Research Quarterly for Exercise and Sport

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/urqe20

Effects of Cognitively Engaging Physical Activity on Preschool Children's Cognitive Outcomes

Myrto F. Mavilidi, Caterina Pesce, Emiliano Mazzoli, Sue Bennett, Fred Paas, Anthony D. Okely & Steven J. Howard

To cite this article: Myrto F. Mavilidi, Caterina Pesce, Emiliano Mazzoli, Sue Bennett, Fred Paas, Anthony D. Okely & Steven J. Howard (2023) Effects of Cognitively Engaging Physical Activity on Preschool Children's Cognitive Outcomes, Research Quarterly for Exercise and Sport, 94:3, 839-852, DOI: 10.1080/02701367.2022.2059435

To link to this article: https://doi.org/10.1080/02701367.2022.2059435

RESEARCH QUARTERLY FOR EXERCISE AND SPORT
2023, VOL. 94, NO. 3, 839–852
https://doi.org/10.1080/02701367.2022.2059435

Routledge
Taylor & Francis Group

Effects of Cognitively Engaging Physical Activity on Preschool Children's Cognitive Outcomes

Myrto F. Mavilidi[a], Caterina Pesce[b], Emiliano Mazzoli[c], Sue Bennett[a], Fred Paas[a,d], Anthony D. Okely[a], and Steven J. Howard[a]

[a]University of Wollongong; [b]University of Rome "Foro Italico"; [c]Deakin University; [d]Erasmus University Rotterdam

ABSTRACT

Research combining physical activity with the training of cognitive skills such as executive functions is emerging as a novel and fruitful intervention approach for children. **Purpose:** This study aimed to examine the impact of an intervention program including cognitively engaging physical activity on preschool children's cognitive outcomes and physical activity. **Methods:** Children (N = 144, 65 female; M_{age} = 4.41 years, *SD* = 0.61), randomly assigned to one of three groups: cognitively engaging physical activity (CPA; i.e., storytelling, cognitive activities, and motor tasks, n = 55), cognition (i.e., storytelling and cognitive activities without motor tasks, n = 48), or control (i.e., traditional storytelling, n = 41). Sessions lasted approximately 17 minutes, conducted twice a week, for 6 weeks. Children's executive function, self-regulation, and related outcomes (i.e., numeracy) were assessed at baseline and again—along with perceived enjoyment—at the end of the program. Accelerometers measured children's physical activity during each session. Teachers completed a logbook for each session, and two fidelity checks per preschool took place by the researcher. Main analyses used linear mixed models adjusted for covariates (age, sex) and clustering at the preschool level. **Results:** Results showed no significant group by time interaction for executive function, self-regulation, numeracy, enjoyment. During the sessions, children in the CPA group were more physically active than children in the cognition and control groups. **Conclusion:** While we did not find the expected amplified cognitive benefits, making storytelling more active has the potential to meet two needs (increase cognitive stimulation and physical activity levels) in one deed.

ARTICLE HISTORY
Received 1 December 2021
Accepted 24 March 2022

KEYWORDS
Executive function; physical activity; storytelling

Early interventions can result in lifelong skill formation, supporting children's social, psychological, and cognitive development (Heckman et al., 2010), with far-reaching benefits later in life (e.g., civic engagement, productivity, and economic return in society; Astuto & Ruck, 2017). Identifying viable and foundational targets for early intervention, abilities that are essential to learning and learning-conducive behaviors, such as executive function and self-regulation, have been implicated. Executive function and self-regulation are associated bi-directionally, accounting for unique variance in early academic skills in preschool children (Howard, Vasseleu et al., 2021). Diamond and Lee (2011) argue that executive function skills are more important for predicting academic performance than even IQ. This is perhaps unsurprising considering that executive function skills relate to the ability to stay focused and resist temptations (i.e., inhibition), hold information in mind while mentally working with it (i.e., working memory), and switch focus of attention easily and flexibly (i.e., cognitive flexibility; Diamond, 2010).

Executive functions develop rapidly during ages 3–6 years, but they are important throughout life, helping exert control over processes extending across social, psychological, and mental domains (Diamond, 2010). They have been linked to educational outcomes (e.g., school readiness, early literacy and numeracy, academic achievement; Ahmed et al., 2019; Best et al., 2011), as well as psychosocial and physical health (Liang et al., 2014; Reinert et al., 2013). Given their relevance, finding ways to support children's executive function development has become a focus both for researchers and educational policymakers. The approaches that are most successful in generating executive function growth, educational approaches targeting the whole-child (physical, cognitive, psychosocial) seem to be more efficacious than those narrowly focusing on a passive sedentary instruction (Diamond, 2010).

A theory-based review suggests that the execution of motor and cognitive tasks simultaneously may enhance declarative memory (Tomporowski & Qazi, 2020). According to embodied learning, action and perception are interconnected (Barsalou, 2003). Combining body movements during learning in educational contexts can facilitative memory encoding and retrieval (Mavilidi, Ouwehand et al., 2021). In particular, children's recall of words and sentences can be enhanced by having them perform task-related actions, such as enacting those words and sentences (Zimmer & Cohen, 2001).

For example, preschool children showed increased verbal and social engagement (Vazou et al., 2017) and attention scores (Vazou & Mavilidi, 2021) when classroom sessions involved physical activity (PA) sessions compared to when they did not. PA participation offers significant gains for preschool children's physical, motor, cognitive, and psychosocial development (Carson et al., 2017). Regular PA in children and

CONTACT Myrto F. Mavilidi myrto.mavilidi@uow.edu.au Early Start/ School of Education, University of Wollongong, Northfields Avenue, Keiraville, NSW 2522, Australia.
Supplemental data for this article can be accessed on the publisher's website.

adolescents can enhance their engagement, academic achievement, executive function skills, and metacognition (Álvarez-Bueno, Pesce, Cavero-Redondo, Sánchez-López, Garrido-Miguel, & Martínez-Vizcaíno, 2017; Álvarez-Bueno, Pesce, Cavero-Redondo, Sánchez-López, Martínez-Hortelano, & Martinez-Vizcaino, 2017; Owen et al., 2016).

The World Health Organization (2019) recommends that children aged 3–4 years engage in a minimum of 180 minutes of PA per day, of which 60 minutes should be within the moderate-to-vigorous intensity range. A systematic review of 55 studies in 13,956 preschool children reported low levels of PA (i.e., less than 10 min/hr of moderate-to-vigorous PA) and high levels of sedentary time (between 27 and 57 min/hr), although highly variable across different studies (O'Brien et al., 2018). Children's engagement in sedentary activity may be a reason for high and increasing levels of obesity found in early childhood (Carson et al., 2017).

Children spend a large amount of their waking hours in preschool centers, so these settings are of critical importance in promoting a physically active lifestyle (OECD, 2017). However, opportunities for children to be physically active during their time at the preschool are decreasing while basic requirements in Australian early childhood education and care (ECEC) services are constantly increasing (e.g., reporting, assessment, planning, curricula; Australian Government, Australian Institute of Health and Welfare, 2021). It is imperative to use that time to best effect, combining PA with other pursuits, rather than time for PA or reading time in separation.

Various barriers to providing opportunities for children to be more active at preschool have been reported by staff including lack of time, training, access to natural settings, and safety concerns (Coleman & Dyment, 2013; Ellis et al., 2018). To counterbalance these barriers, classroom-based PA through the form of physically active lessons or active breaks has had promising effects on enhancing children's cognitive outcomes and increasing their PA levels (Bedard et al., 2019; Mavilidi, Ruiter et al., 2018; Norris et al., 2019; Watson et al., 2017). For example, studies in preschool children in which PA was integrated with different academic domains such as foreign language, mathematics, geography, and science, have shown positive effects on children's learning outcomes as well as increases in children's PA levels (Mavilidi et al., 2015, 2016, 2017; Mavilidi, Ruiter et al., 2018).

There is emerging and promising evidence on the effects of cognitively engaging PA (i.e., physical and cognitive demands into one task) on children's executive functions, in alignment with theoretical predictions related to embodied cognition. This line of research suggests that the qualitative characteristics of PA (e.g., selection of mental strategies, task innovation, complexity, and difficulty; Pesce, 2012) may offer additional cognitive benefits compared to only quantitative characteristics (e.g., dose, intensity; Vazou et al., 2019). Schmidt et al. (2020) found that kindergarten children who were assigned to a physical-cognitive condition (e.g., "Lizard Edy says" to jump) showed greater improvements in cognitive flexibility than those who continued with usual practice. Mazzoli et al. (2021) found that in services where children implemented the breaks as prescribed, showing a negative change in sitting and a positive change in standing, there were improvements in response inhibition.

In canvasing opportunities in ECEC that may lend themselves to PA, group reading is a pervasive and cognitively engaging (yet sedentary) activity that most children experience. Storytelling can enhance language complexity, story comprehension (Isbell et al., 2004), as well as cognitive flexibility (Ruffini et al., 2021) in children aged 3–5 years. In a 12-week program that included motor skills during storytelling related to characters in popular children's books, the preschool participants had improved their motor skill performance (i.e., jump, throw, catch, run, stationary dribble, kick, roll) at the end of the program compared to the baseline assessments (although the absence of a control condition precluded ascribing the results to intervention effects; Eyre et al., 2020). Lastly, a six-week program combined movement and storytelling on preschool children's motor competence and naming vocabulary (Duncan et al., 2019). It was found that children's language ability and motor competence were improved after the intervention compared to the movement or storytelling only groups.

Nevertheless, these theorized (and preliminary) effects of motor and/or cognitive tasks combined with storytelling on preschool children's cognitive functions remain under-examined. Yet it has potential to maximize two important outcomes, without a commensurate increase in time that would be required by doing each separately. The present study examined the effects of an intervention program that incorporated cognitively engaging PA with story time in preschool settings. The story adopted was selected from previous research involving cognitive activities integrated with story time, which showed significant gains in children's executive functions skills, with the effects still present two months later (Howard et al., 2017). PA was further integrated with the story by adding motor actions that the character and children need to follow to surpass challenges. It was hypothesized that children in the cognitively engaging PA condition would show better cognitive performance than those in the cognition (i.e., only cognitive engagement) and control groups (i.e., traditional storytelling).

Method

Participants

Children were recruited from ECEC services in the Illawarra region of New South Wales, Australia. Demographics of this region are highly diverse, and largely in line with population proportions for Australia more broadly. Directors of ECEC were eligible for participation if they were located within an 80-km range from the University of Wollongong, Ethical approval was obtained from the University of Wollongong Health & Medical Human Research Ethics Committee (Ethics No: 220/261). Parents provided a written consent form, indicating their child's age and sex, while children gave their oral assent for participation. Children were eligible to participate if they spoke English as their main language and had not been diagnosed with developmental or learning disabilities. They also needed to attend the preschool center at least two days per week. ECEC were randomized at baseline, using a computerized random number generator, assigned to the cognitively engaging physical activity (CPA) group, cognition (COG) or control groups. The study followed the Consolidated Standards of Reporting

Trials (CONSORT) Statement (Schulz et al., 2010) and Extension to Cluster Randomized Trials (Campbell et al., 2004).

Pilot study

A 4-week home-based program, including videos with recorded reading sessions and self-running activities with instructions and demonstrations, assessed the potential feasibility and acceptability of the program. Parents were instructed to watch the videos and perform the activities with their children twice a week. The story and activities were based on the book "Quincey Quokkas Quest" (Howard et al., 2017). The book embedded executive function activities, integrated within the story as obstacles that children had to overcome to help the main character of the story come through. At the end of each page/activity, an additional counting activity was involved (e.g., "let's count how many frogs you can see in this page"). The counting component was the same across all groups. Each experimental group performed the following (see detailed examples in Appendix A):

Cognitively engaging physical activity group (CPA): 3–4 activities with combined motor and cognitive tasks.

Cognition group (COG): 3–4 cognitive activities

Control group: Passive storytelling (reading) of the whole book without complementary activities.

The first author organized two Zoom sessions (during the first and third weeks of the program) with each parent and their child and sent weekly e-mails with suggestions to support the program delivery. During these sessions, the lead author evaluated quantitatively the adherence to the program (i.e., if children performed the activities as intended, ranging from 1, "did not do the activities," to 3, "performed as intended"). Children's executive functions, parent-reported self-regulation, and numeracy were assessed at baseline and after four weeks by the first author, not blinded to the group allocation, at a quiet area at the Early Start Discovery Space of the University of Wollongong. Preliminary results are reported in Appendix B.

The results of the pilot study showed that the program was well perceived and accepted by parents, while the intervention components (e.g., length and frequency of videos) and measures were appropriate. Both parents and children enjoyed the program. Based on the feedback received (Mavilidi, Bennett et al., 2021), a wider selection of activities was added, while a hard copy of the book was given as an option to use it along with the videos. In order to ensure that the majority of children received the minimum dosage of reading sessions, we suggested a 6-week intervention program at the ECEC as a buffer against any child absences or missing reading sessions due to programming variations. In the original study of Howard et al. (2017), the executive function training dose varied from twice per week for 5 weeks, to once a week for seven and nine weeks.

Main study

Procedure

A 6-week intervention program was implemented at ECEC services twice a week, as a group activity during the normal daily routine, either in the form of short videos (approx. 9–15 min per group) or delivered by educator reading after providing them with children's picture book. Educators were recommended to use the videos for the first sessions, and use the book once they became familiar with the activities and instructions. A hard copy with instructions for each activity and variations for more complex activities was also given to educators to guide them when using the book (see Appendix A). The videos and activities per condition were the same as in the pilot study, despite the mode of engagement (i.e., video or book). In the videos, a narrator read the story, while educators from preschool centers read the story in the book. Educators were asked to use the videos for the first two weeks of the program to familiarize themselves with the content. Although optional, qualitative evidence showed that educators in both experimental conditions preferred the use of the book instead of the video (Mavilidi, Bennett et al., 2021). The same detailed instructions were given for the narrated video and the teachers reading the book to ensure highest similarity of conditions. After three weeks of implementation, variations for progressing to more complex activities were added in the videos or the book activities.

Measures

Assessments were conducted individually at baseline and at 6-week of follow-up by trained research assistants in a quiet area of ECEC services, under supervision of the educators between April and June 2021. Apart from the first author, who was aware of the experimental conditions, research assistants were blinded.

Executive function skills. Executive function skills were assessed using the Early Years Toolbox, psychometrically validated and high reliable for preschool children (Howard & Melhuish, 2017). It consisted of three iPad-based games that included standardized instructions, a practice block, feedback, and scoring on visual-spatial working memory ('Mr Ant'), inhibition ('Go/No-Go'), and shifting ('Card Sort').

'Mr Ant': Children were presented with an image of an ant with a number of colored dots placed in different spatial locations on its body. After a predetermined time limit (5 sec), these dots disappeared and the child was asked to recall the spatial locations of the dots by tapping the corresponding locations on the ant's body. This task took up to 8 minutes for completion.

'Go/No-Go': Children were presented with fish and sharks and were instructed to tap the iPad screen when they see a Fish ('catch the fish') and refrain from responding when a Shark appears ('avoid the sharks'). This task took up to 6 minutes for completion.

'Card Sort': Participants were presented with 'cards' that vary along two dimensions (e.g., shape and color) and were asked to sort each card (e.g., red rabbits and blue boats) first by one dimension (e.g., color) and then, after a number of trials, by another dimension (e.g., shape). This task took up to 6 minutes for completion.

Educator-reported self-regulation. Each participating child's preschool teacher completed a self-regulation questionnaire (revised Strengths and Difficulties Questionnaire; SDQ+; Goodman, 1997), which consisted of 25 items pertaining to children's everyday behaviors (e.g., 'restless, overactive, cannot stay still for long' and 'Waits his/her turn in games'). For each item, the educator selected one of three options to indicate whether the statement was 1, 'Not true,' to 3, 'Certainly true' about the child. This survey took < 5 minutes per child to complete.

Numeracy. It consisted of two tasks: *Counting*: Children were asked to count from 1 to 20 normally and backwards. The correct answer was given up to the point of the first error. For example, if a child counted "1, 2, 3, 5," he or she received 3 points. The highest score children could receive was 40. *Numerical magnitude comparison*: Children needed to choose which number was bigger between sets of two digits (e.g., 4 vs. 9). The highest score children could receive was 6. Numeracy score was the aggregated scores from counting and numerical magnitude. This material was part of a learning tool designed to examine preschool children's numeracy skills after integrating physical activity during learning, with a reliability coefficient (Cronbach's alpha) previously established of .89 (Mavilidi, Ruiter et al., 2018), and adapted by Ramani and Siegler (2008).

Enjoyment. At the end of the follow-up test (6 weeks), children were asked to evaluate whether they enjoyed the reading sessions on a 5-point Likert scale with semantic anchors (expressed as smiley faces) ranging from 1 ("I didn't like it/ Not at all") to 5 ("I liked it a lot/I would love to"). Specifically, children were asked: "Did you like watching the videos and doing the activities?" and "Would you like to listen to the story again?." This scale was adapted from previous studies (Mavilidi et al., 2016, 2017; Mavilidi, Ruiter et al., 2018). The total score of enjoyment consisted of the average of these two questions. A coefficient alpha of .75 was obtained for these questions in a previous study (Mavilidi, Ruiter et al., 2018).

Process evaluation

PA. Children's PA was measured using ActiGraph accelerometers (model GT3X, Pensacola, FL) worn around the waist on an elastic belt with the accelerometer positioned over the anterior aspect of the right hip during the reading sessions for three weeks (constraining use to only half of the intervention period was due to practical reasons; i.e., insufficient number of accelerometers for all children). Accelerometers are instruments designed to measure time-specific acceleration used for PA assessments. ActiGraph accelerometers have established utility, validity, and reliability in children aged 3–5 years (Cliff et al., 2009).

An accelerometer was placed on each child by the educators —who had received training on the proper positioning of accelerometers on their child's waist—at the beginning of the learning activity and was removed at the end. Accelerometer data were processed using ActiLife version 6.12.1 software and were recorded for the scheduled 15–20 min time period of the reading activity. The epoch length was set at 15-s intervals, a time that is recommended for use in preschool children, and age-appropriate cut-points were used to define intensity of activity while the magnitude of the recorded accelerations over an epoch was measured in activity counts as an estimate of total PA data (Cliff et al., 2009). Cut-points were set at 25 counts/15 s for sedentary behavior and at 420 counts/15 s for moderate- to vigorous-intensity PA (Pate et al., 2006), most accurate in young children (Janssen et al., 2013). Data were reported as minutes spent in moderate- to vigorous-intensity PA (MVPA) and the average activity counts per minute (CPM), representing the average intensity activity during each session.

Teacher log diary. Educators completed the time the sessions started and finished each week, the names of participating children, and rated children's engagement with the activities from 1, ("not engaged/ did not do the activities") to 3, ("fully engaged/activities exactly as intended").

Researcher fidelity checks. The first author conducted two visits per ECEC service to evaluate the program implementation and ensure that activities were administered in the manner intended. Children were rated in terms of their engagement in the activities, ranging from 1 ("did not do the activities") to 3, ("activities exactly as intended"). Educators were rated on the extent to which they were attempting to stimulate engagement, ranging from 1, ("no prompts or hints"), to 3, ("actively encourage participation").

Statistical analyses

Statistical analyses were conducted using linear mixed models in IBM SPSS (version 26). This statistical approach is consistent with the intention-to-treat principle, assuming missing data at random (MAR), modeled using a likelihood-based analysis. The advantage of this approach is that the specification of random effects allows the components of variance due to multiple levels in the study design to be separated and quantified. To control for the missing data, we conducted a sensitivity analysis with complete cases only, showing no differences in the current results.

Regarding executive function, self-regulation, and numeracy, the models included time (treated as categorical: baseline and posttest), group (CPA, cognition, and control) and the group-by -time interaction as fixed effects (i.e., (intervention posttest mean—intervention baseline mean)—(control posttest mean—control baseline mean)). To account for the clustered nature of the data (i.e., children located in preschools), the mixed models included random intercepts for preschools. The model was also adjusted for the confounding effects of age and sex. As the pattern of results with and without these covariates did not differ, results are reported without these covariates. Enjoyment and PA were analyzed with group as a predictor, adjusted for clustering in preschools. Cohen's d was calculated to provide a measure of effect size (adjusted difference between each experimental group over time divided by the pooled standard deviation of change; Vacha-Haase & Thompson, 2004).

Results

Participants included 144 children aged 3–5 years (65 females; M_{age} = 4.41 years, SD = 0.61). Preschool centers were randomly assigned to the CPA group (n = 55; 25 females; M_{age} = 4.34 years, SD = 0.58), cognition (n = 48; 22 females; M_{age}

= 4.44 years, *SD* = 0.67), or control group (n = 41; 18 females; M_{age} = 4.41 years, *SD* = 0.61). The initial consent rate for participation in the study was 96.5%. At follow-up, due to Covid-19 lockdown restrictions, seven children were not assessed in the cognition group because they did not attend the ECEC, and four were assessed by early childhood educators at follow-up after receiving 1-h training (similar to the training given to the research assistants) and written step-by-step instructions on how to proceed with the assessments from the lead author (as visitors were not allowed). One child in the CPA group withdrew from the ECEC in the intervention period, and two children in the control group were absent for follow-up assessments. The flow of participants is depicted in Figure 1.

Table 1 presents a detailed summary of results for variables measures before and after the intervention by group. No significant group by time interactions were observed for executive function, self-regulation, and numeracy.

Enjoyment: There were no significant differences found across the cognitively engaging physical activity group (*M* = 4.41, *SE* = 0.14), cognition (*M* = 4.06, *SE* = 0.15), and control (*M* = 4.34, *SE* = 0.17) groups ($F(2,107) = 1.63$, $p = .201$).

Process evaluation

PA

In total, 122 cases were included in the analysis (CPA n = 53; COG n = 32; control n = 37), while 14 cases from one ECEC in the cognition group were removed because children did not wear the accelerometers. Significant differences across conditions on children's minutes spent in MVPA ($F(2,119) = 103, 81$, $p = < .001$), and counts per minute ($F(2,119) = 52.43$, $p = < .001$), respectively, were found. Children in the CPA group (MVPA: *M* = 5.83, *SE* = 0.30; CPM: *M* = 612.94, *SE* = 42.52) were more active than children in the cognition (MVPA: *M* = 0.09, *SE* = 0.38 *p* = < .001; CPM: *M* = 2.17, *SE* = 54.72, *p* = < .001), and control groups (MVPA: *M* = 0.22, *SE* = 0.36, *p* = < .001; CPM: *M* = 64.96, *SE* = 50.89, *p* = < .001). There were no differences between children in the cognition and control groups (MVPA: *p* = .687; CPM: *p* = .402).

Teacher log diary

In the CPA group, educators reported that they completed 11/12 sessions, lasting per average 20.5 minutes, while children were engaged during the majority of the sessions (2.4/3). In the cognition group, educators reported that they completed 10.5/12 sessions, lasting 18.5 minutes. Educators in both preschools of the cognition group did not complete the log diary regarding children's engagement levels.

Researcher fidelity checks

Children engagement in the CPA group was rated as 2.8/3, whereas teacher encouragement was 2.5/3. In the cognitive group, children engagement was rated as 2.3/3 and teacher encouragement was 2.0/3.

Discussion

The current study was designed to investigate the effects of a 6-week program that injected PA into cognitively engaging activity through reading sessions from a book or a video. Results did not reveal any significant group by time interactions in executive function, self-regulation, or numeracy. During the reading sessions, children in the CPA group were more physically active compared to children in the cognition and control groups.

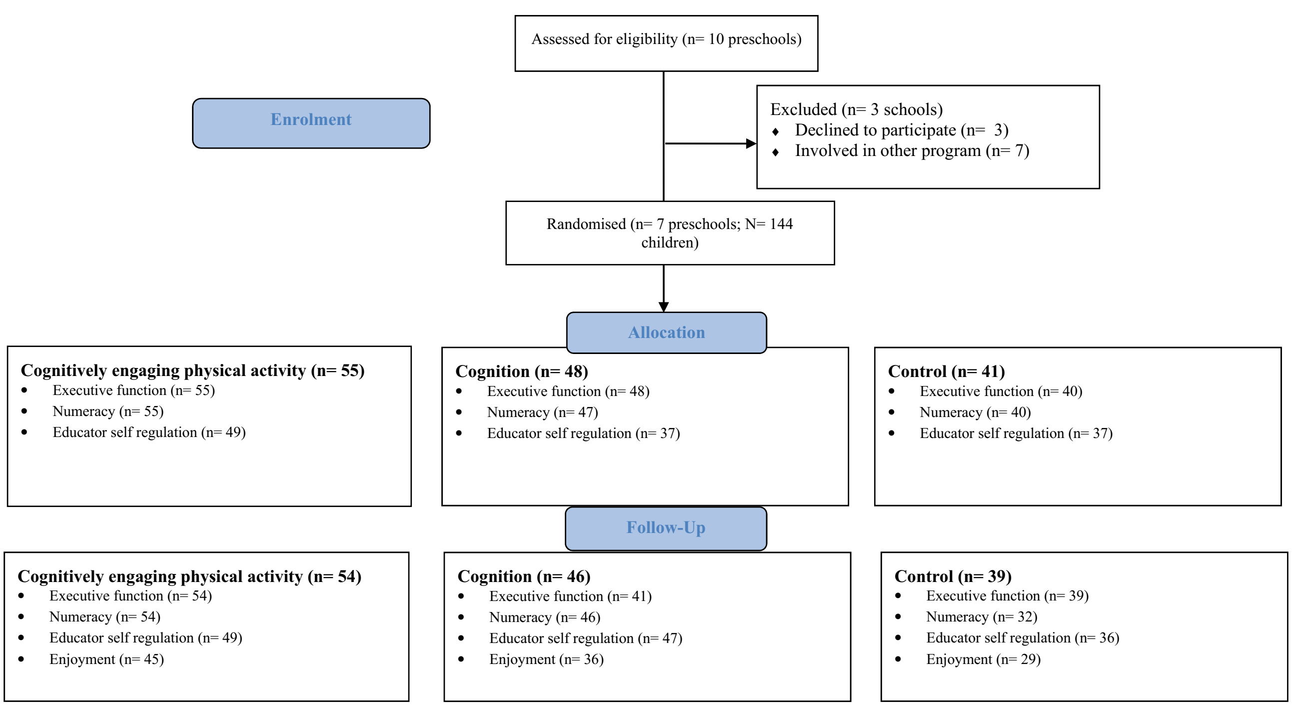


Figure 1. Flow diagram of participants.

Table 1. Summary of outcome variables per group.

	Control Group		COG Group		CPA group		Adjusted difference between groups								
							CPA-control			COG-control			COG-CPA		
Variables	Baseline Mean (95% CI)	Posttest Mean (95% CI)	Baseline Mean (95% CI)	Posttest Mean (95% CI)	Baseline Mean (95% CI)	Posttest Mean (95% CI)	Mean change (95% CI)	*p* value	Cohen's d	Mean change (95% CI)	*p* value	Cohen's d	Mean change (95% CI)	*p* value	Cohen's d
Executive Function															
Inhibition	0.54 (0.45, 0.62)	0.63 (0.55, 0.72)	0.46 (0.36, 0.56)	0.57 (0.47, 0.68)	0.49 (0.39, 0.58)	0.53 (0.43, 0.62)	0.06 (−014, 0.26)	.425	0.2	0.07 (−0.22, 0.36)	.832	0.3	−0.02 (−0.22, 0.19)	.832	−0.1
Working Memory	0.85 (0.41, 1.29)	1.09 (0.64, 1.55)	1.16 (0.63, 1.70)	1.28 (0.73, 1.83)	1.22 (0.69, 1.76)	1.19 (0.66, 1.73)	0.27 (−0.58, 1.13)	.371	0.2	0.14 (−1.09, 1.37)	.638	0.1	0.13 (−0.77, 1.02)	.667	0.1
Shifting	7.07 (5.55, 8.58)	7.35 (5.81, 8.90)	7.71 (5.93, 9.49)	7.24 (5.37, 9.10)	7.18 (5.41, 8.95)	7.41 (5.63, 9.18)	0.05 (−3.76, 3.87)	.970	0.0	−0.71 (−4.96, 3.55)	.653	−0.1	0.76 (−3.04, 4.56)	.613	0.1
Numeracy	22.55 (14.86, 30.25)	24.31 (16.63, 31.99)	18.21 (8.69, 27.73)	20.11 (10.63, 29.59)	16.24 (6.60, 25.89)	22.15 (12.57, 31.72)	−4.14 (−8.84, 0.55)	.072	−0.2	−3.99 (−9.98, 1.99)	.113	0.0	−0.15 (−4.88, 4.58)	.939	0.0
Educator self-regulation	1.98 (1.89, 2.07)	1.98 (1.88, 2.07)	1.87 (1.75, 1.97)	1.92 (1.81, 2.04)	1.93 (1.82, 2.04)	1.94 (1.83, 2.06)	−0.62 (−0.08, 0.04)	.607	−0.1	0.05 (−0.01, 0.11)	.127	0.2	−0.06 (−0.12, 0.00)	.056	−0.2

CPA = Cognitively engaging physical activity group; COG = Cognition group; 95% CI = Confidence Intervals.

Contrary to our hypothesis, we did not find an improvement on children's executive functions. A previous study using the same book, which integrated cognitive activities with story time but without a motor component, has found improvements on children's executive functions skills, with sustained effects two months later (Howard et al., 2017). In addition, a six-week program combining movement and storytelling improved preschool children's language ability (Duncan et al., 2019). However, this was not the case for our study. Although parents and early childhood educators reported a change on children's numeracy skills (Mavilidi, Bennett et al., 2021), it was not confirmed quantitatively in this study.

Research on cognitively engaging PA is emerging with mixed effects for improving preschool children's executive function skills. For example, a 12-week afterschool program with 36 preschool children participating in enriched physical activity, consisting of practice in motor skill learning, contextual interference (i.e., performing shifts across multiple skills, or variations of a skill), mental control (stopping, updating, switching) and discovery (of motor solutions in open-ended tasks), revealed improved working memory but not inhibition or cognitive flexibility skills compared to children assigned to swimming lessons or control group with no physical activity exposure (Biino et al., 2021).

Similarly, Schmidt et al. (2020) found improvements on updating skills after 6 weeks in kindergarten children who engaged with games combining physical and cognitive demands (e.g., rule changes) compared to the children who encountered usual practice, but no changes on their inhibition and working memory performance. Lastly, no changes in preschool children's executive functions were found after participating in an 8-week program that integrated fundamental movement skills with academic concepts, executive function, and socio-emotional skills (Vazou & Mavilidi, 2021).

Inconclusive findings on cognitively engaging PA programs are also evident in older ages: studies have shown selective positive changes on primary school children's executive function skills (e.g., cognitive flexibility, Egger et al., 2019; working memory and attention; Dania et al., 2021), whereas others reported no changes (Aadland et al., 2019; Bedard et al., 2021; Pesce, Lakes et al., 2021). Meta-analyses on active learning report no significant effect on children's cognition (Bedard et al., 2019; Norris et al., 2019; Watson et al., 2017). However, a meta-analysis in children and adolescents found positive effects of PA on core executive functions (ES = 0.20), including working memory (EF = 0.14), inhibition (ES = 0.26), and cognitive flexibility (ES = 0.11; Álvarez-Bueno, Pesce, Cavero-Redondo, Sánchez-López, Martínez-Hortelano, & Martinez-Vizcaino, 2017).

Plausible explanations for the null results of the current study are explored: this program may work under certain conditions (e.g., specific cognitive activities, or type of connection between action and perception), or for certain children (e.g., those with low executive function skills). Importantly, a possible reason for these results could be the potential of children's overexertion and/or narrow transference of executive function training during the intervention to the outcome variables. This explanation was suggested by Bedard et al. (2021) for the lack of executive function effects in primary children after participating in cognitive engaging physical activity. This suggestion can also be confirmed in the study of Schmidt et al. (2019) who found significant positive learning effects on children's learning (i.e., foreign language), but negative effects on their focused attention scores, measured directly after the learning session.

Alternatively, a longer duration of the program or higher intensity of PA may elicit the desirable cognitive changes. Evidence from a systematic review indicated that preschoolers spend the majority of their time (between 12.4 and 55.8 min/hour) at the preschool in sedentary activities (O'Brien et al., 2018). Australian preschool children spend 48.4% of their time sitting (Ellis et al., 2017), engaged in group or individual activities such as story time, making puzzles or drawing sitting down at a table (Ellis et al., 2018). Within educational settings, to breakup prolonged periods of sitting time, PA needs to be better integrated with variations to existing activities and practices, without sacrificing cognitive and educational tasks. It is imperative that future research identifies the conditions under which such integrations yield benefits to both abilities integrated. Although the same instructions were given for the narrated video and the teachers reading the book to ensure highest similarity of conditions, it cannot be excluded that virtual vs real narration might have influenced the outcomes differently. This manipulation warrants further research.

Nevertheless, research suggests that motor and cognitive skills development have common underlying mechanisms apparent in exercise, sports, and performance arts (Tomporowski & Pesce, 2019). Future studies should consider several contextual factors in the design of interventions (e.g., physical activity type, setting, delivery mode) for the academic classroom (Pesce, Vazou et al., 2021). These factors may be especially informative for policymakers and practitioners, helping to understand what physical activity interventions are most efficacious on improving cognition, under which circumstances, and for whom (Pesce, Vazou et al., 2021). Importantly, we need to consider the role of individual differences that may render children differentially responsive to the PA and engagement conditions. For instance, a recent study in pre-kindergarten children showed that for those with low aerobic fitness levels, time spent in moderate to vigorous PA could predict their executive function scores (Becker & Abi Nader, 2021). However, no associations were found for children with high aerobic fitness. Research should emphasize the promotion of practice variability, allowing children to engage in different learning experiences through exploration, taking into account their individual differences (Stodden et al., 2021).

The current study included measures of enjoyment, with no differences depicted across groups (even though a descriptively higher rate for enjoyment is observed on the CPA group). Notably, the control group involved reading a new book, which might have increased children's interest relative to typical practice. Also, when children watched the video, the narrator may have been more engaging as a new person involved, compared to the ordinary educator reading the book. Previous studies have found higher enjoyment levels when children were engaged in physically active lessons compared to usual practice, but no differences on children's enjoyment levels between physically active lessons and non-task relevant PA (Mavilidi et al., 2016, 2017; Mavilidi, Okely et al., 2018), or between cognitively engaging and cognition groups (Schmidt et al., 2020).

Interestingly, PA during the reading sessions, was higher when children combined motor with cognitive tasks compared to being engaged only cognitively or listening to the story. This finding is important considering the potential benefits of PA in young children (Carson et al., 2017). Intervention programs targeting PA promotion and participation in early childhood have not always been successful, finding null or small changes on children's time spent in MVPA and/or number of steps (Jones et al., 2016; Mavilidi, Rigoutsos, & Venetsanou, 2021). Active learning may act as an intervention for PA targeting behavior change in managing obesity prevention and control (Robinson, 2010).

Overall, the current study emphasizes the importance of initially evaluating the feasibility, implementation, acceptability, demand, practicality, and limited-efficacy testing of interventions (Bowen et al., 2009), to identify likely areas of impact and fruitful revisions. The contribution of this program lies on its innovative integration, including cognitively engaging PA in young children through storytelling, which is a common daily practice for this age group, ensuring more chances of adoption. Child-centered approaches that target movement exploration through play, highlight the synergistic effects on children's physical, social-emotional, cognitive, and self-concept development (Stodden et al., 2021).

Another strength of this program includes the process evaluation measures, both teacher daily logbook and researcher fidelity checks. Process evaluation measures allow us to infer about adherence to program protocols (i.e., implementation, theory building, program efficacy; Harachi et al., 1999). Program adherence is a determinant factor of program success. Recently, a review on movement integration programs pinpointed that half of them were researcher-led, undermining their possibilities for sustainability, dissemination, and scalability, whereas teacher-led programs should be more consistent on reporting fidelity during their delivery (Vazou et al., 2020).

Limitations of the study include the non-standardized numeracy measure. Possibly, a more thoroughly evaluated tool for this age group would allow us to draw firmer conclusions on children's numeracy (e.g., Early Years Toolbox Early Numeracy assessment; Howard, Neilsen-Hewett et al., 2021). In addition, although results remained insignificant, there were some baseline differences (see Supplementary File 1 for the baseline measures of inhibition, numeracy, and educator self-regulation). We need to be vigilant when interpreting these results, as the small sample size and number of clusters during randomization may have failed to ensure equal distribution of confounders. Regardless, a larger sample size is needed for a well-powered study and allow for generalizability of results to the greater population. Covid-19 and lockdown restrictions applied, did not permit us from collecting data to more children in preschool centers, as well as conducting the pilot study there instead of a home setting.

There is a call for further research to identify different facets of pedagogies best suited to challenge specific executive function skills, as well as specific measures of information processing, long-term memory and word fluency across several age groups (Rudd et al., 2019). A mere focus should be placed on using larger randomized controlled trials, ensuring dissemination, and reach to more children along with measures to maintain sustainability of successful programs in the long term beyond the research purposes.

Conclusion

In the current study, cognitively engaging PA promoted PA without compromising academic benefits (yielding similar outcomes to usual practice), one of the main concerns reported by early childhood educators when greater frequency or duration of other activities are encouraged (Ellis et al., 2018; Macdonald et al., 2021). This research responds to a need for integrated activities in the preschool environment, and inclusion of process evaluation measures to support implementation fidelity.

Acknowledgements

The authors would like to thank the parents, educators, and the children for their participation in the study.

Author contributions

MM: Was responsible was all steps of the study (Conceptualization, Methodology, Supervision, Analysis, Writing).
SB, FP, AO: Reviewed the manuscript.
CP, EM: Drafted and reviewed the manuscript.
SH: Methodology, supervision, and writing

Disclosure statement

No potential conflict of interest was reported by the author(s).

IRB approval

This study received approval from the University of Wollongong Human Research Ethics Committee (Ethics No: 220/261).

Funding

This study was funded by the 2020 University of Wollongong Vice Chancellor Postdoctoral Fellowship Award.

ORCID

Myrto F. Mavilidi http://orcid.org/0000-0003-2661-8709
Caterina Pesce http://orcid.org/0000-0002-4245-3898
Emiliano Mazzoli http://orcid.org/0000-0002-9207-4167
Anthony D. Okely http://orcid.org/0000-0002-1626-8170
Steven J. Howard http://orcid.org/0000-0002-1258-3210

References

Aadland, K. N., Ommundsen, Y., Anderssen, S. A., Aadland, K. N., Brønnick, K. S., Moe, V. F., Resaland, G. K., Skrede, T., Stavnsbo, M., & Aadland, E. (2019). Effects of the Active Smarter Kids (ASK) physical activity school-based intervention on executive functions: A cluster-randomized controlled trial. *Scandinavian Journal of Educational Research*, *63*(2), 214–228. https://doi.org/10.1080/00313831.2017.1336477

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology*, *111*(3), 446–458. https://doi.org/10.1037/edu0000296

Álvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sánchez-López, M., Garrido-Miguel, M., & Martínez-Vizcaíno, V. (2017). Academic achievement and physical activity: A meta-analysis. *Pediatrics*, *140*(6), e20171498. https://doi.org/10.1542/peds.2017-1498

Álvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sanchez-Lopez, M., Martínez-Hortelano, J. A., & Martinez-Vizcaino, V. (2017). The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry*, *56*(9), 729–738. https://doi.org/10.1016/j.jaac.2017.06.012

Astuto, J., & Ruck, M. (2017). Growing up in poverty and civic engagement: The role of kindergarten executive function and play predicting participation in 8th grade extracurricular activities. *Applied Developmental Science*, *21*(4), 301–318. https://doi.org/10.1080/10888691.2016.1257943

Australian Government, Australian Institute of Health and Welfare. (2021). *Childcare and early childhood education*. https://www.aihw.gov.au/reports/australias-welfare/childcare-and-early-childhood-education

Barsalou, L. (2003). Situated simulation in the human conceptual system. *Language and Cognitive Processes*, *18*(5–6), 513–562. https://doi.org/10.1080/01690960344000026

Becker, D. R., & Abi Nader, P. (2021). Run fast and sit still: Connections among aerobic fitness, physical activity, and sedentary time with executive function during pre-kindergarten. *Early Childhood Research Quarterly*, *57*(4), 1–11. https://doi.org/10.1016/j.ecresq.2021.04.007

Bedard, C., Bremer, E., Graham, J. D., Chirico, D., & Cairney, J. (2021). Examining the effects of acute cognitively engaging physical activity on cognition in children. *Frontiers in Psychology*, *12*, Article 1775. https://doi.org/10.3389/fpsyg.2021.653133

Bedard, C., St John, L., Bremer, E., Graham, J. D., & Cairney, J. (2019). A systematic review and meta-analysis on the effects of physically active classrooms on educational and enjoyment outcomes in school age children. *PloS one*, *14*(6), e0218633. https://doi.org/10.1371/journal.pone.0218633

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, *21*(4), 327–336. https://doi.org/10.1016/j.lindif.2011.01.007

Biino, V., Tinagli, V., Borioni, F., & Pesce, C. (2021). Cognitively enriched physical activity may foster motor competence and executive function as early as preschool age: A pilot trial. *Physical Education and Sport Pedagogy*. Advance online publication. https://doi.org/10.1080/17408989.2021.1990249

Bowen, D. J., Kreuter, M., Spring, B., Cofta-Woerpel, L., Linnan, L., Weiner, D., Bakken, S., Kaplan, C. P., Squiers, L., Fabrizio, C., & Fernandez, M. (2009). How we design feasibility studies. *American Journal of Preventive Medicine*, *36*(5), 452–457. https://doi.org/10.1016/j.amepre.2009.02.002

Campbell, M. K., Elbourne, D. R., & Altman, D. G. (2004). CONSORT statement: Extension to cluster randomised trials. *BMJ*, *328*(7441), 702–708. https://doi.org/10.1136/bmj.328.7441.702

Carson, V., Lee, E. Y., Hewitt, L., Jennings, C., Hunter, S., Kuzik, N., Stearns J. A., Unrau S. P., Poitras V. J., Gray C., &, Adamo K. B. (2017). Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health*, *17*(5), 33–63. https://doi.org/10.1186/s12889-016-3962-4

Cliff, D. P., Reilly, J. J., & Okely, A. D. (2009). Methodological considerations in using accelerometers to assess habitual physical activity in children aged 0–5 years. *Journal of Science and Medicine in Sport*, *12*(5), 557–567. https://doi.org/10.1016/j.jsams.2008.10.008

Coleman, B., & Dyment, J. E. (2013). Factors that limit and enable preschool-aged children's physical activity on child care centre playgrounds. *Journal of Early Childhood Research*, *11*(3), 203–221. https://doi.org/10.1177/1476718X12456250

Dania, A., Kaltsonoudi, K., Ktistakis, I., Trampa, K., Boti, N., & Pesce, C. (2021). Chess training for improving executive functions and invasion game tactical behavior of college student athletes: A preliminary investigation. *Physical Education and Sport Pedagogy*. Advance online publication. https://doi.org/10.1080/17408989.2021.1990245

Diamond, A. (2010). The evidence base for improving school outcomes by addressing the whole child and by addressing skills and attitudes, not just content. *Early Education and Development*, *21*(5), 780–793. https://doi.org/10.1080/10409289.2010.514522

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Duncan, M., Cunningham, A., & Eyre, E. (2019). A combined movement and story-telling intervention enhances motor competence and language ability in pre-schoolers to a greater extent than movement or story-telling alone. *European Physical Education Review*, *25*(1), 221–235. https://doi.org/10.1177/1356336X17715772

Egger, F., Benzing, V., Conzelmann, A., & Schmidt, M. (2019). Boost your brain, while having a break! The effects of long-term cognitively engaging physical activity breaks on children's executive functions and academic achievement. *PloS one*, *14*(3), e0212482. https://doi.org/10.1371/journal.pone.0212482

Ellis, Y. G., Cliff, D. P., Janssen, X., Jones, R. A., Reilly, J. J., & Okely, A. D. (2017). Sedentary time, physical activity and compliance with IOM recommendations in young children at childcare. *Preventive Medicine Reports*, *7*, 221–226. https://doi.org/10.1016/j.pmedr.2016.12.009

Ellis, Y. G., Cliff, D. P., & Okely, A. D. (2018). Childcare educators' perceptions of and solutions to reducing sitting time in young children: A qualitative study. *Early Childhood Education Journal*, *46*(4), 377–385. https://doi.org/10.1007/s10643-017-0867-5

Eyre, E. L., Clark, C. C., Tallis, J., Hodson, D., Lowton-Smith, S., Nelson, C., Noon, M., & Duncan, M. J. (2020). The effects of combined movement and storytelling intervention on motor skills in south Asian and white children aged 5–6 years living in the United Kingdom. *International Journal of Environmental Research and Public Health*, *17*(10), Article 3391. https://doi.org/10.3390/ijerph17103391

Goodman, R. (1997). The strengths and difficulties questionnaire: A research note. *Journal of Child Psychology and Psychiatry*, *38*(5), 581–586. https://doi.org/10.1111/j.1469-7610.1997.tb01545.x

Harachi, T. W., Abbott, R. D., Catalano, R. F., Haggerty, K. P., & Fleming, C. B. (1999). Opening the black box: Using process evaluation measures to assess implementation and theory building. *American Journal of Community Psychology*, *27*(5), 711–731. https://doi.org/10.1023/A:1022194005511

Heckman, J. J., Moon, S. H., Pinto, R., Savelyev, P. A., & Yavitz, A. (2010). The rate of return to the HighScope Perry Preschool Program. *Journal of Public Economics*, *94*(1–2), 114–128. https://doi.org/10.1016/j.jpubeco.2009.11.001

Howard, S. J., & Melhuish, E. (2017). An early years toolbox for assessing early executive function, language, self-regulation, and social development: Validity, reliability, and preliminary norms. *Journal of Psychoeducational Assessment*, *35*(3), 255–275. https://doi.org/10.1177/0734282916633009

Howard, S. J., Neilsen-Hewett, C., de Rosnay, M., Melhuish, E. C., & Buckley-Walker, K. (2021). Validity, reliability and viability of preschool educators' use of early years toolbox early numeracy. *Australasian Journal of Early Childhood*. Advance online publication. https://doi.org/10.1177/18369391211061188

Howard, S. J., Powell, T., Vasseleu, E., Johnstone, S., & Melhuish, E. (2017). Enhancing preschoolers' executive functions through embedding cognitive activities in shared book reading. *Educational Psychology Review*, *29*(1), 153–174. https://doi.org/10.1007/s10648-016-9364-4

Howard, S. J., Vasseleu, E., Neilsen-Hewett, C., de Rosnay, M., Chan, A. Y. C., Johnstone, S. J., Mavilidi, M., Paas, F., & Melhuish, E. C. (2021). Executive function and self-regulation: Bi-directional associations and prediction of early academic skills. *Frontiers in Psychology*, *12*, e733328. https://doi.org/10.3389/fpsyg.2021.733328

Isbell, R., Sobol, J., Lindauer, L., & Lowrance, A. (2004). The effects of storytelling and story reading on the oral language complexity and story comprehension of young children. *Early Childhood Education Journal*, *32*(3), 157–163. https://doi.org/10.1023/B:ECEJ.0000048967.94189.a3

Janssen, X., Cliff, D. P., Reilly, J. J., Hinkley, T., Jones, R. A., Batterham, M., Ekelund, U., Brage, S., & Okely, A. D. (2013). Predictive validity and classification accuracy of ActiGraph energy expenditure equations and cut-points in young children. *PLoS ONE*, *8*(11), e79124. https://doi.org/10.1371/journal.pone.0079124

Jones, R. A., Okely, A. D., Hinkley, T., Batterham, M., & Burke, C. (2016). Promoting gross motor skills and physical activity in childcare: A translational randomized controlled trial. *Journal of Science and Medicine in Sport*, *19*(9), 744–749. https://doi.org/10.1016/j.jsams.2015.10.006

Liang, J., Matheson, B. E., Kaye, W. H., & Boutelle, K. N. (2014). Neurocognitive correlates of obesity and obesity-related behaviors in children and adolescents. *International Journal of Obesity*, *38*(4), 494–506. https://doi.org/10.1038/ijo.2013.142

Macdonald, K., Milne, N., Pope, R., & Orr, R. (2021). Factors influencing the provision of classroom-based physical activity to students in the early years of primary school: A survey of educators. *Early Childhood Education Journal*, *49*(3), 361–373. https://doi.org/10.1007/s10643-020-01076-y

Mavilidi, M. F., Bennett, S., Paas, F., Okely, A. D., & Vazou, S. (2021). Parents' and Early Childhood Educators's Perceptions on Movement and Learning Program Implementation. *International Journal of Environmental Research and Public Health*, *18*(22), 1–22. https://doi.org/10.3390/ijerph182211913

Mavilidi, M. F., Okely, A. D., Chandler, P., Cliff, D. P., & Paas, F. (2015). Effects of integrated physical exercises and gestures on preschool children's foreign language vocabulary learning. *Educational Psychology Review*, *27*(3), 413–426. https://doi.org/10.1007/s10648-015-9337-z

Mavilidi, M. F., Okely, A., Chandler, P., Domazet, S. L., & Paas, F. (2018). Immediate and delayed effects of integrating physical activity into preschool children's learning of numeracy skills. *Journal of Experimental Child Psychology*, *166*, 502–519. https://doi.org/10.1016/j.jecp.2017.09.009

Mavilidi, M. F., Okely, A. D., Chandler, P., & Paas, F. (2016). Infusing physical activities into the classroom: Effects on preschool children's geography learning. *Mind, Brain, and Education*, *10*(4), 256–263. https://doi.org/10.1111/mbe.12131

Mavilidi, M. F., Okely, A. D., Chandler, P., & Paas, F. (2017). Effects of integrating physical activities into a science lesson on preschool children's learning and enjoyment. *Applied Cognitive Psychology*, *31*(3), 281–290. https://doi.org/10.1002/acp.3325

Mavilidi, M. F., Ouwehand, K., Schmidt, M., Pesce, C., Tomporowski, P. D., Okely, A. D., & Paas, F. (2021). Embodiment as a pedagogical tool to enhance learning. In L. Shapiro & S. Stoltz (Eds.), *The body, embodiment, and education: An interdisciplinary approach* (pp. 183–203). Routledge.

Mavilidi, M. F., Rigoutsos, S., & Venetsanou, F. (2021). Training early childhood educators to promote children's physical activity. *Early Childhood Education Journal*. Advance online publication. https://doi.org/10.1007/s10643-021-01191-4

Mavilidi, M. F., Ruiter, M., Schmidt, M., Okely, A. D., Loyens, S., Chandler, P., & Paas, F. (2018). A narrative review of school-based physical activity for enhancing cognition and learning: The importance of relevancy and integration. *Frontiers in Psychology*, *9*, Article 2079. https://doi.org/10.3389/fpsyg.2018.02079

Mazzoli, E., Salmon, J., Teo, W. P., Pesce, C., He, J., Ben-Soussan, T. D., & Barnett, L. M. (2021). Breaking up classroom sitting time with cognitively engaging physical activity: Behavioural and brain responses. *Plos one*, *16*(7), e0253733. https://doi.org/10.1371/journal.pone.0253733

Norris, E., van Steen, T., Direito, A., & Stamatakis, E. (2019). Physically active lessons in schools and their impact on physical activity, educational, health and cognition outcomes: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *54*(14), 826–838. http://doi.org/10.1136/bjsports-2018-100502

O'Brien, K. T., Vanderloo, L. M., Bruijns, B. A., Truelove, S., & Tucker, P. (2018). Physical activity and sedentary time among preschoolers in centre-based childcare: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 1–16. https://doi.org/10.1186/s12966-018-0745–6

OECD. (2017). *Building skills for all in Australia. Policy insights from the survey of adult skills*. https://www.oecd-ilibrary.org/sites/9789264281110-en/index.html?itemId=/content/publication/9789264281110-en

Owen, K. B., Parker, P. D., Van Zanden, B., MacMillan, F., Astell-Burt, T., & Lonsdale, C. (2016). Physical activity and school engagement in youth: A systematic review and meta-analysis. *Educational Psychologist*, *51*(2), 129–145. https://doi.org/10.1080/00461520.2016.1151793

Pate, R. R., Almeida, M. J., McIver, K. L., Pfeiffer, K. A., & Dowda, M. (2006). Validation and calibration of an accelerometer in preschool children. *Obesity*, *14*(11), 2000–2006. https://doi.org/10.1038/oby.2006.234

Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport and Exercise Psychology*, *34*(6), 766–786. https://doi.org/10.1123/jsep.34.6.766

Pesce, C., Lakes, K. D., Stodden, D. F., & Marchetti, R. (2021). Fostering self-control development with a designed intervention in physical education: A two-year class-randomized trial. *Child Development*, *92*(3), 937–958. https://doi.org/10.1111/cdev.13445

Pesce, C., Vazou, S., Benzing, V., Álvarez-Bueno, C., Anzeneder, S., Mavilidi, M. F., Leone, L., & Schmidt, M. (2021). Effects of chronic physical activity on cognition across the lifespan: A systematic meta-review of randomized controlled trials and realist synthesis of contextualized mechanisms. *International Review of Sport and Exercise Psychology*. Advance online publication. https://doi.org/10.1080/1750984X.2021.1929404

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, *79*(2), 375–394. https://doi.org/10.1111/j.1467-8624.2007.01131.x

Reinert, K. R., Po'e, E. K., & Barkin, S. L. (2013). The relationship between executive function and obesity in children and adolescents: A systematic literature review. *Journal of Obesity*, *2013*, Article 820956. https://doi.org/10.1155/2013/820956

Robinson, T. N. (2010). Stealth interventions for obesity prevention and control: Motivating behavior change. In L. Dube, A. Bechara, A. Dagher, A. Drewnowski, J. Lebel, P. James, & R. Yada (Eds.), *Obesity prevention: The role of brain and society on individual behavior* (pp. 319–328). Elsevier.

Rudd, J. R., O'Callaghan, L., & Williams, J. (2019). Physical education pedagogies built upon theories of movement learning: How can environmental constraints be manipulated to improve children's executive function and self-regulation skills? *International Journal of Environmental Research and Public Health*, *16*(9), 1630. https://doi.org/10.3390/ijerph16091630

Ruffini, C., Spoglianti, S., Bombonato, C., Bonetti, S., Di Lieto, M. C., & Pecini, C. (2021). Dialogic reading to empower executive functions in preschoolers. *Children*, *8*(5), 1–13. https://doi.org/10.3390/children8050373

Schmidt, M., Benzing, V., Wallman-Jones, A., Mavilidi, M. F., Lubans, D. R., & Paas, F. (2019). Embodied learning in the classroom: Effects on primary school children's attention and foreign language vocabulary learning. *Psychology of Sport and Exercise*, *43*, 45–54. https://doi.org/10.1016/j.psychsport.2018.12.017

Schmidt, M., Mavilidi, M. F., Singh, A., & Englert, C. (2020). Combining physical and cognitive training to improve kindergarten children's executive functions: A cluster randomized controlled trial. *Contemporary Educational Psychology*, *63*, Article 101908. https://doi.org/10.1016/j.cedpsych.2020.101908

Schulz, K. F., Altman, D. G., & Moher, D. (2010). CONSORT 2010 statement: Updated guidelines for reporting parallel group randomised trials. *Trials*, *11*(1), 1–8. https://doi.org/10.1186/1745–6215-11-32

Stodden, D., Lakes, K. D., Cote, J., Aadland, E., Brian, A., Draper, C. E., Ekkekakis, P., Fumagalli, G., Laukkanen, A., Mavilidi, M. F., Mazzoli, E., Neville, R. D., Niemosto, D., Rudd, J., Schmidt, M., Tomporowski, P. D., Tortella, P., Vazou, S., & Pesce, C. (2021). Exploration: An overarching focus for holistic development: Exploration and holistic development. *Brazilian Journal of Motor Behavior*, *15*(5), 301–320. https://doi.org/10.20338/bjmb.v15i5.254

Tomporowski, P. D., & Pesce, C. (2019). Exercise, sports, and performance arts benefit cognition via a common process. *Psychological Bulletin*, *145*(9), 929–951. https://doi.org/10.1037/bul0000200

Tomporowski, P. D., & Qazi, A. S. (2020). Cognitive-motor dual task interference effects on declarative memory: A theory-based review. *Frontiers in Psychology*, *11*, Article 1015. https://doi.org/10.3389/fpsyg.2020.01015

Vacha-Haase, T., & Thompson, B. (2004). How to estimate and interpret various effect sizes. *Journal of Counseling Psychology*, *51*(4), 473–481. https://doi.org/10.1037/0022-0167.51.4.473

Vazou, S., Mantis, C., Luze, G., & Krogh, J. S. (2017). Self-perceptions and social–emotional classroom engagement following structured physical activity among preschoolers: A feasibility study. *Journal of Sport and Health Science*, *6*(2), 241–247. https://doi.org/10.1016/j.jshs.2016.01.006

Vazou, S., & Mavilidi, M. F. (2021). Cognitively engaging physical activity for targeting motor, cognitive, social and emotional skills in the preschool classroom: The Move for Thought pre-K–K program. *Frontiers in Psychology*, *12*, Article 5286. https://doi.org/10.3389/fpsyg.2021.729272

Vazou, S., Pesce, C., Lakes, K., & Smiley-Oyen, A. (2019). More than one road leads to Rome: A narrative review and meta-analysis of physical activity intervention effects on cognition in youth. *International Journal of Sport and Exercise Psychology*, *17*(2), 153–178. https://doi.org/10.1080/1612197X.2016.1223423

Vazou, S., Webster, C. A., Stewart, G., Candal, P., Egan, C. A., Pennell, A., & Russ, L. B. (2020). A systematic review and qualitative synthesis resulting in a typology of elementary classroom movement integration interventions. *Sports Medicine-Open*, *6*(1), 1–16. https://doi.org/10.1186/s40798-019-0218-8

Watson, A., Timperio, A., Brown, H., Best, K., & Hesketh, K. D. (2017). Effect of classroom-based physical activity interventions on academic and physical activity outcomes: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 1–24. https://doi.org/10.1186/s12966-017-0569-9

World Health Organization. (2019). *Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age*. https://www.who.int/news/item/24-04-2019-to-grow-up-healthy-children-need-to-sit-less-and-play-more

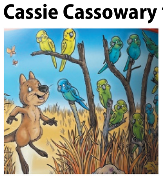
Zimmer, H. D., & Cohen, R. L. (2001). Remembering actions. In H. D. Zimmer, R. L. Cohen, M. J. Guynn, J. Engelkanp, R. Kormi-Nouri, & M.A. Foley (Eds.), *Memory for action: A distinct form of episodic memory?* Oxford University Press

Appendix A. Examples of activities per condition

Activities	Counting	CPA	COG	Control
Cross the river 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: In 1–2 steps, choose grass/rocks/ turtles to cross the other side, moving along with jumps. **Complex**: Adding 3–4 steps, cross the river and come back to the first side, following the same path as before, while hopping on one foot. When you meet the log: lie down and pretend paddling/ swimming. Options: Pair children and ask to hop while holding hands.	**Simple**: In 1–2 steps, point at grass/rocks/ turtles to cross the other side. **Complex**: Adding 3–4 steps, cross the river and come back to the first side, following the same path as before.	Read the story without any actions.
Cora copperhead 'Criss-cross" 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: Run sideways for big fish and squat jump for small fish **Complex**: Opposite actions and different instructions (squat jump—orange fish)	**Simple**: Say "big" when you see a big fish and "small" when you see a small fish. **Complex**: Say "orange" when you see a purple fish" and "purple" when you see an orange fish.	Read the story without any actions.
Serena sea eagle's "Copy me" 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: Copy the expressions and actions of frogs/lizards, adding 1 jump each time you move to a new action. **Complex**: Repeat twice, the second time choose the other animal, while running on the spot each time you move to a new action. Options: Pair children to copy opposite animals.	**Simple**: Copy the expressions of frogs/lizards. **Complex**: Repeat twice, the second time choose the other animal.	Read the story without any actions.
Wesley Wedge-tailed Eagle's "Say the opposite" 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: Say "hiss" when you see a snake and pretend slithering, and "ribbit" when you see a frog and do one frog jump. **Complex**: Say "hiss" when you see a frog and do a frog jump, and "ribbit" when you see a snake and pretend slithering. Options: Ask children to choose one animal and say "hiss/ribbit" only during their turn.	**Simple**: Say "hiss" when you see a snake and "ribbit" when you see a frog **Complex**: Say "hiss" when you see a frog and "ribbit" when you see a snake.	Read the story without any actions.
Gloria Golden "List it back" 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: Remember 2–3 animals and copy their movements. **Complex**: Add more animals (5–6) and copy the movements. Close the book and ask children to recall the animals caught by the spider.	**Simple**: Remember 2–3 animals. **Complex**: Add more animals (5–6). Close the book and ask children to recall the animals caught by the spider.	Read the story without any actions.

(*Continued*)

(Continued).

Activities	Counting	CPA	COG	Control
Dave Dingo's "Do it Differently" 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: Choose one color/shape to follow the path to the stream. Each color/shape corresponds to a different activity (e.g., hopping, walking sideways, crab walking). **Complex**: Choose one color/shape to follow the path to the stream. When you reach the stream, change to a different color/shape and activity (e.g., hopping, walking sideways, crab walking). Options: Add physical objects with similar colours/shapes and ask children to recreate the path.	**Simple**: Choose one color/shape to follow the path to the stream. **Complex**: Choose one color/shape to follow the path to the stream. When you reach the stream, change to a different color/chape.	Read the story without any actions.
Cassie Cassowary "Chirp challenge" 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: When you hear "chirp," say "chirp chirp," and do 2 lunges. When you hear "chirp chirp," say "chirp" and do 1 lunge. **Complex**: When you see a yellow bird, say "chirp chirp," and do 1 star jump. When you see a blue bird say "chirp" and do 2 star jumps.	**Simple**: When you hear "chirp," say "chirp chirp," and when you hear "chirp chirp," say "chirp" **Complex**: When you see a yellow bird, say "chirp chirp," and when you see a blue bird say "chirp."	Read the story without any actions.
Tiger Quoll, Animal Spotter 	Animals **Simple**: 1–20 **Complex**: Backwards	**Simple**: Find hidden animals and repeat their movements. **Complex**: Change the order of the hidden animals and repeat their movements and current positions (e.g., platypus swimming/walking). Close the book and ask children to recall the animals.	**Simple**: Find hidden animals. **Complex**: Change the order of the hidden animals. Close the book and ask children to recall the animals.	Read the story without any actions.

Physical activity options: Running on the spot, high knees, lunges, jump high/low, scissors, walking sideways/backwards, star jumps, crab walking, frog jump. Alternate across activities and variations (i.e., simple/complex).

Appendix B. Results of pilot data

	Baseline *M (SD)*			4-weeks *M (SD)*		
	Condition					
Variables	CPA (n = 3)	COG (n = 2)	Control (n = 1)	CPA (n = 3)	COG (n = 2)	Control (n = 1)
Working memory	2 (1)	1.83 (1.18)	1.3*	1 (0.7)	1.66 (0.47)	0*
Inhibition	0.53 (0.18)	0.69 (0.39)	0.58*	0.65 (0.07)	0.8 (0.2)	0.45*
Shifting	8.3 (2.1)	9 (1.4)	9*	9.3 (1.54)	9.5 (0.70)	6*
Numeracy	14 (5.2)	18.5 (16.3)	15*	18 (4.3)	29 (22.6)	29*
Externalizing problems	2.2 (0.4)	2.2 (1.1)	2.4*	1.9 (0.4)	2.2 (0.9)	2.2*
Internalizing problems	1.5 (0.6)	2.0 (0.8)	1.6*	1.0 (0.0)	1.7 (0.7)	1.6*
Prosocial behavior	4.1 (0.3)	3.9 (0.4)	4.4*	4.1 (0.1)	3.7 (0.1)	4.2*
Behavioral self-regulation	4.1 (0.1)	3.4 (0.6)	3.7*	4.1 (0.4)	3.5 (0.9)	3.5*
Cognitive self-regulation	3.2 (0.7)	3.6 (0.6)	3.8*	4.0 (0.3)	3.6 (0.0)	3.6*
Emotional self-regulation	3.6 (0.5)	3.4 (0.6)	3.0*	3.8 (0.4)	3.3 (0.1)	3.2*
Enjoyment				4.8 (0.3)	2.8 (2.5)	4*

Note: CPA = Cognitively engaging physical activity group; COG = Cognition group; *M* = Mean; *SD* = Standard Deviation.
*Actual score from 1 participant.

Self-regulation was reported by parents completing the *Child Self-Regulation & Behavior Questionnaire* (CSBQ; Howard & Melhuish, 2017) on an iPad. This questionnaire includes 34 items related to typical children's everyday behaviors (e.g., 'Persists with difficult tasks'). Each item was rated on a 5-point Likert scale ranging from 1, 'Not true' to 5, 'Certainly true.' Ratings on individual items were averaged to generate subscales of cognitive, behavioral and emotional self-regulation, prosocial behavior, sociability, internalizing problems and externalizing problems.