .48$). The working memory improvements were higher for 4th class students comparing to 6th class students [$F(1,35) = 5.585$, $p = .024$, $\eta^2 = .138$], with an overall increase of 14.58% for 4th year students (pre-test $M = 28.46$, $SE = .65$; post-test $M = 32.61$, $SE = .53$), in comparison to an overall increase

of 6.60% for 6th year ones (pre-test M = 30.16, SE = .59; post-test M = 32.15, SE = .48).

For inhibition, the repeated measures MANOVA analysis, with Greenhouse-Geisser correction due to violations of sphericity (Mauchly's W = .66, p = .001), revealed a non-significant interaction effects for both Intervention x Time x Gender [F(2,57) = .551, p = .543, η2 = .015] and Intervention x Time x Class [F(2,57) = 3.286, p = .054, η2 = .086]. The interaction effect for Intervention x Time was statistically significant with a large effect size [F(2,57) = 15.675, p < .001, η 2= .309]. All remaining interaction effects were not statistically significant (p > .05). The main effects of Time [F(1,52) = 4.310, p = .045, η2 = .110] and Intervention [F(2,52) = 6.979, p = .004, η2 = .166] were also statistically significant with medium effect sizes.

The univariate follow-up pairwise comparisons with Bonferroni adjustments indicated that PE improved more students' inhibition, comparing to SP [$F(1,35) = 20.891$, $p < .001$, $\eta^2 = .374$] and UP [$F(1,35) = 27.859$, $p < .001$, $\eta^2 = .443$] interventions. PE intervention improved students' inhibition by 10.15% (pre-test M = 32.13, SE = .59; post-test M = 35.39, SE = .27), while UP improved it by .25% (pre-test M = 35.39, SE = .25; post-test M = 35.48, SE = .29), and, during SP, inhibition levels declined by 3.01% (pre-test M = 35.52, SE = .25; post-test M = 34.35, SE = .80). 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, one UP recess session and one 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 inhibition, no gender and class differences were observed. However, for working memory, there were statistically significant higher improvements for 4th class than 6th class students. Considering regularly reported differences between boys and girls in their movement skills (Junaid and Fellowes, 2006), our findings suggest that this specific whole-school PA programme benefited both boys and girls in their EF.

Hillman et al. (2009) suggested that age differences in the PA effects on EF may be associated with developmental stages. This seems present in our study specifically for working memory, implying higher sensitivity to the developmental stages than inhibition. Furthermore, it has been stated that inhibition is less sensitive to the effects of acute exercise during adolescence than it is in childhood (Stroth et al., 2009). The findings in this study confirm varying sensitivities to particular EFs (Stroth et al., 2009) at different development stages considering outcomes that are more positive for the 4th class pupils, possibly due to a greater age-related intervention sensitivity.

Our findings aligned with the reported divergence of outcomes from Rasberry et al. (2011) as minimal isolated declines were noted for UP/working memory and SP/inhibition for all students, and particularly for 6th class. Still, the current findings further reinforced the cognitive value of PE for both dimensions of the assessed EF as more responsive to cognitively engaging activities (Jackson, Davis, Sands, Whittington, and Sun, 2016), compared to a less cognitively demanding PA through SP and UP (Vazou et al., 2016). This research illustrates positive acute effects of a whole-school PA policy on the pupils' EF. 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).

Some limitations need to be considered. As the sample size referred to a single school setting, the generalisation power is limited. Moreover, the results may not fully reflect the PA policy effect on all classes within the school as this research was conducted under the context of a whole-school PA policy, and it was not possible to consider a concomitant non-exercise control group. Lastly, while random versions of the EF tests were carried out to minimise a learning effect, day-to-day effects cannot be discarded.

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 recently introduced in Ireland to inform a progressive spiral curriculum providing the best possible learning opportunities for the students. With a higher priority weighting on the education agenda, PA planning could be streamlined nationally and maximise time for PA in schools. Specifically, PE should be prioritised when developing whole-school PA policy but always combining other forms of PA for holistic effects in students' development.

The Acute Effects of Multiple Components in a Whole-School Physical Activity Policy on Executive Functions of Primary Level Students

Abstract

A growing body of literature examines the relationship between physical activity (PA) with executive functions (EF) and academic achievement in children and adolescents. The present study aimed at examining how multiple components in a whole-school PA policy intervention in a primary school setting affected the EF (i.e. working memory and inhibition) of students. The PA policy had three components, Physical Education (PE), Structured Play (SP) and Unstructured Play (UP). Testing of EF for working memory and inhibition was carried out with a sample of 43 students from the 4th and 6th class before and after each component of the PA policy, once a week for four weeks, after a one-week pilot. 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. The effect of each component of the PA intervention on working memory and inhibition was analysed with two separate repeated measures MANOVA, controlling gender and class as between-subject factors. For both working memory and inhibition, PE was more beneficial for all students comparing to SP and UP ($p<.001$). Regarding inhibition, no gender and class differences were observed. However, for working memory there were higher improvements for 4th class comparing to 6th class students ($p<.05$). PE appeared to be more beneficial for improving students' EF and is suggested to be prioritised when developing PA policy in schools. Further research is warranted with longitudinal studies.

Keywords: Academic performance, executive functions, inhibition, working memory, physical activity, whole-school-policy.

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