PHYSICAL ACTIVITY BEHAVIOR, COGNITION AND PSYCHOLOGICAL WELL-BEING IN EDUCATIONAL SETTINGS

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PHYSICAL ACTIVITY BEHAVIOR, COGNITION AND PSYCHOLOGICAL WELL-BEING IN EDUCATIONAL SETTINGS

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Cognitively Engaging Physical Activity for Targeting Motor, Cognitive, Social, and Emotional Skills in the Preschool Classroom: The Move for Thought preK-K Program

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Despite the growing body of research indicating that integrated physical activity with learning benefits children both physically and cognitively, preschool curricula with integrated physical activities are scarce. The "Move for Thought (M4T) preK-K" program provides activities on fundamental motor skills that are integrated with academic concepts, executive function, and social-emotional skills in the preschool environment. The aim of this study was to evaluate the feasibility, usability, and effectiveness of the M4T preK-K program over an eight-week period in 16 preschool centers ($N = 273$; $M_{age} = 4.22$ $SD = 0.61$) that were randomly assigned to the intervention (8 M4T; $n = 138$; $M_{age} = 4.31$ $SD = 0.61$) and the control (8 traditional; $n = 135$; $M_{age} = 4.13$ $SD = 0.60$) group. In both groups, teacher ratings of children's attention, behavioral control, and social skills (i.e., cooperation, assertion, and self-control) in the classroom, as well as children's perceived motor skill competence and executive functions, were collected before and after the intervention. A daily teacher log measured intervention fidelity and perceived experiences with the program. Results showed a significant improvement on attention scores for children in the M4T preK-K group, compared to the control group. No significant differences emerged for behavioral control, social skills, executive functions, and perceived motor competence among groups. A significant time effect was evident for executive functions, with both groups improving over time. Further, the program was well-received, easy to implement in the preschool classroom and with high rates of satisfaction for both children and teachers. The M4T preK-K program is promising in helping teachers prepare preschool children for future educational success.

Keywords: integrated learning, early education, attention, behavioral control, perceived competence, hot executive functions , cool executive functions

INTRODUCTION

Pioneering research has placed training of goal-directed behaviors responsible for thinking, acting, and problem-solving (i.e., executive function skills) as the main target areas for young children's cognitive development (Diamond and Lee, 2011). Students who learn to acknowledge and regulate emotions, form positive relationships, work well with their peers, and deal effectively with conflict, exhibit stronger executive function skills and self-regulation, and thrive in the school environment (Denham and Brown, 2010; Eisenberg et al., 2010; Nadeem et al., 2010). A bidirectional developmental model argues that brain areas linked with executive functions reciprocally interact with those areas underlying attention control, stress physiology, and emotion (Blair and Ursache, 2011). Notably, executive functions and self-regulation are both influenced by experience and have been shown to predict academic performance in later school years (Bull and Scerif, 2001; Bull et al., 2008; Blair and Ursache, 2011; Durlak et al., 2011).

However, recent evidence distinguishes between cool (i.e., cognitive) and hot (i.e., affective) executive functions corresponding to different neural trajectories in the prefrontal cortex (Leshem et al., 2020). Hot executive functions are associated with the orbitofrontal cortex, anatomically suited for the integration of affective and non-affective information, and regulation of motivated responses (Happaney et al., 2004). Thus, they are addressing social and emotional skills, based on emotion regulation (Garon, 2016; Pesce et al., 2020). Cool executive functions are linked to the lateral prefrontal cortex and can be elicited by abstract, decontextualized problems, and affective neutral conditions (e.g., sorting by shape or size; Pesce et al., 2020). The core executive function skills consist of inhibition (i.e., the ability to stay focused and resist temptations), working memory (i.e., the ability to information in mind while mentally working with it), and cognitive flexibility (i.e., the ability to easily and quickly switch focus of attention; Diamond, 2013).

A recent meta-analysis found that training executive function skills can be more effective and enjoyable for children when is embedded in everyday activities, such as constantly challenging games (Takacs and Kassai, 2019). For example, the "Tools of Mind" program, initially, was based on Vygotski's theory and in particular on the notion that learning promotes cognitive development when it occurs within a sociocultural context (Bodrova and Leong, 2006). This program has been expanded nowadays primarily in private education, known as Montessori pedagogy, offering activities for promoting both cool and hot executive functions, including self-regulatory private speech (e.g., telling yourself what to do), dramatic play and aids to facilitate memory and attention. It was found that preschool children in the intervention group that used the Tools of the Mind program had highest scores in executive function tasks, especially the most demanding ones, than children in the control group (Diamond et al., 2007). Practices targeting social and emotional learning, such as children following directions, taking turns and sharing, persisting at challenging tasks, creating greater enjoyment for school, and paying attention, have been identified in the literature as vital for school programs to be effective, especially if those qualities are also integrated with academic learning (Bierman et al., 2017).

Child development experts emphasized that to optimize academic outcomes, the environment needs to target both cool and hot executive functions by nurturing the social, emotional, physical, and cognitive abilities of children (Diamond and Ling, 2016; Bierman et al., 2017). In 2010, Diamond argued toward a whole-child approach by addressing skills and attitudes instead of content. In particular, she stated that the most efficient and cost-effective ways to enhance children's academic outcomes are to focus on academic, social, emotion, and physical development. To this vein, physical health can also be enhanced by targeting emotional, social, and cognitive wellness (Diamond, 2010). Nearly a decade later, Tomporowski and Pesce (2019) advocated that skills acquisition is the common underlying mechanism during training of motor and cognitive tasks, evident in exercise, sports, and performance arts. When dual tasks (i.e., motor and cognitive) are performed simultaneously, mental processes activated may enhance declarative memory (Tomporowski and Qazi, 2020).

Physical activity participation and motor skill development offer substantial benefits for preschool children's physical, motor, cognitive, and psychosocial development (Bart et al., 2007; Piek et al., 2008; Carson et al., 2017). Benefits of physical activity in preschool children include improved motor development and fitness, as well as bone and skeletal health (Carson et al., 2017). Physical activity in children and adolescents has been shown to improve academic achievement, student engagement, executive function skills, and metacognition (Owen et al., 2016; Álvarez-Bueno et al., 2017a,b). Recent recommendations by the World Health Organization (2019) suggest that preschool children should spend at least 180 min in a variety of types of physical activity at any intensity, of which at least 60 min is moderate-to-vigorous intensity physical activity, spread throughout the day. Children with high levels of actual and perceived physical competence (i.e., ability or perceived ability to perform motor tasks) are more likely to engage in higher level of physical activity, with mutual benefits on both areas of physical competence and activity (Stodden et al., 2008; Barnett et al., 2015).

Early childhood centers are important settings because children spend a large amount of their waking hours there (OECD, 2017). However, physical activity is becoming compromised as children are mostly engaged in sedentary activities (O'Brien et al., 2018). The integration of physical activity in the academic classroom has received increased interest by educators, researchers, and professional organizations (Institute of Medicine, 2013; ASCD, 2014; Webster et al., 2015), and the number of intervention programs has rapidly increased during the last decade (Vazou et al., 2020). A body of research on movement integration (i.e., physically active lessons or active breaks and cognitively engaging physical activity) has shown physical and cognitive benefits in children and adolescents (e.g., academic achievement and on-task behavior; Watson et al., 2017; Daly-Smith et al., 2018; Bedard et al., 2019; Norris et al., 2020).

Research in the area of cognitively engaging physical activity is leaning toward the qualitative characteristics (e.g., task novelty, complexity, and selection of mental strategies for problem-solving), rather than the quantitative aspects (i.e., dose, intensity, and duration) of physical activity (Pesce, 2012). Current empirical evidence is mainly targeting cool executive functions. For instance, in a six-week program, 14 kindergarten classes were randomly assigned to one of the three experimental conditions (Schmidt et al., 2020): In the physical-cognitive condition, children were engaged with games combining physical and cognitive demands. These games were adapted from original common games (e.g., Simon says) but inherently included training of cool executive function skills (e.g., rule changes and response to target stimuli and inhibit from non-target stimuli). The cognitive condition included the same game with the physical-cognitive condition, but children were engaged with fine motor movements of light intensity. Finally, children in the control condition did not alter their usual daily practice. Results showed that the physical-cognitive and cognitive conditions elicited improvements on children's updating performance, with children reporting equal levels of enjoyment, but no changes on inhibition and shifting. In the "Red Light, Purple Light" program, preschool children practiced inhibition with physically active games during circle time. Greater gains were found in self-regulation and academic achievement over the preschool year for the intervention group (Schmitt et al., 2015), as well as significant gains in letter-word identification after an 8-week implementation period (Tominey and McClelland, 2011).

Few physical activity programs have included hot executive functions: For instance, the "Animal Fun" program with duration of 6 months imitated animal movements to enhance preschool children's social and behavioral outcomes (Piek et al., 2015). Children's prosocial behavior and inattention were improved after 6 months and maintained after 18 months of follow-up. Acute positive effects on verbal and social engagement in the classroom were evident after structured physical activity lessons that challenged executive functions and social-emotional skills, compared to the non-physically active days in preschoolers (Vazou et al., 2017). Other programs, including sport games, found less peer-relationship and emotional problems as well as higher scores in prosocial behaviors of preschool children (Griffith et al., 2010). Physical play in the classroom was found to be positively related to emotional competence (i.e., peer relationships) in boys (Linsey and Colwell, 2003).

Overall, despite the strong consensus among educators, researchers, and policy makers that education should have a more holistic approach with equal focus on cognitive, social-emotional, and physical development (ASCD, 2014; Bierman et al., 2017), classroom-based physical activity programs targeting explicitly psychosocial, cognitive and physical development, are lacking. Physical activity programs, including both cool and hot executive functions in early education, are scarce (Diamond and Lee, 2011; Vazou et al., 2019). This is one of the very few studies designed in the preschool classroom, combining a whole-child approach, integrating physical activity with academic content, executive functions, and social-emotional skills (self-regulation, self- and social awareness, and relationships skills). The program focused on providing enjoyable and cognitively engaging physical activities targeting motor skill development, as well as regulation of executive function and social–emotional skills. Concomitantly, social environment is fundamental in influencing feelings of competence and social acceptance, which is also, impacting motivation and behavior (Harter, 1978).

The present feasibility study was designed to help researchers and practitioners determine whether the "Move for Thought (M4T) preK-K" program should be recommended for a larger scale and potentially implemented as a physical activity program on preschool children's motor, socio-emotional, and cognitive skills. Our study goals were aligned with current literature emphasizing the importance of early examinations of the feasibility of interventions with a focus on acceptability, demand, implementation, practicality, and limited-efficacy testing (Bowen et al., 2009). Specifically, the first purpose was to examine the feasibility and usability of the M4T preK-K program on children's physical and cognitive engagement during the preschool day. The second purpose was to assess effectiveness of the program by examining changes in children's attention and behavioral control, social skills, executive functions, and perceived motor skill competence, from the beginning to the end of the intervention period. It was expected that children would manifest improved social and cognitive skills as well as perceived motor skill competence and executive functions, at the end of the implementation of the M4T preK-K program, compared to the control group.

MATERIALS AND METHODS

Participants

Participants included 273 preschool children 3–5 years and their early childhood educators (n = 16) from 16 preschool classrooms across the State of Iowa. Preschool education is not mandatory in the United States. Children were randomly assigned to the intervention (8 classrooms, 138 children) or control conditions (8 classrooms, 135 children). Some outcomes (EF and perceived motor competence) were collected with a subsample from the existing sample, consisting of 141 children from 4 control ($n = 73$, $M_{age} = 4.00$ $SD = 0.61$) and 4 intervention preschool classrooms ($n = 70$, $M_{age} = 4.34$ $SD = 0.62$). The study was exempt from the State University Institutional Review Board as the activities were offered as part of the regular instructional strategies by teachers and no children were identified in the data collection (student list was coded by the teachers). Teacher's and school's consent were obtained before the implementation of the program. Children's assent was obtained before each testing. Parents were informed about the study and could have their child opt out from the data collection if desired.

Children's and teachers' demographic characteristics are presented in **Table 1** whereas the flow of participants in portrayed in **Figure 1**.

Experimental Design

This study involved a randomized controlled trial at the school level. Randomization occurred after the pretest assessments using a computer-based algorithm by an independent researcher. Children were not aware of the purpose of the study or the experimental conditions. Implementation was done at the class level by the preschool teacher during regular classroom activities and school hours. All teachers were blind to the conditions and were informed that they would receive access to the M4T preK-K resources either immediately or at a later time due to limited research support (i.e., the control group received delayed implementation upon completion of the program for the intervention group).

Procedure

Outcome measures were assessed by early childhood educators at pretest and at the end of 8 weeks for both groups. The full sample was assessed by early childhood educators on attention, behavioral control, assertion, cooperation, and self-control. Moreover, a subsample of children was assessed on inhibition and perceived motor skill competence at the preschool center individually by trained research assistants blinded to the experimental conditions.

Upon completion of the pretest measures, the intervention group received a printed copy of the M4T preK-K resources (book with the activities, CD with the M4T preK-K music, supporting academic materials, such as flashcards with pictures from the recommended literacy books) and a printed copy of the daily teacher log. An 1 h of training (webinar) was provided by the research team to the intervention group to become familiar with the program and the questionnaires. During the implementation period, early childhood educators in the intervention group completed the teacher log daily whenever they included a M4T preK-K activity during the preschool day. In the control group, teachers were instructed to continue with their usual practices without any changes in their regular instructional format.

Intervention

The teachers in the intervention group were instructed to use one cognitively engaging physical activity per day from the M4T preK-K program, for eight consecutive weeks during fall and before the holiday break. No further instructions were provided as the goal was for teachers to have the autonomy to select which, when, and how to integrate the physical activities during the school day, based on their students' needs and their own level of comfort. This approach was followed to increase external and ecological validity by evaluating the real-world feasibility of the intervention. The M4T preK-K program was developed for children in the preschool and kindergarten environment and includes a total of 57 activities for large group, small group, and transitions in the classroom, as well as outdoor activities for large play areas, without the need of expensive equipment apart from the already existing ones in the preschool and kindergarten environment (e.g., popular age-appropriate children's books, scarves, beanbags, small balls, tape, and hula hoops). The duration of the activities can vary based on the level of integration and the goals of the teacher, with some activities being very short (2–3 min; e.g., transitions), some lasting for 15–20 min (e.g., when explaining concepts like what comes first, next, and last in a story or a book), while the majority of the activities aimed to last about 10 min. All activities have recommendations for progression and for additional challenges. The M4T preK-K program is freely available on the website of Iowa State University.[1]

Each activity in the M4T preK-K program was designed to assist in meeting physical activity needs, improving physical

[1]www.moveforthought.org

TABLE 1 | Baseline characteristics of study sample.

Characteristics	Intervention ($n = 130$)	Control ($n = 129$)	*t*-test	*p*
Child age (in years), mean (SD)	4.31 (0.61)	4.13 (0.60)		
Child female participants, n (%)	63 (48.5%)	61 (47.2%)		
Preschools	4	6		
Classrooms (No of teachers)	8	8		
Female teachers	7	8		
Age of teacher (years), mean (SD)	36.5 (7.67)	41 (15.07)	0.57	0.464
Race of teacher	100% White	100% White		
Years teaching preschool, mean (SD)	10.25 (9.03)	9.94 (7.20)	0.006	0.940
Size of preschool	3 small schools (4–7 staff)	3 small schools (3 staff)		
N children in classroom	16.50	17.75		
N children per preschool, mean (SD)	84.12 (58.09)	85.37 (58.88)	0.002	0.967
Low parental income*	49%	75%	1.34	0.271
Full-day program	6 classes	7 classes		
Headstart classes*	2	3		
PA throughout preschool day	120.63 min (37.74)	131.25 min (73.77)	0.132	0.722

*PA, physical activity *as an indicator of low socioeconomic status.*

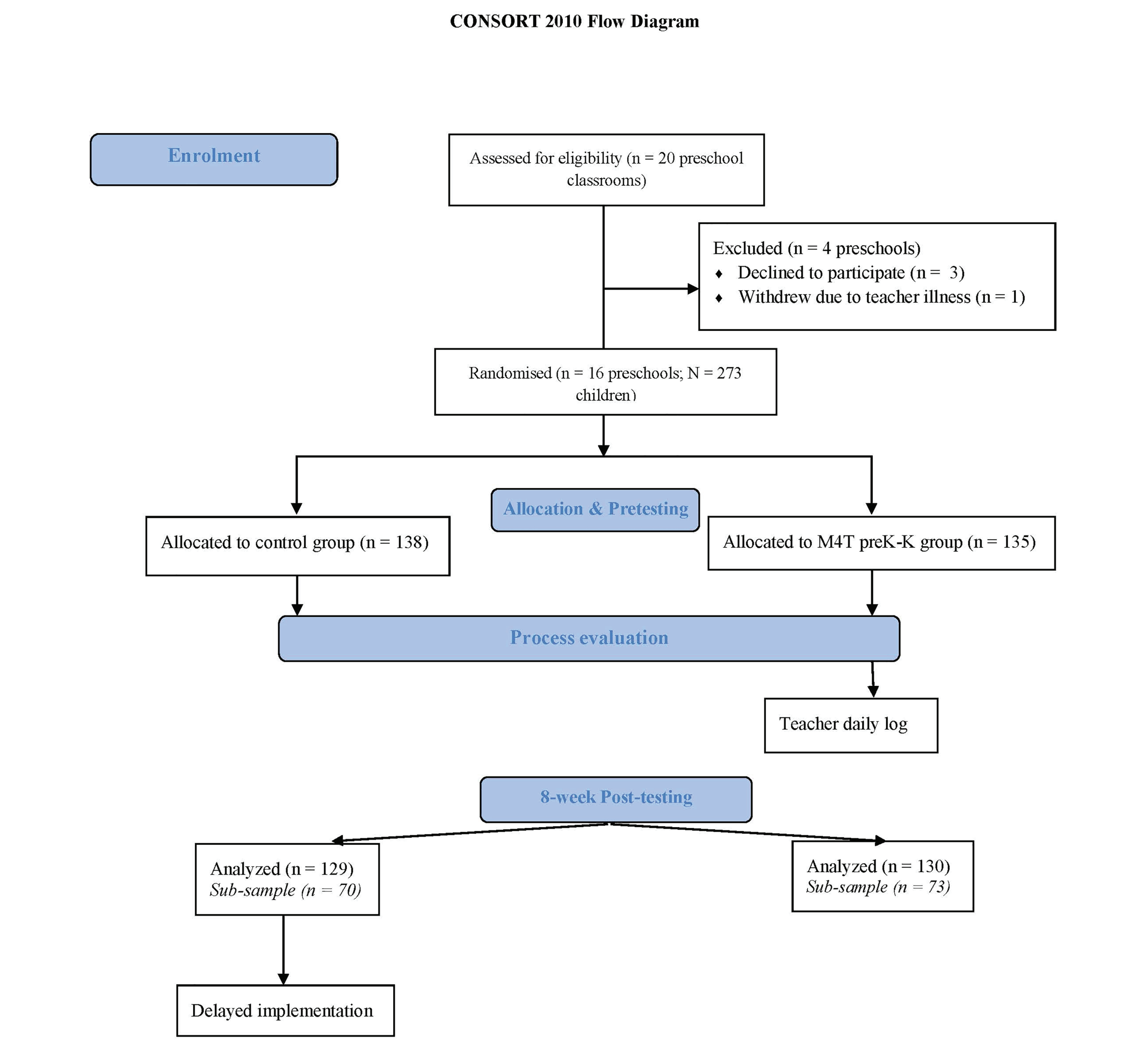

FIGURE 1 | Flow Chart of Participants.

literacy and fundamental gross motor skills (locomotor, non-locomotor, and manipulative skills) and adopt a "whole-child" approach by practicing children's physical, cognitive, social, and emotional skills. More specifically, in the M4T preK-K program, each activity aimed to help children: (1) achieve fundamental motor skill goals through modification and developmentally appropriate progression after practice and learning, (2) practice and be assessed in physical, cognitive, socio-emotional and academic domain, (3) explore rhythmic and musical concepts through singing and dancing in original music, (4) explore age-appropriate popular books and develop positive experiences with math, literacy, and learning, (5) feel autonomous by encouraging them to have choices and self-exploration, (6) self-regulate by identifying emotions, practicing self-control, cognitive flexibility, and responsible decision making, and (7) develop social awareness and relationship skills by cooperating, sharing, and communicating with others through positive interactions with peers and their teachers. **Figure 2** (panels A and B) provides an example of the structure and components of the M4T preK-K activities for each skill area. As shown in the figure, each activity includes the MOVE and CARE acronyms that refer to: MOVE-Mission (name of activity), Organization (instructions for activity; e.g., set up and equipment required), Variations (suggestions for progression in more complex motor tasks), Extra tips to keep children motivated. CARE stands for: Choose (different options

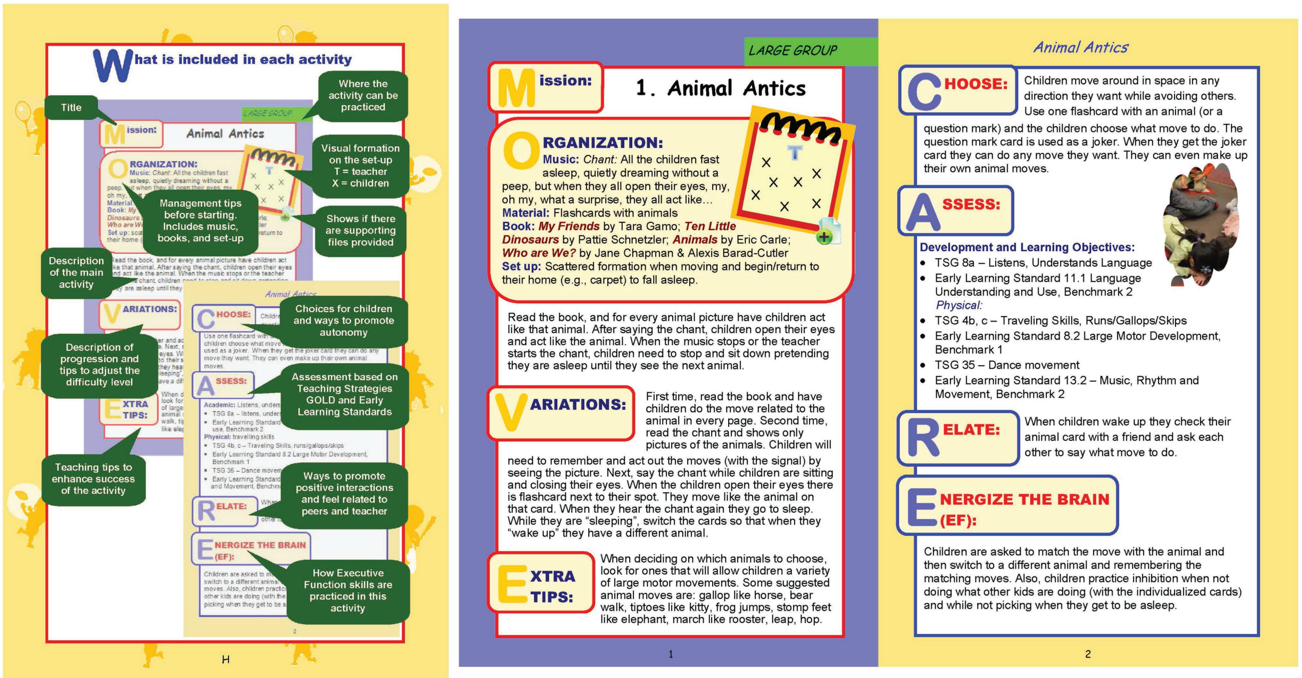

FIGURE 2 | Example of "Move for Thought" preK-K Activities.

to support autonomy), Assess (assessments based on preschool learning standards), Relate (recommendations for training peer social awareness and relationship skills among children), and Energize the brain (examples to train executive functions).

Measures

Demographic information was received *via* a questionnaire completed by teachers. The full sample of children was assessed on:

Attention and Behavioral Control in the Classroom

Attention (9 items) and Behavioral Control (i.e., 9 items) in the classroom was measured using the 18-item Strength and Weaknesses of ADHD symptoms and normal behavior (SWAN) questionnaire (Swanson et al., 2012). Teachers responded on a 7-point Likert scale ranging from 1 "far below average" to 7 "far above average" for each student. Example questions include "settle down and rest (control constant activity)" for behavioral control and "Gives close attention to detail and avoids careless mistakes" for attention. The SWAN questionnaire has been distributed in a number of population-based studies with clinical and typical development groups, producing normal distributions in school-based studies, and having high internal consistency ($\alpha = 0.94–0.95$; Swanson et al., 2012). It has also been shown to be appropriate from children as young as preschool (Lakes et al., 2012). Cronbach's α coefficients of internal consistency were high ($\alpha = 0.94–0.95$) for both factors.

Hot Executive Function Skills

Cooperation, Assertion, and Self-Control in the classroom was used using the 30-item Social Skills Rating Scale questionnaire (Gresham and Elliot, 1990). The Cooperation subscale includes behaviors such as helping others, sharing materials, and complying with rules. The Assertion subscale includes initiating behaviors, such as asking others for information, and responding to the actions of others. The Self-control subscale includes behaviors that emerge in conflict situations (e.g., responding to teasing) and in non-conflict situations (e.g., taking turns and compromising). Teachers responded on a 3-point Likert scale ranging from 1 "never" to 3 "very often." Example questions include "participates in game" and "follows directions" (i.e., cooperation), "invites others" and "make friends" (i.e., assertion), and "waits turns" and "accepts peer ideas" (i.e., self-control). This questionnaire has been previously used in preschool children (Frey et al., 2011). In the current study, the alpha coefficient of internal consistency was high for all factors ($\alpha = 0.87–0.94$).

The subsample was also assessed on:

Cool Executive Function Skills

The computerized Stroop-like "DayNight" (Gerstadt et al., 1994) was used to measure inhibition and task switching. The test consisted of a set of pictures showing either a picture of the moon or the picture of the sun. Children were instructed to say "day" to a picture of moon and "night" to a picture of sun (e.g., "When you see the picture of a sun, I want you to say "night"). During this task, the child must inhibit and switch simultaneously to provide the correct answer without receiving any feedback. The task included 2 practice trials (up to 3 practice sessions if the child misses either trial in practice) and 16 testing trials (half are sun pictures and half are moon pictures). The stimulus presentation time was 1500 ms. Children's answers were recorded with a microphone and were processed using the Audacity software. Children received 1 point for correct responses, with an aggregated score for accuracy.

Perceived Movement Skill Competence

The "Pictorial scale for Perceived Movement Skill Competence (PMSC) for young children" (Barnett et al., 2016) tool was used. The 12-item questionnaire assesses six locomotor (run, gallop, hop, leap, horizontal jump, and slide) and six object control skills (striking a stationary ball, stationary dribble, catch, overhand throw, and underhand roll). A pictorial plate presentation format is used, comprising of two gender-specific pictures displayed side by side. The pictures depict one child competent in a particular task and a child who is not. Children are asked to choose the picture that represents them the most (e.g., picture that looks more like him/her). If children choose the competent picture, they are asked "are you really good at ….?." Children's responses score in a 4-point Likert scale between 1, "poorly skilled child" to 4, "highly skilled child." Cronbach's alpha coefficient of internal consistency was acceptable ($\alpha = 0.81$, 0.77, for pre and post-test, respectively).

Process Evaluation

Daily Teacher Log

Session fidelity in the intervention group was recorded by early childhood educators on a daily basis. If there were no M4T preK-K activities on a particular day, the daily log was not completed. The daily long included questions regarding: (1) name, frequency, and duration of M4T preK-K activities, (2) area the activity was conducted, and (3) teacher overall experience from the M4T preK-K program, which was broken down into:

1. Teacher and child satisfaction on the M4T preK-K activities, on 5-point scale (1, "very unsatisfied" to 5, "very satisfied").
2. Children's physical and cognitive engagement during M4T preK-K activities, on a 3-point scale (1, "not at all" to 3, "very").
3. Evidence of children's engagement regarding working with others, regulating emotions, and exhibiting self-control ("yes" or "no" checklist).

Upon completion of the implementation period, teacher overall reflection in implementing the M4T program was measured. Using a 5-point scale (1 = not at all to 5 = very much), teacher's ability to: (1) lead physical activities in the classroom, (2) teach motor skills, (3) implement the M4T preK-K program, and (4) implement variations of the activities (progression) were reported by teachers. Further, teachers were asked whether they believed they needed additional training on how to use the M4T preK-K activities during the implementation period, using the same response scale.

Statistical Analyses

Data derived from the teacher logs were analyzed with Excel and are presented descriptively. Statistical analyses were conducted using IBM SPSS (version 26), and alpha level was set at $p < 0.05$ for the quantitative data. Mixed ANOVAs were conducted with two groups (intervention vs. control) for the between-subject factor and two time points (pre vs. post) for the within-subject factor, separately for each outcome. To account for the nesting nature of the data, follow-up analyses of the significant outcomes were conducted using linear mixed models in IBM SPSS Statistics, version 26.0 (2010 SPSS Inc., IBM Company). Linear mixed models adjusted for clustering at the class level were used to assess the impact of the group (M4T, AB or control), time (treated as categorical with levels baseline and 8 weeks), and the group-by-time interaction. A random intercept was used to account for the repeated measures of each participant. Cohen's d provided a measure of effect size (adjusted difference between intervention and control group over time divided by the pooled standard deviation of change; Vacha-Haase and Thompson, 2004). Cohen's $d = 0.2$ were considered small, $d = 0.5$ medium, $d = 0.8$ as large effect sizes (Cohen, 1988; Vacha-Haase and Thompson, 2004).

RESULTS

A summary of the detailed descriptive statistics of the outcomes is presented on **Table 2**.

Mixed Analyses of Variance

Attention

Both the main effect of time [$F(1, 255) = 13.00$, $p < 0.001$, $\eta^2 = 0.048$] and interaction between time and condition [$F(1, 255) = 11.18$, $p < 0.001$, $\eta^2 = 0.028$] on children's attention scores were found significant. The main effect of condition [$F(1, 255) < 1$, $p = 0.734$] was not significant. At post-test, both groups improved their scores; however, the intervention group outperformed the control group. After accounting for the nesting nature of the data, the interaction between time and condition on children's attention was significant for the intervention group (Adjusted mean difference = 0.26, 95% CI 0.06 to 0.45, $p = 0.013$) but not for the control group (Adjusted mean difference = 0.03 CI −0.17 to 0.23, $p = 0.757$).

Behavioral Control

The main effects of time [$F(1, 255) = 1.36$, $p = 0.245$] and condition [$F(1, 255) < 1$, $p = 0.496$] on children's behavioral control scores were not significant. However, the interaction between time and condition [$F(1, 255) = 11.71$, $p < 0.001$, $\eta^2 = 0.044$] was significant. At post-test, the intervention group performed better than the control. After accounting for the nesting nature of the data, the interaction between time and condition on children's behavioral control was not significant (Adjusted mean difference = 0.24, 95% CI −0.04 to 0.52, $p = 0.094$).

TABLE 2 | Means (and standard deviations) per outcome as a function of condition.

Variables	Move for Thought				Control			
	N	Pre M (SD)	Post M (SD)	Post-pre ES	N	Pre M (SD)	Post M (SD)	Post-pre ES
Attention[a] *(SWAN)*	129	4.12 (0.74)	4.36 (0.76)	0.32	128	4.21 (0.81)	4.21 (0.76)	0.00
Behavioral Control[a] *(SWAN)*	129	4.07 (0.75)	4.24 (0.81)	0.22	128	4.26 (0.90)	4.18 (0.75)	−0.10
Hot Executive Functions Assertion[b] *(SSRS)*	130	2.35 (0.68)	2.43 (0.62)	0.12	129	2.40 (0.66)	2.42 (0.76)	0.03
Cooperation[b] *(SSRS)*	130	2.69 (0.56)	2.70 (0.53)	0.02	129	2.73 (0.47)	2.70 (0.47)	−0.06
Self-Control[b] *(SSRS)*	130	2.49 (0.61)	2.51 (0.63)	0.03	129	2.67 (0.49)	2.66 (0.49)	−0.02
Cool Executive Function[c] *(DayNight)*	53	10.94 (4.59)	11.93 (4.16)	0.23	52	10.39 (4.77)	12.00 (4.00)	0.37
Perceived FMS[d] *(PMSC)*	55	3.35 (0.56)	3.36 (0.50)	0.02	47	3.40 (0.47)	3.53 (0.50)	0.27

M, mean; SD, Standard deviation; Post-pre Effect Size (ES), Cohen's d; FMS, Fundamental movement skills.
[a]*5-point Likert scale.*
[b]*3-point Likert scale.*
[c]*accuracy scores.*
[d]*4-point Likert scale.*

Hot Executive Function Skills

There were no main effects of time [$F(1, 257) < 1$, $p = 0.439$] and condition [$F(1, 257) < 1$, $p = 0.743$] on children's cooperation skills. In addition, the interaction between and time and condition was not significant [$F(1, 257) = 1.04$, $p = 0.310$].

There were no main effects of time [$F(1, 257) = 2.4$, $p = 0.122$] and condition [$F(1, 257) < 1$, $p = 0.778$] on children's assertion skills. Also, the interaction between time and condition was not significant [$F(1, 257) < 1$, $p = 0.364$].

The main effects of time [$F(1, 257) < 1$, $p = 0.859$] and interaction between time and condition [$F(1, 257) < 1$, $p = 0.447$] were not significant on self-control skills. However, the main effect of condition [$F(1, 257) = 6.48$, $p = 0.012$] was statistically significant. Regardless of time, the intervention group had lower scores on self-control, compared to the control group.

Cool Executive Function Skills

The main effect of time was found to be significant [$F(1, 103) = 8.78$, $p = 0.004$]. However, the main effect of condition [$F(1, 103) < 1$, $p = 0.744$] and the interaction between time and condition were not significant [$F(1, 103) < 1$, $p = 0.471$].

Perceived Fundamental Movement Skills

The main effects of time [$F(1, 100) = 1.44$, $p = 0.233$], condition [$F(1, 100) = 1.80$, $p = 0.182$], and interaction between time and condition [$F(1, 100) = 1.25$, $p = 0.267$] were not significant.

Process Evaluation

Teacher Log Data

All early childhood educators (8/8) returned the daily teacher log. They reported that the dose of the intervention was implemented as intended on average 98% ($SD = 0.10$), meaning once per day. The average duration of each session was 10.65 min ($SD = 3.17$). Early childhood educators reported high satisfaction with the program and activities ($M = 4.23/5$, $SD = 0.45$), as well as high satisfaction from the children ($M = 4.12/5$, $SD = 0.69$). Early childhood educators reported that children were both physically ($M = 2.81/3$, $SD = 0.12$) and cognitively engaged ($M = 2.59/3$, $SD = 0.35$) during the M4T preK-K activities. Finally, teachers reported that children during the M4T sessions were given several opportunities to exhibiting self-control ($M = 85\%$, $SD = 0.14$), whereas the focus on regulating emotions ($M = 35\%$, $SD = 0.67$) and working with others ($M = 42\%$, $SD = 0.29$) was less evident.

The majority of the activities were conducted inside the classroom ($M = 65\%$, $SD = 0.14$). Alternatively, activities were conducted in the common area ($M = 23\%$, $SD = 0.13$), while only few occurred outside ($M = 7\%$, $SD = 0.05$). One-fourth of the times the early childhood educators used the supporting files ($M = 22\%$, $SD = 0.17$), and about one-third of the lessons incorporated the M4T preK-K music ($M = 31\%$, $SD = 0.15$). Detailed responses per class are portrayed in **Figure 3**. Further, teachers' confidence in their ability to teach motor skills and PA in the classroom, in general, was 4.5/5 ($SD = 0.53$), to implement the M4T preK-K program was 4.43 ($SD = 0.53$), and to implement variation of the M4T preK-K (as a progression) was 4.37 ($SD = 0.52$). Lastly, the teachers reported low to somewhat need for additional training on the M4T preK-K program ($M = 2.12$, $SD = 0.64$).

DISCUSSION

This study examined the feasibility, usability, and effectiveness of an 8-week intervention study in preschool children with the M4T preK-K program that integrated physical activity with academic content, executive function, social, and emotional skills. The study targeted improving children's attention and behavioral control, social skills, executive functions, and perceived motor skill competence, which are acknowledged as crucial for school readiness and academic success. Results showed that children's attention was significantly improved after the intervention, compared to the control group. However, behavioral control, social skills, inhibition on a computerized task, and perceived motor competence were not improved for both groups. In addition, intervention fidelity results showed that the implementation of short (i.e., around 10 min) M4T preK-K sessions daily was a feasible and realistic goal for preschool children, who were both physically and cognitively engaged.

Confirming our hypotheses, children's attention performance improved significantly after participating in cognitively engaging physical activities, compared to the control group. However, children's behavioral control scores remained unaffected. The high levels of cognitive engagement were also evident in the teachers' daily log, reporting that during the M4T preK-K sessions, children were both physically and cognitively engaged. These results are in line with previous literature, supporting that integrating physical activity during learning process can contribute to cognitive benefits in children without compromising academic time (Mavilidi et al., 2018, 2019). For example, a series of studies found improved learning outcomes in preschool children when integrating physical activity during several academic domains, such as language, geography, math, and science (Mavilidi et al., 2015, 2016, 2017, 2018; Toumpaniari et al., 2015). Notably, the preschool environment is typically the first structured environment for young children, so training programs that help children exhibit higher levels of self-regulation in the classroom are beneficial for school readiness and constitute an aspirational goal in the educational system (Greenberg and Weissberg, 2018).

The M4T preK-K program was predicated on the idea that providing physical activities in the classroom in integration with cognitive (literacy books and academic content) and motor skills is both appropriate and beneficial for the children's development. Emerging evidence suggests that we should shift the focus of quantitative characteristics (e.g., dose, intensity, and frequency) toward qualitative characteristics of physical activity (e.g., movement coordination, type, novelty, and complexity of movement, activation of mental strategies; Pesce, 2012; Vazou et al., 2019). In particular, the role of motor competence in the exercise-cognition interplay is essential (van der Fels et al., 2015; Tomporowski and Pesce, 2019).

In this study, children's perceptions of motor skill competence were measured for object control and locomotor skills, as practiced in the M4T preK-K program, with no significant changes for both groups. The absence of a significant change in perhaps unsurprising considering the self-reported nature of the scale and that the sample was a little younger than the typical age the scale has been used before ($M_{age} = 4.2$, $SD = 0.60$, in this study, whereas $M_{age} = 4.7$, $SD = 0.46$ and $M_{age} = 6.5$, $SD = 0.8$, in the Barnett et al., 2015, 2016, respectively). Children that young tend to have relatively undifferentiated and exaggerated perceptions of competence as they lack extensive experience in applying those skills in games, which might result in low validity of the scale. The lack of a clear perception on motor skill competence may have led to a ceiling effect, as evidenced by the very high scores of 3.35–3.55 on a 4-point scale (with $SD = 0.50$). Overcoming this limitation of the study, future research can consider (1) the use of objectively measures of motor skill competence and (2) the use of accelerometers to account for the intensity of physical activities (Cliff et al., 2009).

Importantly, the current study was consisted of cognitively engaging physical activity in the form of challenging games with continuous change of rules and instructions with simultaneous focus on preacademic concepts. Research shows that these qualitative characteristics may transform physical activity into meaningful learning experiences for cognitive development (Pesce et al., 2019). Cognitively engaging physical activity which combines motor and cognitive tasks may act as brain stimulators, explicitly training skills, such as executive functions (Diamond and Ling, 2016; Pesce and Ben-Soussan, 2016). For example, a recent study in preschool children found improvements in updating performance after participating in games consisting cognitively engaging physical activity (Schmidt et al., 2020). However, even though there were significant changes on attention, contrary to our hypothesis, there were no significant differences between groups on inhibitory control, as measured with the subsample. All children regardless of their group improved on the sun/moon task from the beginning to the end of the 8-week period, which likely reflects a learning effect, possibly modulated by the environment and experience. The non-significant differences among groups could be attributed to the small subsample size, which is a limitation of this study, possible methodological challenges with the task due to the young age of the sample (e.g., accurate measure of perceived competence in young children), and/or insufficient dose of implementation. A replication of this finding with a large sample and with a longer intervention (more weeks) is warranted.

Of note, the vast body of current research focuses mostly on executive functions, with rare examples existing targeting hot executive functions (Diamond and Lee, 2011; Vazou et al., 2017; Pesce et al., 2020). For example, a mindful martial arts training program occurring two-three 45-min sessions/week for 3 months in children from kindergarten through Grade 5 found improvements on their cognitive, affective, and physical self-regulation, as well as classroom conduct and prosocial behavior (Lakes and Hoyt, 2004). The present study included training of children's social and emotional self-regulation skills. However, contrary to previous literature, we did not find any changes between the control and intervention group at end of the program (Lakes and Hoyt, 2004; Diamond et al., 2007; Piek et al., 2015; Vazou et al., 2017). Assertion and cooperation skills remained stable for both groups whereas self-control skills, as well as inhibitory control skills, improved for both groups.

As reported by early childhood educators, fidelity check evaluations confirmed that teachers targeted more on children's physical and cognitive engagement and less on practicing their social and emotional skills (see **Figure 3**, panel F). In fact, in some classes, activities engaging children with "regulating emotions" and "working with others" were absent. "Exhibiting self-control" was practiced more often. If early childhood educators did not engage children's social and emotional skills as intended per protocol, it is logical to assume that there could not be improvements after the end of the program on such skills. Interestingly, this program provided with instructions and variations to task complexity based on children's responses and progress level as increased scaffold. However, early childhood educators chose to implement the easiest options of the activities. Possibly, early childhood educators lack deeper understanding on improving social and emotional skills in integration with physical activity in preschool children or lack time to explore and progress on the more advanced versions of the activities without any guidance or support. The training included in this study was very limited as we wanted to explore the level of feasibility of the program based on teachers' existing experience and knowledge. Hence, it is evident that future research should incorporate more explicit guidance through concrete examples (e.g., video-based resources) to support teachers on progression and implementation of these components.

Another possible explanation for the null findings of this study on hot and cool executive function skills could be attributed to the short duration of the program. Previous studies had substantially longer durations (e.g., 3 months, Lakes and Hoyt, 2004; 6 months with sustained effects at 18-month follow-up, Piek et al., 2015; 1–2 years; Diamond et al., 2007). Of note, the post-intervention effect sizes of the intervention group are small but positive compared to the pre-intervention values, whereas in the control group are smaller for assertion (M4T preK-K ES = 0.12 vs. control ES = 0.02), and negative for cooperation and self-control. Longer duration of the program may have been able to provoke larger effects.

Finally, another purpose of the study was to examine the feasibility and usability of the M4T preK-K program. The results based on the daily teacher logs were positive. The duration of M4T preK-K program was well-received by early childhood educators with the dose of the physical activity sessions delivered as intended (98% and an average duration of approximately 10 min daily). Both early childhood educators and children reported high levels of satisfaction with the program (**Figure 3**). These findings are very encouraging rendering this approach as an effective solution for overcoming teacher barriers related to lack of time (Naylor et al., 2015). Furthermore, this program was found to be feasible, with potential for future acceptability, adaptation, and implementation by early childhood educators.

Despite the fact that this study focused on the feasibility and effectiveness of the M4T preK-K program on preschoolers, the activities expand to the Kindergarten years. Programs with cognitively engaging physical activity aiming at kindergarten children may offer a smoother transition to the school environment. Previous research found kindergarten to be more responsive to improvements on attention and behavioral control compared to preschool and 2nd grade children (Vazou et al., 2021). Further examination of the feasibility and effectiveness of the program with kindergarteners is warranted. Additionally, a replication of the study with a larger sample in a cluster randomized controlled trial of longer duration should be considered in the future. It is important to note that the

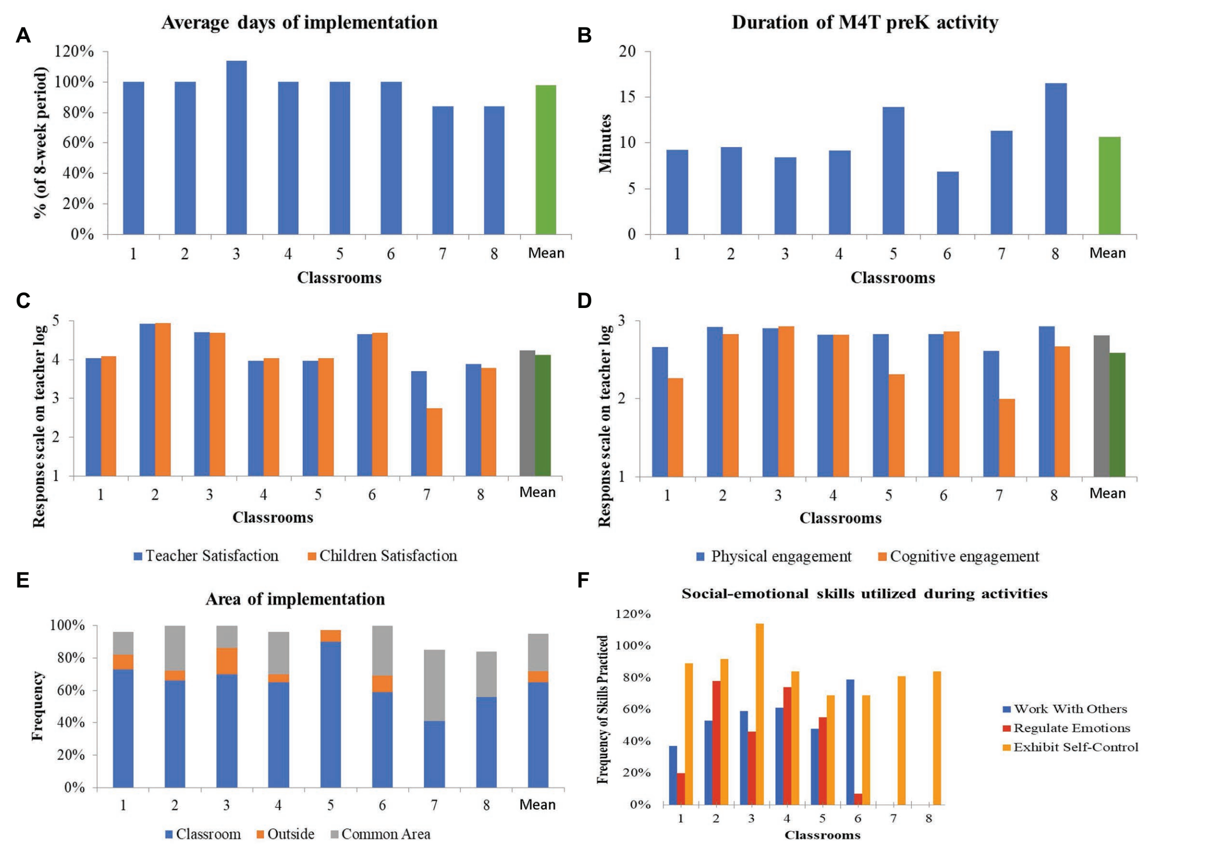

FIGURE 3 | Process Evaluation Results for Intervention Class. **Panel A:** Days of Implementation, **Panel B:** Average Duration of a M4T preK-K Activity, **Panel C:** Teacher and Student Satisfaction from Implementation, **Panel D:** Level of Physical and Cognitive Engagement during Implementation, **Panel E:** Area of Implementation, and **Panel F:** Social-Emotional Skills (Working with Others, Regulating Emotions, Exhibiting Self-Control) Practiced During Implementation.

small sample size of this study (especially for the subsample) limits statistical power and restricts generalizability to the broader population of preschoolers. Notably, the significant results on children's attention scores were completed by the not-blinded teachers, while measures which were executed by blinded research assistants were not significant. Another limitation of the study was the measurement of the outcome variables with the teacher reported scales, presenting challenges for possible biases in providing desirable responses, even though such scales are acceptable in research involving preschool children. Overall, intervention programs in children need to be tailored based on children's age, skill levels, and cognitive development.

Nevertheless, an undisputable strength of the present study is its inclusion of both cool and hot executive function skills. To the best of our knowledge, there is no other such physical program existing for preschool children in the academic classroom. In particular, the emphasis of the present study on enhancing preschool children's cognitive, motor, social, and emotional skills through integrating physical activity during the classroom instruction provides a unique contribution to the field. Programs usually include only one element, most commonly cool executive functions, whereas programs on hot executive functions are scarce.

Diamond (2015, p.963) proposed that interventions that improve executive functions: (1) train and challenge diverse motor and executive function skills, (2) bring joy, pride, and self-confidence, and (3) provide a sense of belonging. Concomitantly, training of executive function skills has been shown to be more enjoyable and effective when is incorporated in everyday activities and games (Takacs and Kassai, 2019). The current program included all these components and is aligned with self-determination theory, advocating that relatedness, competence, and autonomy are comprising the basic psychological needs, contributing to intrinsic motivation and positive motivational outcomes (e.g., commitment, effort; Ryan and Deci, 2000). Indeed, there was a clear focus of the program on team work and collaboration.

Lastly, the inclusion of evaluation of the implementation and delivery of the program constitute another strength of the present study. The findings from fidelity checklists showed that pragmatic implementation of the program was successful, permitting for greater confidence in generalizing the findings to real-world school settings. A recent systematic review showed that around half of the interventions with movement integration were researcher-led, undermining their possibilities for sustainability, dissemination, and scalability (Vazou et al., 2020). It was concluded that regarding delivery of interventions, researchers should be more consistent on reporting fidelity.

CONCLUSION

Physical activity programs could serve as the basis of a holistic approach to child development, supporting not only physical health but also cognitive, motor, social, and emotional benefits in children (Diamond and Ling, 2016; Carson et al., 2017). The present study was well-received by early childhood educators and children, providing evidence of the feasibility and usability of a physical activity program integrating with academic instruction, with potential benefits on children's cognitive, social, and emotional skills. Promoting interventions in early childhood is fundamental for school readiness, academic performance, and success in career and life in the long-term (Moffitt et al., 2011).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Iowa State University. Written informed consent from the participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SV: contributed in all steps of the study (conceptualization, methodology, supervision, analysis, and writing). MM: analysis, writing, and interpretation of the results. All authors reviewed and approved the final manuscript.

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Individual Differences in the Effects of Physical Activity on Classroom Behaviour

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Background: Promoting physical activity (PA) in children is associated with a wide range of desired outcomes. With children increasingly not meeting recommended levels of activity, the school setting offers many opportunities to improve this. Increasing children's on-task behaviour is of particular importance to teachers, and while it has previously been suggested that PA can improve classroom behaviour, a consensus on the dose-response relationship of PA content, and its interaction with children's individual differences, is yet to be reached. This study aimed to investigate this relationship more closely and assess the differences between objective and subjective measures of PA intensity.

Method: Data was collected from 76 primary school-aged children (*M* age = 9.3 years, *SD* = 0.7 years; 46 females). The PE lesson intervention followed a 3 (intensity: low, medium, high) by 2 (complexity: low, high) within-person design. Children's task-behaviour was observed pre- and post-the intervention PE lesson during "business as usual" classroom lesson. PA was measured objectively with wrist-worn accelerometer devices for 24 h before the intervention, and subjectively rated on a five-point Likert scale after each intervention lesson.

Results: The results indicated a difference in subjective and objective measures of PA intensity on children's on-task behaviour. Objective measures positively predicted task-behaviour at moderate to high intensities, whereas subjective ratings were beneficial only at sub-maximal intensity. Findings suggested that boys' on-task behaviour improved at higher intensities, whereas girls were also responsive to lower intensity lessons. Less active children showed more improvement in on-task behaviour after a range of lessons, whereas more active children only benefited from the highest intensity lessons. Finally, children exhibiting the highest levels of off-task behaviour improved their on-task behaviour after all intervention lessons.

Conclusion: The findings suggest that higher intensities of PA have a generally positive effect on children's subsequent behaviour, although certain individual characteristics make children more responsive to lower PA intensities. Furthermore, passive off-task behaviours were less prevalent after lower-intensity PA. Thus, individual differences, as well as the target behaviour, are important factors to take into account when designing optimal PE lessons for improving classroom behaviour.

Keywords: physical activity, physical education, objective intensity, subjective intensity, classroom behaviour

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1 INTRODUCTION

Children and adolescents around the world are not meeting the minimum daily requirement of moderate-to-vigorous physical activity (MVPA), with only one in four children aged 11 being sufficiently active in 2017/18 (Inchley et al., 2020), and a declining trend from early adolescence into early adulthood (van Sluijs et al., 2021). Physical activity (PA) is widely accepted to be beneficial to physical, mental, and cognitive health, both during childhood and into later life (van Sluijs et al., 2021), making PA behaviour in youth a crucial target for interventions. The school environment is widely accepted to be a fitting setting to implement PA. Especially as many children are limited in their opportunities for exercise available to them, school becomes the ideal environment to ensure that children have the opportunity to partake in PA (Mahar, 2011). Yet, recent meta-analyses show that PA interventions in schools fail to reach the desired outcome of increasing activity levels in youth, and especially in girls (Owen et al., 2017; van Sluijs et al., 2021). Coupled with a trend in schools for decreasing the time allocated to breaks and PE lessons, increasing PA participation in schools is an imperative topic to investigate. It is vital to develop an intervention that will successfully engage students in the activity while also yielding the desired outcomes across physical, mental, and cognitive health domains. We investigated the dose-response relationship between the PA content of PE lessons (complexity, objective, and subjective intensity—the dose) and subsequent task-behaviour in primary school classrooms (the response), and whether this relationship differed based on the individual characteristics of the participants (BMI, sex, habitual PA, and baseline task-related behaviour). We posed the following research questions:

1) Is there a difference between the effects of subjective and objective measures of PA intensity on on-task behaviour?
2) Does the response to PA differ for passive and active off-task behaviours?
3) Are there specific sub-samples of participants who respond more or less favourably to PA? And if so, which subgroups and which PA parameters?

We hypothesised that 1) higher intensity PA would have the greatest positive effect (Ma et al., 2014), and that this response would not differ between subjective and objective measures of PA. Based on the cognitive-energetic model (Unsworth & Robinson, 2020), we expected that 2) active off-task behaviours would be most strongly reduced after medium and high intensity PA. Yet, for passive off-task behaviour, we expected that medium, but not high intensity PA would lead to the greatest reduction, as high intensity PA may induce tiredness rather than a state of activation. Finally, we expected 3) more positive effects for all PA types and intensities for children who have lower baseline on-task behaviour (Mahar et al., 2006), for boys (van Sluijs et al., 2021), and for those who are more regularly active (Jäger et al., 2015). We did not expect to find effects of BMI (Martin et al., 2018).

To increase PA levels in children, Beets et al. (2016) suggest the theory of expanded, extended, and enhanced opportunities for physical activity. Although this theory is not limited to PA opportunities in schools, all three strategies are applicable to the school setting. Expanding involves increasing the frequency of MVPA opportunities (i.e., more breaks or PE lessons), extending means increasing the duration of MVPA opportunities (i.e., longer breaks), and enhancing is improving the quality of the PA opportunities available to increase the amount of MVPA (i.e., reducing time spent listening to instructions, quicker transitions between tasks). The PA opportunities in schools need to be of high quality, implementing developmentally appropriate activities which children will benefit from the most: improving their physical, mental, and cognitive health, including behaviour, executive functions and other developmental outcomes. Moreover, these interventions need to be designed for sustained, large-scale implementation (van Sluijs et al., 2021).

1.1 PA and Learning Behaviour

There is increasing evidence that behavioural engagement in the classroom, operationalised as time-on-task or on-task behaviour, is improved by PA (Masini et al., 2020). Studies in both pre-adolescents (e.g., De Greeff et al., 2016) and adolescents (e.g. Kubesch et al., 2009; Mavilidi et al., 2021) indicate that attention and on-task behaviour are positively affected by PA. Although results are heterogeneous, for example Goh et al. (2018) finding no significant improvement in on-task behaviour post-intervention, the majority of studies investigating on-task behaviour in primary school classrooms have found positive effects of PA on time-on-task (e.g., De Greeff et al., 2018; Masini et al., 2020). This improvement in task-focus has been attributed to the break from school work provided by a physical activity (Mavilidi et al., 2019), improved executive functions, including inhibition (Vogan et al., 2018; Mahar, 2019), and improvements in affective state (Lubans et al., 2016; Burns et al., 2017). The focus in the wider literature appears to be on improving on-task behaviour, while reduction in off-task behaviour is implied, and less often measured or reported explicitly. Literature on the specific nature of off-task behaviours (passive or active) in relation to PA is scarce and this study contributes to this field by not only investigating the effects of PA on on-task behaviour, but also on passive and active off-task behaviours separately. Ma et al. (2014) found that both active and passive off-task behaviour in 2nd and 4th grade pupils was reduced after PA breaks. Active off-task behaviours, in particular motor behaviour, were reduced more greatly than passive off-task behaviours (ES = 0.31–0.45 vs ES = 0.48–1.08) in their study (Ma et al., 2014). On the contrary, Snyder et al. (2017) found a significant reduction in passive off-task behaviour in their intervention classroom compared with the control classroom, and no significant effect for off-task active behaviours in the intervention group. Therefore, some ambiguity in the findings is present and this emphasises the need to further investigate and differentiate off-task behaviours. A common characteristic of numerous studies is the nature of the interventions being classroom-based (e.g., Goh et al., 2016;

Snyder et al., 2017; Goh et al., 2018; Maykel et al., 2018), whereas the present study aims to assess a purposefully designed PE lesson intervention instead. Therefore, this is a further gap in the literature that we aim to contribute to.

1.1.1 Physical Activity Intensity

Vigorous PA is important to physical health. For example, Buchan et al. (2011) found moderate and high intensity PA to significantly improve physical fitness, but only high intensity PA improved physiological outcomes such as systolic blood pressure. There appears to also be a favorable indication that, compared to low intensity, more vigorous PA is related to both achievement and elements of cognitive development. Cross-sectional findings suggest that the intensity of PA needs to be over a certain threshold to have an association with academic achievement; Ayan et al. (2014) found a positive correlation between higher achievement and more PA at high intensities in children aged 12–14. Similar findings were identified in younger children, where those who partook in vigorous PA scored higher on measures of school readiness and self-regulation (Kybartas et al., 2021).

Acute PA intensity has also been directly linked to on-task behaviour. The cognitive-energetic model (Unsworth & Robinson, 2020) poses that a physical state of activation after PA—and in particular when this is coupled with feelings of positivity—has a beneficial impact on cognitive performance and behaviours. The percentage of PA time spent at MVPA has been positively associated with the percentage of time-on-task during subsequent instructional time (Szabo-Reed et al., 2017). And, in another investigation of on-task behaviour, Grieco et al. (2016) found that behavioural engagement increased far more after moderate-to-vigorous (ES = 1.22) than low-to-moderate intensity (ES = 0.43) PA breaks.

However, in their meta-analysis, Sember et al. (2020) noted that a limitation in many studies investigating classroom PA interventions is that the intensity of the physical activity implemented is not reported. In fact, they suggest that PA improves academic achievement not only through increased frequency of PA, but also the intensity. Therefore, in the present study it was decided to measure PA both objectively and subjectively, using accelerometer watches and children's self-reports, respectively. A complication in vigorous PA promotion in school settings is that, for many, objective PA intensity recording is not practical without the involvement of research teams and the practicality and cost of measuring equipment. And, as interventions need to be not only effective, but applicable at a larger scale (van Sluijs et al., 2021), this study investigated objective and subjective PA intensity alongside each other. Therefore, it was important for this research to incorporate subjective PA in order to establish whether children's subjective perceptions of exertion are comparable to objectively measured ratings in terms of their relationship to subsequent task-related behaviour. Subjective ratings of intensity can easily be obtained by teachers during PE lessons or PA breaks to monitor PA intensity, making them a vital aspect of school-based PA research.

1.1.2 Physical Activity Complexity

In recent years, complex, or cognitively engaging, and PA is increasingly being investigated. It is assumed that during PA, the overlapping brain regions for motor skills and cognitive functions vital to learning and attention are stimulated, which facilitates subsequent learning activity (Steinlin, 2007). Recent studies have concluded that a combination of MVPA and cognitively engagement in chronic PA is most beneficial to academic performance (Egger et al., 2019; de Bruijn et al., 2020) and executive functions (Ishihara et al., 2017), although not all studies found cognitive engagement to enhance the effects of PA interventions. For example, Meijer et al. (2021) found that the MVPA content of the intervention predicted cognitive outcomes beyond the element of cognitive engagement during PA. The acute effects of cognitively engaging PA are equally unclear, with Egger et al. (2018) reporting a deterioration in shifting performance in children directly after complex PA, whilst Benzing et al. (2016) found that cognitive flexibility of young male adolescents was improved after cognitively engaging PA. Finally, no main effect of complexity on subsequent on-task behaviour was found in the current sample in previously published results (Heemskerk et al., 2019).

1.2 Individual Characteristics

This study investigated the role of individual characteristics in the relationship between acute PA and task-behaviour. Characteristics included in the analyses are BMI, sex, habitual PA participation, and baseline task-related behaviour in the classroom.

1.2.1 Baseline Task-Behaviour

Children who spent less than 50% of instructional time on-task in the study by Mahar et al. (2006) responded far more strongly to PA breaks and improved their on-task behaviour with an effect size of d = 2.2. Although it may seem obvious that those who start at a lower baseline have more room for improvement, and thus may respond more strongly to interventions, this still has strong educational implications. When students are off-task, they not only affect their own learning potential, but also that of those around them (Godwin & Fisher, 2011). This is particularly the case when the off-task behaviour is active, which can disrupt whole classrooms. This study specifically investigated how PA influences those students who have the lowest levels of on-task behaviour, as well as those with the highest levels of both passive and active off-task behaviours.

1.2.2 Sex

Although childhood inactivity is a problem in both boys and girls (Inchley et al., 2020), girls have been found to be between 5 and 30% less active than boys (Jurakić & Pedišić, 2013) and to benefit less from PA interventions in the school setting (Owen et al., 2017; van Sluijs et al., 2021). Individual studies have found differences in effects based on sex; Ma et al. (2014) reported favourable results for boys; although passive off-task behaviour was reduced in both sexes, and only boys reduced their active off-task behaviour. However, Wilson et al. (2016), in an all-boys sample, found no results of PA breaks outside of the classroom. And Grieco et al. (2016) found that changes in on-task behaviour after PA were unrelated to sex, fitness level, and or BMI.

1.2.3 Habitual Physical Activity

Participation in leisure time PA has been positively linked to academic outcomes in children (Erickson et al., 2015). Moreover, Syväoja et al. (2018) found that aerobic fitness—an outcome of regular exercise—positively mediated the relationship between PA and academic achievement in 9–15 year-olds. These studies did not, however, assess children's response to *acute* PA in light of their regular PA or level of fitness. Jäger et al. (2015) did find that the acute effects of a PA intervention session on executive functioning were significant only in higher-fit participants. This result related to updating performance, not inhibition or working memory, and no measure of behavioural engagement was involved in this study (Jäger et al., 2015).

1.2.4 BMI

Results on the role of BMI in the effect of PA on task-behaviour are sparse. Often, overweight and obese samples are investigated in isolation, or BMI is used as a control variable rather than a predictor. In a systematic review of PA interventions for overweight and obese youth, Martin et al. (2018) found no evidence of increased inhibition control after PA. This is in line with the results from a study by Mora-Gonzalez et al. (2019), who found no association of chronic MVPA or sedentary time with EF in an overweight and obese sample. In contrast to these results, Sun et al. (2021) report a standardised mean difference of SMD = 0.30 [95% CI 0.002–0.600] for chronic PA on core EF in studies of obese and overweight children. This is somewhat greater than the effect found by Álvarez-Bueno et al. (2017) in a meta-analysis including studies of both healthy- and overweight children (ES 0.20, [95% CI 0.10–0.30]). Moreover, for the domain of inhibition and selective attention, they carried out a subgroup analysis based on weight status. They report an effect size for the whole sample of ES = 0.26 [95% CI 0.10–0.41], and an overweight and obese subgroup effect size of ES = -0.02 [95% CI −0.22–0.17], suggesting a smaller effect of PA on inhibition and selective attention in overweight and obese children, compared to healthy-weight children (Álvarez-Bueno et al., 2017). Finally, in a review of studies on the effects of chronic PA and weight-status on cognitive performance, Chang et al. (2017) concluded that in studies applying models where the effects of chronic PA were moderated by BMI, results have been inconclusive. Worse effects for those with higher BMI were reported in studies with samples of morbidly obese adults, whilst a mixture of positive and null results were found in studies with children (Chang et al., 2017).

Results from studies of acute PA are also mixed. In a laboratory-based study, Vazou and Smiley-Oyen (2014) found that PA prevented the worsening of reaction times on a standard flanker task (a measure of inhibition) only in overweight children. Reaction times of healthy-weight children remained stable after both the physically active and seated maths conditions, whereas overweight children performed worse after the seated, but not the active maths task (Vazou & Smiley-Oyen, 2014), suggesting that BMI positively moderates the effect of PA on cognition. Yet, in a classroom-based study with a sample of both overweight and healthy-weight children, and specific to on-task behaviour, Grieco et al. (2016) found that the effects of PA in children aged 7 to 9 did not differ based on BMI. Moreover, Grieco et al. (2016) report that, although on-task behaviour decreased more greatly during inactive classroom lessons in children with higher BMI, PA intensity did not interact with BMI.

TABLE 1 | Sample descriptives.

Variable	Categories	*n*	*M*/%	*SD*	Min	Max	n_{ti}[1]
Age (years)		76	9.25	0.66	7.90	10.44	
BMI[2]		76	0.60	1.27	−1.55	3.71	
Observations		76	49.7	1.2	40	50	38,933
Self-reports	Classroom	76	29.7	7.1	2	36	2,259
	PE	76	5.5	0.9	1	6	418
Sex	Girl	46	60.5%				
	Boy	30	39.5%				
Handedness	Left	10	13.2%				
	Right	66	86.8%				
Year group	Y3	12	15.8%				
	Y4	39	51.3%				
	Y5	25	32.9%				
Attainment	below ARE[3]	12	15.8%				
	at ARE	35	46.1%				
	above ARE	29	38.2%				
Active child[4]	yes	35	58.3%				
	no	25	41.7%				

Note: [1] Total number of items, nested in weeks, nested in participants. [2] BMI z-score for age and sex, based on WHO guidelines (de Onis et al., 2007). [3] ARE = Age-Related Expectation for academic achievement. [4] Active child = achieved government recommendation for physical activity (Chief Medical Officers, 2019) on at least 75% of recorded study days.

2 MATERIALS AND METHODS

2.1 Sample and Procedure

The study obtained ethical approval from the Departmental Research Ethics Committee at the University of Oxford Department of Education. A total sample of 108 children from grades 3–5 of four primary schools in Oxfordshire, South-East England were recruited to be part of the study. Sufficient data for analysis was available from 76 children (*M* age = 9.3 years, *SD* = 0.7 years; 46 females), including valid behaviour observations and objective and subjective PA records. Written consent was obtained from parents allowing their children to participate. Prior to commencing the study, all child participants also provided written assent and their weight and height were recorded using digital scales (Salter, model 9018 SSV3R) and measuring tape. This allowed for BMI z-scores to be calculated for each child in accordance with WHO parameters for age- and sex-adjusted BMI (M = 0.60, range = −1.55–3.71). To measure objective PA, child participants wore GENEActiv accelerometers (Activeinsights, 2012) on the wrist of their non-dominant hand. The research team fitted the accelerometers on the children prior to them leaving school on the day before the intervention was to take place, so that children wore the accelerometers for 24 h. Teachers rated participants' level of academic achievement on a 3-point scale: below, at, or above age-related expectation (ARE). As on-task behaviour is considered a prerequisite for positive academic outcomes (Fredricks et al., 2004), we used these teacher ratings to control for academic achievement level in all analyses. See **Table 1** for a full overview of the sample descriptives.

The design of the PE lesson intervention followed a 3 (intensity: low, medium, or high) by 2 (complexity: low or high) within-person design, with the order of lessons in each classroom being randomised. For a more detailed description of every individual PE lesson please consult previous publication (Heemskerk et al., 2019). Twelve children were observed during "business as usual" classroom lessons pre- and post-the PE intervention lesson, by two trained researchers using a momentary time sampling protocol. Some transition time occurred as children returned to the classroom after the PE lessons. Between classes, the process for transition to the classroom was the same (plenary, questionnaire, lining up, and walking back to the classroom without getting changed back into uniform). Within classes, the transition time was similar across the six conditions, and as the distance traveled from PE to the classroom was the same each week. Both the children and teachers were encouraged to resume the regular lesson post-PE as quickly and seamlessly as possible. Observations resumed when both observers agreed that the teacher was initiating the classroom lesson. In order to maintain ecological validity, this process was not timed or controlled across classrooms. It is likely and expected that some children would re-focus more quickly and easily than others, and this is some of the naturally occurring variance we aimed to capture an investigate.

In cases where more than twelve children had parental consent, the class teacher chose the twelve students to take part in the study to ensure an even distribution of sex and academic achievement. In addition, children rated their learning experiences at the start, middle and end of each observation period, and at the end of the PE lesson, and using a purpose-built app.

2.2 Physical Activity

The six intervention lessons were designed in accordance with the United Kingdom National Curriculum for PE requirements, which includes athletics, health-related fitness, games and dance. No specialist equipment was required for any of the lessons, and the minimal equipment used for some lessons was already available in the schools. Two PE lessons each were designed to ensure the participants reached adequate levels of VPA, MPA, and LPA. The intensity level was manipulated by adjusting the pace of movements (walking, jogging, or sprinting), the amount of locomotion required (stationary drills or moving) and the amount of vertical movement (jumping). For example, in one low intensity lesson, children worked on flexibility and flexibility testing, whereas in the high intensity lesson they performed sprinting races and sprint relays. At each of the three intensity levels, one of two lessons required simple and automated movements, while the other challenged participants with more complex movements, external pacing and/or rapidly changing environments the children needed to adapt to. For example, in the low complexity high intensity lesson, the participants sprinted in straight lines, which is an automated movement for children. In the corresponding high complexity lesson, they did aerobics. This involved music-directed pacing and the complex combination of arm and leg movements.

Children's activity levels were tracked using the accelerometer devices during the PE lessons, as well as their free-living PA, which was recorded for up to 24 h leading up to the intervention lesson. The activity recordings of the PE lessons were removed from the free-living PA data for analysis purposes. The free-living data was used to ascertain whether children met the United Kingdom government's 60 min of daily MVPA guideline (Chief Medical Officers, 2019).

2.3 Self-Reports

Children reported their learning experiences (task enjoyment, perceived task difficulty, tiredness, positive, and negative affect) on a 6-point Likert scale, three times during their regular classroom lesson before and after the PE intervention, and once after the PE lesson. As this was a repeated measure, the questionnaire was kept short and concise and took around 30 s to complete. Affect was measured with eight items (four positive, four negative), using the question "How do you feel right now?". In the classroom, enjoyment, difficulty, and tiredness were measured by one item each ("Do you like doing this task?", "How hard is this task?", and "Are you tired?", respectively). Affect and tiredness in the classroom were not analysed in the context of the results presented here. Classroom task enjoyment and perceived difficulty were used as control variables, as the lessons before and after PE were on different subjects. At the end of PE lessons, with one item each, participants rated how much they had enjoyed the PE lesson and provided their rate of perceived exertion (RPE) as a subjective measure of the PE lesson intensity, using the same 6-point Likert scale. A 7-step version of Borg's RPE scale has previously been validated for use with children (Groslambert et al., 2001). We decided to keep to our 6-point scale for conformity with the other questionnaire items. Answer options were simplified with the use of emoji's (Rane, 2017) and were given as a rating from zero to five stars.

2.4 Behaviour Observations

Two trained researchers carried out the observations; their inter-rater reliability was good (Cohen's Kappa = 0.8). The observation protocol required the observers to record each participants' behaviour every 30 s for 25 min. Each observation was rated as either "on-task" if the child showed goal-directed behaviours and was completing a task as set by the teacher, "off-task passive" if the child did not demonstrate any goal-directed behaviours but was instead inactive (e.g., staring or daydreaming), "off-task active" if no goal-directed behaviours were observed and the child was active (e.g., non task-related talking, fidgeting in their seat or out of their seat moving), or "other" if the observed behaviour did not fit one of the three aforementioned categories, or the child was out of sight (e.g., left the classroom, another person obstructing the view of the observer). As it has previously been found that on-task behaviour depends on and varies according to the type of instructional activity the children are engaging in (Godwin et al., 2013; Heemskerk and Malmberg, 2020), the researchers recorded the type of task that was set by the teacher at each observation (teacher-led whole class instruction, teacher one-to-one support, independent work, partner work, small group work, test, and or other).

2.5 Analytic Strategy

2.5.1 Variable Creation

The accelerometery data was processed with GGIR in R (Migueles et al., 2019). We aggregated data in 1-s epochs, and extracted the duration participants were sedentary, and engaged in light, moderate, and vigorous activity for sections of the 24 h period during which the device was worn: “after school”, “night-time” (8 pm until 7 am), “before school”, “morning school”, “lunchtime”, “afternoon before PE”, “PE”, and “afternoon after PE”. Cut-points for sedentary, moderate, and vigorous PA from Hildebrand et al. (2014) for wrist-worn GENEActiv monitors were applied. Files with a minimum of 8 h of valid data during the daytime (7 am until 8 pm) were included for analyses of free-living PA. For PE lessons, at least 30 min of valid data was required for inclusion. PA during PE lessons was excluded from free-living PA variables due to the intervention manipulation having a potential impact on the values. Free-living data was used for the calculation of the “active child” variable, reflecting if a child met the government guidelines for MVPA (Chief Medical Officers, 2019) on a regular basis (≥75% of recorded days). This applied to 58.3% of those with sufficient PA data to calculate this variable (35 of 60 participants). For analyses of objectively achieved PA during PE, the duration of MVPA was coded into quintiles and used as a categorical predictor (quintile 1: < 14%, quintile 2: 14–21%, quintile 3: >21 and <27.2%, quintile 4: 27.2 and <33.5%, quintile 5: ≥33.5%).

Observations where behaviour and task were concurrently coded “other” (indicating the child was absent or obscured from view) were deleted, and only lessons with a minimum of 40 valid observations were included in the analyses. Classroom behaviour data was then recoded into three binary variables (on-task, passive off-task, and active off-task). Trait task-behaviour was coded into three binary indicators. For each participant, their mean proportion of on-task, passive off-task, and active off-task behaviour across all classroom lessons before PE only was calculated. Children who were in the bottom 33% of the sample for on-task behaviour (on-task < 66%) or the top 33% for passive (passive off-task > 11.5%) or active off-task (active off-task > 15%) behaviour were coded “low on-task”, “high passive off-task”, and “high active off-task” respectively.

BMI values were coded into z-scores for sex and age using the WHO guidelines (de Onis et al., 2007). For use in the binary model, a categorical variable was created on the basis of the z-scores, using cut-points for underweight (z < −1) (Cole et al., 2007), overweight (z > 1.04), and obese (z > 1.64) (Vanderwall et al., 2018). The “healthy weight” category (z ≥ −1 and ≤1.04) was used as the comparison category.

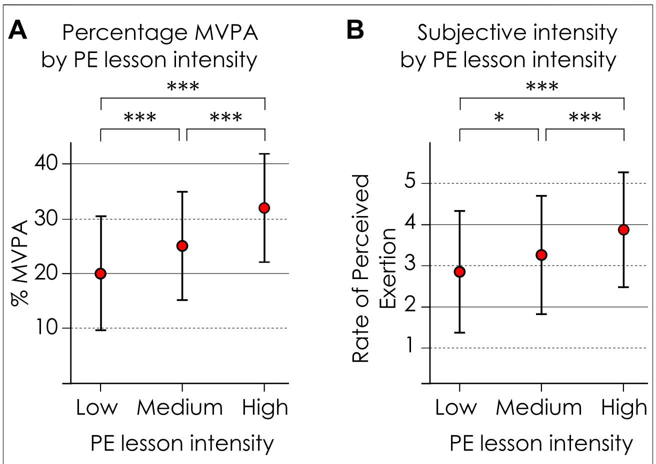

FIGURE 1 | Difference in objective and subjective intensity of PE lessons. **(A)** Percentage MVPA by PE lesson Intensity **(B)** Subjective intensity by PE lesson intensity. *Note.* PE = Physical education. MVPA = Moderate-to-vigorous physical activity. $^{*}p \le 0.05$, $^{**}p \le 0.01$, and $^{***}p \le 0.001$.

2.5.2 Manipulation Checks

First, we used SPSS 27 (IBM Corporation, 2020) to carry out t-tests to investigate if the objective or subjective intensity of the PE lessons differed between low and high complexity PE lessons. Objective PA intensity (% of PE lesson time spent at MVPA) did differ between low and high complexity lessons, with more MVPA recorded during high complexity lessons ($M_{low} = 8.31$, $M_{high} = 9.40$, and $t_{(326)} = -11.02$, $p < 0.001$). As high complexity lessons involved more object manipulation activities, it was expected that the wrist-worn accelerometers may pick up additional activity during high complexity lessons. We therefor also analysed the subjective intensity (rate of perceived exertion) in relation to lesson complexity. This was not significantly different between low and high complexity lessons ($M_{low} = 3.34$, $M_{high} = 3.14$, $t_{(402)} = 1.36$, and $p = 0.175$).

Next, we carried out a one-way ANOVA to investigate if the percentage of lesson time spent in MVPA differed between low, medium, and high intensity lessons. This was the case ($F_{(2,456)} = 68.79$, $p < 0.001$), and post-hoc tests revealed that during low intensity lessons, participants achieved significantly less MVPA than during medium intensity lessons, and during medium intensity lessons they achieved significantly less MVPA than during high intensity lessons (see **Figure 1A**). The same pattern was found for subjective intensity level, which also differed significantly between the three PE lesson intensities (*Welch's* $F_{(2,375.34)} = 24.92$, $p < 0.001$), (see **Figure 1B**).

2.5.3 Analytic Models

We used binary three-level models (time points, nested in weeks, nested in participants) with random intercepts and slopes in MLwiN (Charlton et al., 2019) to analyse the effect of PA on classroom behaviour. The intra-class correlations for each behaviour were calculated at the week-level and ID-

TABLE 2 | Response of on-task behaviour to objective and subjective PA.

Variable	On-task behaviour					
	Probability pre-PE	Probability post-PE	χ^2	*p*-value	Odds ratio	*d*
Overall	0.647	0.709			1.33	0.16
Low intensity lesson	0.662	0.710	3.10		1.25	0.12
Medium intensity lesson	0.629	0.683	3.65		1.27	0.13
High intensity lesson	0.651	0.735	10.08	***	1.49	**0.22**
MVPA[1] quintile 1	0.647	0.703	2.89		1.30	0.14
MVPA quintile 2	0.658	0.722	3.32		1.35	0.16
MVPA quintile 3	0.629	0.676	1.67		1.23	0.12
MVPA quintile 4	0.607	0.701	6.03	*	1.52	**0.23**
MVPA quintile 5	0.609	0.747	12.26	***	1.90	**0.35**
RPE[2] 1	0.658	0.722	3.40		1.35	0.17
RPE 2	0.669	0.687	0.22		1.09	0.05
RPE 3	0.633	0.704	3.90	*	1.37	0.18
RPE 4	0.619	0.719	6.62	**	1.57	**0.25**
RPE 5	0.627	0.667	1.30		1.19	0.10

*Note: [1] MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles. [2] RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring). *p ≤ 0.05, **p ≤ 0.01, and ***p ≤ 0.001. Effect sizes indicating a small (d ≥ 0.2), medium (d ≥ 0.5), or large (d ≥ 0.8) effect are highlighted in bold font.*

level. For on-task behaviour, greater variance between weeks than between participants was found (ICC_{weeks} = 0.080, $ICC_{participants}$ = 0.047), whereas for off-task behaviour the variance did not greatly differ, and was slightly greater between participants than between weeks (active off-task: ICC_{weeks} = 0.096, $ICC_{participants}$ = 0.099; passive off-task: ICC_{weeks} = 0.090, and $ICC_{participants}$ = 0.094).

We answered the first research question by entering PA into the model in the following three ways; in the first model, the intensity level of the six intervention conditions (low, medium, or high) was used as the predictor. In the second model, the percentage of time spent in MVPA as quintiles was entered. In model three, participants' subjective PA intensity during PE was used. To answer our second research question, the models using MVPA for objective PA and RPE for subjective PA were computed twice more each, once with active off-task and once with passive off-task behaviour as the outcome variable. Finally, to investigate the effect of individual differences and answer our third research question, interaction effects of BMI category, sex, habitual PA participation (active child), and mean on-task and off-task behaviours in pre-PE lessons were entered into the models. For the analytical models we present chi^2 values derived from Wald tests in MLwiN for the comparison of pre- and post-PE lessons, along with associated p-values (cut-point for significance set at $p \leq 0.05$). Effect sizes are presented as odds ratios (OR) and Cohen's d (small effect $d \geq 0.2$, medium effect $d \geq 0.5$, and large effect $d \geq 0.8$). The reported predicted probabilities for on- and off-task behaviours are calculated from the logit coefficients provided by MLwiN, using the equation "probability = (exp(logit)/(1 + exp(logit)))". All models were controlled for age, sex, BMI, achievement level, task enjoyment, perceived task difficulty, and instructional activity. Full model specifications are available from the corresponding author upon request.

3 RESULTS

3.1 RQ1: Is There a Difference Between the Effects of Subjective and Objective Measures of PA Intensity?

Participants were on-task on average 71.6% of the observed pre-PE lessons, and 77.0% of the post-PE lessons. Lessons that were intended to be high-intensity had a small positive effect on on-task behaviour (χ^2 = 10.08, p < 0.001, and d = 0.22). Based on recorded MVPA, lessons with more than 27.2% MVPA (4th and 5th quintile) had a small positive effect on subsequent on-task behaviour (χ^2 = 6.03, p < 0.05, d = 0.23 and χ^2 = 12.26, p < 0.001, d = 0.35, respectively). This did not directly translate to participants' RPE; only lessons rated 4 out of 5 had a small significant positive effect (χ^2 = 6.62, p < 0.01, and d = 0.25). When RPE was 3 out of 5, subsequent on-task behaviour was significantly greater (χ^2 = 3.90, p < 0.05), but this effect was very small (d = 0.18) see **Table 2**; **Figure 2**.

3.2 RQ2: Is There a Difference Between the Effects of PA on Active and Passive Off-Task Behaviour?

Across the afternoon, active off-task behaviour was more prevalent than passive (pre: $M_{passive}$ = 10.5%, M_{active} = 14.4%; post: $M_{passive}$ = 7.5%, M_{active} = 13.3%). Active off-task behaviour was significantly reduced only after PE lessons with high MVPA content (quintile 5, χ^2 = 5.46, p < 0.05, and d = −0.27). No significant effects of subjective intensity ratings on active off-task were found (see **Table 3**; **Figure 3**, dark grey bars). Passive off-task behaviour was lower after several different PE lessons of low and moderate—but not high—intensity. When intensity was measured objectively, lessons with MVPA in quintile 2 had a small negative effect (χ^2 = 7.98, p < 0.01, and d = −0.3). When PA was measured

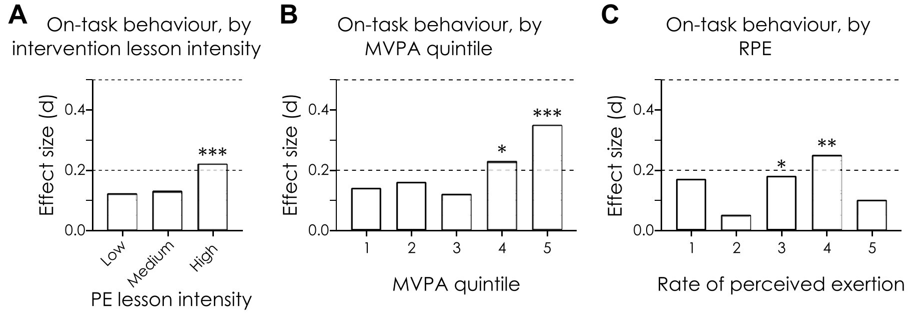

FIGURE 2 | Change in on-task behaviour in response to physical activity intensity. **(A)** On-task behaviour, by intervention lesson intensity **(B)** On-task behaviour, by MVPA quintile **(C)** On-task behaviour, RPE. *Note.* MVPA = Moderate-to-vigorous physical activity. Small (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect sizes are indicated by the dashed grid lines. *$p \leq 0.05$, **$p \leq 0.01$, and ***$p \leq 0.001$.

TABLE 3 | Response of active off-task behaviour to objective and subjective PA.

Variable	Active off-task behaviour					
	Probability pre-PE	**Probability post-PE**	χ^2	***p*-value**	**Odds ratio**	***d***
Overall	0.193	0.177			0.89	−0.06
MVPA[1] quintile 1	0.175	0.156	0.62		0.87	−0.08
MVPA quintile 2	0.180	0.159	0.61		0.86	−0.08
MVPA quintile 3	0.193	0.206	0.20		1.09	0.05
MVPA quintile 4	0.202	0.192	0.11		0.94	−0.04
MVPA quintile 5	0.237	0.160	5.46	*	0.61	**−0.27**
RPE[2] 1	0.190	0.177	0.23		0.92	−0.05
RPE 2	0.168	0.189	0.50		1.16	0.08
RPE 3	0.214	0.196	0.35		0.90	−0.06
RPE 4	0.188	0.173	0.26		0.90	−0.06
RPE 5	0.219	0.197	0.58		0.87	−0.07

*Note: [1] MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles. [2] RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring). *p ≤ 0.05, **p ≤ 0.01, and ***p ≤ 0.001. Effect sizes indicating a small (d ≥ 0.2), medium (d ≥ 0.5), or large (d ≥ 0.8) effect are highlighted in bold font.*

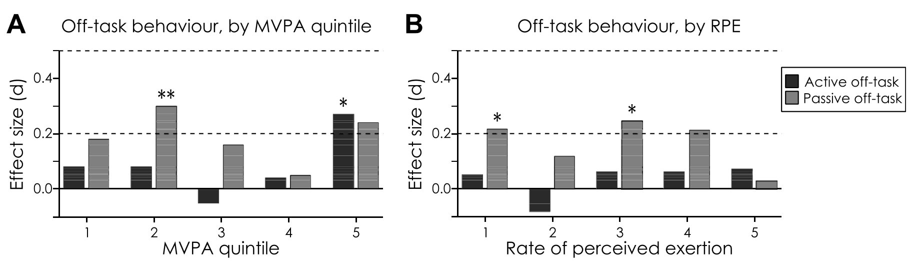

FIGURE 3 | Change in off-task behaviour in response to physical activity intensity. **(A)** Off task behaviour, MVPA quintile **(B)** Off-task behaviour, by RPE. *Note.* MVPA = Moderate-to-vigorous physical activity. Effect sizes have been transformed so that positive numbers reflect favourable effects (less off-task behaviour). Small (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect sizes are indicated by the dashed grid lines. *$p \leq 0.05$, **$p \leq 0.01$, and ***$p \leq 0.001$.

subjectively, low (RPE = 1) as well as moderate (RPE = 3) intensity lessons had a small negative effect on passive off-task behaviour ($\chi^2 = 4.27$, $p < 0.05$, and $d = -0.22$; $\chi^2 = 5.45$, $p < 0.05$, and $d = -0.25$, respectively). Although lessons in MVPA quintile 5 and rated as RPE = 4 did achieve small effect sizes, these results were not significant (see **Figure 3**, light grey bars and **Table 4**).

3.3 RQ3: Are There Specific Sub-Samples of Participants Who Respond More or Less Favourably to PA?

3.3.1 Trait On-Task Behaviour

Participants who were the least on-task before PE benefited from all PE lessons, regardless if subjective or objective measures were

TABLE 4 | Response of passive off-task behaviour to objective and subjective PA.

Variable	Passive off-task behaviour					
	Probability pre-PE	Probability post-PE	χ^2	*p*-value	Odds ratio	*d*
Overall	0.146	0.115			0.76	−0.15
MVPA[1] quintile 1	0.184	0.140	3.67		0.72	−0.18
MVPA quintile 2	0.185	0.117	7.98	**	0.58	**−0.30**
MVPA quintile 3	0.184	0.145	2.34		0.75	−0.16
MVPA quintile 4	0.137	0.126	0.25		0.91	−0.05
MVPA quintile 5	0.148	0.102	3.37		0.65	**−0.24**
RPE[2] 1	0.156	0.111	4.27	*	0.67	**−0.22**
RPE 2	0.139	0.114	1.05		0.80	−0.12
RPE 3	0.152	0.103	5.45	*	0.64	**−0.25**
RPE 4	0.160	0.113	3.56		0.67	**−0.22**
RPE 5	0.140	0.134	0.08		0.95	−0.03

*Note: [1] MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles. [2] RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring). *p ≤ 0.05, **p ≤ 0.01, and ***p ≤ 0.001. Effect sizes indicating a small (d ≥ 0.2), medium (d ≥ 0.5), or large (d ≥ 0.8) effect are highlighted in bold font.*

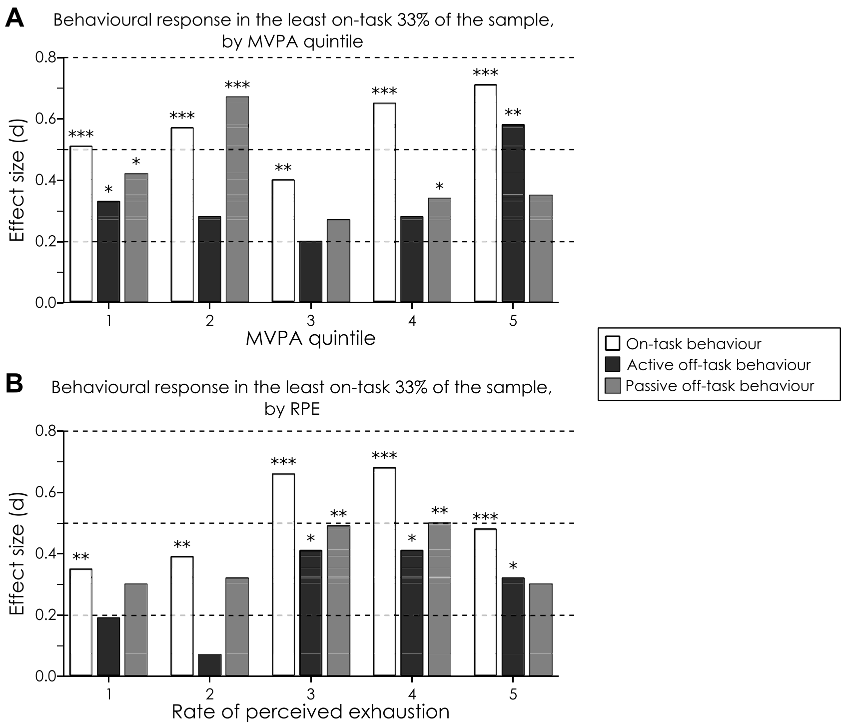

FIGURE 4 | Change in behaviour in response to objective and subjective measures of physical activity intensity in the least on-task participants. **(A)** Behavioural response in the least on-task 33% of the sample, MVPA quintile **(B)** Behavioural response in the least on-task 33% of the sample, by RPE. *Note.* MVPA = Moderate-to-vigorous physical activity. Effect sizes have been transformed so that positive numbers reflect favourable effects (more on-task behaviour, less off-task behaviour). Small (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect sizes are indicated by the dashed grid lines. **p* ≤ 0.05, ***p* ≤ 0.01, and ****p* ≤ 0.001.

used. Full results can be found in **Table 5**. Every PE lesson had a positive effect on their subsequent on-task behaviour (objective: $d = 0.40–0.71$, subjective: $d = 0.35–0.68$). Children with low trait levels of on-task behaviour reduced their passive off-task behaviours after PE lessons of sub-maximal intensity—both for subjectively and objectively measured PA the maximum intensity category failed to reach significance (MVPA quintile 5: $\chi^2 = 3.60$, $p > 0.05$; RPE 5: $\chi^2 = 3.70$, $p > 0.05$). Active off-task behaviour was lower in this subgroup after subjective intensities of 3 and above ($\chi^2 = 4.51–5.81$, $p < 0.05$, and $d = −0.32$ to $−0.41$). Objectively measured PA did not affect active off-task behaviour in a systematic way (see **Figure 4**).

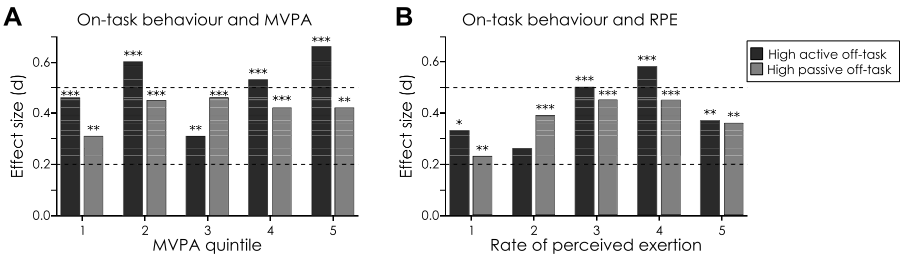

FIGURE 5 | Change in behaviour in response to objective and subjective measures of physical activity intensity in the most off-task participants. **(A)** On-task behaviour and MVPA **(B)** On-task behaviour and RPE. *Note.* MVPA = Moderate-to-vigorous physical activity. Effect sizes have been transformed so that positive numbers reflect favourable effects (more on-task behaviour, less off-task behaviour). Small (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect sizes are indicated by the dashed grid lines. *$p \le 0.05$, **$p \le 0.01$, and ***$p \le 0.001$.

TABLE 5 | Response of task behaviour to objective and subjective PA in the least on-task sub-sample.

Variable	On-task behaviour				Active off-task behaviour				Passive off-task behaviour			
	χ^2	*p*-value	Odds ratio	*d*	χ^2	*p*-value	Odds ratio	*d*	χ^2	*p*-value	Odds ratio	*d*
MVPA[1] quintile 1	16.39	***	2.54	**0.51**	4.31	*	0.55	**−0.33**	6.62	**	0.47	**−0.42**
MVPA quintile 2	18.45	***	2.81	**0.57**	2.98		0.60	**−0.28**	6.62	***	0.29	**−0.67**
MVPA quintile 3	10.09	***	2.06	**0.40**	1.61		0.70	**−0.20**	2.90		0.61	**−0.27**
MVPA quintile 4	24.34	***	3.24	**0.65**	3.11		0.60	**−0.28**	3.97	*	0.54	**−0.34**
MVPA quintile 5	25.04	***	3.62	**0.71**	11.42	***	0.35	**−0.58**	3.60		0.53	**−0.35**
RPE[2] 1	7.94	**	1.90	**0.35**	1.45		0.71	−0.19	3.14		0.58	**−0.30**
RPE 2	6.97	**	2.03	**0.39**	0.13		0.89	−0.07	2.54		0.56	**−0.32**
RPE 3	23.79	***	3.29	**0.66**	5.81	*	0.48	**−0.41**	7.29	**	0.41	**−0.49**
RPE 4	22.26	***	3.41	**0.68**	5.17	*	0.48	**−0.41**	6.78	**	0.41	**−0.50**
RPE 5	17.03	***	2.39	**0.48**	4.51	*	0.56	**−0.32**	3.70		0.58	**−0.30**

Note: [1] *MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles.* [2] *RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring).* *$p \le 0.05$, **$p \le 0.01$, *and* ***$p \le 0.001$. *Effect sizes indicating a small* ($d \ge 0.2$), *medium* ($d \ge 0.5$), *or large* ($d \ge 0.8$) *effect are highlighted in bold font.*

TABLE 6 | Response of on-task behaviour to objective and subjective PA in the most off-task sub-samples.

Variable	Most active off-task				Most passive off-task			
	χ^2	*p*-value	OR[1]	*d*	χ^2	*p*-value	OR	*d*
MVPA[2] quintile 1	19.75	***	2.30	**0.46**	9.32	**	1.77	**0.31**
MVPA quintile 2	30.93	***	2.97	**0.60**	18.22	***	2.25	**0.45**
MVPA quintile 3	8.68	**	1.76	**0.31**	18.16	***	2.31	**0.46**
MVPA quintile 4	22.50	***	2.60	**0.53**	14.94	***	2.14	**0.42**
MVPA quintile 5	33.35	***	3.34	**0.66**	7.51	**	2.13	**0.42**
RPE[3] 1	6.28	*	1.82	**0.33**	2.64		1.52	**0.23**
RPE 2	2.74		1.60	**0.26**	6.44	*	2.04	**0.39**
RPE 3	12.84	***	2.49	**0.50**	11.29	**	2.27	**0.45**
RPE 4	16.29	***	2.85	**0.58**	9.67	**	2.24	**0.45**
RPE 5	8.41	**	1.97	**0.37**	9.02	**	1.92	**0.36**

Note: [1] *OR = Odds Ratio.* [2] *MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles.* [3] *RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring).* *$p \le 0.05$, **$p \le 0.01$, *and* ***$p \le 0.001$. *Effect sizes indicating a small* ($d \ge 0.2$), *medium* ($d \ge 0.5$), *or large* ($d \ge 0.8$) *effect are highlighted in bold font.*

TABLE 7 | Response of task-behaviour to objective and subjective PA by sex.

Outcome	Variable	Sex							
		Boys				Girls			
		χ^2	*p*-value	OR[1]	*d*	χ^2	*p*-value	OR	*d*
On-task behaviour	MVPA[2] quintile 1	0.08		0.93	−0.04	2.71		1.51	**0.23**
	MVPA quintile 2	0.00		1.00	0.00	3.01		1.54	**0.24**
	MVPA quintile 3	0.03		1.05	0.02	1.52		1.36	0.17
	MVPA quintile 4	0.53		1.22	0.11	5.33	*	1.85	**0.34**
	MVPA quintile 5	3.93	*	1.74	**0.31**	5.61	*	1.96	**0.37**
	RPE[3] 1	0.03		1.05	0.02	4.49	*	1.71	**0.30**
	RPE 2	1.42		1.42	0.19	0.00		1.02	0.01
	RPE 3	1.91		1.44	**0.20**	1.92		1.39	0.18
	RPE 4	0.00		1.01	0.00	8.80	**	2.162	**0.43**
	RPE 5	0.15		0.91	−0.05	2.40		1.45	**0.20**
Passive off-task behaviour	MVPA quintile 1	2.27		0.66	**−0.23**	0.82		0.77	−0.14
	MVPA quintile 2	1.12		0.66	−0.19	4.95	*	0.53	**−0.35**
	MVPA quintile 3	0.64		0.71	−0.14	1.09		0.74	−0.17
	MVPA quintile 4	3.20		1.72	**0.30**	4.31	*	0.52	**−0.37**
	MVPA quintile 5	1.49	*	0.67	**−0.22**	1.68		0.64	**−0.25**
	RPE[3] 1	1.25		0.72	−0.18	2.30		0.62	**−0.26**
	RPE 2	1.70		0.61	**−0.27**	0.23		0.86	−0.08
	RPE 3	0.83		0.75	−0.16	3.34		0.59	**−0.29**
	RPE 4	0.00		1.01	0.01	4.38	*	0.51	**−0.37**
	RPE 5	0.09		1.09	0.05	0.24		0.87	−0.08

Note: [1] *OR = Odds Ratio.* [2] *MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles.* [3] *RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring). *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001. Effect sizes indicating a small (d ≥ 0.2), medium (d ≥ 0.5), or large (d ≥ 0.8) effect are highlighted in bold font.*

TABLE 8 | Response of task-behaviour to objective and subjective PA by regular moderate-to-vigorous physical activity.

Outcome	Variable	Regular participation in MVPA[1]							
		No				Yes			
		χ^2	*p*-value	OR[2]	*d*	χ^2	*p*-value	OR	*d*
On-task behaviour	MVPA quintile 1	1.84		1.36	0.17	0.00		0.99	0.00
	MVPA quintile 2	8.08	**	1.98	**0.38**	0.09		0.93	−0.04
	MVPA quintile 3	0.31		1.57	0.08	1.36		1.32	0.15
	MVPA quintile 4	4.44	*	1.71	**0.30**	0.27		1.14	0.07
	MVPA quintile 5	1.23		1.45	**0.20**	5.76	*	1.85	**0.34**
	RPE[3] 1	5.52	*	1.90	**0.36**	0.05		1.06	0.03
	RPE 2	0.00		1.00	0.00	0.11		1.26	0.05
	RPE 3	1.69		1.44	**0.20**	0.72		1.26	0.13
	RPE 4	2.75		1.62	**0.27**	2.70		1.63	**0.27**
	RPE 5	0.97		1.29	0.14	0.04		1.06	0.03
Passive off-task behaviour	MVPA quintile 1	32.71	***	0.64	**−0.24**	13.80	***	0.81	−0.12
	MVPA quintile 2	21.65	***	0.58	**−0.30**	20.83	***	0.56	**−0.32**
	MVPA quintile 3	10.84	***	0.90	−0.06	22.30	***	0.57	**−0.31**
	MVPA quintile 4	6.25	*	1.23	0.11	11.76	***	0.87	−0.08
	MVPA quintile 5	3.20		1.36	0.17	20.59	***	0.57	**−0.31**
	RPE 1	2.56		0.61	**−0.27**	0.91		0.73	−0.18
	RPE 2	0.01		1.05	0.02	1.61		0.65	**−0.24**
	RPE 3	7.91	**	0.39	**-0.52**	1.42		0.68	**−0.21**
	RPE 4	1.13		0.70	**−0.20**	2.56		0.57	**−0.31**
	RPE 5	1.46		1.43	**0.20**	2.09		0.63	**−0.26**

Note: [1] *MVPA = Moderate-to-Vigorous Physical Activity during physical education, coded into quintiles.* [2] *OR = Odds Ratio.* [3] *RPE = Rate of Perceived Exertion, rated from 1 (not at all tiring) to 5 (extremely tiring). *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001. Effect sizes indicating a small (d ≥ 0.2), medium (d ≥ 0.5), or large (d ≥ 0.8) effect are highlighted in bold font.*

3.3.2 Trait Off-Task Behaviour

Finally, for pupils who displayed the highest levels of active and passive off-task behaviour, we found significant positive effects of all but one PE lesson intensities on on-task behaviour (**Figure 5**; **Table 6**). For pupils high on passive disengagement, effect sizes were small (d = 0.23–0.46). For those high on active disengagement, effects were small to medium (d = 0.26–0.66). In both groups, it was noticeable that for perceived exertion the

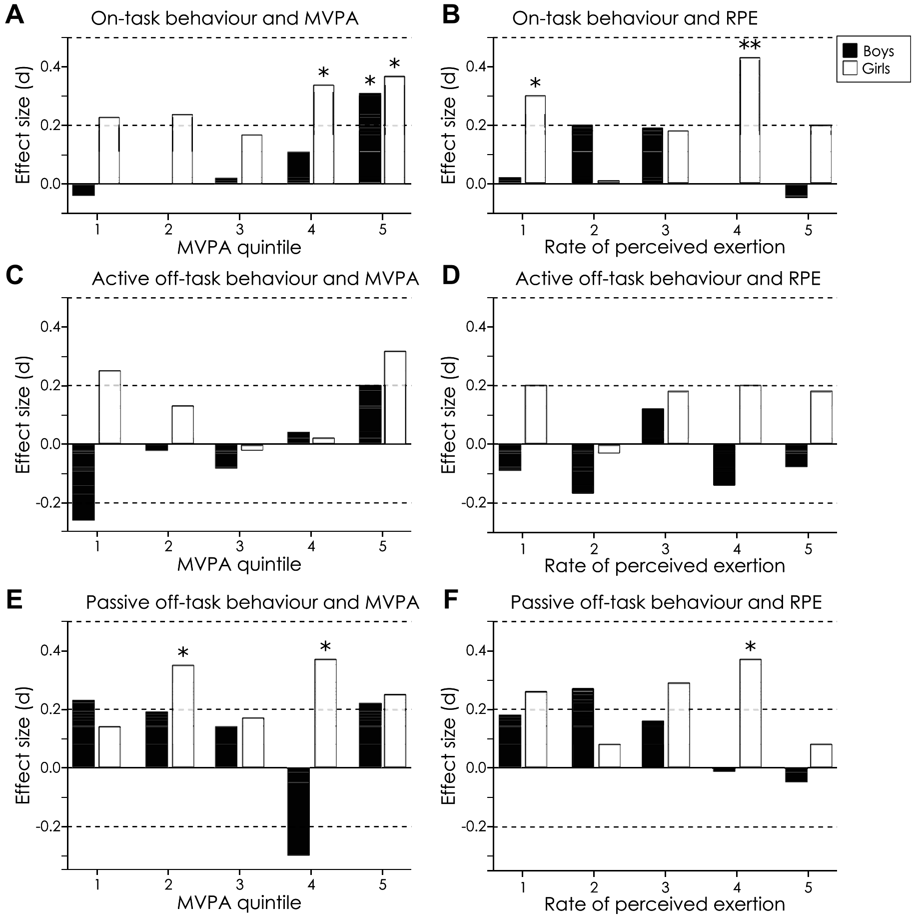

FIGURE 6 | Change in behaviour in response to objective and subjective measures of physical activity intensity, by sex. **(A)** On-task behaviour and MVPA **(B)** On-task behaviour and RPE **(C)** Active off-task behaviour and MVPA **(D)** Active off-task behaviour and RPE **(E)** Passive off-task behaviour and MVPA **(F)** Passive off-task behaviour and RPE. *Note.* MVPA = Moderate-to-vigorous physical activity. Effect sizes have been transformed so that positive numbers reflect favourable effects (more on-task behaviour, less off-task behaviour). Small (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect sizes are indicated by the dashed grid lines. *$p \leq 0.05$, **$p \leq 0.01$, and ***$p \leq 0.001$.

greatest increase in on-task behaviour happened after sub-maximal intensity lessons (RPE 3 and 4), with a tailing off of the effect for lessons rated at RPE 5. This tailing off was not evident in the objectively measured PA results.

3.3.3 Sex

We found interaction effects of sex (see **Figure 6** and **Table 7**). In terms of on-task behaviour, boys responded only to the highest percentile of MVPA (>33.5%, χ^2 = 3.93, $p < 0.05$, and d = 0.31), whereas girls also experienced positive effects of lower MVPA contents (MVPA percentile 4 and 5; χ^2 = 5.33, $p < 0.05$, d = 0.34 and χ^2 = 5.61, $p < 0.05$, d = 0.37, respectively, see **Figure 6**A). For active off-task behaviour, we found no interactions of sex (**Figures 6**C,D). Passive off-task behaviours were not systematically reduced in relation to subjective or objective intensity ratings in either sex (**Figures 6**E,F), but whereas girls' passive behaviour was reduced after a range of medium-intensity lessons (χ^2 = 4.31–4.95, $p < 0.05$, d = −0.35 to −0.37), boys' passive off-task behaviour was not significantly affected by PA.

3.3.4 Regular MVPA

Those who regularly met United Kingdom government guidelines for MVPA in children (Chief Medical Officers, 2019) benefited from fewer PE lessons than those who were less regularly active (see **Table 8**). For active children, only after lessons with the highest MVPA content (quintile 5, χ^2 = 5.76, $p <$ 0.05, and d = 0.34) was their on-task behaviour significantly greater. On the other hand, lesser-active children also benefited from lower-intensity lessons (MVPA quintile 2 and 4, and RPE 1, χ^2 = 4.44–8.08, $p < 0.05$, and d = 0.30–0.38, see **Figures 7A,B**). Similar to sex, no interaction effect of regular MVPA was found for active off-task behaviour (**Figures 7C,D**). Passive off-task behaviour was lower only after low-MVPA PE lessons in lesser-active children (quintiles 1 and 2, χ^2 = 32.71, $p < 0.001$, d = −0.24 and χ^2 = 21.65, $p < 0.001$, d = −0.30, respectively), whilst in regularly active children it was reduced after every intensity lesson, with three medium to high intensity lessons reaching small effect sizes (χ^2 = 20.59–22.30, $p < 0.001$, d = −0.31 to −0.32, **Figure 7E**). Subjective intensity predicted less passive off-task

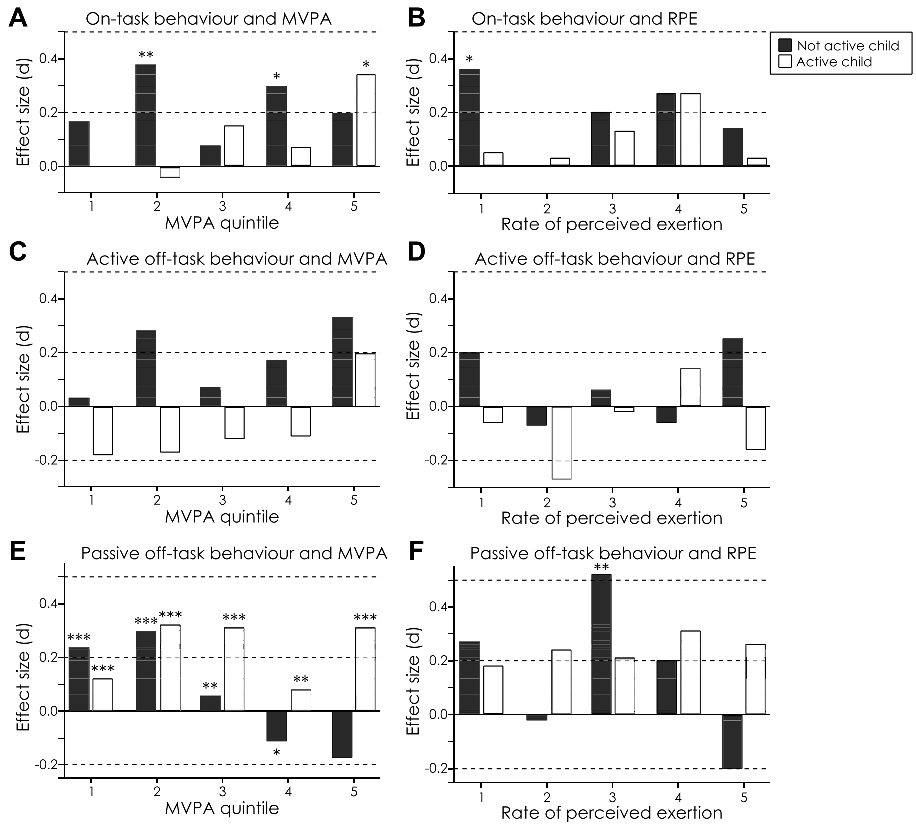

FIGURE 7 | Change in behaviour in response to objective and subjective measures of physical activity intensity, by regular moderate-to-vigorous physical activity. **(A)** On-task behaviour and MVPA **(B)** On-task behaviour and RPE **(C)** Active off-task behaviour and MVPA **(D)** Active off-task behaviour and RPE **(E)** Passive off-task behaviour and MVPA **(F)** Passive off-task behaviour and RPE. *Note.* MVPA = Moderate-to-vigorous physical activity. Effect sizes have been transformed so that positive numbers reflect favourable effects (more on-task behaviour, less off-task behaviour). Small (d = 0.2), medium (d = 0.5), and large (d = 0.8) effect sizes are indicated by the dashed grid lines. $^*p \le 0.05$, $^{**}p \le 0.01$, and $^{***}p \le 0.001$.

behaviour only for lesser-active children, and only for lessons perceived to be moderately active, with a medium effect size (RPE 3, $\chi^2 = 7.91$, $p < 0.01$, $d = -0.52$, see **Figure 7F**).

3.3.5 BMI

We found no systematic interaction effects of PA intensity and BMI category on any type of behaviour, regardless of whether objective or subjective PA measure were entered into the model.

4 DISCUSSION

4.1 The On-Task Response to Physical Activity Differs Between Objectively and Subjectively Measured Activity

In answering the first research question the results indicated that high intensity lessons had the greatest positive effect on behaviour, in line with the first part of our hypothesis. However, a difference between objective and subjective measures of PA intensity was evident. More specifically, PE lessons where the intensity was in the 4^{th} and 5^{th} quintiles of MVPA, as measured objectively with the accelerometer watches, and were found to significantly predict more on-task behaviour subsequently. However, children's subjective measures of perceived exertion were not as clear; "*neutral tiring*" and "*little tiring*" rated lessons were found to significantly affect on-task behaviour, however, with very small effect sizes ($d < 0.2$). Coupled with our finding that the high intensity designed lessons also significantly improved subsequent on-task behaviour, the results confirm previous findings that high intensity PA interventions are optimal for improving task-related behaviour (Ma et al., 2014; Szabo-Reed et al., 2017). Subjective measures of PA intensity did not align with the objective measures. The incongruence in these findings could be ascribed to children's inaccuracy in estimating the intensity of their PE lesson; children who are more active may not perceive high intensity lessons as tiring, or lower-fit children may rate lessons with less PA as highly intense. Schneider and Schmalbach (2015) found that adolescents (M age = 11.09 years) who were fitter recorded lower RPE at higher heart rates during exercise than those who were less fit.

4.2 Passive Off-Task Behaviours Are More Responsive to Low-Intensity Physical Activity Than Active Off-Task Behaviours

The second research question aimed to explore the effects of PA on active and passive off-task behaviour. The findings suggest that PE lessons with MVPA content in the 5^{th} quintile reduced subsequent active off-task behaviour in the classroom confirming the hypothesised direction of effects. However, no significant effects where found for children's perceived exertion and active off-task behaviour. The pattern for passive off-task behaviour differed from the response in active off-task behaviour; a significantly reduction was found after PE lessons where the content intensity was in the 2^{nd} quintile (low-to-moderate intensity). In relation to subjectively measured PA intensity, lower-intensity lessons were also most effective in reducing passive off-task behaviours, with "*not at all tiring*" and "*neutral tiring*" leading to significant reductions. Although we had expected the greatest effect on passive behaviour for moderate intensity (Unsworth and Robinson, 2020), our hypothesis that active behaviours are reduced by higher intensity activity than passive behaviours was confirmed. However, a previous study (Mullender-Wijnsma et al., 2015) did not find an association between MVPA and time-on-task in post-intervention lessons. These opposing results may be due to their intervention being classroom-based, whereas our took place during PE lessons. In addition, Mullender-Wijnsma et al. (2015) did not differentiate between passive and active off-task behaviour in their observation tool, therefore, the present analysis goes beyond previous literature. An important contribution of the findings is the importance of distinguishing between passive and active off-task behaviour, and that a different response in children's behaviour can be expected depending on the intensity of the PE lesson.

4.3 Children Respond Differently to Physical Activity Intervention

Our data confirm that children respond differently to PA depending on their individual characteristics. Below we discuss the differences in their response based on their level of on-task or specific off-task behaviour before the PE lesson, their sex, and habitual engagement in MVPA.

4.3.1 The Least On-Task Pupils Become Less Disruptive

As hypothesised, and in line with Mahar et al. (2006) among others, we found that those who have the lowest level of trait on-task behaviour responded most favourably to the intervention, improving their on-task behaviour regardless of the PE lesson content. Those who were mostly actively off-task responded with a small to moderate increase in on-task behaviour. On the other hand, the on-task behaviour of those who were mostly passively off-task increased only with small effect size. Thus, although for the whole sample, passive off-task behaviours appear to be most responsive to PA intervention (**Figure 3**), pupils who are most actively disengaged—and potentially disruptive to their peers - most strongly increased their on-task behaviour in response to PA (**Figure 5**). What appears to be most beneficial for these pupils is that they have the opportunity to be active, and preferably moderate-to-vigorously so, before they engage in their classroom tasks.

4.3.2 Girls Respond to a Greater Range of Activity Intensities Than Boys

Our findings with regard to sex did not confirm our hypothesis, and are opposite also to those by Ma et al. (2014), who's results indicated greater effects of PA breaks for boys than girls. In particular, Ma et al. (2014) found that active off-task behaviours were greatly reduced in boys. In our study, no significant effects of PA of any intensity on active off-task behaviour were found for either sex. With regard to on-task behaviour, we found that girls responded to a wider range of higher-intensity (MVPA quintile 4 and 5) than boys (MVPA quintile 5 only). the same was evident for passive off-task behaviour, where girls responded positively to low-to-moderate PE lessons as well as moderate-to-high intensity lessons, whereas boys' behavioural response did not reach significance at all. It may be that due to the generally lower levels of PA in girls (van Sluijs et al., 2021), their response to lower-intensity PA is greater than in boys. Moreover, the results from Ma et al. (2014) were obtained after a 10-min activity in the classroom, rather than a full PE lesson. Thus, it may be that the sustained nature of the exercise for an entire PE lesson induces greater effects in girls, even at lower intensities, if they are less accustomed to high levels of PA than boys. The meta-analysis off school-based PA interventions for girls by Owen et al. (2017) did include a range of PA interventions, but they investigated *only* results for girls, rather than compare these to boys' results. Their conclusion that PA interventions for girls yield very small to small effects (Owen et al., 2017) does correspond with the findings of this study, as all effect sizes for girls found here were smaller than $d = 0.5$.

4.3.3 Inactive Children Become More On-Task and Less Passively Off-Task After Low-To-Medium, but Not High-Intensity Physical Activity

We hypothesised that more regularly active children would benefit more greatly from the intervention. Our results did not confirm this hypothesis, as we found that the results differed, based on which behaviour was specified as the outcome variable. When on-task behaviour was examined, lesser-active children responded favourably to a range of lower-intensity lessons, and whereas more regularly fit children only benefited from lessons with the highest MVPA content. It may be that children who do not regularly engage in MVPA have a stronger physiological response to the MVPA content of PE lessons, thus benefiting from lower-intensity lessons than those who do regularly engage in MVPA. When we examined passive off-task behaviours, the same pattern was found, with regularly active children responding more favourably to higher MVPA content than lesser-active children. Our findings are in line with Snyder et al. (2017), who found significant reductions in passive off-task behaviour. Our results further demonstrate the importance of incorporating intensity levels in intervention designs of this nature, to establish their differential effects. However, for this outcome variable, regularly active children had a significant ($p < 0.05$) and meaningful ($d \geq 0.2$) response to three of the PE lesson MVPA quintiles, versus only two for the lesser-active sub-sample. We therefore can conclude that children respond differently to PA intensity based on their habitual engagement in MVPA, but we cannot say that lesser-active or higher-active children respond more favourably to PA overall.

4.3.4 BMI Does Not Interact With PE Lesson Intensity

Our hypothesis regarding the effect of BMI was confirmed; we did not find systematic interaction effects of BMI and PA intensity. This is in line with the review by Chang et al. (2017), reporting inconclusive moderation effects of BMI on the relationship between PA and cognitive performance. Similarly, our results correspond with the findings of the meta-analysis by Sun et al. (2021), which details effects for PA in overweight and obese samples that are of a similar magnitude to what has previously been reported in samples of healthy-weight children or mixed samples (e.g., Owen et al., 2016; De Greeff et al., 2018). Specific to the acute effects of PA on task-behaviour in a classroom context, our results also correspond with those from Grieco et al. (2016), who found that BMI only interacted with PA when activity was compared to inactive classroom lessons, and not with PA intensity levels. As this study compared PE lessons of various intensities, without an inactive control group, and the absence of an interaction effect for BMI is in line with the current literature.

4.4 Strengths and Limitations

The conclusion drawn from the results are validated by the ecological validity of the study. The intervention was designed so as to be implemented with minimal disruption to the "business as usual" lessons. The nature of observations was also such that the trained observers did not interfere with the class teacher and the lesson, so that children's learning, and behaviour was minimally affected. Furthermore, the PE lessons themselves were carefully designed to reflect the national curriculum for PE in the United Kingdom, and delivered in the same manner to every class. The rigorous methodological design ensured a detailed and intensive observational measure which enabled the researchers to collect a large number of observations or data points suitable for the analysis conducted. An additional strength of the study was its within-person design, where all participants took part in all the different PE intervention lessons, allowing the analysis of both within- and between-person variance. The study also had certain limitations. For example, a smaller sub-sample was used to answer the third research question, as the sample was split into smaller sub-samples. This may have contributed to the absence of effects for BMI, as the sample was split across four categories, rather than the two categories in analyses of interactions of regular MVPA and sex. While the findings from our study are promising, a larger scale replication would be beneficial, with a similar study design and distinction between levels of intensity and different types of off-task behaviour, which is sparse in the wider literature. Finally, it must be noted that in observation studies, a certain level of inference cannot be avoided. Moreover, it was not possible to blind the observers to the conditions of the PE lesson. To address these limitations and ensure the observations were of high quality, one of the two observers was blind to the hypotheses of the study, and inter-rater reliability checks were regularly carried out throughout the data collection period, with Cohen's Kappa > 0.8 at all times.

4.5 Implications

The present findings further add to the wider literature in emphasising the importance of PA in school and its potential subsequent positive effect on children's learning behaviour. Completing the required class-work demands a level of focus and concentration, which can be facilitated if on-task behaviour can be increased. These results also have direct implications for primary school teachers, as they can use the content of PE lessons to support their pupils' learning in the classroom, and in particular the behaviour of the most disruptive pupils. Moreover, our finding that children's improvement in on-task behaviour is dependant on whether they are actively or passively off-task, is an important one. Teachers' awareness of the type of off-task behaviour their class is exhibiting can enable them to better tailor the intensity of PE lessons for optimal effectiveness. Furthermore, individual differences are important for teachers to take into account, notably children's PA levels outside of school. The lesser-active children in our sample did not benefit from the highest-intensity lessons, which they rated as highly tiring. Therefore, a substantial implication of the findings is that PE lessons and PA breaks during learning are not a "one-size-fits-all", and positive effects can be maximised if the intensity level is adjusted to the individual child.

4.5.1 Conclusion

The present study aimed to investigate the effects of different intensity PE lessons on on- and off-task behaviour in the classroom in primary school-aged children. The results have demonstrated that individual differences in children play a role in their response to different types of PE lessons. By distinguishing between different intensities of PA, the results demonstrated the nuance necessary in furthering our understanding of the effects of PA on on-task behaviour. Overall, the findings emphasise the importance of the positive effects of PE on children's classroom behaviour. Our findings, in line with the wider literature, reinforce the importance for schools to expand, extend, and enhance opportunities for PA in the curriculum.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Oxford University Department of Education Departmental Research Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CH: Conceptualisation; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing—original draft; Writing—review and editing. MS: Data curation; Investigation; Writing—original draft; Writing—review and editing. SS: Supervision; Conceptualisation; Methodology. LM: Supervision; Conceptualisation; Data curation; Formal analysis; Methodology; Writing—review and editing.

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Examining the Link Between Physical Activity and Cognitive Function: A Parallel Mediation Model of Health and Wellbeing Among Adolescents

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Background: Adolescents' engagement in daily physical activity brings multiple benefits, including reduction in obesity, improvement of mental health, and enhancement of cognitive function (CF). While prior studies have examined the link between physical activity and cognitive function, little is known regarding the extent to which this relationship is shaped by health and wellbeing factors. This study examines how subjective wellbeing (SWB) and general health (GH) mediate the relationship between adolescents' physical activity and cognitive function.

Methods: This study estimates a parallel structural equation model using the Program for International Student Assessment 2018 dataset. Specifically, a total of 63,228 15-year-old subjects in nine countries/economies satisfied the study inclusion criteria, including in Bulgaria, Georgia, Hong Kong, Ireland, Mexico, Panama, Serbia, Spain, and United Arab Emirates. Frequency of moderate physical activity (MPA, ≥3.0 Metabolic Equivalent Task) was reported weekly; SWB and GH were assessed using an internationally validated multi-item standardized questionnaire. SWB was measured by students' self-evaluated satisfaction with their health, life, and schooling. GH was measured by students' physical health and mental health status. Cognitive function (CF) was modeled as a latent function consisting of plausible values derived using item response theory on reading, mathematics, and science achievement tests.

Results: Findings indicated that increase in weekly MPA was positively associated with higher levels of SWB ($p < .001$), GH ($p < .001$), and CF ($p < .001$) among the study subjects. Parallel mediation analyses revealed that more frequent weekly MPA had relatively large direct effects ($p < .001$) on CF, and indirect effects channeling through improvements in SWB and GH were non-trivial ($p < .001$). Heterogeneity results showed that boosts to CF, associated with MPA, were larger for mathematics and science than for reading ($p < .001$).

Conclusion: This study used a large-scale international dataset to show that the positive relationship observed between MPA and CF among adolescents was robust, and that SWB and GH were two critical mediators through which physical activity positively bolster CF.

Keywords: moderate physical activity, subjective wellbeing, general health, PISA, structural equation modeling

INTRODUCTION

Physical activity is defined as bodily movement that involves skeletal muscles and energy expenditure (Physical Activity Guidelines Advisory Committee, 2018; Sneck et al., 2019). Adolescents are advised by the World Health Organization (WHO) to participate in at least 60 min of moderate physical activity (MPA) each day in order to stay healthy (World Health Organization, 2010). This volume of physical activity is also recommended by U.S. Department of Health and Human Services (2012), citing its instrumental influence on obesity prevention. However, as academic pressure encroaches on adolescents' life, engagement in MPA has rapidly declined while increase in sedentary behavior has been widely observed (Van Stralen et al., 2014; Hartikainen et al., 2021). This trend, evidenced in recent literature, is likely to pose detrimental risks to adolescents' health, wellbeing, and cognitive function (Corder et al., 2015; Hale et al., 2021).

With regard to adolescents' health and wellbeing, the decreasing level of engagement with MPA negatively influences their musculoskeletal development, diet, sleep, body mass index (BMI), and sensory-motor interaction (Have et al., 2016; Zayed and Jansen, 2018; Barbosa et al., 2020). In addition, studies show that the reduction of MPA involvement can have adverse impacts on adolescents' life satisfaction, self-image, and self-acceptation (Chen et al., 2021). Worryingly, there is a global trend of adolescents' increasing sedentary behavior, which leads to the decline in their MPA involvement (Hale et al., 2021). Accordingly, this is likely to hinder their cognitive, motor, and social development, and is related to lower level of cognitive function (CF) among adolescents due to narrowing chances for neurogenesis, angiogenesis, and enhancement of central nervous system metabolism (Barbosa et al., 2020). As a result, adolescents' executive function may be impacted (Singh et al., 2019). To address these concerns, previous studies have investigated the relationship between MPA involvement and CF, and have found that adolescents' general health (GH) and subjective wellbeing (SWB) benefit from MPA and are both important factors in determining CF (Aadland et al., 2017; Barbosa et al., 2020).

In terms of mechanisms of how MPA influences adolescents' CF, existing evidence has identified three lines of potential channels, including physiological factors, executive function, and learning dispositions. As for the physiological factors, routine MPA is associated with the increase of brain-derived neurotrophic factor, insulin-like growth factor-1 and vascular endothelial growth factor, all of which are strong determinants of developmental growth, maintenance and plasticity of the brain, and are related to CF (Barbosa et al., 2020). Neural growth and enhancement of synaptic transmission can lead to changes in adolescents' prefrontal cortex and improvement of their executive functions including abstract reasoning, planning, and problem solving (Kopp, 2012). In addition, different types of MPA are found to influence CF in different ways. Some MPA can increase physiological arousal, leading to better attention and the release of neurotransmitters, whereas more aerobic MPA improves cardiovascular fitness and ameliorate oxygen saturation and glucose delivery, bringing benefits to neurogenesis and angiogenesis in brain areas that are responsible for CF (Egger et al., 2019; Singh et al., 2019). Besides influencing core executive function, benefits of MPA on adolescents' CF are also mediated by the cultivation of learning dispositions and learning behaviors during their engagement of MPA which can help them excel in CF tests. The learning dispositions and qualities include organization skills, on-task behaviors and improved school attendance (Álvarez-Bueno et al., 2016).

More importantly, it has been well documented that adolescents' MPA benefits both their physical and mental health (Penedo and Dahn, 2005; Barbosa et al., 2020), thus enhancing the level of their general health (GH) (Carson et al., 2016). On the one hand, in regard to physical health, MPA can ameliorate adolescents' visual-motor coordination and improve their cardiovascular fitness (Cosgrove et al., 2018). MPA can also keep adolescents' physically fit by reducing the chance of obesity and cardio-metabolic disease (Zayed and Jansen, 2018). MPA is also associated with a healthy diet, better sleep and can enhance adolescents CF (Cosgrove et al., 2018). On the other hand, as for the mental health, MPA is related with positive self-image, self-esteem, and self-efficacy. It can effectively reduce depressive symptomatology, psychological stress, and anxiety (Carson et al., 2016; Hale et al., 2021). Adolescents' physical and mental health can in turn benefit cognitive performance and brain development, laying the physiological foundations for CF (Haverkamp et al., 2020). The lack of MPA is, therefore, seen as a major threat for adolescents' GH and CF.

Additionally, subjective wellbeing (SWB) is a critical dimension of adolescents' wellbeing and is a key indicator reflecting quality of life. It is a notion that describes people's life satisfaction, pleasant and unpleasant affect (Hale et al., 2021). Research shows that SWB has close relationship with people's sports involvement. Body image, self-esteem, and personal experience in sports can pose as barriers in sports participation (Martin et al., 2015). Likewise, regular exercise can improve life satisfaction, reduce depressive symptoms and improve mood (Jodra and Domínguez, 2020). By helping people gain social integration, social support and a sense of belonging, MPA is associated with self-acceptation, positive relationship, personal growth, environmental mastery, and purpose of life (Chen et al., 2021).

Despite the above discussions on adolescents' MPA, GH, SWB and CF, there are important gaps needed to fill. Previous research mainly focused on acute physical activity interventions in pre-adolescent children (Haverkamp et al., 2020) and there is a relative lack of research on adolescents and on the effects of regular physical activity (Verburgh et al., 2013; Li et al., 2017; Xue et al., 2019). Furthermore, while most studies examined the effects of MPA on CF, few studies described its effects on CF embodied by the specific fields of language, math, and science (Haapala, 2012). Also, as previous research mainly used interventional approach or conducted metanalysis of the existing study (Egger et al., 2019; Haverkamp et al., 2020), large scale and cross-cultural studies are needed. Finally, little is known about whether GH and SWB, two significant factors benefited from MPA, can mediate the effects of MPA on adolescents' CF.

MATERIALS AND METHODS

Constructs and Measures

This study leveraged the publicly-available Program for International Student Assessment (PISA) 2018 dataset,[1] which is the flagship project of the Organization for Economic Cooperation and Development (OECD) and sampled 612,004 15-year-old students in more than 70 economies (Liu and Steiner-Khamsi, 2020). PISA used a multi-stage and multi-strata sampling design, for which schools were sampled with students aged 15–16 at the time of assessment (OECD, 2020). In the first stage, schools were selected using a probability-proportional-to-size sampling approach from a systematic list of eligible schools within participating economies. In the second stage, students were randomly selected from a complete list of eligible 15-year-old students within each sampled school. In terms of data collection, each sampled student provided detailed background information and completed CF assessment on math, reading, and science competency, in addition to filling a separate youth wellbeing assessment questionnaire which encompassed a series of questions covering life satisfaction, health status, and physical activity.

Program for International Student Assessment contains tests on key cognitive domains and is widely used as an instrument to assess and compare students' school performance and learning dispositions across different countries and regions (Lee and Stankov, 2018). The major cognitive domains in PISA are reading, math and science (Liu, 2019; OECD, 2020), as the knowledge and skills embodied in these domains are widely seen as indicators for the successful participation in contemporary societies and are key to the sustainable growth of modern economy (Heckman and Jacobs, 2009; OECD, 2019; Araújo et al., 2020). Reading domain in PISA tests an individual's capacity to understand, use, evaluate, reflect on and engage with texts to achieve one's goals, develop one's knowledge and potential, and participate in society; math is to examine students' competence to analyze, reason and communicate ideas effectively as they pose, formulate, solve and interpret solutions to mathematical problems; and science domain deals with students' ability to engage with science-related issues, to reason with the ideas of science, as a reflective citizen (OECD, 2020). The results of the cognitive domains in PISA tests attract wide public attention as they offer insights, from a comparative perspective, into the effectiveness of educational policy making and provide large-scale, cross-cultural data for research analysis (Araújo et al., 2017).

Apart from the cognitive domains, two key constructs in this study, SWB and GH, are anchored on the PISA 2018 wellbeing survey. In broad strokes, the PISA wellbeing questionnaire was designed to maximize cross-cultural comparability by choosing clear, translatable, quantifiable, and vignette-based Likert-scale items (OECD, 2019). This study leveraged data availability of students' frequency of engagement in MPA, level of SWB and GH, as well as CF assessment in math, reading, and science. Below, a more detailed descriptions of the predictor variable, mediator variables, and outcome variables are to be reported.

Firstly, MPA [≥3.0 Metabolic Equivalent Task (MET)] was the predictor variable in this study. In PISA, MPA is referred as physical activities including but not limited to walking, climbing stairs, riding bicycles, for a total of at least 60 min per day. Respondents in PISA reported how many days they engaged in these physical activities during the past 7 days.

Secondly, SWB and GH, the two mediator variables in this study, were assessed using an internationally validated multi-item standardized Likert-scale questionnaire in PISA. For SWB, respondents answered ten Likert-scale questions regarding their self-evaluated satisfaction with health, life, and school. The 10 questions are "Your health; the way that you look; what you learn at school; the friends you have; the neighborhood you live in; all the things you have; how you use your time; your relationship with your parents/guardians; your relationship with your teachers; your life at school." For GH, respondents answered nine Likert-scale questions on how often they had some physical or mental health status, including headache, stomach pain, back pain, feeling depressed, irritability or bad temper, feeling nervous, difficulties in getting to sleep, feeling dizzy, and feeling anxious.

Thirdly, CF as the outcome variable was modeled as a latent construct. In PISA's cognitive assessment, emphasis was put on respondents' complex CF, particularly on individuals' capacity to understand, evaluate, formulate, reason, and reflect (OECD, 2018). It was measured by performance in mathematics, reading, and science domains. Leveraging item response theory, ten plausible values were generated for each respondent per subject, and a probability distribution for a student's ability is estimated instead of a direct estimation of a student's ability (OECD, 2009).

Hypotheses

Based on the discussions of the relationships between MPA, GH, SWB, and CF, the following hypothesis were made (see **Figure 1**): adolescents' MPA influences CF (embodied by their performance in PISA math, reading, and science tests), and that GH and SWB, mediate the effects of MPA on adolescents' CF.

Sample Characteristics

The inclusion criteria for study subjects were as follows: (1) reported frequency of MPA (≥3.0 MET); (2) reported SWB and GH using multi-item standardized Likert-scale; and (3) completed cognitive test results for math, reading, and science. A total of 63,228 subjects satisfied the inclusion criteria, and the descriptive statistics for the participating students were presented in **Table 1**. These 63,228 students are from nine countries and economies, including Bulgaria, Georgia, Hong Kong, Ireland, Mexico, Panama, Serbia, Spain, and United Arab Emirates. Among these students, 32,562 (51.5%) were female. The participants' age ranged from 15.812 to 15.816 (M = 21.26, SD = .29). On average, these students in the sample reported 3.168 times of MPA. The average scores of their test results on math, reading, and science were 474.004, 471.488, and 470.640, respectively.

[1]https://www.oecd.org/pisa/data/2018database/

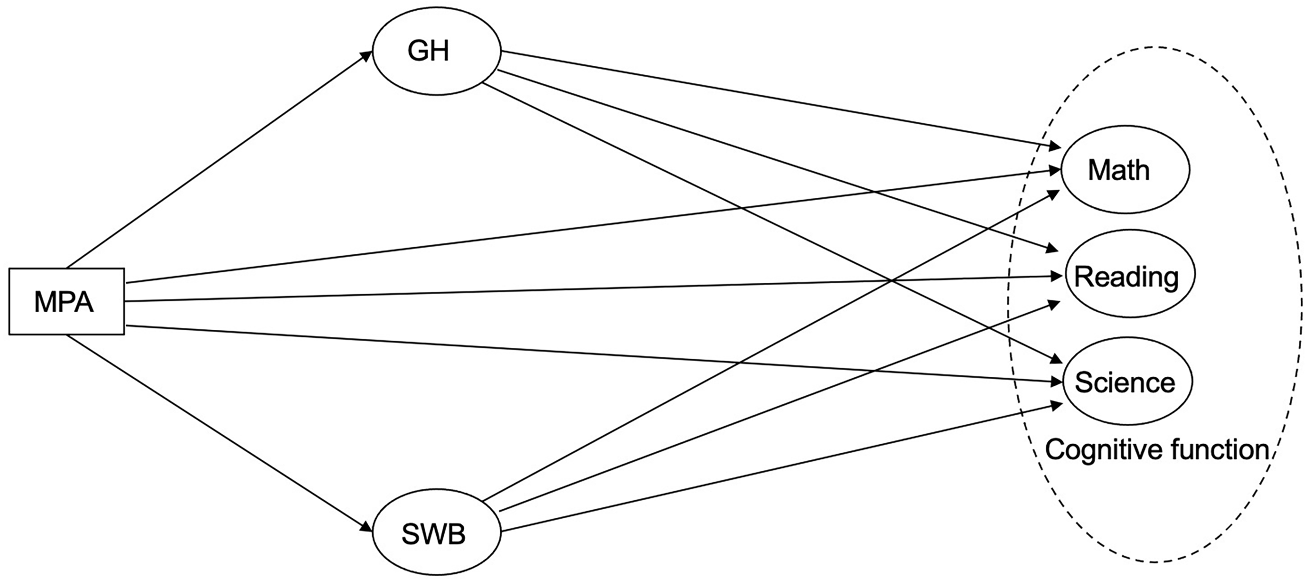

FIGURE 1 | Conceptual diagram.

TABLE 1 | Demographic information of participants and descriptions of predictor and outcome variables ($N = 63{,}228$).

Variable	Mean	SD	95% CI	
			Lower	Upper
Female	.515	–	–	–
Age	15.814	.290	15.812	15.816
MPA	3.168	.010	3.149	3.186
Math (10 plausible values)	474.004	98.867	375.137	572.871
Reading (10 plausible values)	471.488	101.444	370.044	572.932
Science (10 plausible values)	470.640	97.026	373.614	567.666

Statistical Analysis

The study utilized structural equation modeling (SEM) to examine the relationship between MPA and CF, and fitted a parallel mediation model to evaluate the extent to which SWB and GH mediated their relationship. In recent decades, SEM has grown in popularity in scientific inquiry, especially among new applications in educational psychology research (Karimi and Meyer, 2014). Methodologically speaking, SEM allows the researcher to statistically examine the extent to which proposed hypotheses are supported by empirical data to reflect theoretical predictions (Kline, 2015).

This present study utilized partial least squares SEM model (PLS-SEM). All analyses were performed using STATA version 15.0 (Stata, StataCorp LLC, College Station, TX, United States) software. Several goodness of fit indices was tested to evaluate how well the structural models fitted the data. The comparative fit index was computed to be .912, while Tucker-Lewis index was computed to be .905. Both were higher than .9, suggesting that the data displayed a reasonable fit for the model (Bentler, 1990). The value of Root Mean Square Error of Approximation was .104, which was marginally above the goodness-of-fit threshold of .10 (McDonald and Marsh, 1990).

RESULTS

Measurement Model

While PISA 2018 has already categorized survey items by broad construct groupings, we report psychometric properties of presumed scales and assess measurement model fit (Matsunga, 2010). **Tables 2** and **3** presented results from the measurement models, with information on factor loadings. Importantly, all item loading values were above .60, showing good explanation of each factor, which indicated good internal consistency and construct validity (Hair et al., 2010, 2016). The internal consistency of both variables was assessed using Cronbach's α, which was .892 for SWB and .880 for GH. In **Table 4**, we reported correlation coefficients between constructs, and found that all construct pairs exhibited significant and positive associations.

Structural Equation Modeling

The estimation of standardized direct effects was reported in **Table 5**. MPA had significant positive effects on both GH and SWB. The path coefficient from MPA to GH was significant (.189, $p < .001$), and so was the path coefficient from MPA to SWB (.183, $p < .001$). That is, both GH and SWB were influenced by students' MPA.

CF was assessed using three cognitive test domains in PISA. MPA was positively related to students' scores on math. The

TABLE 2 | Reliability and convergent validity of subjective wellbeing (*N* = 63,228).

Items	Factor loadings
1. Your health	.691
2. The way that you look	.694
3. What you learn at school	.691
4. The friends you have	.699
5. The neighborhood you live in	.699
6. All the things you have	.756
7. How you use your time	.711
8. Your relationship with your parents/guardians	.735
9. Your relationship with your teachers	.721
10. Your life at school	.751

TABLE 3 | Reliability and construction validity of general health (*N* = 63,228).

Items	Factor loadings
1. Headache	.688
2. Stomach pain	.673
3. Back pain	.627
4. Feeling depressed	.757
5. Irritability or bad temper	.753
6. Feeling nervous	.749
7. Difficulties in getting to sleep	.699
8. Feeling dizzy	.745
9. Feeling anxious	.754

path coefficient from MPA to math was .036 ($p < .001$). This result demonstrated that each additional MPA per week was associated with .036 more standardized scores on math. Students' performance on reading was also positively influenced by their MPA (.027, $p < .001$). Moreover, positive effect was in correlation with MPA on the subject of science. The path coefficient from MPA to science was .034 ($p < .001$), indicating that each additional MPA active day was related to .034 higher standard deviations on CF in math.

GH showed direct effects on CF. According to the model, the path coefficient from GH to math was significant (.013, $p < .001$). Meanwhile, the path coefficient from GH to reading was also positive and significant (.006, $p < .000$). It can be also observed that GH had positive and significant effects on students' achievements on science tests in PISA (.011, $p < .001$). The results suggested that students who reported higher level of GH were likely to achieve more on math, reading, and science.

Subjective wellbeing had a positive and significant effect on math (.004, $p < .001$). From SWB to reading, there was also a direct path with a significant path coefficient (.008, $p < .001$). Moreover, it can be also observed that SWB (.005, $p < .001$) had a positive and significant effect on students' science tests in PISA. Therefore, students' higher level of SWB was associated with better CF.

According to the model, a consistent pattern was observed among math, reading, and science. Students' CF on math, reading, and science was all found to be related to MPA, while there were differences on the path coefficients. The results of the model suggested that each additional MPA per week indicated additional .036 standard scores on math, .034 standardized scores on science, and .027 standardized scores on reading. Furthermore, GH was demonstrated to have positive and significant effects on all the subjects. Similarly, the positive effect of GH was comparatively higher on math (.013) and science (.011), and lower on reading (.006). In the meantime, all the three subjects were directly associated with the variable of SWB. Whereas, students with higher level of SWB tended to score higher on reading (.008, $p = .000$), math (.004, $p = .000$), and science (.005, $p = .000$).

The analysis above addressed the direct effect of MPA on CF, the influence of the mediators, GH and SWB, is shown in **Figure 2** and **Table 6** and is to be reported below. Firstly, as for the effects of MPA on math, this study tested the indirect effects *via* the influence of SWB and GH respectively. Both SWB (standardized indirect effect = .001) and GH (standardized indirect effect = .003) were simultaneously. Both indirect path coefficients tested in our models were positive and significant. Combined with the direct effect (direct effect = .036), the total effect of MPA on math was .039.

Secondly, concerning the effects of MPA on reading, MPA had indirect effects on reading through GH (standardized indirect effect = .001) and through SWB (standardized indirect effect = .002) respectively. Both these indirect path coefficients in models were positive and significant. Thus, with the direct effect (.027), the total effect of MPA on reading was computed as .029.

Lastly, as for the effects of MPA on science, both GH and SWB were found to be mediators (standardized indirect effects are .002 and .001 respectively). The total indirect effect was .003. Adding to the direct effect of MPA on science (direct effect = .034), the total effects of MPA on science were .037.

DISCUSSIONS AND CONCLUSIONS

This study investigated the effects of MPA on student's CF. Existing research have demonstrated the significance of MPA on CF. Yet there is a lack of study focusing on the effects of MPA among adolescents and the mediating roles of GH and SWB. To fill the gap, this study explored the direct effects of MPA on adolescents' CF based on large-scale, cross-cultural data and examined the mediating channels of GH and SWB.

Our findings demonstrated that MPA had both direct and indirect positive effects on students' CF. The path coefficient from MPA to GH was .189 ($p < .001$), while the path coefficient from MPA to SWB was .183 ($p < .001$). MPA was found to have positive direct effects on math (path coefficient = .036, $p < .001$), reading (.027, $p < .001$), and science (.034, $p < .001$). GH and SWB were found to play significant mediating roles. Through the mediation of GH, MPA had an indirect influence on math (.003, $p = .000$), reading (.001, $p = .000$), and science (.002, $p = .000$). Meanwhile, SWB mediated the effects of MPA on math (.001, $p = .000$), reading (.002, $p = .000$), and science (.001, $p = .000$). To put this number in broader context, OECD (2016) reported .25 to .30 standard deviations as the

TABLE 4 | Correlation matrix of SEM input measures (N=63,228).

	1	2	3	4	5	6
1. MPA	–					
2. SWB	.072***	–				
3. GH	.051***	.351***	–			
4. Math	.093***	.114***	.152***	–		
5. Reading	.071***	.116***	.097***	.829***	–	
6. Science	.088***	.114***	.135***	.845***	.881***	–

****p<.001.*

TABLE 5 | Standardized direct effects of the SEM model (N=63,228).

Pathways	Std. coefficient	SE	Value of *p*	95% CI	
				Lower	Upper
MPA→GH	.189	.014	.000	.163	.216
MPA→SWB	.183	.009	.000	.165	.202
MPA→Math	.036	.001	.000	.034	.039
MPA→Reading	.027	.001	.000	.024	.030
MPA→Science	.034	.001	.000	.031	.037
GH→Math	.013	.000	.000	.012	.014
GH→Reading	.006	.000	.000	.005	.007
GH→Science	.011	.000	.000	.010	.012
SWB→Math	.004	.001	.000	.003	.005
SWB→Reading	.008	.001	.000	.007	.009
SWB→Science	.005	.001	.000	.004	.007

CFI=.912; TLI=.905; RMSEA=.104; $\chi^2(487)=37{,}8631.66$.

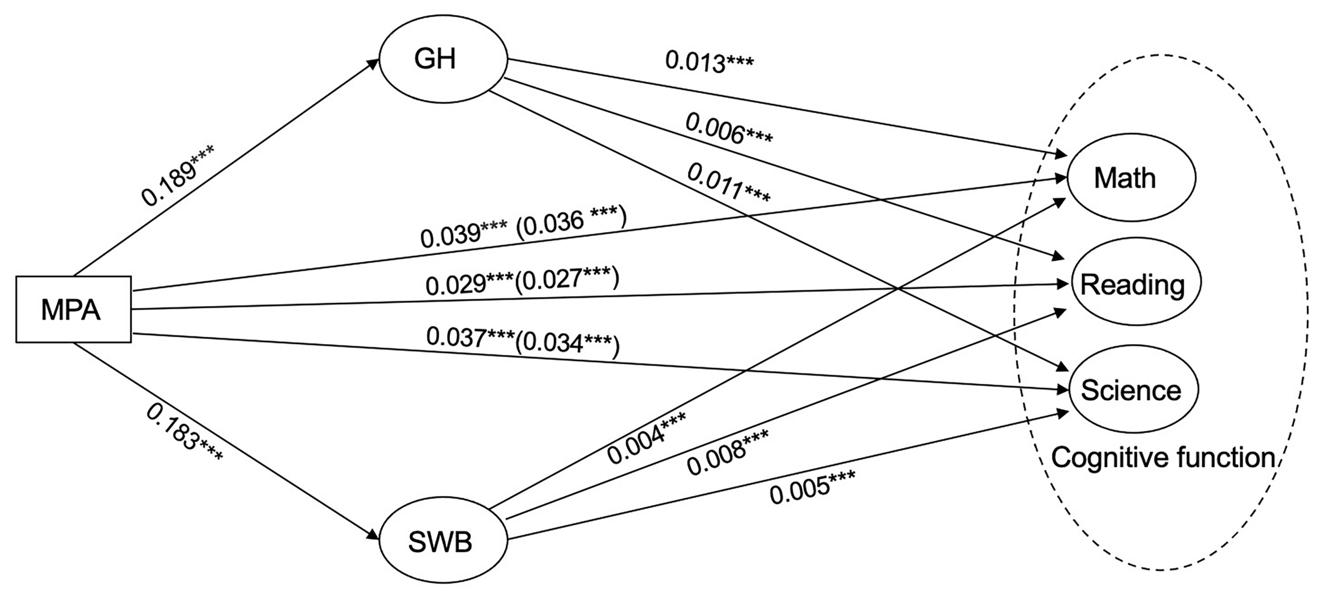

FIGURE 2 | The full parallel mediation model. ***p<0.001, parenthetical=after adding mediating variable coefficients.

amount of expected learning gains per year among middle-to-high income countries, while Evans and Yuan (2019) estimated learning gains per year between .15 and .21 standard deviations among low-to-middle income countries. Based on these prior estimates, conservative calculations indicated that our findings of .036 standard deviations increase in student

TABLE 6 | Standardized indirect effects and 95% confidence intervals for the model (*N* = 63,228).

Pathways	Std. coefficient	SE	Value of *p*	95% CI	
				Lower	Upper
MPA→GH→Math	.003	.000	.000	.002	.003
MPA→SWB→Math	.001	.000	.000	.001	.001
MPA→Math	.003	.000	.000	.003	.004
MPA→GH→Reading	.001	.000	.000	.001	.001
MPA→SWB→Reading	.002	.000	.000	.001	.002
MPA→Reading	.003	.000	.000	.002	.003
MPA→GH→Science	.002	.000	.000	.002	.002
MPA→SWB→Science	.001	.000	.000	.001	.001
MPA→Science	.003	.000	.000	.003	.004

learning outcomes approximately corresponded to between 1.4 and 1.8 additional months of learning in a typical 9-month school year.

The fulfillment of the hypothesis and contributions of this study are discussed as follows. First, since PISA 2018 dataset included information on students' MPA and cognitive test results for math, reading, and science, this study managed to utilize SEM to evaluate the relationship between MPA and CF. Our analysis indicated that adolescents' MPA had positive and significant direct effects on CF, which was consistent with previous research highlighting the role of physical activities in improving academic performance (Bedard et al., 2019; Barbosa et al., 2020).

Second, this study conceptualized students' CF as their math, reading, and science achievements in PISA 2018. Through our analysis, it turned out that the effects of MPA were positive and significant on all the three subjects. In contrast, previous studies have reported inconsistent findings. For instance, Spruit et al. (2016) found positive effects of physical activities on science, including math, but not on language. While Álvarez-Bueno et al. (2016) reported positive effects on both language and math. Using a large and cross-cultural sample, this study reexamine inconclusive findings in existing literature.

This study also examined two potential mediation factors, adolescents' GH and SWB, were found to mediate the effects of MPA on CF. By utilizing SEM, this study evaluated the extent to which SWB and GH mediated their relationship. These results have deepened to the understandings on the indirect effects of MPA on adolescents' academic performance discussed in previous research (Sneck et al., 2019).

This study has the following implications: on the methodological level, it advanced the current discussions on MPA and CF. It used large and cross-cultural data, to study the relationship between MPA and adolescents' CF and how GH and SWB mediate it. On the policy level, it reminds policymakers that it is beneficial to encourage MPA in schools; also, in order to improve adolescents' CF, and school performance, educational stakeholders, including governments, schools, community, and parents, should work together to improve adolescents' GH and SWB are important mechanism factors to consider.

This study mainly depended on the large, statistical data. Future research can go deep into the mechanism to explore the physiological foundations of the model. Pedagogical research is also needed to study how curriculum and educational reforms may benefit from these findings. The reasons behind differences among the subjects were not fully explored in the current study, which also requires further investigation.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found online at: https://www.oecd.org/pisa/data/2018database/; OECD:PISA 2018 Database.

AUTHOR CONTRIBUTIONS

XLuan organized the team, managed the research project, and participated in the analysis of data and the preparation of manuscript. JL conceived and designed the study. XLuo did the literature review, participated in the analysis of data, and managed the corresponding issues. All authors contributed to the article and approved the submitted version.

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Giving Ideas Some Legs or Legs Some Ideas? Children's Motor Creativity Is Enhanced by Physical Activity Enrichment: Direct and Mediated Paths

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Approaches to foster motor creativity differ according to whether creative movements are assumed to be enacted creative ideas, or solutions to emerging motor problems that arise from task and environmental constraints. The twofold aim of the current study was to investigate whether (1) an enriched physical education (PE) intervention delivered with a joint constraints-led and cognitive stimulation approach fosters motor creativity, and the responsiveness to the intervention is moderated by baseline motor and cognitive skills and sex; (2) the intervention may benefit motor creativity through gains in motor coordination, executive function, and creative thinking. Ninety-five children, aged 6–9 years, participated in a 6-month group randomized trial with specialist-led enriched PE vs. generalist-led conventional PE. Before and after the intervention, Bertsch's Test of Motor Creativity, Movement Assessment Battery for Children, Random Number Generation task and Torrance Test of Creative Thinking were administered. Linear mixed models were run accounting for the random effects of data clusters. Multiple mediation analysis was performed to assess whether motor coordination, executive function and creative thinking mediated any improvement of motor creativity. Results showed that (1) specialist-led enriched PE, compared to generalist-led conventional practice, elicited a more pronounced improvement in all motor creativity dimensions (fluency, flexibility, and originality) independently of baseline levels of motor and cognitive skills and sex; and (2) improved motor creativity was partially mediated by improved motor coordination and, as regards motor flexibility, also by improved inhibitory ability. In conclusion, enriching PE with tailored manipulations of constraints and variability may enhance the ability to create multiple and original task-pertinent movements both directly and through indirect paths. The results are discussed extending to motor creativity a theoretical framework that distinguishes different creativity modes. The intervention may have fostered the generation of creative movements directly through the exposure to variation in constraints, activating the sensorimotor ‘flow’ mode of creativity that bypasses higher-order cognition, but also indirectly through a systematic and conscious convergence on solutions, activating the ‘deliberate’ mode of creativity that relies on inhibition to reject common or task-inappropriate movement categories.

Keywords: divergent movement, creative thinking, executive function, development, physical education, constraints-led approach, cognitive stimulation

INTRODUCTION

Physical activity (PA) is increasingly acknowledged by exercise scientists as an investment in human capital, with PA outcomes framed as capitals in the physical, mental, and socio-emotional domains (Bailey et al., 2013). Similarly, creativity researchers point to the age of human capital we are living in and propose that creativity is the currency of the modern era (Kell et al., 2013). At the crossroad of these two perspectives on the role of physical activity and creativity to build human capital lies the domain of proficient and creative movement.

In the last decade, there has been a flourishing of research suggesting the centrality of motor competence for children to develop the full potential of their multifaceted capital (van der Fels et al., 2015; Barnett et al., 2021; Pesce et al., 2021a). However, within the ongoing debate on what is motor competence (Bardid and Utesch, 2018) and how it should be assessed (Eddy et al., 2020) and trained (Jiménez-Díaz et al., 2019), motor competence is mostly conceived as proficient performance of fundamental movement skills, such as running or throwing, and tested by observing the reproduction of predefined movement skill patterns or measuring their efficacy. Recent attempts to broaden the scope of motor competence have proposed to shift the focus from ‘fundamental’ to ‘foundational’ skills. They encompass also ‘non-fundamental’ movement skills considered important for promoting PA (e.g., cycling; Hulteen et al., 2018), or a wider range of variable skills that emerge through exploration and detection of opportunities for action (Ng and Button, 2018) also referred to as ‘functional’ movement solutions (Rudd et al., 2021a).

This shift from discrete fundamental movement skills performed under stable conditions to multiple nested movement skills performed in complex and fluid situations fits within the broader framework of physical literacy. Beyond the usual definition as the competence, confidence and knowledge to be physically active for life, a recent overarching model highlights the holistic nature of physical literacy and the reciprocal and reinforcing relations of motor competence with knowledge, motivational, affective and social processes that emerge from the person-context interaction in various real life settings (Cairney et al., 2019). Parallel to and partly driven by this extension of the meaning of motor competence, motor creativity – the ability to produce functional or expressive solutions to movement tasks that are novel, original, and pertinent (Memmert, 2011) – and related constructs, such as movement variability (Orth et al., 2017; Pesce et al., 2019), adaptability (Richard et al., 2018b), functional novelty (Hristovski et al., 2011) and exploration (Stodden et al., 2021) – are gaining momentum. Nevertheless, interventional evidence on how to foster it is limited.

Theory-based interventional research performed in sport and gross-motor performance arts (such as dance) suggests that motor creativity is sensitive to tailor-made intervention programs in both adult skilled performers (e.g., Memmert, 2011; Torrents et al., 2015) and children and adolescents (e.g., Rasmussen and Østergaard, 2016; Santos et al., 2017; Thomaidou et al., 2021). In early childhood education, movement-based creativity programs have been employed to foster not so much motor creativity *per se*, but creative thinking in the embodied and kinaesthetic way that characterizes discovery learning and cognitive development in the early years (Grammatikopoulos et al., 2012). In school-aged children, evidence of benefits of motor creativity programs in physical education (PE), though promising, mostly lacked a theoretical base (Bournelli, 1998; Bournelli and Mountakis, 2008; Chatoupis, 2013) with few exceptions (Richard et al., 2018a).

Richard et al. (2018a) compared the effects two PE programs (conventional vs. creative) on multiple dimensions of motor creativity and creative thinking. The creative motor program included the same content of the conventional program but was delivered according to non-linear pedagogical principles in PE drawn from the Ecological Dynamics theory (Rudd et al., 2021b). Non-linear pedagogy focuses on the interaction between the learner and the environment that constrains their action and is characterized by teaching strategies that exploit functional movement variability. This differs from teaching with linear pedagogy, which relies on repeated, model-oriented skill practice (Rudd et al., 2021b). Richard et al. (2018a) found that the creative motor program improved fluency and flexibility in moving, and originality in thinking. To interpret the effect on originality in thinking but not in moving, the authors suggested that children’s motor experience and skills might have been insufficient to translate increased original ideas into original movements, or their cognitive control insufficient to suppress the tendency toward performing more common movements.

Evidence on the relation between motor creativity and motor coordination development in children is mixed, showing either a positive association (Milić, 2014; Santos and Monteiro, 2021), or no association (Scibinetti et al., 2011; Marinšek and Lukman, 2021). Also the role of cognition in children’s motor creativity is an open issue. On the one side, creative movements are hypothesized to be enacted creative ideas. This hypothesis is consistent with cross-sectional associations between creative thinking and creative sport performance (Santos et al., 2017; Santos and Monteiro, 2021) and underlies the suggestion that designed PA programs may foster motor creativity in children through the development of divergent cognitive processes (Bournelli and Mountakis, 2008). On the other side, creative solutions to motor problems are suggested to arise from

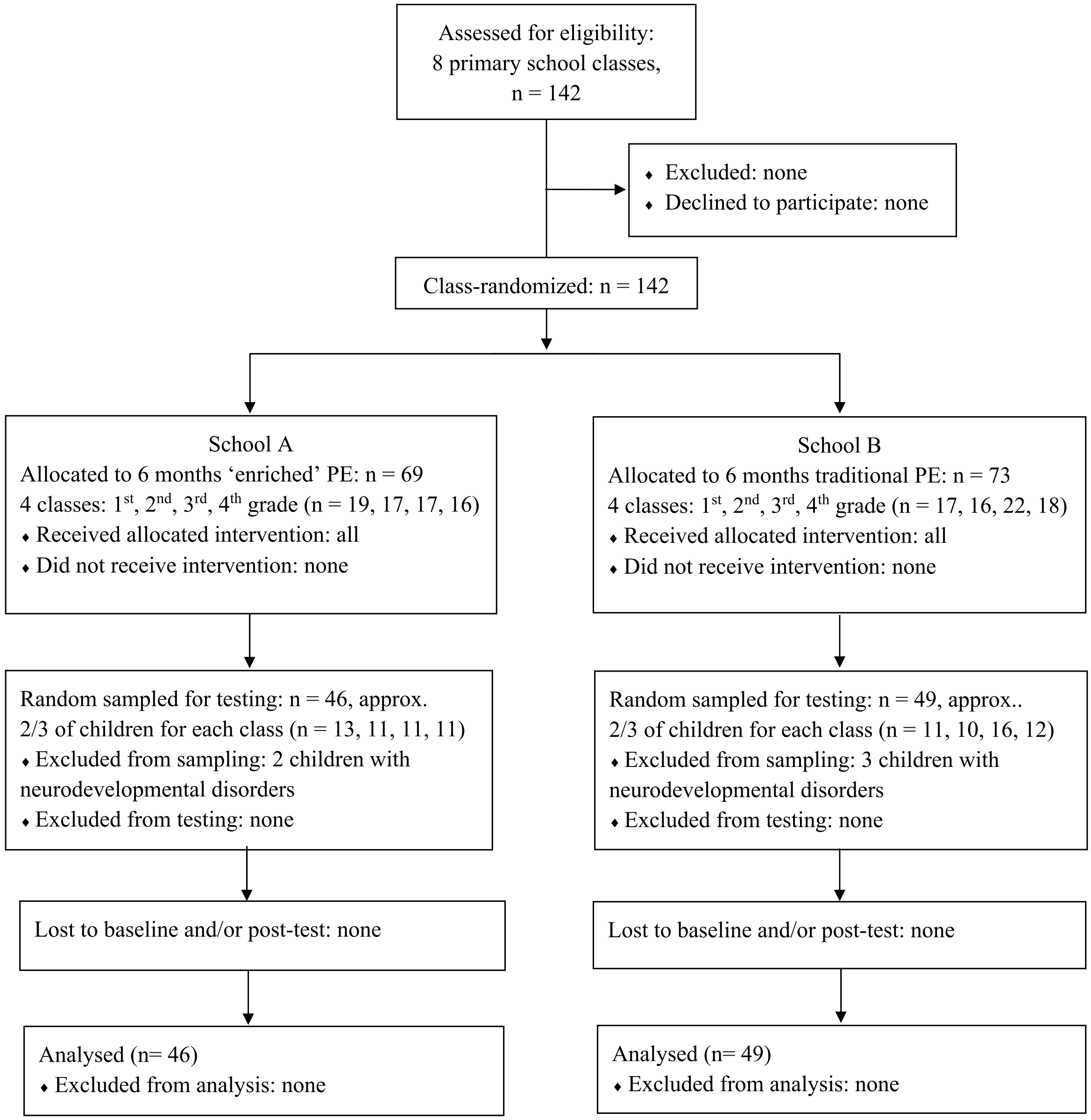

FIGURE 1 | Study flow diagram for the class-randomized controlled trial.

task and environmental constraints without any abstract rule representation of the emerging creative behavior (Hristovski et al., 2011; Orth et al., 2017). This view is supported by evidence on working memory – a cognitive executive function enabling to hold and update task-relevant information in mind, which seems unrelated to the generation of creative movement actions by children (Scibinetti et al., 2011) and adults (Furley and Memmert, 2015; Moraru et al., 2016) but involved in the divergent generation of creative thoughts (De Dreu et al., 2012). Instead, inhibition – an executive function allowing to control interference and suppress routine thoughts and behaviors – seems related to the ability to produce original movements (Scibinetti et al., 2011), whereas it is unclear whether inhibition (Khalil et al., 2020) or disinhibition (Radel et al., 2015) is involved in creative thinking.

The primary aim of this study was to verify whether a theory-based enriched PE program, grounded on the constraints-led approach and variability of practice (Tocci and Scibinetti, 2007; Richard et al., 2018a; Pesce et al., 2019; Scibinetti, 2019) may aid children's motor creativity. We also verified whether children's responsiveness to the motor creativity intervention may be enhanced in presence of a high baseline level of creative thinking, as hypothesized by Richard et al. (2018a), or higher baseline levels of motor coordination and executive function, and be different in males and females. Secondarily, we explored whether improved motor coordination, executive function (particularly inhibition) and creative thinking mediate improvements in motor creativity dimensions. We hypothesized two potential paths (Dietrich, 2019). On the one hand, the manipulation of constraints might lead to creative perception-action couplings, relying on motor coordination and bypassing higher-order cognition and consciousness. On the other hand, enhanced inhibition might support a deliberate mode of creativity (Dietrich, 2019) and convergent creative processes (Zhang et al., 2020), allowing to converge on creative solutions by refraining from more common ones. Inhibition is a multifaceted construct as early as childhood (Huizinga et al., 2006). We targeted a specific facet of the inhibition construct – cognitive inhibition (Diamond and Ling, 2020), which is the ability to inhibit routine thoughts and memories and seems related to motor creativity (Scibinetti et al., 2011). We hypothesized that if creative motor behaviors are enacted ideas, then cognitive inhibition may help suppress thinking routines that would not allow diverging from habitual ideas and behaviors.

MATERIALS AND METHODS

The study is part of a broader longitudinal research program approved by the Ethics Committee of the "Umberto I" hospital of the First Rome University (Ref. No 2950) and authorized by the school Committees and students' parents, who gave written informed consent. We did not seek child assent, as this study was part of regular PE classes.

Study Design

In a class-randomized trial, eight classes were randomly assigned to either an intervention of specialist-led enriched PE designed to foster motor creativity or generalist-led conventional PE. The participants were tested during the curricular school time on primary motor creativity outcomes (fluency, flexibility, originality in moving, and overall motor creativity) and secondary outcomes potentially contributing to motor creativity in the motor domain (motor coordination [evaluated as motor impairment scores]: manual dexterity, aiming and catching skills, balance, and overall motor impairment) and in the cognitive domain (creative thinking: fluency, flexibility, originality in thinking, and overall creative thinking; executive functions: inhibition and working memory) at baseline and after 6-month intervention, corresponding to the end of the school year. At baseline, demographic information on age, sex (assigned at birth), body weight and height, outdoor play and structured physical activity/sport training was also collected.

Participants

Participants were 142 primary school children, recruited from eight (1st to 4th grade) classes of two urban schools in the municipality of Alba (in the Northern of Italy). Within each school, one class for each school grade was stratified randomly included in the study and the two participating schools were randomly assigned to the intervention or control condition. The regional and local PE coordinators invited school principals to participate within the broader frame of a whole-child initiative of PA promotion supported by a Public-Private-Partnership. School principals and teachers were provided information on the aim of the study and offered in-person presentation, and principals were invited to provide written organizational consent. Following school recruitment, a school liaison person from each school (identified by the consenting school) was provided with a plain language descriptions of the study and a consent form for parents/guardians.

To collect data within the time constraints for test administration posed by the participating schools and at the same time limit the cluster effect of the class-based recruitment, two-thirds of the 142 children were selected from each of the eight classes with systematic random sampling, with cluster size ranging from 10 to 16 children ($M = 12 \pm 2$). Thus, the final sample comprised 95 children aged 6–9 years ($M = 7.8 \pm 1.3$). The progress through the phases of enrolment, intervention allocation, and final sample for data analysis is represented in **Figure 1**. Children with certified neurodevelopmental and/or mental health conditions (e.g., children diagnosed with mild intellectual-relational disability or developmental learning disorder) were excluded from within-class random sampling to avoid too large deviations in the dataset. This applied to two in the intervention classes and three in the control classes. Further demographic characteristics such as socio-economic status, considered sensitive information by the schools, could not be assessed.

Intervention

Content and Delivery

The intervention was designed in a theory-based manner, including key elements of two theoretical approaches grounded on different assumptions, yet complementary for our purposes: the constraints-led and the cognitive stimulation approach. For this integration, we relied on emerging evidence on the advantage of hybridizing pedagogical models that seems best suited to promote outcomes in multiple domains, overcoming the boundaries of single theoretical approaches (González-Víllora et al., 2018).

According to the principles of the constraint-led approach, the primary role of the teachers involved in the intervention was not that of an instructor, who aims at modeling children's movement skills, but rather that of a facilitator of the interaction of the learners with the environment through the purposeful manipulation of environmental and task constraints. In line with Orth et al.'s (2017) viewpoint, we designed a progressive manipulation of the environmental and task constraints to facilitate children's exploration of both new coordination solutions (i.e., different movement patterns, corresponding to the flexibility dimension of creativity) and new control solutions (i.e., different parametrizations of the same movement pattern, contributing to the fluency dimension of creativity). As an example of environmental constraints, obstacles of different size/height may generate different affordances (i.e., opportunities for action in the environment) for children to produce different solutions to overcome the obstacles, either exploring new coordination solutions (e.g., vaulting instead of jumping if the child may rely on adequate skills and the obstacle surface allows vaulting supported by the hands), or exploring a new control solution (e.g., changing some joint angles to jump over a higher obstacle without substantially changing the jump coordination). As regards task constraints, we adopted both direct and indirect releasing (Hristovski et al., 2011). Directly releasing constraints means using less stringent instructions that increase the affordances that can satisfy constraints; indirectly releasing means using more stringent instructions that, while hindering more common solution pathways, direct the learners in otherwise unexplored directions and promote the perception and utilization of new affordances. As an example of indirect releasing of task constraints, constraining the parts of the body that can touch the floor while moving (e.g., supporting the body on only one hand and one foot, or no feet, or neither hands nor feet) leads children to explore new locomotor coordination solutions beyond the common bipodalic ones.

Thus, our methodology embraced the viewpoint that a constraints-led exploration may enhance the variability of functional movement patterns and promote divergent movement ability directly rather than through the enactment of an antecedent creative idea (Orth et al., 2017), in line with a flow mode of creativity that relies on sensorimotor coupling rather than higher-level cognition (Dietrich, 2019). However, it has been suggested that a creative act may not be the manifestation of only one creativity mode, as we can also evaluate, select and converge on creative solutions by means of a deliberate mode of creativity that relies on top-down cognitive control (Dietrich, 2019). Thus, we complemented the constraints-led approach with the cognitive stimulation approach. To operationalize in the motor domain the stimulation of cognitive control processes, we adopted principles of variability of practice applied in motor learning with linear and non-linear pedagogies, as both provide opportunities to generate cognitive engagement (Pesce et al., 2019). Linear pedagogy relies on the classical theory of motor learning stages that conceives learning as a progression from an initial cognitive stage to a final autonomous stage of maximal movement automaticity and minimal cognitive engagement (Schmidt et al., 2011). Following Tomporowski et al. (2010), teachers of the intervention classes introduced systematic changes to the motor learning tasks to generate contextual interference and new cognitive challenges, and keep children 'on the learning curve.' To foster the deliberate, cognitively engaging mode of creativity, teachers also manipulated the time constraints on the search for solutions and asked children to select the rarest and most original ones within different time frames. This was assumed to challenge cognitive inhibition, which is the inhibition of routine thoughts and memories (Diamond and Ling, 2020) and children's awareness that we tend to produce habitual movement actions if there is not enough time to inhibit most common ideation solutions and evaluate the originality of different emerging alternatives. These principles were applied in designed PA games. Two sample games with game alterations and task analysis to zoom into the game demands are presented in **Supplementary Data Sheet 1**. The first game ("Magnets and mechanisms") is an example of constraint-led approach and non-linear pedagogy to foster the search for solutions to satisfy constraints with a focus on cooperation and cooperative creativity, which are meaningful goals of school education (Torrents et al., 2021a). The second game ("A friend is a treasure") is an example of hybridization of pedagogical models. It is provided in two versions: the first is targeted to cognitive stimulation through systematic variations of coordinative demands applied with both linear and non-linear pedagogy; the second version adds further manipulation of task and time constraints along with teaching through questions to foster awareness of the creative process.

Instead, generalist teachers of the control classes were instructed to perform their 'business as usual'. Within the Italian primary education, PE lessons are traditionally conducted by generalist and not specialist teachers. Generalists, though having competence in student-centered pedagogy, during their formal tertiary training do not receive specific training on how to use a student-centered pedagogy concretely for delivering PE lessons. Their scarce knowledge, competence and confidence in the own PE teaching skills translates into 'conventional' PE lessons characterized by mainly prescriptive tasks and teaching strategies primarily driven by teachers' safety concerns and control efforts, rather than mastery-oriented strategies that require exploration and a certain degree of risk-taking.

Setting, Duration, Blinding, and Fidelity

The intervention was performed in the gym or sports court of the school during the curricular PE time for 1 h once a week, as prescribed by school regulation, and lasted 6 months from November to April with a total amount of 24 intervention hours divided into four 6-week teaching modules. The teacher–child ratio was about 1:18 in the control classes but was altered in the intervention classes, where a specialist PE teacher delivered the intervention in the presence of the generalist classroom teacher; however, this latter did not actively participate to the PE delivery except for a limited supportive role for individual children. Due to the presence of the PE specialist, teacher and children could not be blinded with respect to the assignment to generalist-led or specialist-led PE but were blinded as to the expected outcomes.

To ensure implementation fidelity but also an adequate degree of adaptability, PE specialists used a handbook, which describes the pedagogical principles and the PA games designed to foster motor creativity, with each game including several alterations to help teachers adapt the games to their children's skills and needs (Pesce et al., 2016a). The teaching materials also included sheets with tree diagrams to identify the task demands of each game in different domains and how they were altered in the game variations. Moreover, PE specialists underwent a 6-h teacher training every 6 weeks and participated to regular group discussions with the generalist teachers of their intervention classes. These group discussions were aimed to align the contents of each teaching module across classes and discuss teaching issues arisen in the previous module, as well as to foster generalists' learning of the enriched PE methodology for future application after the end of the intervention. During training, PE specialists were taught how to use the handbook and the tree diagram sheets for task analysis, and how to create nuanced game variations according to the pedagogical principles outlined in the handbook.

No adverse events or side effects occurred in specialist-led enriched or generalist-led conventional PE classes.

Assessment Instruments and Procedures

Measurement tools were selected according to following criteria: (1) evidence of validity and reliability; (2) space and time requirements appropriate to ensure feasibility in the ecological PE context. All tests were administered in the school setting during the curricular school time. Detailed information on assessment tasks, validity and reliability are reported with reference to primary articles in **Supplementary Data Sheet 2**.

Primary Outcome: Motor Creativity

Children's motor creativity was assessed with the Bertsch's test (1983). This test is composed of four tasks to be performed individually, in randomized order on the floor, with a bench, a hoop or a ball, respectively. These tasks are available in two separate versions (form A and B) varying in the degrees of freedom of the movement tasks, with form A providing no specific performance modality and form B partially defining it. For this study, we used the Bertsch's test form B. During each task, children's motor behavior was video recorded. The tasks lasted 2 min and 30 s (hoop and floor) or 3 min (ball and bench) for a total test duration of about 20 min including the initial instruction and breaks between tasks (for more information: Bertsch, 1983; Scibinetti et al., 2011).

Motor Creativity Tasks

Floor. Two parallel lines delimited a 2.5-m^2 area on the floor. The verbal instruction was: "Your task is to move from one line to the other. You are free to do anything you want between these two lines. Show me all possible ways you know or that may come to your mind to do that."

Bench. A bench was located in the middle of a room, with two hoops positioned at the two ends of the bench representing the starting and arrival point. The verbal instruction was: "You have to go from one hoop to the other and back, keeping a part of your body always in contact with the bench."

Hoop. Two parallel lines representing the starting and arrival point were put at 3.5 m. The verbal instruction was: "Your task is to move the hoop from one line to the other. You can let it go on its own or take it with you. Show me anything you can do that comes to mind."

Ball. Children were situated in the middle of a 2.5-m^2 square. Their task was to use a ball to hit seven 1-m^2 targets outside the square and positioned on the wall, floor, and ceiling, one at a time. The verbal instruction was: "You see all the targets around you. Imagine they are glasses. Try to break them with this ball without going out of your home (i.e., the square). What's important is not so much to break all the glasses but to try to break them every time in a different way."

Data Coding and Scoring

Motor behaviors were coded and scored by a blinded expert investigator. A further blinded investigator independently coded a subsample of motor behaviors and inconsistencies were solved by consultation (inter-observer agreement rate > 80%). Data coding consisted in assigning scores on three dimensions: fluency, flexibility, and originality. Fluency was scored in terms of the number of different behaviors displayed by the child during each motor task. Flexibility and originality were coded and scored based on Bertsch's (1983) normative data. Flexibility was scored referring to movement behavior categories identified by Bertsch for each task (16 for the hoop and the ball tasks, 44 for the bench task, and 36 for the floor task). Such categories summarize motor behaviors as a function of body position, movement direction and type. The flexibility score was the sum of movement categories, identified as a function of body position, movement direction and type, for which at least one behavior was observed, categories with two or more observed behaviors being counted only once. Originality was quantified assigning a score ranging from 0 (low originality) to 3 (high originality) to each behavior in each category based on the relative frequency of such behavior in Bertsch's normative sample. To obtain a total score for each creativity dimension, scores for the four tasks were standardized and averaged. Furthermore, a grand average of creative thinking at pre and post-test was computed by merging the three creative thinking variables.

Secondary Outcomes in the Motor Domain: Motor Coordination

Children's motor coordination was assessed individually with the Italian version of the Movement Assessment Battery for Children (M-ABC; Henderson and Sudgen, 1992). The more recent version (M-ABC-2, Schulz et al., 2011) was not available to the researchers. This test is composed of three subheadings: manual dexterity (three tasks), aiming and catching skills (two tasks), and static and dynamic balance (one and two tasks, respectively), with the eight tasks differentiated in four age-related difficulty levels (for more information: Henderson and Sudgen, 1992; Croce et al., 2001).

Motor Coordination Tasks

Manual Dexterity. Based on children's age, the first task was 'posting coins,' 'placing pegs,' or 'shifting pegs by rows': the second task was 'threading beads,' 'threading lace,' or 'threading nuts on bolt'; and the third task was 'bicycle trail' or 'flower trail.'

Aiming and Catching Skills. Based on children's age, the first task was 'catching bean bag,' 'one-hand bounce and catch,' or 'two-hand catch'; and the second task was 'rolling ball into goal' or 'throwing bean bag into box.'

Static and Dynamic Balance. Based on children's age, the task evaluating static balance was 'one-leg balance,' 'stork balance,' or 'one-board balance'; the first task evaluating dynamic balance was 'jumping over cord,' 'jumping in squares,' or 'hopping in squares'; and the second one was 'walking heels raised,' 'heel-to-toe walking,' or 'ball balance.'

Data Coding and Scoring

For each of the three subheadings, data were transformed into impairment scores of motor function according to age-related normative data (Henderson and Sudgen, 1992). Then, the three scores were summed up to obtain a total impairment score, indicating the extent to which a child falls below the level of his/her age peers.

Secondary Outcomes in the Cognitive Domain: Executive Function and Creative Thinking

Executive Function

Random Number Generation Task. In the Random Number Generation (RNG) task, version validated for children aged 5 years and older (Towse and McIachlan, 1999), children were tested individually and instructed to verbally generate a random sequence of numbers between 1 and 10 to each beat of a 70-beat sequence with an inter-beat interval of 1.5 seconds. They were presented the RNG as a game involving numbers with a game-like instruction. Both the omission of a number generation in correspondence to one tone and the production of numbers < 1 or >10 were considered errors and discarded. The 70-number generation sequence was preceded by an identical familiarization trial. The whole test lasted about 6–8 min (for more information: Towse and Neil, 1998; Towse and McIachlan, 1999).

Inhibition and Working Memory Indices Computation. The randomness of the generated numbers was estimated by means of 18 different indices (Towse and Neil, 1998). Six of them were selected: three reflecting the ability to inhibit mental counting routines [turning point index (TPI), adjacency score (Adj), runs score (Runs)], and three the ability to update information held in working memory [redundancy score (Red), coupon score (Coupon), and mean repetition gap (MeanRG)]. All indices were standardized (i.e., *z*-scores) and average indices of inhibition and working memory were computed. Since high levels of TPI and MeanRG, but low values of Adj, Runs, Red, and Coupon reflect a good inhibition and working memory updating ability, Adj, Runs, Red, and Coupon were reversed before averaging (for more information see: Miyake et al., 2000; Audiffren et al., 2009).

Creative Thinking

The Italian version of the Torrance Test of Creative Thinking (TTCT), Figural Form A (Torrance, 1988), designed for individuals in kindergarten through graduate school and beyond, was group administered. It consists of three timed pencil and paper picture construction and completion activities lasting 10 min each with 1 min break between tasks for a total working time of about 30 min (for more information: Torrance and Ball, 1984; Torrance, 1988; Cramond et al., 2005; Kim, 2006).

Creative Thinking Tasks.

Activity I: Picture Construction. Children had to construct a picture using a darkened curve shape (jellybean or teardrop) provided on a page as a stimulus to be integrated in the picture construction.

Activity II: Picture Completion. Children had to use 10 incomplete figures to make a figure or object drawings to the incomplete figures, avoiding usual and obvious completions.

Activitiy III: Parallel Lines. Children had to use 30 pairs of straight lines drawn on three pages to make an original picture out of each pair of lines.

Data Coding and Scoring. Torrance Test of Creative Thinking pictures were coded and scored by a blinded expert investigator based on three sub-scales of norm-referenced measures: fluency, flexibility, and originality. A further blinded investigator independently coded and scored a subsample of pictures (inter-observer agreement rate $> 80\%$). Fluency was scored by the number of figural images produced by the child; flexibility by the variety of categories of relevant responses; and originality by the number of statistically infrequent responses based on normative data (Torrance, 1988). Raw scores were converted into standard scores to have comparable ranges for fluidity, flexibility, and originality. Furthermore, a grand average of creative thinking at pre and post-test was computed by merging the three creative thinking variables.

Demographic Variables

At baseline, children's body mass and height were measured for body mass index (BMI, kg/m^2) computation. Children's spontaneous play habits in outdoor environments were estimated by means of the Children's Outdoor Play assessment questionnaire (Veitch et al., 2009; Italian validation: Pesce et al., 2016b). Parents reported the number of days their child spent at least 10 min playing in locations such as their yard at home, a friend's or neighbor's yard, their street or court or footpath, a park or playground in out-of-school hours on weekdays (eight items on a five-point scale) and weekend days (eight items on a six-point scale) during a typical week. Parents also answered few questions regarding their children's actual practice (e.g., number of days/week, session duration) of after-school sports or any other structured PA training (for more information: Veitch et al., 2009; Pesce et al., 2016b).

Preliminary Analyses

Manipulation Checks

Manipulation checks were used to ensure that PE 'enrichment' in the intervention classes was operationalized by teachers with teaching strategies that truly involved problem solving, guided and divergent discovery, and cognitive challenges, and to evaluate to what extent these qualitative delivery characteristics were independent from or coupled with different levels of enjoyment.

Teaching Strategies

All intervention and control classes were video recorded during a representative PE session for analysis of teaching behaviors. The lesson was recorded at about midpoint of the intervention period. To ensure representativeness, no indication was given except that the lesson should not deviate from usual PE praxis (e.g., it should not be devoted to the preparation of a special sport-related or cultural event). The qualitative features were categorized by two independent experienced raters as behavioral categories of teaching strategies and quantified by means of event sampling as percentage (%) of events for time unit (20 s). A satisfactory inter-observer reliability ($>80\%$) was reached. The behavioral categories of teaching strategies used for the analysis were (Rink, 2006): (1) Interactive teaching (instructional process controlled by teacher); (2) peer teaching (reciprocal feedback and evaluation by students); (3) cognitive strategies (teaching through questions, problem solving, guided, and divergent discovery); (4) cooperative learning (achievement of meaningful goals through teamwork).

Specialist PE teachers in the intervention classes exerted control over the entire instructional process less frequently than generalist teachers in the control classes (interactive teaching: 23% vs. 87% of events) and used teaching strategies in a more differentiated way, shifting from themselves to the children specific decisions/responsibilities along the instructional process (Mosston and Ashworth, 2008). Expectedly, specialists frequently used cognitive strategies (47%), mainly based on problem solving with convergent and divergent discovery (45%), only rarely used by generalists (3%). Specialists also used peer and cooperative teaching (20 and 11%, respectively) more frequently than generalists (10 and 0%, respectively).

Physical Activity Enjoyment

The PA Enjoyment Questionnaire (Di Cagno et al., 2006) comprised six semantic differential items (e.g., anchored by "pleased/unpleased," and "enjoyed/bored") with a 5-point picture-based Likert scale evaluating whether the child enjoyed the PA tasks composing the PE lesson. The specialist-led enriched PE group showed a slightly higher average enjoyment score than the generalist-led conventional PE group ($M = 4.67 \pm 0.41$ vs. 4.28 ± 0.45), as emerged from the non-parametric Mann–Whitney test applied to the negatively skewed data ($U = 580$, $n = 95$, $p < 0.001$) (for more information: Di Cagno et al., 2006).

Design Effect

Since children in the intervention and control groups were clustered in eight classes, with observations within each cluster being not independent, the cluster design effect was computed and used as a multiplier of sample size determined with *a priori* power analysis. The design effect computation takes into account that the variance of the mean computed from a clustered sample is larger by a factor of $[1 + (n - 1) * \text{ICC}]$, modified to consider differences in cluster size (i.e., number of children tested in each class) as follows:

$$\textbf{Cluster effect} = \left\{1 + \left[\left(\mathbf{CV^2 + 1}\right) \times \mathbf{n - 1}\right] \times \mathbf{ICC}\right\}$$

where n = number of children within each cluster, CV = coefficient of variation for n and ICC = intraclass correlation coefficient [σ^2 between-cluster/(σ^2 between-cluster + σ^2 within-cluster)]; Hedges and Hedberg, 2007). Given the absence of ICC reference values for the primary outcome of motor creativity and the low ICC reference values available for the secondary outcomes (motor coordination and executive function: 0.04 and 0.02, respectively; Aadland et al., 2019), we used a conservative estimate of ICC recommended in previous research on PA effects on children's motor and cognitive development (ICC = 0.15, Resaland et al., 2015). With a mean cluster $n = 11.87$ (± 1.88), a CV = 0.16 and the conservatively assumed ICC = 0.15, the estimated cluster design effect was 2.68. This design effect value was used as a multiplier of sample size determined with *a priori* power analysis for $\alpha = 0.05$, $\beta\text{-}1 = 0.80$ and the minimal detectable effect size (ES [f, i.e., $\eta_p^2/(1 - \eta_p^2)$]) = 0.26 for motor fluency and 0.23 for motor flexibility according to Richard et al.'s (2018a) findings. The estimated sample size to detect intervention effects on motor fluency and flexibility was 86 and 102, respectively. Our sample size ($n = 95$) was between these estimates.

RESULTS

Preliminary Analyses

Table 1 presents children's demographics and background characteristics, as well as pre- and post-intervention values of primary and secondary outcome variables separately for group and sex. Mahalanobis distance was computed to identify multivariate outliers in the outcome variables used for analysis. Two outliers were identified, with p of Mahalanobis distance < 0.001. Main analyses were run both with and without outliers. Since the pattern of results remained substantially unchanged, the outliers were maintained.

Group Differences at Baseline

One-way ANOVAs with group as factor were performed on demographic and PA variables (age, spontaneous outdoor play, structured physical activity/sport training), primary outcome variables (fluency, flexibility, and originality in moving) and secondary outcome variables in the motor domain (motor coordination [evaluated as motor impairment scores]: manual dexterity, aiming and catching skills, static and dynamic balance) and in the cognitive domain (executive function: inhibition and working memory; creative thinking: fluency, flexibility, originality in thinking). Group differences were found only in working memory [$F(1,93) = 4.22$, $p = 0.043$, $\eta_p^2 = 0.04$] and manual dexterity [$F(1,93) = 85.52$, $p = 0.021$, $\eta_p^2 = 0.06$], with the intervention group showing a higher baseline working memory performance and manual dexterity (i.e., lower impairment score) as compared to the control group.

Correlations of Outcome Variables at Baseline

Spearman's correlation coefficients computed to estimate the level of association, at baseline, of motor creativity with the other outcome variables (motor coordination, executive function, and creative thinking) are reported in **Table 2** for the entire sample and separately for males and females. Results showed significant weak to moderate correlations of all three dimensions of motor creativity (fluency, flexibility, originality) with a majority of dimensions of motor coordination and creative thinking, and with inhibition but not working memory. Correlations were overall stronger in males than females, only males showing significant correlations of motor creativity with creative thinking and inhibition. Sex differences in correlation were statistically tested: they were significant only for manual dexterity with motor fluency ($z = 1.73$, $p = 0.042$), and inhibition with motor fluency ($z = -1.78$, $p = 0.037$) and flexibility ($z = -1.91$, $p = 0.028$).

Main Analyses

Analyses and Results of Intervention Effects

To test the hypothesis of intervention effects, we used linear mixed models (LMM). Fixed effects were computed for group

TABLE 1 | Demographics, spontaneous outdoor play and structured sports training, and pre- and post-intervention values of primary outcome variables (motor creativity: fluency, flexibility, and originality in moving) and secondary outcome variables in the motor domain (motor coordination [evaluated as motor impairment scores]: manual dexterity, aiming and catching skills and balance) and in the cognitive domain (executive function: inhibition and working memory; creative thinking: fluency, flexibility, and originality in thinking) of 6–9 year-old children assigned to the specialist-led enriched or generalist-led conventional physical education (PE).

Group		**Specialist-led enriched PE**		**Generalist-led conventional PE**	
N		46		49	
Sex (*n* males/*n* females)		23/23		24/25	
Age (years)	Pre-intervention	7.7 ± 1.2		7.8 ± 1.4	
Body mass index (BMI) §	Pre-intervention	17.8 ± 2.9		18.0 ± 3.0	
Lean [*n* (%)]		30 (65%)		35 (71%)	
Overweight [*n* (%)]		16 (35%)		14 (29%)	
Spontaneous outdoor play (score ± *SD*)	Pre-intervention	33.6 ± 9.6		34.4 ± 10.8	
Structured sports training (min/week ± *SD*)	Pre-intervention	126 ± 95		126 ± 92	
Motor creativity (std score ± *SD*)		Males	Females	Males	Females
Fluency	Pre	0.05 ± 0.81	−0.31 ± 0.67	−0.18 ± 0.84	−0.32 ± 0.69
	Post	0.51 ± 0.72	0.42 ± 0.54	−0.02 ± 0.72	−0.10 ± 0.73
Flexibility	Pre	0.01 ± 0.74	−0.28 ± 0.61	−0.18 ± 0.82	−0.39 ± 0.65
	Post	0.52 ± 0.75	0.42 ± 0.47	0.06 ± 0.74	−0.11 ± 0.64
Originality	Pre	0.19 ± 0.74	−0.24 ± 0.60	−0.16 ± 0.84	−0.31 ± 0.54
	Post	0.45 ± 0.77	0.35 ± 0.64	0.01 ± 0.72	0.24 ± 0.53
Motor coordination (impairment score ± *SD*)		Males	Females	Males	Females
Manual dexterity	Pre	5.26 ± 3.43	5.07 ± 3.32	7.79 ± 3.70	5.81 ± 2.97
	Post	3.72 ± 3.15	3.48 ± 3.02	4.95 ± 3.38	4.65 ± 3.51
Aiming/catching skills	Pre	2.89 ± 2.66	3.61 ± 2.96	2.59 ± 2.67	3.23 ± 2.96
	Post	0.57 ± 1.30	1.41 ± 2.25	1.70 ± 2.16	1.62 ± 2.39
Static/dynamic balance	Pre	4.78 ± 3.56	2.26 ± 3.13	3.74 ± 2.94	3.06 ± 3.25
	Post	1.41 ± 1.76	1.91 ± 3.56	1.99 ± 2.06	1.77 ± 2.05
Executive Function (std score ± *SD*)		Males	Females	Males	Females
Inhibition	Pre	−0.51 ± 0.99	−0.23 ± 1.11	−0.38 ± 1.04	0.07 ± 1.04
	Post	0.42 ± 0.48	0.35 ± 0.69	0.26 ± 0.49	0.01 ± 0.78
Working memory	Pre	0.22 ± 0.50	0.03 ± 1.08	−0.16 ± 0.93	−0.35 ± 0.84
	Post	−0.02 ± 0.70	0.09 ± 0.60	0.04 ± 0.49	0.18 ± 0.64
Creative thinking (score ± *SD*)		Males	Females	Males	Females
Fluency	Pre	16.52 ± 8.69	19.16 ± 6.17	16.99 ± 5.82	20.31 ± 6.39
	Post	21.13 ± 7.12	25.03 ± 7.66	22.32 ± 7.38	24.28 ± 6.13
Flexibility	Pre	14.09 ± 7.01	14.57 ± 4.41	12.98 ± 4.67	16.49 ± 5.04
	Post	17.74 ± 5.02	18.75 ± 5.36	15.60 ± 4.97	18.34 ± 4.06
Originality	Pre	16.65 ± 9.85	16.62 ± 8.15	16.07 ± 7.80	20.61 ± 6.42
	Post	24.13 ± 9.94	26.42 ± 9.66	21.05 ± 9.39	22.92 ± 8.24

§ *Lean vs. overweight status based on age-referenced cut-off values of BMI (Cole et al., 2000).*

(specialist-led enriched vs. generalist-led conventional PE), time (pre vs. post) and their interactions. Separate LMM were run on fluency, flexibility and originality in moving and in thinking, on inhibition and working memory, and on manual dexterity, aiming/catching skills and balance. Random effects were computed to account for clustering of children in classes. Age and baseline values of PA session enjoyment, which resulted higher in the intervention group (see Section "Group differences at baseline") were included as covariates.

To test the hypothesis that a higher baseline level of motor coordination, executive function, or creative thinking might influence the intervention effects on motor creativity, these four variables were individually included as moderators in separate runs in four further LMM that were run on motor creativity variables (2 Groups × 2 Times × 2 Baseline Motor Coordination or Inhibition or Working Memory or Creative Thinking). To this aim, the grand averages of creative thinking and executive function were dichotomized to obtain binary low vs. high level variables, and the motor impairment scores were used to create, according to M-ABC normative data, a binary variable of typical vs. atypical (borderline movement problems or developmental coordination disorder, DCD) motor development. Moreover, considering some evidence of a higher motor originality of males with the ball (Tocci et al., 2004) that fits with the consistent evidence of males' superiority in object-control skills (Barnett et al., 2016), a fourth LMM was run adding the factor sex as a moderator.

Planned pairwise comparisons (*t*-tests) were run in the case of significant interactions and effect sizes (Cohen's *d*)

TABLE 2 | Correlations (Spearman's Rho) at baseline of motor creativity with the other outcome variables in the motor (motor coordination) and cognitive domain (executive function and creative thinking).

Baseline	Motor coordination (impairment score)			Executive function (std score)		Creative thinking (score)		
Motor creativity (std score)	Manual dexterity	Aiming/catching	Static/dynamic Balance	Inhibition	Working memory	Fluency	Flexibility	Originality
Fluency	#			#				
Females	−0.01	−0.33*	−0.17	0.07	−0.12	0.09	0.21	0.15
Males	−0.36*	−0.47*	−0.36*	0.42*	−0.02	0.26	0.39*	0.41*
All	−0.16	−0.40*	−0.20*	0.22*	−0.04	0.14	0.27*	0.27*
Flexibility				#				
Females	−0.06	−0.35*	−0.20	0.13	−0.10	0.02	0.14	0.15
Males	−0.34*	−0.56*	−0.41	0.49*	−0.03	0.29	0.42*	0.45*
All	−0.18	−0.45*	−0.23*	0.28*	−0.02	0.13	0.27*	0.30*
Originality								
Females	−0.12	−0.37*	−0.22	0.17	−0.15	0.05	0.13	0.10
Males	−0.36*	−0.52*	−0.41*	0.40*	0.01	0.22	0.39*	0.41*
All	−0.21*	−0.43*	−0.24*	0.26*	−0.03	0.10	0.24*	0.25*

Significant ($p < 0.05$); #significant difference in correlation between females and males.

were computed for significant pairwise differences. Bonferroni correction was applied to account for three comparisons ($p < 0.016$) in the *post hoc* analysis of two-way Group × Time interactions (pre-post comparisons separately for the specialist-led enriched and generalist-led conventional PE group and between-groups comparison at post-test) and six comparisons ($p < 0.008$) for three-way interactions with each additional moderator.

Primary Motor Creativity Outcomes

For all three dimensions of motor creativity, there were a main effect for Time [fluency: $F(1,94) = 44.36$, $p < 0.001$; flexibility: $F(1,95) = 55.62$, $p < 0.001$; originality: $F(1,95) = 25.41$, $p < 0.001$] and a significant Group × Time interaction (**Table 3**). *Post hoc* comparisons showed a significant pre-to-post increment of motor fluency and flexibility in both groups, more pronounced in the specialist-led enriched PE group than in the generalist-led conventional PE group, leading to a significant group difference at post-test (**Figures 2A,B**). For originality, the pre-to-post improvement was significant in the enriched PE group only, leading to a significant group difference at post-test (**Figure 2C**).

Adding to the model each of the dichotomous baseline motor and cognitive variables in separate runs, main effects of these variables emerged without the hypothesized significant three-way interaction with Group and Time (p-values $\geq$ .245). The effect of typical/atypical motor development at baseline was significant for motor fluency [$F(1,92) = 15.68$, $p < 0.001$], flexibility [$F(1,93) = 12.58$, $p = 0.001$], and originality [$F(1,93) = 12.37$, $p = 0.001$]; typical motor development was associated with higher motor fluency (difference in std. score between children with typical/atypical motor development [Δ z-score] = 0.52), higher motor flexibility and originality (Δ z scores: 0.44 and 0.43, respectively). The effect of inhibition at baseline was significant for motor flexibility [$F(1,91) = 6.32$, $p = 0.014$] and originality [$F(1,93) = 5.52$, $p = 0.021$], but not for fluency ($p = 0.143$); higher baseline inhibition was associated with higher motor flexibility (Δ z-score between children with low/high inhibition = 0.28) and higher motor originality (Δ z-score = 0.28). Working memory at baseline did not affect motor fluency, flexibility, and originality (p-values $\geq$ 0.443). The effect of creative thinking at baseline was significant for motor fluency [$F(1,83) = 8.53$, $p = 0.005$], flexibility [$F(1,94) = 7.95$, $p = 0.006$], and originality [$F(1,94) = 8.70$, $p = 0.004$]; higher baseline creative thinking was associated with higher motor fluency (Δ z-score between children with low/high creative thinking = 0.36), higher motor flexibility and originality (Δ z-scores = 0.32 and 0.34, respectively). The effect of sex at baseline only approached significance for motor originality ($p = 0.066$, with males tending to be generally more original than females) but did not differentially influence the size of the intervention effect in males and females. There was no significant three-way Group × Time × Sex interaction for any of the motor creativity dimensions (p-values $\geq$ 0.147).

Secondary Motor Coordination Outcomes

For manual dexterity, there were neither a main effect for Time ($p = 0.851$), nor a significant Group × Time interaction. For static and dynamic balance, there was only a main effect for Time [$F(1,95) = 7.40$, $p = 0.008$], but no significant Group × Time interaction. For aiming/catching skills, instead, there were both a main effect for Time [$F(1,95) = 10.64$, $p = 0.002$] and a significant Group × Time interaction (**Table 3**). *Post hoc* comparisons showed a significant pre-to-post amelioration of aiming/catching skills in both groups (**Table 3**), which was more pronounced in the specialist-led enriched PE group than in the generalist-led conventional PE group (Δ impairment score = −2.26 vs. −1.24); however, the two groups did not significantly differ at post-test (**Table 3**).

Secondary Executive Function Outcomes

For inhibition, there were both a main effect for Time [$F(1,95) = 20.40$, $p < 0.001$] and a significant Group × Time interaction (**Table 3**). *Post hoc* comparisons showed that the pre-to-post improvement was significant only in the specialist-led

TABLE 3 | Results of main and *post hoc* analyses: group [specialist-led enriched PE intervention group, IG vs. generalist-led conventional control group, CG] × Time [pre vs. post] interactions.

Group × Time	*F* (df), *p*	ICC	*t* (df), *p*, *Cohen's d*		
			IG pre vs. post	CG pre vs. post	IG vs. CG at post
Motor creativity					
Fluency	10.59 (1,95), 0.002	0.15	−6.42 (45), <0.001, 0.69	−2.54 (48), 0.015, 0.03	3.78 (93), <0.001, 0.70
Flexibility	7.44 (1,95), 0.008	0.13	−7.42 (45), <0.001, 0.74	−3.20 (48), 0.002, 0.04	3.66 (93), <0.001, 0.72
Originality	7.70 (1,95), 0.007	0.19	−5.22 (45), <0.001, 0.58	n.s., 0.099	3.80 (93), <0.001, 0.62
Motor coordination					
Manual dexterity	n.s., 0.380	0.12			
Balance	n.s., 0.434	0.05			
Aiming and catching	3.23 (1,95), 0.044	0.21	5.71 (45), <0.001, 0.95	4.00 (48), <0.001, 0.49	n.s., 0.116
Executive function					
Inhibition	5.94 (1,95), 0.017	0.04	−4.44 (45), <0.001, 0.50	n.s., 0.080	n.s., 0.056
Working memory	5.75 (1,95), 0.018	0.02	n.s., 0.571	−2.51 (48), 0.016, 0.49	n.s., 0.546
Creative thinking					
Fluency	n.s., 0.354	0.13			
Flexibility	n.s., 0.061	0.17			
Originality	6.60 (1,95), 0.012	0.19	−5.42 (45), <0.001, 0.13	−3.12 (48), 0.003, 0.04	n.s., 0.117

enriched PE group (**Table 3**; Δ *z*-score = 0.75). For working memory, there was only a significant Group × Time interaction (**Table 3**). *Post hoc* comparisons showed an improvement in the conventional PE group (which approached significance [$p = 0.016$] after applying the Bonferroni correction [adjusted $p < 0.016$]) and no group difference at post-test because the traditional PE group, being worse at baseline, merely caught up over time (i.e., regression to the mean).

Secondary Creative Thinking Outcomes

For fluency and flexibility in thinking, there was a main effect for Time [fluency: $F(1,95) = 50.00$, $p < 0.001$; flexibility: $F(1,95) = 34.41$, $p < 0.001$] but no significant Group × Time interaction (**Table 3**). For originality in thinking, instead, there were both a main effect for Time [$F(1,95) = 39.52$, $p < 0.001$] and a significant Group × Time interaction (**Table 3**). *Post hoc* comparisons showed a significant pre-to-post amelioration of originality in thinking in both groups, more pronounced in the specialist-led enriched PE group than in the generalist-led conventional PE group (Δ originality score = 8.64 vs. 3.61); however, the two groups did not significantly differ at post-test (**Table 3**).

Analyses and Results of Mediating Mechanisms

In the case of enriched PE effects on both motor creativity and other motor and cognitive skills that might mediate them, multiple mediation analyses were performed with PROCESS macro for SPSS (Hayes, 2013). Specifically, regression analyses were performed on pre-, post-intervention, and pre-post delta data to assess the effects of: (1) the independent variable (X: PE intervention type) on the dependent variable (Y: individual motor creativity dimensions); (2) the independent variable on each mediator (M: total motor impairment, inhibition, working memory, total creative thinking); (3) the independent variable (X) and the potential mediators (M) on the dependent variable (Y). The potential mediators were entered simultaneously in the regression equation to include the covariances among them and the independent variable and verify whether their introduction (i.e., total indirect effect of X on Y through Ms) reduced the direct effect of the PE intervention on the motor creativity dimensions. Bootstrapping was applied to empirically estimate the sampling distribution of the indirect effect and generate 95% confidence intervals (CI).

Results showed that the difference in post-intervention improvement of motor fluency, flexibility, and originality between children who participated in the specialist-led enriched or generalist-led conventional PE was partially mediated by the extent to which children ameliorated their total motor coordination (i.e., diminished their total motor impairment score; **Figures 3A–C**). Only the group difference in post-intervention improvement of motor flexibility was also partially mediated by the extent to which children ameliorated their inhibitory ability (**Figure 3B**). The path linking Inhibition to Flexibility (panel 'b') reached significance after removal of the two non-significant mediators (working memory and creative thinking) from the model (see note of **Figure 3**). Significant mediation results are indicated by the 95% CI of bootstrap estimates of the indirect effect, which did not include the zero value. The same mediation models applied to pre-intervention and to pre-post delta values did not yield any significant mediation result.

DISCUSSION

The primary aim of this study was to verify the efficacy of an enriched PE intervention that integrates two different yet complementary theoretical approaches – the constraints-led (Tocci and Scibinetti, 2007; Orth et al., 2017; Scibinetti, 2019; Torrents et al., 2021b) and the cognitive stimulation

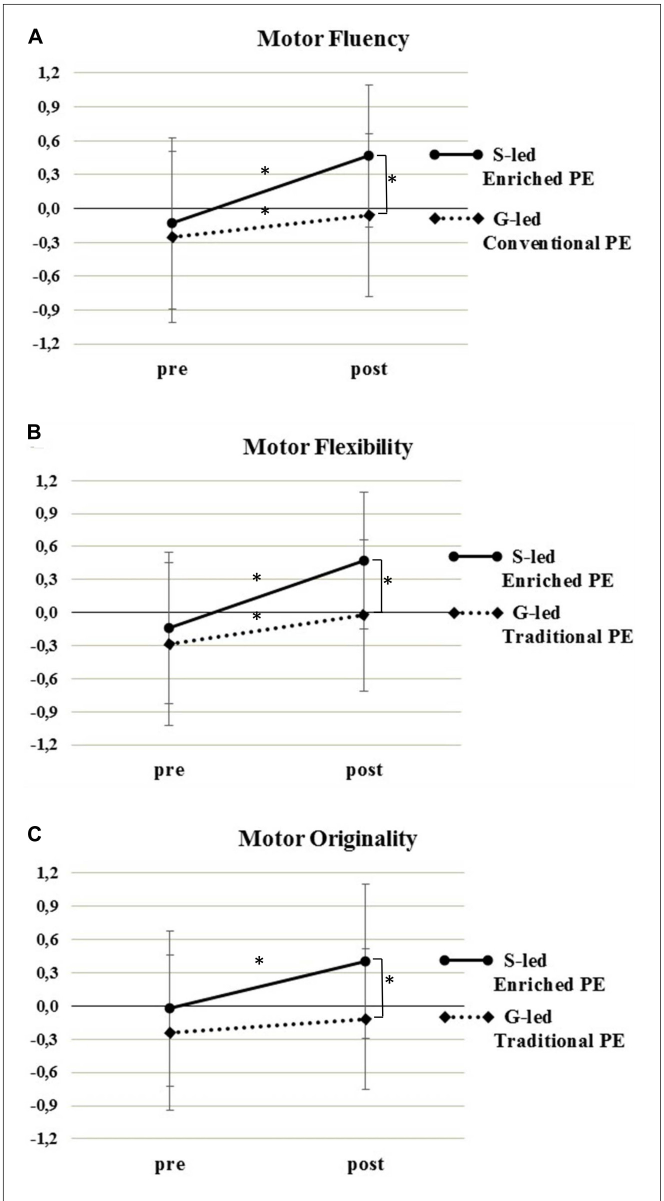

FIGURE 2 | Motor creativity [fluency – panel **(A)**; flexibility – **(B)**; originality – **(C)**] assessed with Bertsch's test of motor creativity before (pre) and after (post) a specialist-led (S-led) enriched PE intervention or generalist-led (G-led) conventional PE. $^*p < 0.016$ (adjusted for three comparisons).

approach (Tomporowski et al., 2015b; Pesce et al., 2019). The specialist-led enriched PE program, as compared to generalist-led conventional PE, led to more pronounced improvements and higher post-intervention values of motor creativity in all its dimensions, but benefited creative thinking limitedly to its originality dimension. The improvement in motor creativity was not influenced (moderated) by the baseline level of its potential motor and cognitive prerequisites (motor coordination, executive function, and creative thinking) or by sex, but was partially explained (mediated) by improved motor coordination, suggesting that the enriched PE fostered the ability to use improved motor skills to explore the solution space. Moreover, the improved flexibility in moving was jointly explained by motor coordination and cognitive inhibition, suggesting that this latter may prevent from routine thoughts and actions and allow to exploit environmental affordances and motor skills for expanding the solution space to different movement categories.

Evidence on motor creativity promotion is at the core of the motor competence discourse in its broadest meaning and of those interventional strategies that involve a tailored exploration of movement opportunities in the person-context interaction (Stodden et al., 2021). An optimal frame for this discourse is that of physical literacy. Indeed, the notion of engaging 'positive challenges' in the exploration of opportunities for action is common to both physical literacy and motor creativity (Jefferies, 2020). Creative problem solving and decision making exercised in PA and sport when coping with movement challenges under varying constraints is proposed to contribute to the development of motor creativity and physical literacy (Rudd et al., 2020), which in turn may lead to positive physical, mental and social health outcomes (Cairney et al., 2019).

Enriched Physical Education Enhances Creativity in Moving and Originality in Thinking

The primary finding of improved ability to discover many different motor solutions (fluency, **Figure 2A**) and to make a differentiated and flexible use of various movement categories (flexibility, **Figure 2B**) to deal with open-ended tasks corroborates previous findings of studies that employed a constraint-led approach and divergent discovery teaching (Chatoupis, 2013; Richard et al., 2018a). Nevertheless, Richard et al.'s (2018a) data presented baseline differences and a pattern of pre-to-post change that could include in the expected intervention effect also a regression to mean (for fluency) or a ceiling effect (for flexibility). Our results reinforce more univocally the interpretation of the differential pattern of pre-to-post change between groups in terms of intervention effect, as we found similar motor creativity gains as Richard et al. (2018a) but without differences at pre-test and with significant differences in favor of the specialist-led enriched PE group at post-test.

Thus, the manipulation of constraints seems a viable way to release degrees of freedom and capitalize on movement variability to produce multiple and diversified movement solution. According to Hristovski et al. (2011), we alternated less and more stringent constraints that hinder common routes and orient the discovery of new affordances. Counterintuitively, constraints may foster the emergence of multiple, diversified and original solutions that are pertinent to solve a motor problem at hand (Torrents et al., 2021b). This apparent paradox of 'constraining to release degrees of freedom' in motor behavior is discussed from an Ecological Dynamics perspective and insightfully depicted with the quotation of the Russian composer Igor Stravinsky (The poetics of music) we wish to echo (Torrents et al., 2021b, p. 340): "*My freedom will be so much the greater and more meaningful the more narrowly I limit my field of action and*

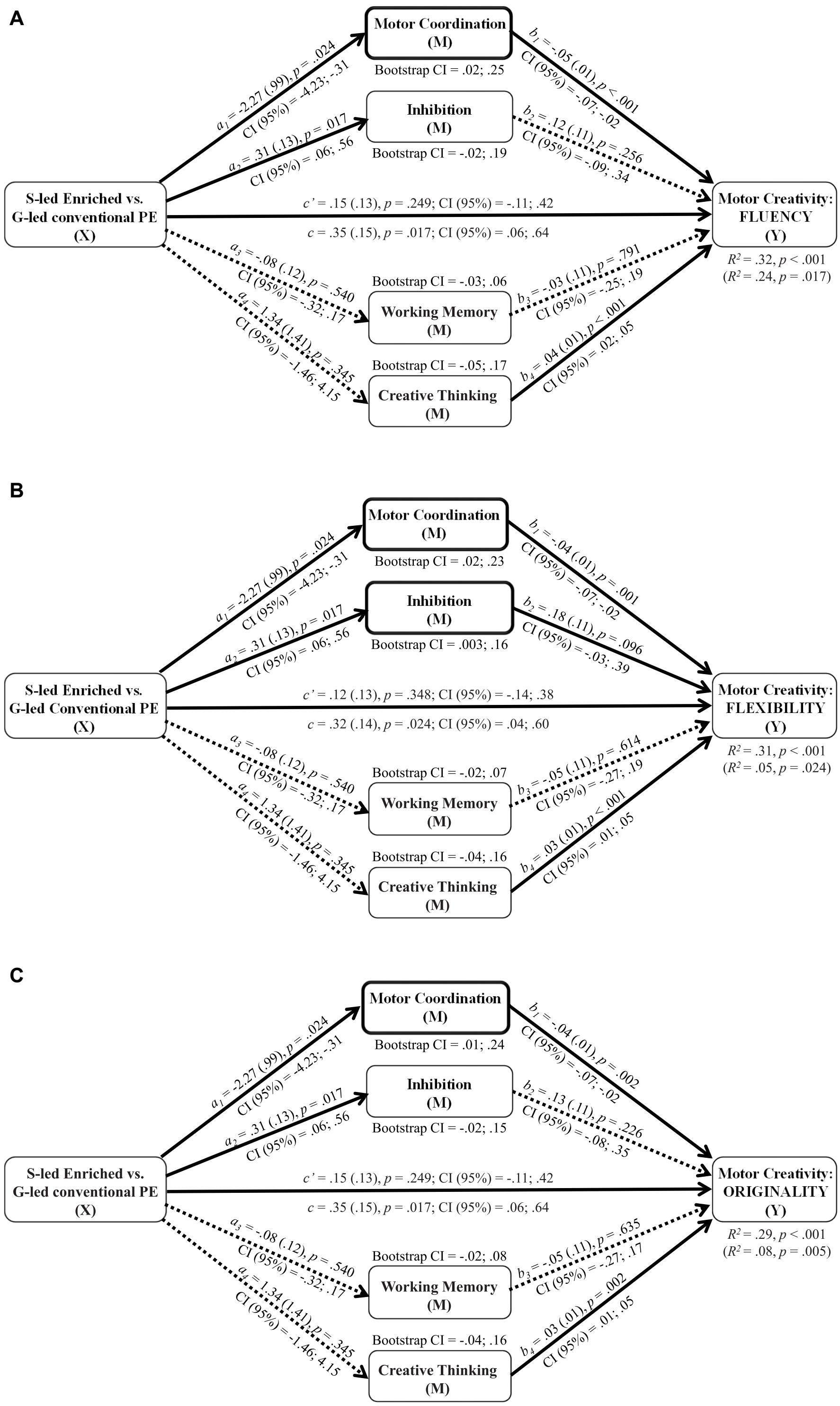

FIGURE 3 | Multiple mediation model: effects of PE group ('X': specialist-led [S-led] enriched vs. generalist-led [G-led] conventional) on post-intervention motor creativity [Y: fluency – panel **(A)**; flexibility – **(B)**; originality – **(C)**] mediated by post-intervention level of motor coordination (all motor creativity dimensions) and of inhibitory ability (flexibility only). *a, b, c*: regression coefficients with (SE), *p* and CI (95%) values. *c*: total effect; $a_1{*}b_1$, $a_2{*}b_2$, $a_3{*}b_3$, $a_4{*}b_4$: indirect effects; c': direct effect after accounting for mediators. R^2 values with/(without) mediators and bootstrap CI (95%) for indirect effects are also reported. Solid lines: significant paths; dotted lines: non-significant paths. *Note*. Panel 'b': the path linking Inhibition to Flexibility reached significance ($b_2 = .22(.11)$, $p = .037$; CI (95%) = .01; .44) after removing the two non-significant mediators from the model. CI of bootstrap estimates of the indirect effect of Group on Flexibility through Inhibition: .01; .19).

the more I surround myself with obstacles. Whatever diminishes constraint diminishes strength. The more constraints one imposes, the more one frees one's self of the chains that shackle the spirit."

In our study, manipulation checks provided a supportive 'quantification' of the fidelity of the qualitative characteristics of the intervention in terms of teaching strategies (Rink, 2006). Children in the specialist-led enriched PE classes experienced problem solving with convergent and divergent discovery much more often than children in generalist-led conventional PE classes. Discovery learning strategies are inherent in the constraints-led approach, though not overlapping with it, as they are rooted in different pedagogical theories. Both motor creativity programs focused on the manipulation of constraints (Richard et al., 2018a) or on divergent discovery teaching strategies (Chatoupis, 2013) were able to foster fluency and flexibility in moving similar to the benefits obtained in the present study.

Our findings also confirmed those by Richard et al. (2018a) in relation to creative thinking, showing an intervention benefit only for the dimension of originality in thinking. Since the children in the intervention group of Richard et al.'s (2018a) study exhibited a high baseline level of fluency and flexibility in thinking, the authors speculatively hypothesized that this might have enabled them to exploit the stimuli provided by the enriched PE intervention to improve motor creativity. We tested this hypothesis and did not find support for a moderating role of baseline creative thinking level, nor of other potential cognitive and motor prerequisites of motor creativity. We found that being less or more creative in thinking, less or more able to inhibit routine thoughts, being with typical or atypical motor development are features associated with children's motor creativity, but do not impact their ability to respond to motor creativity training. Consistent with previous developmental and adult research on motor and sports creativity (Scibinetti et al., 2011; Furley and Memmert, 2015; Moraru et al., 2016), we found working memory being unrelated to motor creativity.

The gain in original thinking in the present study was paralleled by improved originality in moving (**Figure 2C**). This might be attributable to the fact that we adopted principles of variability of practice, applied with both linear and non-linear pedagogies that have been proposed to stimulate both thinking and motor skills (Pesce et al., 2019), thus contributing to the increased ability to think originally and perform fluent, flexible and original movements. The beneficial effect on originality may also be due to the manipulation of the time constraints on the search for solutions. From an Ecological Dynamics perspective, constraints act at different time scales, with the selected affordance being the temporarily most attractive one (Torrents et al., 2021b). Extending the time frame available to produce new motor solutions under given task constraints may have enhanced the probability that other less immediate affordances could be selected and more original sensorimotor solutions be produced with a flow mode of creativity (Dietrich, 2019). From a cognitive perspective, extending the time frame of the creative search may have allowed for comparatively slow strategic planning (Tomporowski et al., 2015a). This, rather than rapid online processing, is likely needed for preparing to solve motor problems, evaluate the originality of emerging alternatives and then monitor the progress toward a specific goal with a deliberate mode of creativity (Dietrich, 2019).

Enriched Physical Education Effects on Motor Creativity: Direct and Mediated Paths

The mediation analysis provided some evidence on whether motor coordination and inhibition, as hypothesized by Richard et al. (2018a), and divergent creative thinking, as hypothesized by Bournelli and Mountakis (2008), are mechanisms that underlie the efficacy of motor creativity training programs. Although the specialist-led enriched PE caused significantly larger gains than generalist-led conventional PE in inhibition and in some facets of motor coordination and creative thinking, the extent to which these motor and cognitive skills improved did not explain the gains in motor fluency, flexibility, and originality, as indicated by the absence of a mediation path between pre-post delta scores. In the ecological school context, several influential and co-varying factors may have impeded to detect significant relations between intervention-related gains. Mediating mechanisms were found after the intervention, but not before it. Thus, whatever the size of the intervention-related gains, the enriched PE seems to align motor creativity to the level of specific prerequisites, likely rendering children capable to capitalize on these latter for moving creatively.

The hypothesis on the role of motor coordination was confirmed, as it partially explained the improved fluency, flexibility, and originality in moving after the intervention (**Figures 3A–C**). This suggests that children exposed to the enriched PE were able to use improved motor skills (or less impaired motor skills for those with atypical motor development at baseline) to explore and produce multiple, diversified and original movement solutions. Indeed, one of the cornerstones of the enriched PE was that the motor skills learnt were not conceived as the endpoint of learning but as new tools to extend, with non-linear pedagogy, the range of opportunities to explore and find new solutions (Adolph and Hoch, 2019). The constraints were manipulated to balance the extent to which the solution space was explored and the likelihood that children would vary either between different coordination categories or within one category (Hristovski et al., 2011).

Our results did not support the hypothesis of a mediating mechanism by creative thinking for any dimension of motor creativity. This fits with the emerging view that creative actions may not be the enactment of previously generated creative ideas, but are rather prompted by the affordances in the environment and their purposeful manipulation (Orth et al., 2017). This view has large similarity with Dietrich's definition of flow mode of creativity, whose essence is proposed to be the perception-action coupling without any conscious control and creative thinking effort. In Dietrich's words (2019, p. 4), "*The importance of a skilled movement sequence as a defining feature of the flow mode* (of processing in creativity) *cannot be overstated,*" as the motor system is deeply involved in creative thinking (Matheson and Kenett, 2020). To become fluent and original in moving, children seem not to require an enhanced efficiency of those cognitive processes that allow them to think out of the box. Rather, their ability to detect and exploit affordances, likely fostered by PE enrichment, may have translated into an ability to explore the 'infinity' within the box, that is, the variability potential of alternative ways to control a same coordination, without necessarily switching to new movement categories.

Instead, the improved ability to switch between movement coordination categories (i.e., motor flexibility) observed after the intervention was jointly explained by motor proficiency and inhibition (**Figure 3B**). The role of inhibition, which at a first sight seems to ground motor creativity in a cognitive framework has instead the potential to bridge the arguments on the emergence of motor creativity provided in the framework of Ecological Dynamics. Its non-linear pedagogical approach is assumed to facilitate the emergence of new functional patterns of motor coordination and control, because it maintains the perceptual-motor system in a region between stability and instability (meta-stable region; Hristovski et al., 2011; Torrents et al., 2021b). Speculatively, the ability to inhibit well-learnt, more common and therefore stable coordination patterns might help maintain the perceptual-motor system in this region of temporarily stable motor solutions which emerge based on actually selected affordances. Later on along the creative process, inhibition might come into play to enable a deliberate mode of processing and selection of creative behaviors (Cheng et al., 2016). Therefore, not inhibition *per se*, but an adaptive engagement of inhibition may matter (Benedek et al., 2012).

Limitations

This study is not without limitations. Teachers and children could not be blinded; the higher session enjoyment in the enriched PE group might have been coupled with a tendency toward higher engagement. Nevertheless, adding the enjoyment as a covariate to the analysis did not alter the pattern of intervention effects. The intervention outcomes cannot be univocally attributed to the features of the enriched PE intervention, since this latter was delivered by specialists whereas the conventional PE was delivered by generalist classroom teachers. However, the qualitative analysis of teaching behaviors suggested the fidelity of the specialists' teaching strategies to the targeted type of intervention and its likely contribution to the observed benefits. Moreover, the present study may have been underpowered to detect whether males and females are differently responsive to motor creativity interventions. Since evidence on sex differences in children's motor creativity is scarce and mixed (Tocci et al., 2004; Ouhassine et al., 2020), future studies are warranted. A further limitation regards the low generalizability to school contexts in countries, which have jurisdictions with PE specialist teachers in every primary school. Furthermore, this study did not assess maintenance of the obtained improvements. Although a mediating role of the overall motor impairment score was found, the discriminative power of the M-ABC as a measure of motor coordination in children without DCD was suboptimal, as this tool is better suited to detect differences between typical and atypical motor development. The absence of mediating effects by working memory and those of inhibition being limited to only one facet of motor creativity might depend on the fact that executive functions were investigated with a task that taps them in decontextualized and affectively neutral conditions (i.e., 'cool' executive function) not comparable to an emotionally laden creative process in the motor domain. This raises the issue of how valid is, from an ecological perspective, a narrowly framed measurement of cognitive functions that consistently exhibit a narrow transfer (Kassai et al., 2019) to detect the multi-domain effects of holistic and hybridized pedagogical models (González-Víllora et al., 2018).

Conclusions: Giving Ideas Some Legs or Legs Some Ideas?

The title provocatively asked whether children exposed to enriched PA learn how to give their ideas some legs, or how to give their legs some ideas. 'Giving ideas some legs' means 'embodying' creative ideas in pertinent and meaningful actions; 'giving legs some ideas' means, conversely, 'enactive' creativity that emerges through the intertwined processes of perceiving and acting (Malinin, 2019). Our study has mainly provided evidence in favor of enactive creativity promoted by the exposure to variation in constraints and supported by improved motor coordination (i.e., the sensorimotor 'flow' mode of creativity), but also some nuanced indication in support of embodied creativity through cognitive inhibition that likely enables to reject common or task-inappropriate movement categories and select novel ones (i.e., the 'deliberate' mode of creativity). This limited evidence for an involvement of 'cool' executive functions calls for research that assesses the role of 'hot' executive functions with affective aspects as those related to risk taking in decision making (Zelazo and Carlson, 2012). Cognitive functions that contribute to motion with e-motion may better reflect the motivational salience of the motor creativity context (Rudd et al., 2020) and are inherent in a recent overarching model of how enriched PA may enhance the creative potential (Richard et al., 2021). The need to address the salience of the context and the physical, cognitive, emotional and social facets of PA enrichment is emerging in movement sciences also in the first systematic attempt to identify contextualized mechanisms acting in the physical activity-cognition relation (Pesce et al., 2021b). These intriguing convergences may inspire future research that empirically develops at the intersection of ecological approaches to creativity, cognitive and movement sciences.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of legal restrictions (i.e., national privacy legislation and inclusion, in the informed consent signed by parents/guardians, only of permission for communication of data in aggregated form). Data for secondary analyses (e.g., meta-analyses) can be rendered available by the corresponding author to individual researchers upon request. Requests to access the datasets should be directed to CP, caterina.pesce@uniroma4.it.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the "Umberto I" hospital of the First Rome University (Ref. No 2950). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CP, NT, and PS: conceptualization and methodology. EM and MM: validation. CP, EM, and MS: formal analysis. IM: investigation. NT, PS, and IM: data curation. CP: writing—original draft preparation and review, project administration, and funding acquisition. NT, PS, EM, MM, and MS: writing—review and editing for important intellectual content. CP and IM: supervision. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.806065/full#supplementary-material

Supplementary Data Sheet 1 | 'Joy of Moving' Sample Games.

Supplementary Data Sheet 2 | Information on assessment tasks, validity and reliability.

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Effects of Desk-Bike Cycling on Phonological Working Memory Performance in Adolescents With Attention Deficit Hyperactivity Disorder

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We investigated the effects of active workstations on cognitive control functions in individuals diagnosed with Attention Deficit Hyperactivity Disorder (ADHD). In a fully counterbalanced randomized control design, we examined the effects of cycling on a desk bike on phonological working memory (WM) in 18 adolescents with ADHD. Adolescents performed a phonological WM test across two separate sessions during which they either cycled or not. It was hypothesized that participants would perform better on the WM task while cycling as compared to seated-rest. Results showed that total WM performance was not affected by desk-bike cycling. Exploratory analyses suggested that cycling during more difficult trials (i.e., high WM demands) is beneficial for WM performance. More research is needed to shed light on how task difficulty moderates the potential compensatory effect of desk-bike cycling on WM performance in adolescent ADHD participants.

Keywords: desk bikes, active workstations, phonological working memory, ADHD, adolescents

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INTRODUCTION

Effects of Desk-Bike Cycling on Phonological Working Memory (WM) Performance in Adolescents With ADHD.

Despite evidence that points to positive associations between physical activity, cognitive function (Hillman et al., 2008), academic performance (Castelli et al., 2007; Donnelly et al., 2016), and overall health (Butte et al., 2007) in school-aged youth, children's opportunities to engage in physical activities during the school day have significantly decreased during the last two decades (Institute of Medicine, 2013). This trend has co-occurred with the increasing prevalence of sedentary behaviors in western society due to advances in technology and environmental changes (Ng and Popkin, 2012) and contributes to chronic health problems across the life span, such as obesity and cardiovascular diseases (Hillman et al., 2008). As a response to these negative developments, organizations have begun to promote physical activity in the classroom (National Association for Sport and Physical Education et al., 2008). In addition, there has been a gradual increase in studies investigating the impact of active teaching lessons or active workstations on health and cognition (see also Kibbe et al., 2011; Donnelly et al., 2016; for a review see Mavilidi et al., 2018; Ruiter et al., 2019).

Recently, it has been suggested that physical activity interventions are especially beneficial for those children characterized by lower cognitive control and self-regulatory behavior[1] (Drollette et al., 2014). That is, overall findings revealed that a single, acute bout of moderate-intensity aerobic exercise facilitates cognitive performance, with more extensive effects observed for the lower-performing group than the higher-performing group on a flanker task. Similarly, Mahar et al. (2006) reported that increasing physical activity opportunities in the classroom to improve on-task behavior were especially beneficial for children who demonstrated poor on-task behavior at baseline. One specific class of individuals with cognitive control impairments is children diagnosed with attention deficit hyperactivity disorder (ADHD). Attention deficit hyperactivity disorder is a psychological outcome that manifests itself during childhood and is characterized by developmentally inappropriate levels of inattention, impulsivity, and hyperactivity (Rapport et al., 2009). Contemporary leading theories have explained the mechanism underlying ADHD-related deficits as an imbalance in the catecholaminergic systems in the brain, leading to dysfunction of attentional circuits (Rapport et al., 2009). Specifically, it has been hypothesized that attentional impairments may be due to depleted levels of dopamine in the prefrontal cortex. The efficacy of psychostimulants in the treatment of ADHD supports this notion (Yu-Kai et al., 2012).

Pontifex et al. (2013) investigated the effect of a single bout of moderate-intensity aerobic exercise on children with and without ADHD using objective measures of attention and brain neurophysiology. Although both groups improved performance on the flanker task following exercise, acute exercise appeared to have an additional benefit for children with ADHD. The ADHD group exhibited an increase in a neuroelectric component (i.e., error-related negativity, ERN) that has been linked to the upregulation of processes involved in action monitoring. Importantly, these exercise-induced facilitations in action monitoring processes resulted in increased task performance following errors in the ADHD group only.

Apart from the reported benefits of physical activities, such as aerobic exercise, recent studies also suggest that self-initiated spontaneous motor activity seems to serve as a positive function for children with ADHD. Rapport et al. (2009) noticed that the relationship between increased rates of activity and ADHD is pervasive, as the disorder is associated with excessive gross motor activity and fidgeting from early childhood (Corkum et al., 1998; Rapport et al., 2009), in both children and adults (Teicher et al., 2012). Moreover, also during the performance of cognitively demanding tasks (i.e., WM, stop-signal, and choice tasks), increased levels of activities among children and adults diagnosed with ADHD have been reported (Rapport et al., 2009; Alderson et al., 2012; Hudec et al., 2014). Rapport et al. (2009) hypothesized that increased movement may serve as a compensatory function to augment chronic cortical under-arousal associated with ADHD (Dickstein et al., 2006). In other words, hyperactivity is a functional and secondary symptom reflective of unconscious efforts to increase arousal to meet cognitive WM demands. This model therefore predicts a positive relation between gross motor activity and cognitive performance for persons with ADHD. Indeed, this functional WM model was substantiated with recent findings showing that higher rates of spontaneous motor activity predicted significantly better phonological WM performance (Sarver et al., 2015) and better cognitive control performance (Hartanto et al., 2016) for children with ADHD. However, findings also showed that increasing set size demands within the context of a phonological WM task was not significantly related to an activity level as one should expect when adhering to the functional model (Rapport et al., 2009; Sarver et al., 2015).

With these recent findings, the widespread assumption that excess gross motor activity interferes with children's ability to actively engage in learning-related activities that challenge executive functions, such as WM, and the subsequent recommendations or measures to target this hyperactivity in the classroom, should be reconsidered. Instead of decreasing the activity levels of children and adolescents diagnosed with ADHD, research should investigate how opportunities for physical activities, particularly, ones that are neither disruptive nor stigmatizing, can be used in academic settings to help children perform cognitively demanding tasks. One promising strategy for increasing physical activity in the classroom is through the use of active workstations, such as desk bikes (Torbeyns et al., 2014; Ruiter et al., 2017).

Given the role of physical activity on cognitive function and academic performance, the aim of the present study was to investigate whether an exercise that is concurrent and of light intensity (i.e., self-paced cycling on a desk bike) could increase cognitive control of adolescents diagnosed with ADHD. Most research in the acute exercise literature has found positive effects on cognitive control processes *after* at least 20 min of moderate exercise (e.g., Hillman et al., 2003) in adults. To our knowledge, very few studies have investigated the effectiveness of a seated concurrent light intensity physical activity for preadolescents or adolescents diagnosed with ADHD (Sarver et al., 2015; Ruiter et al., 2019). Therefore, in the present study, the effects of structured motor activity on a desk bike on phonological WM performance in adolescents diagnosed with ADHD were examined. Desk-bike cycling was used in the study given its feasibility (i.e., allows students to stay seated and is relatively quiet) and affordability to be used in a classroom setting. Based on findings in previous work in which higher rates of spontaneous motor activity predicted significantly better phonological WM performance for children with ADHD (Sarver et al., 2015), it was hypothesized that adolescents with ADHD would benefit from cycling on the desk bike (i.e., concurrent light-intensity activity) and consequently show higher WM performance during cycling than during seated-rest. Since cycling on a desk bike is considered a light intensity activity in this study, no hypothesis was formulated for effects after cycling. We also explored whether WM performance during cycling would be differentially affected by WM load. In addition, we explored the effects of desk-bike cycling on subjective measures of mental effort, enjoyment, and difficulty.

[1] The term "cognitive control" refers to processes that allow information processing and behavior to vary adaptively depending on current goals and include interrelated processes of inhibition, working memory (WM), and cognitive flexibility (Diamond, 2013).

MATERIALS AND METHODS

Participants

Participants were 18 students of a special education school in the Netherlands (age, 15.62 ± 2.20; gender, 17 men), who were recruited through a newsletter and a special participation request letter sent *via* the school to the parents of 49 eligible adolescents. All participants had received the formal diagnosis of ADHD by their psychologist or psychiatrist using the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V) criteria. Given generalizability concerns, adolescents with comorbidities were included. Out of the 18 participants, 10 had a comorbid diagnosis with an Autism Spectrum Disorder, and four with other comorbid diagnoses (i.e., persistent depressive disorder, attachment disorder, adjustment disorder, developmental coordination disorder, and Tourette syndrome). Twelve children were prescribed psychostimulants at the time of assessment. Parents of participants who were taking psychostimulants were asked to withhold these for a minimum of 24 h prior to participating in all assessment sessions. Furthermore, participants were asked to refrain from drinking coffee or high-sodium drinks. This study was approved by the university's Institutional Review Board.

Apparatus

One height-adjustable desk, one desk bike (Worktrainer), and one laptop (Lenovo B590, 15.6 in.) was used in the study. The cycling resilience was kept equal across participants.

Design and Procedure

The present study employed a fully counter-balanced, within-subjects repeated measures design. Each participant took part in two assessment sessions with repeating phonological WM tasks under different conditions. Each session was separated by approximately 8 days (range 5–16). Participants were tested in the same order and in the same room on both occasions. Randomization and counterbalancing of participants occurred before the first session to minimize learning and order effects (i.e., seated-rest–cycling vs. cycling–seated-rest). The students were individually taken out of class, brought to a quiet room, and were seated on a desk bike approximately 0.6 m from a laptop placed on a height-adjustable desk. The resistance rate was kept equal across students and sessions. Participants were given instructions about the task and had to practice several trials. In the cycling condition, they were asked to ride the desk bike for 2 min in order to familiarize themselves with the apparatus and to find a stable, endurable pace of their preference. In the non-cycling condition, participants were asked to sit still for 2 min on the desk bike. After this, the task started and participants completed it while cycling or engaging in seated-rest. Performance was monitored at all times by two trained research assistants who were seated in the same room, but outside participants' view and who wrote down the participants' oral answers. During both sessions, participants were recorded with a camera to register their responses. A session lasted for 30 min.

Measures

Phonological Working Memory Task

The phonological WM task is similar to the Letter-Number Sequencing subtest on the Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV; Wechsler, 2003) and assesses phonological WM based on Baddeley's (2007) model by requiring both central executive processing/manipulation and phonological storage-rehearsal. This cognitive task has often been used in ADHD research (e.g., Rapport et al., 2008; Sarver et al., 2015). Participants were presented with a series of jumbled numbers and a capital letter on a laptop. Each number and letter (4 cm height, font Arial) appeared on the screen for 800 ms, followed by a 200 ms interstimulus interval. The letter was never presented in the first or last position of the sequence to minimize potential primacy and recency effects and was counterbalanced across trials to appear an equal number of times in the other serial positions (i.e., position 2, 3, 4, or 5). Participants were instructed to verbally recall the numbers in order from smallest to largest and ending with the letter (e.g., the sequence 3 H 5 8 is correctly recalled as 3 5 8 H). See **Figure 1** for a graphical representation of the phonological WM task.

Each participant was administered the phonological task at four different cognitive loads (i.e., phonological set sizes consisting of 3, 4, 5, and 6 stimuli) across the two testing sessions. The four WM set size conditions, each contained 24 unique trials of the same stimulus set size, were counterbalanced across the two testing sessions to control for order effects and potential proactive interference effects across set size conditions (Conway et al., 2005). Before the start of the task, five practice trials with four stimuli were given to the participants. The research assistant would let the student practice until the 80% correct criteria were achieved.

Two trained research assistants, shielded from the participant's view, recorded the oral responses. Uncertainties and discrepancies regarding the oral responses were overcome *via* audio-video review. Performance data were calculated using partial-credit unit scoring (proportion of stimuli correct per trial) due to its preferred psychometric properties relative to all-or-nothing scoring (Conway et al., 2005) and control for differences in the number of stimuli available for recall across the set sizes.

Task Evaluation

After task completion, participants were asked to rate their subjective task experience on aspects of difficulty ("How difficult was the task?"), enjoyment ("How much did you enjoy the task?"), and effort ("How much effort did you invest during the task?") on a nine-point Likert scale varying from 1 (very, very low) to 9 (very, very high).

RESULTS

Preliminary Analyses

To check for potential confounding effects of counterbalancing the order of the cycling condition, we ran an additional 2 × 4 mixed ANOVA on proportion correct score where session order (counterbalancing order: seated-rest first, cycling first) was

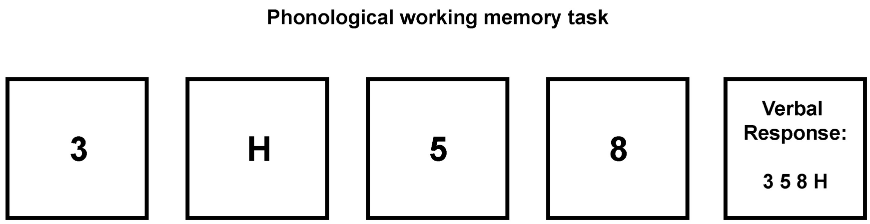

FIGURE 1 | Visual schematics of the phonological working memory (WM) task.

included in addition to the factors of our main analysis. Results showed no significant interaction effects on proportion correct of counterbalancing order with cycling condition, $F_{(1,16)} = 0.075$, $p = 0.788$, $\eta^2_{partial} = 0.005$, indicating that counterbalancing order did not impact the effect of our experimental manipulation.

Phonological Working Memory

Descriptive statistics are shown in **Table 1**. The hypothesis that participants would perform significantly better on the WM task while cycling as compared to seated-rest was tested with a one-way repeated measures ANOVA. The dependent variable was task performance (i.e., total test scores), whereas the independent variable was test condition (i.e., cycling vs. seated-rest). When compared task performance while cycling ($M = 0.775$, $SD = 0.147$) with task performance while sitting ($M = 0.763$, $SD = 0.139$), results indicated that there was no statistically significant difference and thus no statistically significant effect of cycling on task performance compared to sitting; $t(17) = -0.614$, $p = 0.548$, $d = 0.08$. This result demonstrates that students performed on a very similar level on the cognitive task despite the change in test conditions.

We also looked at the effect of condition on the WM task at four different cognitive loads (i.e., phonological set sizes consisting of 3, 4, 5, and 6 stimuli). Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of WM scores, χ^2 $(5) = 13.94$, $p = 0.016$. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.66$). There was a significant main effect of WM set size on task performance, $F_{(1.98,33.64)} = 58.06$, $p < 0.001$, $\eta^2_{partial} = 0.77$, with higher set sizes corresponding with decreased performance (see **Table 1**). There was no significant main effect of condition on task performance, $F_{(1,17)} = 0.68$, $p = 0.421$, $\eta^2_{partial} = 0.04$. Mauchly's test also indicated that the assumption of sphericity had been violated for the interaction effect of WM Scores x Condition, χ^2 $(5) = 18.51$, $p = 0.002$. Again, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.62$). There was a significant interaction effect between condition and WM set size scores, $F_{(1.86,31.71)} = 3.50$, $p = 0.045$, $\eta^2_{partial} = 0.17$. This suggests that conditions had different effects on participants' scores depending on which set size was given.

To explore this interaction as depicted in **Figure 2**, two paired sample t-tests were performed comparing the low (i.e., set sizes 3 and 4) and high (i.e., set sizes 5 and 6) WM set sizes across different conditions. The first paired sample t-test comparing cycling and seated-rest during WM set sizes 3 and 4 revealed no difference between the scores for seated-rest ($M = 1.78$, $SD = 0.19$) and cycling ($M = 1.74$, $SD = 0.26$), $t(17) = 1.11$, $p = 0.284$, $d = 0.02$. Another t-test compared the scores at WM set sizes 5 and 6 revealed a marginally significant difference between cycling ($M = 1.35$, $SD = 0.36$) and seated-rest ($M = 1.24$, $SD = 0.38$), $t(17) = 2.07$, $p = 0.054$, $d = 0.08$. Taken together, these results point in the direction of a specific trend: at low levels of load, WM performance is unaffected by cycling, but when set sizes increase, cycling seems to result in higher WM scores as compared to seated-rest.

TABLE 1 | Means (SDs) of working memory (WM) performance and task evaluation measures across conditions.

	Condition			
	Cycling		Seated-rest	
Measure				
1. WM performance				
a. Set size 3	0.90	(0.12)	0.95	(0.05)
b. Set size 4	0.84	(0.14)	0.83	(0.51)
c. Set size 5	0.73	(0.18)	0.68	(0.20)
d. Set size 6	0.61	(0.23)	0.56	(0.20)
e. Total WM performance	0.77	(0.15)	0.76	(0.14)
2. Task evaluation				
a. Task difficulty	5.44	(1.51)	5.83	(1.58)
b. Mental effort	5.56	(1.79)	5.44	(2.25)
c. Enjoyment	4.56	(1.85)	5.42	(2.14)

WM performance scores are in proportion to stimuli correct. Task evaluation scores were measured on a 9-point Likert scale.

Task Evaluation

Due to the ordinal nature of the task evaluation scores, a Wilcoxon Signed Ranks Test was conducted to compare the effects of both conditions on the dependent variables "task difficulty," "enjoyment," and "mental effort." No significant differences were found between conditions for task difficulty ($Z = -0.960$, $p = 0.337$), enjoyment ($Z = -1.745$, $p = 0.081$), or mental effort ($Z = -0.086$, $p = 0.932$). Consequently, cycling during the WM task did not make a statistically significant difference for participants' rating of task difficulty, enjoyment, and effort as compared to seated-rest. Hence, the task evaluation scores do not offer an explanation for the results.

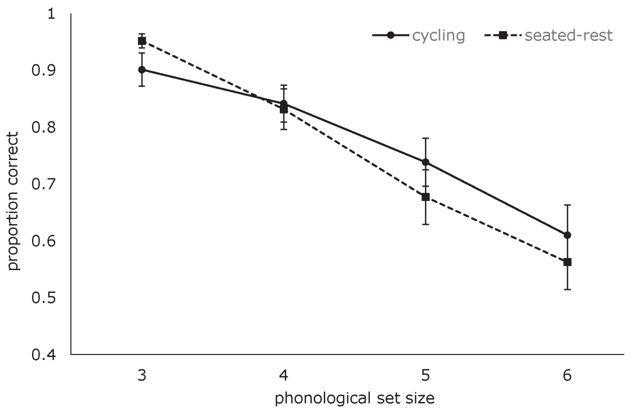

FIGURE 2 | Proportion correct at 4 phonological set sizes. Error bars represent standard error of the mean.

DISCUSSION

This study is the first one to examine whether physical activity in the form of stationary cycling can be used in the classroom to help adolescents diagnosed with ADHD perform cognitively demanding tasks. Based on literature pointing toward a positive association between motor activity and cognitive control for adolescents with ADHD (Drollette et al., 2014; Sarver et al., 2015; Hartanto et al., 2016), we hypothesized that exercise in form of cycling during a phonological WM task would result in increased WM performance. Yet, no statistically significance of cycling was found on total WM performance. The present study therefore fails to substantiate the assumption that facilitating physical activity helps adolescents with ADHD improve their WM performance. This result is in line with several previous studies failing to find a beneficial effect of active workstations on cognitive functioning (Bantoft et al., 2016; Torbeyns et al., 2017). It is important to note, however, that these earlier results have arrived with a different population, namely, adults or typically developing children and not children or adolescents diagnosed with ADHD.

As an additional exploratory analysis, we also looked at the effect of condition on WM task performance at low and high levels of the cognitive load instead of total WM performance. Data revealed that at low levels of load (i.e., set sizes 3 and 4), seated-rest and cycling resulted in comparable WM scores, whereas cycling resulted in better WM performance when set sizes increase (i.e., set sizes 5 and 6).

This result is in line with the study of Hartanto et al. (2016) who found that higher rates of spontaneous motor activity predicted significantly better performance on inhibitory control. In their study, participants' movements were measured by affixing an actometer to their ankles that measured their level of activity while completing the flanker test. The accuracy of the participants with ADHD was significantly improved when they were moving. In other words, correct answers were associated with more motion than incorrect answers. This result suggests that accuracy in ADHD may be enhanced by more intense activities or that when a child with ADHD is using more cognitive resources they are more likely to be engaging in physical activity. One possible mechanism for a relationship between movement and cognitive performance is that children with ADHD use movement to self-regulate alertness. An optimal level of arousal is required for peak cognitive performance (Yerkes and Dodson, 1908). The results of the present investigation and the study of Hartanto et al. (2016) support Rapport et al.'s (2009) model that hyperactivity may serve to compensate for underarousal and acts to improve cognitive performance.

Another explanation for this result can be found in the fact that cycling on a desk bike is a very specific form of structured, continuous movement with the lower body. Possibly, this type of movement will prevent adolescents with ADHD from making more uncontrolled movements with the upper body (e.g., arm movements) that are unrelated to the task at hand and that negatively affect task performance, since they take away the attention necessary for well-performing a task under high WM load conditions (Engle, 2002). More specifically, cycling movements have the potential to channel the surplus of motor activity common to adolescents with ADHD, while keeping a focus on the challenging cognitive task at hand. As a result, performance under high WM load conditions will be increased, while no such performance gains are obtained in tasks under low WM conditions. This explanation resonates well with findings that continuous body movements, as opposed to discrete movements, increase performance on WM tasks under conditions of high cognitive load (Maes et al., 2015). More research is needed to shed light on how task difficulty moderates the potential compensatory effect of cycling on task performance, especially, in children with ADHD. These findings have important implications for the educational field or clinical practice. Desk bikes can be implemented in the classroom to help manage students' hyperactivity symptoms and boost their performance in the classroom on cognitively demanding tasks, without interrupting, or distracting peers or teachers in the classroom.

Limitations and Future Studies

In the present study, cycling was self-paced and mandatory. While the small sample size with the presence of comorbid diagnosis may limit the study's ability to draw robust conclusions, the study is a first step toward examining the effect of concurrent light-intensity exercise on cognitive control. Future studies should replicate the study using a cadence sensor and multiple actigraph devices to gain a deeper insight into activity patterns of the upper and lower body associated with adolescents with ADHD. In addition, the inclusion of a cadence sensor in future studies can also shed light on the complex interplay between motor activity and different WM demands both during conditions of seated-rest and cycling. It would also be interesting to investigate whether mandatory or self-regulated cycling would differentially affect WM performance, since in the latter situation one can manage one's own cognitive load.

Another limitation of the present study is that we exclusively looked at one single phonological WM task and we did not employ pre- and post-test experimental designs. Due to the diffuse nature of the WM construct, multiple tasks tapping the same construct but differing in other respects (e.g., design, modality) would provide a more robust outcome measure than using a single test alone. For instance, one can use the Digit span task, another common neuropsychological test in the WISC-IV battery to assess auditory WM. This task involves repeating a sequence of numbers in the same order right after they have been read aloud. This test differs from the phonological WM test, in which a screen was used to present the numbers and letters. Another essential step would be to investigating the relationship between visuospatial WM and physical activity. This is especially important, since evidence points out that concurrent motor movements, such as finger tapping (e.g., Della Sala et al., 1999), have been shown to produce interference with this aspect of WM. In addition, by using pre- and post-test experimental designs, future studies could also verify if desk-bike cycling increases cognitive performance at an individual level. By doing so, we will be able to investigate different parameters, such as intensity, type of task, individual characteristics, and self-initiation, to understand the mechanism underlying the effect of spontaneous physical activity.

This study was conducted in a controlled classroom setting with limited distractions over a short time period. We recommend follow-up studies with a larger sample size to investigate the long-term effects of desk bikes in a more naturalistic environment. It could not only be investigated whether movement on a desk bike translates to improved WM, which is critical for several academic tasks (Alloway and Alloway, 2010), but more importantly, whether it leads to improved academic attainment among adolescents with ADHD.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Review Committee at the Department of Psychology, Education and Child Studies of Erasmus School of Social and Behavioral Sciences. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MR, EG, SL, and FP conceived and planned the experiments. MR and EG carried out the experiments. MR, SL, JW, and FP contributed to the writing of the manuscript. SL and FP supervised the project. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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The Acute Effects of Standing on Executive Functioning in Vocational Education and Training Students: The Phit2Learn Study

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Research suggests that sedentary behavior (SB) is negatively associated with cognitive outcomes. Interrupting prolonged sitting has been shown to improve cognitive functions, including executive functioning (EF), which is important for academic performance. No research has been conducted on the effect of standing on EF in VET students, who make up a large proportion of the adolescent population and who are known to sit more than other students of this age. In this study, we investigated the acute effects of reducing SB by short time standing on EF in vocational education and training (VET) students. In a randomized crossover study, 165 VET students were first taught for 15 min in seated position. After this, they performed while seated the Letter Memory Test for updating, and the Color Shape Test for shifting and inhibition. Students were randomly assigned to a sitting or standing condition. All students were taught again for 15 min and then took the same tests in the condition they were allocated to, respectively, standing or seated. After 1 week, the test procedure was repeated, in which students switched conditions. Mixed model analyses showed no significant effect of sitting or standing on updating, shifting, or inhibition. Also, no significant differences were found for the order of condition on updating, shifting, or inhibition. Our results suggest that 40 min of standing does not significantly influence EF among VET students.

Keywords: sit-to-stand desk, executive functioning, cognitive functioning, sedentary behavior, vocational education and training students, sitting

INTRODUCTION

Students generally spend a large part of their school day seated (Kariippanon et al., 2019). However, it is well known that sedentary behavior (SB) such as sitting, and especially prolonged periods of SB without interruption, is negatively associated with physical and mental health outcomes (Tremblay et al., 2011; Suchert et al., 2015; Biddle et al., 2019; van der Berg et al., 2019). It has also been suggested that breaking up SB positively affects executive functioning (EF; Mullane et al., 2017; Rosenbaum et al., 2017; Mazzoli et al., 2019). Furthermore, it has been shown that light intensity physical activity (PA), including standing is beneficial for several markers of insulin sensitivity and plasma lipids, and that light intensity PA, such as standing, has a greater health effect than one-time intensive PA (Duvivier et al., 2013, 2017, 2018). Since standing during class is more feasible to implement than other forms of PA, for example, sports into the school day, the aim of the current study was to investigate the effect of standing during class on the EF in vocational education and training (VET) students, who are known to sit more than other students of this age (Bernaards, 2013; van Engen and Christoffels, 2017). Considering the biological mechanisms that have been shown to occur during standing, standing is hypothesized to have small positive effects on the EFs updating, inhibition and shifting compared to sitting.

The term EF refers to a family of top-down mental processes (Diamond, 2013) and to the abilities needed for metacognitive control and direction of mental experience (Lezak et al., 2004). EF is needed to concentrate and to pay attention (Diamond, 2013) and is important for academic performance (Pluck et al., 2019; Wang and Zhou, 2019; Dubuc et al., 2020). EF consists of capacities that enable a person to engage successfully in independent, purposive, self-directed, and self-serving behavior (Lezak et al., 2004). EF involves one's ability to actively maintain task goals and goal-related information and use this information to effectively bias lower-level processing (Miyake and Friedman, 2012). In general, three core EFs are distinguished as: (a) updating, (b) shifting, and (c) inhibition (Miyake et al., 2000). Updating is the act of modifying the current status of a representation of schema in memory to accommodate new input, and entails monitoring and encoding incoming information and appropriately revising the items in working memory (WM), by replacing no longer relevant information with new, more relevant information (Morris and Jones, 1990). Shifting involves moving back and forth between multiple tasks, operations, or mental sets (Monsell, 1996, as cited in St Clair-Thompson and Gathercole, 2006). It is not that demanding to keep doing what you have been doing, but shifting, i.e., shifting back and forth between mental sets, is one of the most demanding EFs (Diamond, 2013). Task switching improves during child development and declines during aging (Diamond, 2013). Inhibition involves the control over stimuli irrelevant to task performance (interference control) and the inhibition of habitual responses (Stroop, 1935). Inhibition enables us to selectively attend, focusing on what we choose and to suppress attention to irrelevant stimuli and involves the discipline to stay on task despite distractions and completing a task despite temptations to give up, to move to more interesting work, or to have a good time instead (Diamond, 2013). EF is strongly and positively associated with school performance and academic success (Christopher et al., 2012; Gray et al., 2015; Samuels et al., 2016). This means that EF covers a broad spectrum of cognitive skills and that fostering EF is important for school performance.

The acute effects of PA, including standing, on cognitive performance and EF seem to be caused by several biological mechanisms, including increased blood circulation in the brain (Weijenberg et al., 2011), improved insulin sensitivity, lower fasting plasma triacylglycerols levels (Duvivier et al., 2013, 2017), and improved sensitization for glucose transport across the blood–brain barrier (Chandrasekaran et al., 2021). These mechanisms are positively correlated to EF (Reay et al., 2006; van den Berg et al., 2009; Gonzales et al., 2010; Guiney et al., 2015; Sliz et al., 2020; Chandrasekaran et al., 2021). Additionally, standing leads to increased heart rate (Ebara et al., 2008), indicating increased arousal (Ebara et al., 2008; Knight and Baer, 2014). Arousal has shown to be associated with attention (Byun et al., 2014).

The effect of standing on EF has been investigated in several studies, for example, in the study of Rosenbaum et al. (2017). In this study, university students stood while executing a 72 item Stroop test measuring inhibition. The students in the standing condition performed better on this test than the students in the sitting condition (Rosenbaum et al., 2017). Additionally, studies with standing interventions of longer duration than conducted in the study of Rosenbaum and colleagues also reported positive effects of standing on EF. For example, one single "reduced sitting" school day, meaning that adolescents sat for 50% less time than during a "normal" school day (i.e., a normal school day consists of 240 min of sitting time) and with no bouts of sitting >20 min, resulted in improvements in mental attention capacity in adolescents (12–15y) at the end of the school day (Penning et al., 2017). Additionally, Mazzoli et al. (2019) demonstrated a weak but significant correlation between more sit-to-stand transitions over two school days and both enhanced attention and improved reaction time in an inhibition test in children (6–8 y; Mazzoli et al., 2019). Similarly, Mullane et al. (2017) found significant improvements in WM and attention in overweight adults who stood for 10, 15, 20, and 30 min, respectively, throughout the day for four consecutive weeks, compared to the control condition, in which participants sat for 4 weeks. However, in the same study, no effect was found of 10, 15, 20, and 30 min standing during the day on shifting. Furthermore, Bantoft et al. (2016) showed that standing up to 60 min compared to sitting did not lead to significant effects on short-time memory, WM, and attention in young adults (22.67 y; Bantoft et al., 2016). Also, Schwartz and colleagues found no significant differences in attention and inhibition performance in students (20–32 y) when comparing alternating sitting and standing, and sitting-only during two assessment days (Schwartz et al., 2018).

In most school systems, the amount of SB increases as children and adolescents progress through the school years. In other words, the average sitting time and the proportion of prolonged sitting without interruption are higher among older students than among younger students, which can partially be explained by the reduced proportion of class time spent on PA among the higher age groups than among the lower age groups (Mooses et al., 2017). Also evidence was found for a clear relationship between school environment and students' PA and SB, namely, through the availability of sit-to-stand desks, the encouragement by the school to exercise, and the teacher's attitude toward PA (Morton et al., 2016). Additionally, an association between students' academic schedule and both SB and PA has been shown (Chim et al., 2020). Thus, interrupting sitting behavior is particularly important among older adolescents.

In summary, results from previous studies on the effect of standing in the classroom on EF are mixed and therefore, no conclusion can be drawn about the effect of acute standing on EF compared to sitting. However, considering the biological mechanisms of standing, a small positive effect can be expected of short-time standing on EF in VET students. Many of the studies had relatively small sample sizes and focused mainly on young children. However, no research has been conducted on the effect of standing on EF in VET students, who make up a large proportion of the adolescent population (CBS, 2013), and who are known to sit more than other students of this age (Bernaards, 2013; van Engen and Christoffels, 2017). Furthermore, VET students are a very diverse group of students which show great differences in the mastery of basic knowledge and skills. They generally find self-regulation of learning difficult, as reflection on learning outcomes and learning strategy use is often limited (van Engen and Christoffels, 2017). In general, they score lower on (digital) problem solving than peers attending university of applied sciences or university, which is strongly related to the application of learning strategies and the level of language and numeracy skills (Christoffels and Steehouder, 2015). Therefore, we aim to investigate the acute effect of standing at sit-to-stand desk versus sitting behind a traditional desk during class on acute EF in VET students.

MATERIALS AND METHODS

Design

The current study is part of the PHIT2LEARN project (PHysical activity InTerventions to enhance LEARNing). Overall, the goal of PHIT2LEARN was to investigate the effects of PA/SB interventions on a variety of outcome measures in VET students. In nine different sub-studies (i.e., the current study concerns only one sub-study), physical activity behavior interventions of VET students and its effects on their cognitive performance and mental wellbeing were examined. Among other things, short-term intervention studies were designed to investigate the acute effect of exercise interventions and breaking up sitting on learning performance measures of VET students. Furthermore, the students' perceptions of the implementation of sit-to-stand desks and what they believe are needed to encourage students to stand more during class. Two of the studies have been published (Golsteijn et al., 2021; Kirschner et al., 2021). The current study was a randomized-controlled trial with a crossover design. Students stood behind sit-to-stand desks or remained seated as a control condition. Ethical approval was obtained from the Research Ethics Committee (cETO) of the Open University (reference U2017/00519/FRO) and the study has been registered in the Dutch Trial Register (NTR6358).

Participants

A total of 219 VET students were invited from 12 classes from the study tracks Child care, Youth care, and Teaching assistant from the levels 2, 3, and 4 of a VET institution in the south of Netherlands. VET is the most practical level of the Dutch tertiary education (CBS, 2013). VET is subdivided into four levels and prepares students for executive jobs or middle management jobs (i.e., dependent on the level). There were no exclusion criteria. All students received oral and written information about the research during an information session. Students were given at least 1 week to consider their participation, after which, if they agreed to participate, they signed an informed consent form.

Initially, we wanted to run an RM ANOVA for the statistical analysis. According to the power analysis conducted for this purpose, using an effect size of 0.15 and a power of 0.8 (Penning et al., 2017), a sample of 128 participants would be sufficient. To achieve a power of 0.95, 196 participants would be sufficient. However, advancing insight made us decide to use mixed model analysis to investigate our main research question. Therefore, the power analysis appropriate for mixed model analysis was performed post-hoc. To do so, a power analysis was conducted by performing a Monte-Carlo simulation study with 1,000 simulated datasets per analysis, using the package simr (Green and Macleod, 2016). Since no suitable literature was found for updating and inhibition with a similar study design, the power calculation was executed based only on previous literature for shifting (Miyake et al., 2004; Graham et al., 2021). For shifting, a difference of 13.75 in decrease in reaction time of the correct answers between the pre-measurement and the post-measurement was specified between the intervention condition and the control condition (i.e., the intervention condition had 13.75 ms more decrease in reaction time of the correct answers in the post-measurement than in the pre-measurement compared to the control condition), calculated from the data obtained from the literature. Thus, our post-hoc power analysis showed that to obtain a power of 0.80 or more, a sample size of at least 920 participants was needed.

Materials

In this study, we applied two well-validated neuropsychological tests that cover the three major domains of executive functioning (i.e., updating, shifting, and inhibition) and have been shown in previous research to have high test–retest reliability in previous research (Paap and Sawi, 2016; Soveri et al., 2018). Both tests were conducted on laptops with a 15.75 inch (i.e., 40 cm) screen, provided by the researchers.

Letter Memory Test

The Letter Memory Test (LMT) measures the updating capacity of the WM (Inman et al., 1998). Participants were presented with a series of five, seven, or nine consonant letters without repeat, one at a time. At the end of each series of letters, the participant had to recall the last three presented letters by clicking these in a provided letter matrix with all possible letters presented. Participants did not have to display the letters in the correct order. When a participant did not remember the last three letters, it was possible to click "blanco" for the letters he/she did not remember. Participants completed three training trials first, followed by twelve test trials. At the beginning of a trial, a fixation cross was displayed for 1,000 milliseconds (ms) in the center of the screen. Each stimulus was displayed for 2,500 ms in the center of the screen. The total number of correctly recalled letters on the LMT was used as a measure of WM/updating. The maximum score that could be obtained was 36 points (i.e., 12 trials with three letters per trial to remember). The median sensitivity and specificity of the LMT have been found to be 0.943 and 1.0, respectively (Inman et al., 1998). The internal reliability was.61 in previous research (Friedman et al., 2008).

Color Shape Test

The Color Shape Test (CST) measures both shifting and inhibition (Miyake et al., 2004; Miyake and Friedman, 2012). The test started with 16 training trials followed by 64 test trials. In each round (i.e., consisting of 64 trials with the same command), participants were presented with a shape (i.e., a triangle or a circle), a colored block (i.e., a red or green block), or a combination of both (i.e., a red triangle, a green triangle, a red circle, or a green circle). For the shape round, participants had to answer whether they saw a circle or a triangle, and for the color round, whether they saw a red block or a green block by pressing the "A" for "red" or "circle" and the "L" for "green" or "triangle." In the first round, shapes (i.e., shape test) were presented; in the second round, colors (color test) were presented. In the third round (i.e., shifting test), shape and colors were presented alternately. The presentation of shapes and colors was at random; in some cases, a task was repeated (i.e., two color trials or two shape trials after each other), and in other cases, the participants needed to switch between the shape task and the color task (i.e., shifting; a color trial after a shape trial or the other way around). In the fourth (i.e., shape inhibition-task) and fifth round (i.e., color-inhibition-task), shapes superimposed on color patches were presented (i.e., a circle superimposed on a red square). Participants had to indicate the shape (i.e., round four) or color (i.e., round five), regardless of the underlying color or superimposing shape, respectively. The interval between response and presentation of next stimulus was 600 ms; the size of a stimulus was 36 mm. The stimulus was presented until the participant had responded. In all rounds, the outcome measure was the mean response time (RT) of the correct answers. Shift costs are the differences in RT of the correct answers between switching trials in round three and the RT of the correct answers in round one and two. Inhibition costs are the differences in RT of the correct answers between inhibition trials in round four and five and the RT of the correct answers in round one and two. In previous research, the reliability was 0.86 (Friedman et al., 2008), whereas the test–retest correlation was 0.75 in previous research (Paap and Sawi, 2016).

Additional Measures

All participants filled in a questionnaire regarding sex, age, and school class, as there are indications that there is a relationship between sex, age, and EF (Jacobsen et al., 2017; Grissom and Reyes, 2019).

Procedure

After the consent of the management and the selection of the participating classes, an information session for the teachers was organized. During this session, the teachers were given oral and written information about the study and were told what was expected of them. Then, during an information session, students were given oral and written information about the study and received an informed consent form. They were given 1 week to consider their participation. After that week, a practice session took place in which participants performed the cognitive tests while seated, to familiarize them with the tests. At the beginning of the practice session, students received an explanation of the tests. After another week, the first test session took place in a classroom at the participants' school, which contained both sit-to-stand desks and traditional desks. Students were randomized into a sitting or standing condition as follows: since dual sit-to-stand desks were used in this study, students were "paired" with a fellow student of the same height; the two tallest individuals formed a pair, the next two students, and so on. These pairs were then randomized into two groups (e.g., a standing and a sitting group) using an online randomizer. After this, the researchers placed a card with the assigned condition, a form with the names of the students who would be sitting at that desk, and for each student a laptop from the research team and a word search with pencil on each desk. Students were then asked to take their seats at the desks with the form with their names on it. When the students were seated, the teacher taught for 15 min about citizenship, during which time all participants remained seated. After this 15-min lesson, participants first filled out the background questions, then performed the LMT and the CST, which took approximately 25 min. Participants who finished the tests early could solve the provided word search. After all participants finished the tests, the students who were assigned to the standing group raised their desks and stood up. When the students assigned to the standing condition were standing, the teacher taught for another 15 min, after which the participants again performed the LMT and CST as a post-measurement immediately after the lesson. Here, the students who were in the standing condition remained standing and the seated students remained seated. This procedure was repeated 1 week later, with participants switching test conditions during the second part of the test session (i.e., those who stood during test session 1 sat during test session 2 and vice versa). Participation in the study was voluntary, but only students who had participated in the practice session could participate in the test sessions. Students who did not give informed consent, or who had not participated in the practice session, were given a "normal" lesson that took place in a separate room or in the back of the classroom. **Figure 1** shows the schematic representation of the study design.

Data Processing

For the LMT, the score per participant per test session and test time (i.e., pre-test or post-test) were calculated. For the CST, the blocks with less than 32 correct answers were removed as it is expected that in that case the participants did not understand the test. Afterward, in the shifting round (i.e., the third round), all non-shifting trials were removed (i.e., a color trial after a color trial or a shape trial after a shape trial). Then, all congruent trials were removed in the inhibition rounds (i.e., the fourth and fifth round, requiring the same key to be pressed for shape and color). Subsequently, all incorrect

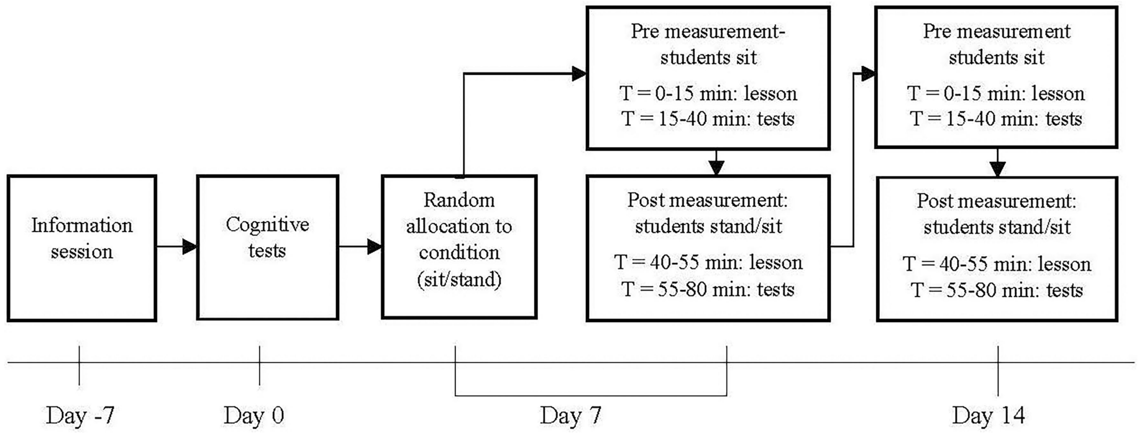

FIGURE 1 | Schematic representation of the study design. Students who sat in the first test session at day 7, stood in the second test session at day 14 and vice versa.

TABLE 1 | Participants' characteristics ($N = 165$) total and per order of condition.

		Total	Sit-stand	Stand-sit
Age [M (SD)]		18.8(7.9)	18.1(1.3)	19.32(10.6)
	Missing	1	0	1
Sex (N)	M	106	44	62
	F	59	29	30
	Missing	0	0	0

M, Mean; SD, Standard deviation; Sit-stand: sitting followed by standing; and Stand-sit: standing followed by sitting.

answers and all latencies of <170 ms and >5,000 ms were excluded as it is assumed that if participants react too quickly, they have not been able to think, and if they react too slowly, they have been distracted (Sternberg, 1999; Miyake et al., 2004; Harrison et al., 2010). Finally, the data were structured in such a way that per participant one line remained with all mean response times for shifting and for inhibition per test session and per test moment. Shift costs were calculated by subtracting the average RT in rounds one and two from the average RT in round three, which was the shifting task. Trials that were not switching tasks (i.e., two consecutive shape or color trials) were excluded from this calculation. Inhibition costs were calculated by subtracting the mean RT in rounds one and two from the mean RT in rounds four and five, which are the inhibition tasks, excluding all congruent trials in the inhibition tasks. Congruent trials are trials in which the stimuli are in agreement with each other (i.e., a triangle on a green patch or a circle on a red patch), require the same response, and thus do not measure inhibition.

Statistical Analyses

Analyses were conducted in SPSS (version 24; SPSS Inc., Chicago, Il, United States) with the significance level set at 0.05. To assess the effects of the sitting or standing condition on the outcomes for updating, shifting, and inhibition, controlling for three covariates (i.e., sex, age, and school class), mixed model analyses were performed. First, it was checked whether mixed model analyses were necessary, this was done by comparing the −2 log likelihoods (−2LL) of a model with a fixed intercept for participants and a model with a random intercept for participants and both condition and order of condition (i.e., first stand then sit or reverse) as independent variable. After these two analyses, models were built in a stepwise way. Separate models were built for each outcome measure (i.e., updating, shifting, and inhibition scores). One covariate was added and the new model was compared to the previous model. If the change in -2LL indicated a significant improvement of the model, the variable was kept in the model. Variables were added in the following order: (I) class code as third level, (II) pre-test scores, (III) test session (i.e., test day), (IV) age, and (V) sex.

RESULTS

Participants' Characteristics

A total of 219 students were invited for this study. Of these, 23 students did not want to participate, resulting in 196 students which we included in the study. During the trajectory, participants dropped out due to the following reasons: logistical reasons ($N = 1$), class/group allocation unclear ($N = 2$), no show up during the test sessions ($N = 20$), and one or more blocks with <33 correctly answered trials in CST ($N = 8$). Additionally, a total of 4 and 20 trials, respectively, were excluded as the latency was <170 ms and >5,000 ms, respectively. Note that no participants were excluded nor were any trial within the latencies indicated above. Ultimately, results of 165 students (106 boys, 18.8 y, SD = 7.9, **Table 1**) were included in the data analyses. A flow diagram including the numbers and reasons for exclusion can be found in **Figure 2**.

Executive Functioning and the Impact of Standing

No significant effect of sitting or standing ($B = 0.51$, SEb = 0.50, 95%CI = [−0.49, 1.51], **Table 2**) or order of these conditions

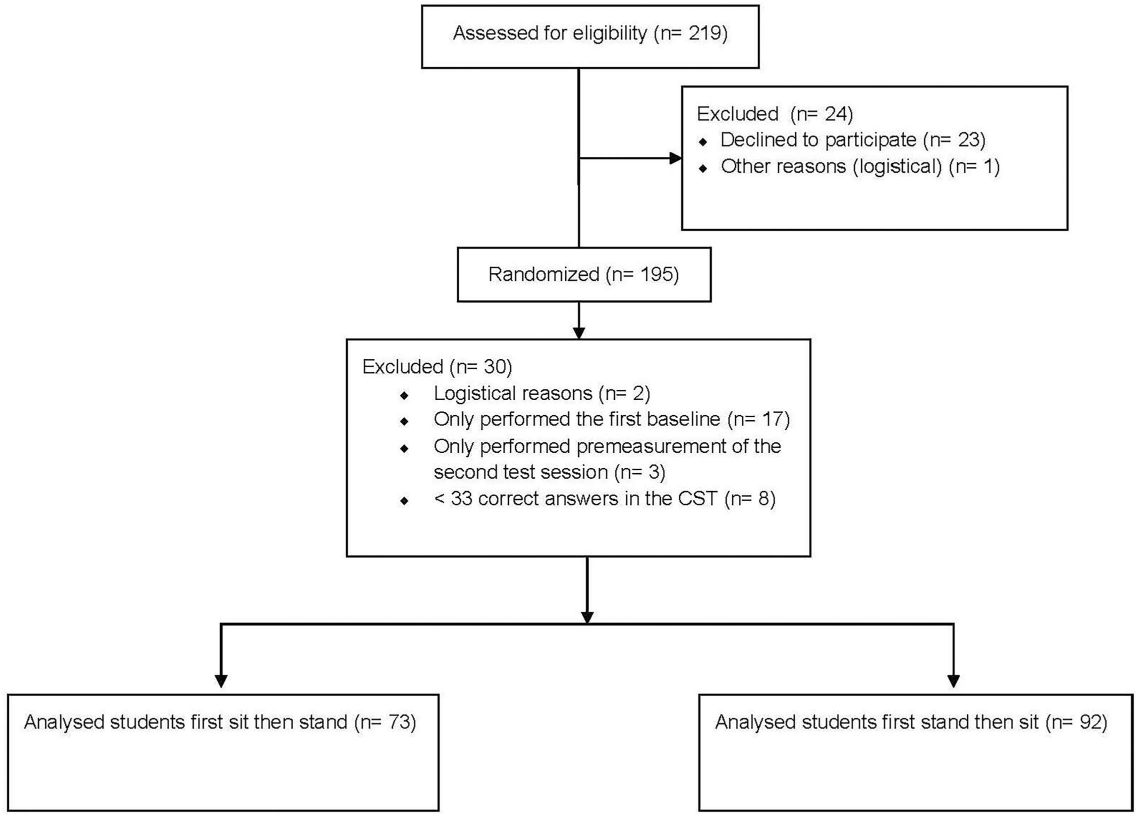

FIGURE 2 | Flow diagram: progress of participants through the trial.

($B = -0.34$, $SEb = 0.60$, 95%CI = [−1.54, 0.85]) on updating scores was found. When comparing the mixed models for the effect of standing on updating, the best model was the model with random intercept, with participant as a second level, class code as a third level, and updating pre-measurement and age as covariates. The only covariate that was significant was updating pre-measurement ($B = 0.86$, $SEb = 0.58$, 95% CI = [0.75, 0.97], **Table 2**), indicating that students who scored better at the pre-test, also scored better at the post-tests. **Table 3** shows an overview of the mean and standard deviation (SD) of scores of the cognitive test.

No significant effect of sitting or standing ($B = -9.47$, $SEb = 15.05$, 95%CI = [−39.30, 20.36], **Table 2**) or condition order ($B = -9.57$, $SEb = 26.39$, 95%CI = [−61.67, 42.54], **Table 2**) on shifting scores was shown. When comparing the mixed models for the effect of standing on shifting, the best model was the model with random intercept and participant as a second level and shifting pre-measurement and age as covariates. The only covariate that was significant was shifting pre-measurement ($B = 0.14$, $SEb = 0.07$, 95% CI = [0.01, 0.28], **Table 2**), indicating that students who scored better at the pre-test, also scored better at the post-tests.

No significant effect of sitting or standing ($B = 0.70$, $SEb = 11.20$, 95%CI = [−21.51, 22.90], **Table 2**) or condition order ($B = 6.61$, $SEb = 14.28$, 95%CI = [−21.61, 34.83], **Table 2**) on inhibition scores was shown. When comparing the mixed models for the effect of standing on inhibition, the best model was the model with random intercept and participant as a second level and age as a covariate. Our analyses revealed that results did not differ with regard to age, gender, and school class.

DISCUSSION

The aim of the current study was to investigate the acute effect of standing at sit-to-stand desk versus sitting behind a traditional desk during class on EF in VET students. It was hypothesized that standing for 40 min would have small positive effects on the EFs updating, inhibition, and shifting. Since the results of our study suggest that 40 min of standing did not significantly change EF among VET students, the hypothesis was not supported.

In line with our results, previous research showed that standing for, respectively, 60 min a day (Bantoft et al., 2016), or regular sit-to-stand transitions during 2 days (Schwartz et al., 2018), or, respectively, 10, 15, 20, and 30 min standing throughout the day for four consecutive weeks (Mullane et al., 2017) had no effects on shifting, short-time memory, WM, selective and sustained attention, information processing speed, and inhibition. In contrast, in the study of Rosenbaum et al. (2017), where students stood while executing a 72 item Stroop test measuring inhibition, improvements in

TABLE 2 | Results of mixed models analyses for effect of standing on updating, shifting, and inhibition scores.

Updating	B	SE b	95% CI
-2LL 1546.875 df 8			
Intercept	2.77	1.94	[−1.06, 6.60]
Condition standing	0.51	0.50	[−0.49, 1.51]
Condition order	−0.34	0.60	[−1.54, 0.85]
Updating pre-measurement	0.86	0.58	**[0.75, 0.97]**
Age	0.03	0.04	[−0.04, 0.10]
Shifting			
-2LL 3223.504 df 7			
Intercept	89.03	36.29	**[17.37, 160.68]**
Condition standing	−9.47	15.05	[−39.30, 20.36]
Condition order	−9.57	26.39	[−61.67, 42.54]
Shifting pre-measurement	0.14	0.07	**[0.01, 0.28]**
Age	1.29	1.52	[−1.72, 4.31]
Inhibition			
-2LL 2678.058 df 6			
Intercept	42.60	17.38	**[8.20, 77.00]**
Condition standing	0.70	11.20	[−21.51, 22.90]
Condition order	6.61	14.28	[−21.61, 34.83]
Age	0.23	0.75	[−1.27, 1.72]

-2LL, −2Log Likelihood; df, degrees of freedom; B = Value; SEb, Standard error; CI. Confidence interval; Significant 95% CI scores are depicted in bold; condition = standing compared to sitting; and condition order = first sit then stand or vice versa.

TABLE 3 | Mean scores of the cognitive tests.

	Sitting pre	Sitting post	Standing pre	Standing post
Updating [M, (SD)]	31.4(5.3)	30.2(6.6)	31.5(5.0)	30.8(6.1)
Shifting [M, (SD)]	163.3(153.6)	135.4(173.1)	157.4(132.5)	120.5(140.0)
Inhibition [M, (SD)]	33.4(79.2)	51.6(92.5)	49.3(90.7)	52.6(92.1)

M, Mean; SD, Standard deviation.

attention were found (Rosenbaum et al., 2017). Furthermore, a 50% reduced school day (Penning et al., 2017), sit-to-stand transitions during 2 days (Mazzoli et al., 2019), and successively 10, 15, 20, and 30 min standing during the whole day (Mullane et al., 2017) also lead to improved attention. As these studies mainly focused on young children or adults (Bantoft et al., 2016; Mullane et al., 2017; Penning et al., 2017; Rosenbaum et al., 2017; Schwartz et al., 2018), the results of those studies may not be generalizable to the population in the current study. An explanation for the fact that we found no effect of short-term standing on the EF of VET students may be that any neurocognitive benefits of standing, responsible for improvements in EF (Duvivier et al., 2013, 2017), might only become apparent after an extended period of time, as the neurological changes as mentioned in the introduction possibly only appear after a longer duration of standing than conducted in the current study. Another explanation may be that the students experienced the CST, which consisted of 5 rounds of testing with 64 stimuli each, as too long. It is thus possible that the length of this test may has affected the results.

The current study has some strengths. One strength is the crossover design, which has the advantage that all participants act as their own control. Furthermore, a crossover design eliminates confounding effects attributable to the characteristics of a specific group (Parienti and Kuss, 2007). Additionally, a strength of the current study is the use of a practice session to reduce the learning effect (Beglinger et al., 2005).

Our study has also some limitations. First, the study was underpowered. Originally, we intended to analyze the study results with a repeated measure ANOVA, but based on advancing insights, we decided that mixed model analysis would be more appropriate since this analysis takes the variance within a participant and the school class in which the participants are in into account. Therefore, we performed a post-hoc power analysis to determine the number of participants needed for this study when utilizing mixed model analysis. This post-hoc power analysis showed that 920 participants were needed to obtain sufficient statistical power. This means that the current study is underpowered, which may have negative consequences for the reliability of the outcomes. However, the current study included many more participants than previous studies in this domain, herewith still adding to the existing knowledge base around the role of standing education for EF. As the study was underpowered for the mixed model analysis executed, we executed additional mixed ANOVA analyses, mixed ANOVA is an extension of RM ANOVA for analyses with multiple independent variables, and the results of these analyses did not differ from the mixed model analysis (see the results in **Supplementary Table S1)** indicating that the results of the mixed model analysis are reliable.

Based on this study's findings, it can be concluded that standing for 40 min does not affect EF in VET students. The results of the current study may be of interest to educational practitioners. Since it is shown that standing once for 40 min does not have an effect on the EF of VET students, it is not useful to let them stand for that duration. However, since previous research has shown that more standing and less sitting are beneficial to health (Duvivier et al., 2013, 2017, 2018), and standing is practical within a classroom and not detrimental to classroom behavior or learning (Sherry et al., 2016), it is recommended that sitting behavior of VET students is reduced by allowing them to stand. Future research could be conducted with enough participants and with a longer standing intervention than applied in the current study. Additionally, the effect of a more intensive PA intervention than short-time standing on EF can be investigated, whereby it is important that the intervention can be realistically implemented in a VET classroom.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://doi.org/10.17026/dans-zmd-jzma.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Research Ethics Committee (cETO) of the Open University (reference U2017/00519/FRO) and the study has been registered in the Dutch Trial Register (NTR6358). Written informed consent to participate in this study was provided by the participants' legal guardian/ next of kin.

AUTHOR CONTRIBUTIONS

RG was responsible for the study design and the funding of the whole Phit2Learn project. PL and IW analyzed the data. PL wrote the first draft of the manuscript, which has been further revised by all the authors. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Effects of Classroom-Based Resistance Training With and Without Cognitive Training on Adolescents' Cognitive Function, On-task Behavior, and Muscular Fitness

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Aim: Participation in classroom physical activity breaks may improve children's cognition, but few studies have involved adolescents. The primary aim of this study was to examine the effects of classroom-based resistance training with and without cognitive training on adolescents' cognitive function.

Methods: Participants were 97 secondary school students (45.4% females, mean age 15.78 ± 0.44). Four-year 10 classes from one school were included in this four-arm cluster randomized controlled trial. Classes were randomly assigned to the following groups: sedentary control with no cognitive training, sedentary with cognitive training, resistance training without cognitive training, and resistance training with cognitive training. Sessions varied in levels of both cognitive demand and resistance training (i.e., high vs. low) and were administered three times per week for 4 weeks (12 sessions). Inhibition, cognitive flexibility, episodic memory, on-task behavior, and muscular fitness were assessed at baseline and post-test. Linear mixed models were used to examine changes within and between groups.

Results: In comparison with the control group, episodic memory improved significantly in the resistance training without cognitive training group (−9.87 units, 95% CI: −17.71 to −2.03, $p = 0.014$, $d = 0.72$). There were no group-by-time effects for inhibition or cognitive flexibility. Classroom activity breaks both with and without cognitive demand improved participants' on-task behavior in comparison with the control and sedentary group. The resistance training programs did not lead to improvements in muscular fitness.

Conclusion: Participation in body weight resistance training without cognitive training led to selective improvements in episodic memory. No training effects were found for inhibition or cognitive flexibility. A longer study period may be necessary to induce improvements in muscular fitness and associated changes in inhibition and cognitive flexibility.

Clinical Trial Registration: https://www.anzctr.org.au/ACTRN12621001341819.aspx, Australian New Zealand Clinical Trials Registry—ACTRN12621001341819.

Keywords: executive function, resistance training, cognition, on-task behavior, cognitive demand

INTRODUCTION

A growing body of evidence suggests a positive association between children's physical activity and their cognitive function. Although the majority of research in this field has been conducted with preschool and primary school-aged populations (Egger et al., 2019; Mavilidi et al., 2020; Schmidt et al., 2020; Bedard et al., 2021), evidence suggests that participation in physical activity can improve cognitive function across school children of different ages. Cognitive functioning exists on a continuum from basic information processing at one end to high levels of executive function at the other (Blair and Raver, 2015). The three core executive functions include inhibition (i.e., the aspect of self-control that involves maintaining focus on relevant aspects of the environment and resisting temptations and not acting impulsively or prematurely), cognitive flexibility (i.e., adjusting to new demands, rules, or priorities), and working memory (i.e., holding information in mind and mentally manipulating it; Diamond, 2013). Similar to working memory, episodic memory is related to pre-frontal and hippocampal brain regions. The development of the episodic memory reflects a change in the capacity to form, store, and retrieve representations binding events to context and is therefore dependent on the regulation of memory processes (Ghetti and Lee, 2011).

Various types of interventions have been shown to foster the development of executive functions, including computer-based trainings, educational programs, and classroom-based physical activity breaks (Diamond and Lee, 2011; Watson et al., 2017; Tomporowski and Pesce, 2019). Of the existing strategies designed to promote executive functions, classroom-based physical activity breaks are perhaps the most attractive for schools because they can provide an important dose of physical activity and enhance student learning (Watson et al., 2017). Compared to sedentary classrooms, participation in short-active classroom breaks (e.g., 5–20 min)can improve students' executive functioning (Graham et al., 2021). In addition, chronic studies examining the longer-term effects of classroom activity breaks have observed improvements in working memory (Schmidt et al., 2020), inhibition (Pesce et al., 2016), and cognitive flexibility (Pesce et al., 2013). Previous studies have largely focused on the quantitative (e.g., exercise duration and intensity) characteristics of physical activity breaks, while the emphasis has now shifted to qualitative (e.g., type of exercise and task complexity) aspects (Pesce, 2012).

Increasing the cognitive demand of a physical activity program is one qualitative strategy to specifically target the development of core executive functions. Increased cognitive demand is thought to intensify cognitive engagement, requiring participants to exert greater cognitive effort in order to perform difficult tasks (Tomporowski et al., 2015). This could be achieved using sequential training, where exercise and cognitive training are undertaken separately or simultaneous or dual-task training, where cognitive training is performed simultaneously with exercise (Tait et al., 2017). It is difficult to draw firm conclusions about the benefits of cognitively demanding physical activity due to the limited number of studies and inconsistent findings (Singh et al., 2019; Leahy et al., 2020). Some studies report that increased cognitive demand has no impact on executive function (Mavilidi et al., 2020; Bedard et al., 2021). Other studies comparing cognitively challenging to non-cognitively challenging physical activity have shown that interventions, such as tag games, team games, or coordinative exercises, have a positive effect on executive functions (Chang et al., 2013; Schmidt et al., 2015; van der Niet et al., 2016). However, these latter studies failed to disentangle the physical and cognitive demands of the interventions. One study in children aged 7–9 years used keywords during games, requiring students to respond by matching the key word to the associated correct movement (Egger et al., 2019). The level of difficulty in the game increased incrementally and required participants to update new information (working memory), inhibit previous responses (inhibition), and shift between the keywords and their associated exercises (cognitive flexibility). Another study delivered 12 games to children aged 4–6, each of which specifically detailed the cognitive requirement (Schmidt et al., 2020). Although increasing the cognitive challenge embedded within a physical activity is one approach to increasing cognitive demand, the practicality of implementing this in a school setting on a regular basis presents several challenges.

Type of physical activity is another qualitative characteristic that requires further exploration. Classroom exercise breaks typically aim for a target intensity rating of moderate-to-vigorous and most studies attempt to achieve these objectives through aerobic exercises (Daly-Smith et al., 2018). Alternatively, resistance training has successfully been used in combination with aerobic exercise to gain improvements in executive functions (So and Kim, 2015), but few studies have examined the effects of resistance training in isolation. Body weight exercise is a scalable form of resistance training that does not require equipment. Evidence suggests that body weight exercise can be used successfully to improve musculoskeletal fitness and general health in adults (Voss et al., 2011), although less is known about the utility of this type of training in adolescent populations (Faigenbaum and Myer, 2010; Kennedy et al., 2018). A meta-analyses of 16 longitudinal datasets indicated resistance training had a positive effect on measures of executive function in adults ($d = 0.39$), while in a separate analysis of the effect of resistance training on working memory was not significant ($d = 0.15$; Landrigan et al., 2019). In a study that compared the effects of three types of physical activity (aerobic, coordination, and strength exercises) on the cognitive performance of children no effect on cognition was found (Van den Berg et al., 2016). All three groups recorded low exercise intensity ratings, which may explain the absence of differential effects between groups and possibly the effects on cognition which contradict previous findings, particularly for aerobic exercise (Van den Berg et al., 2016).

Our study was designed to investigate the impact of body weight resistance training with and without additional cognitive training on participants' cognitive functions, on-task behavior, and muscular fitness. We hypothesized that participants assigned to the *resistance and cognitive training* group would experience larger improvements in cognitive functions than participants in the *resistance training*, *cognitive training*, and *control* groups. We also predicted that participants in the *resistance training* and *cognitive training* groups would experience larger improvements in cognitive function than participants in the control group. We hypothesized that participants in the *resistance and cognitive training* group and the *resistance training* only group would spend more time on task compared to participants in the *cognitive training* and *control* groups. Finally, we hypothesized that participants in both *resistance training* groups would experience improvements in muscular fitness.

MATERIALS AND METHODS

Design

Approval was sought and obtained from the University of Newcastle Human Research Ethics Committee (H-2019-0415), and the Catholic Schools Office in the Maitland-Newcastle Diocese to conduct this study. We conducted a four-arm cluster randomized control trial design to compare the following experimental conditions: sedentary control with no cognitive training (CON), sedentary with cognitive training (SECT), resistance training without cognitive training (RTNC), and resistance training with cognitive training (RTCT). This approach is a non-equivalent groups design with students randomized at the class level due to school timetable constraints. Data were collected at baseline and post-test (4 weeks) for two aspects of executive function (inhibition and cognitive flexibility), episodic memory, on-task behavior, and muscular fitness. An acute rating of perceived exertion of the four conditions (i.e., CON, SECT, RTNC, and RTCT) was recorded before and after each activity break. This study was registered with the Australian New Zealand clinical Trials Registry: ACTRN12621001341819.

Participants

Four high schools located in Maitland, NSW, Australia, were recruited to participate in this study. However, the impact of COVID-19 restrictions and changes to "outside researcher" policy enforced by the schools governing body (The Catholic School Office) reduced the permitted number to one. The school principal and classroom teachers of one school agreed to participate under strict COVID protocols, resulting in 4-year 10 mathematics classes being assigned to the study. To align with school procedures, the intervention would be delivered to the whole class. All students were eligible to participate ($n = 110$), but only students who returned the consent form completed the assessments ($n = 97$, 53 males). Following baseline testing, classes were randomly assigned to one of the four experimental conditions: CON ($n = 23$), SECT ($n = 21$), RTNC ($n = 29$), and RTCT ($n = 24$). See **Figure 1** for the flow diagram of participants.

Procedure

The classroom activity breaks were administered as pre-recorded videos at the start of mathematics lessons. Mathematics was selected to ensure consistency across participants and classes. Each video was designed as a lesson starter, being delivered three times per week, for 4 weeks (12 sessions in total). Prior to the beginning of the study, a 3-h training session was delivered to the participating teachers by the lead author outlining their role in the intervention. The protocol components focused on teacher delivery (i.e., video projection at the beginning of the lesson), motivation techniques for encouraging student participation and management of potential injured students. Classrooms were inspected before the study began to confirm that students could safely complete all tasks. Multimedia displays were checked to ensure that all students could clearly see the screen from the back of the classroom. No alterations were needed for any of the classrooms.

The qualitative focus of the videos was to deliver dual-task challenges that targeted each executive function separately. Each video was presented to the whole class and used a 2-min introduction where students were introduced to the cognitive challenge focus of the day (e.g., inhibition or cognitive flexibility). Each week the level of cognitive demand experienced by the cognitive training groups increased, reflecting a repetitious and challenging intervention. See **Figure 2** for a detailed summary and example of the intervention components per condition.

The video progressed with exercises to target muscular strength and used a Tabata format of 20 s work/10 s rest × 8 sets, with a total workout time of 4 min. To increase the cognitive training and maintain engagement, the 20 s work phase was split into 4 × 5 s exercises. Students in the cognitive training groups were required to make 32 decisions per session.

Each condition performed the following activities and cognitive tasks:

- In the CON group, students enter the classroom with normal practice. No classwork was completed, rather students completed administration activities, e.g., roll marking and homework checking for 6–8 min.
- The SECT group would respond to the video stimulus in their sedentary position by selecting an image on the response wheel on their desk in front of them.
- In the RTNC group, the cognitive demand was removed as students simply copied the set of resistance training exercises shown on the intervention video.
- The RTCT group would respond to the question on the video stimulus by performing the associated resistance training exercise (e.g., one session totals 32 × 5 s of resistance training activities).

All exercises were performed at the desk and included table push-ups, chair triceps dips, and alternate lunges and squats. Isometric holds were also incorporated into the muscular fitness work out offering variety to students and a unique approach to resistance training in limited space. The two resistance training groups (RTNC and the RTCT) performed the same body weight exercises. The cognitive activities were also the same in the cognitive training groups (RTCT and RTNC).

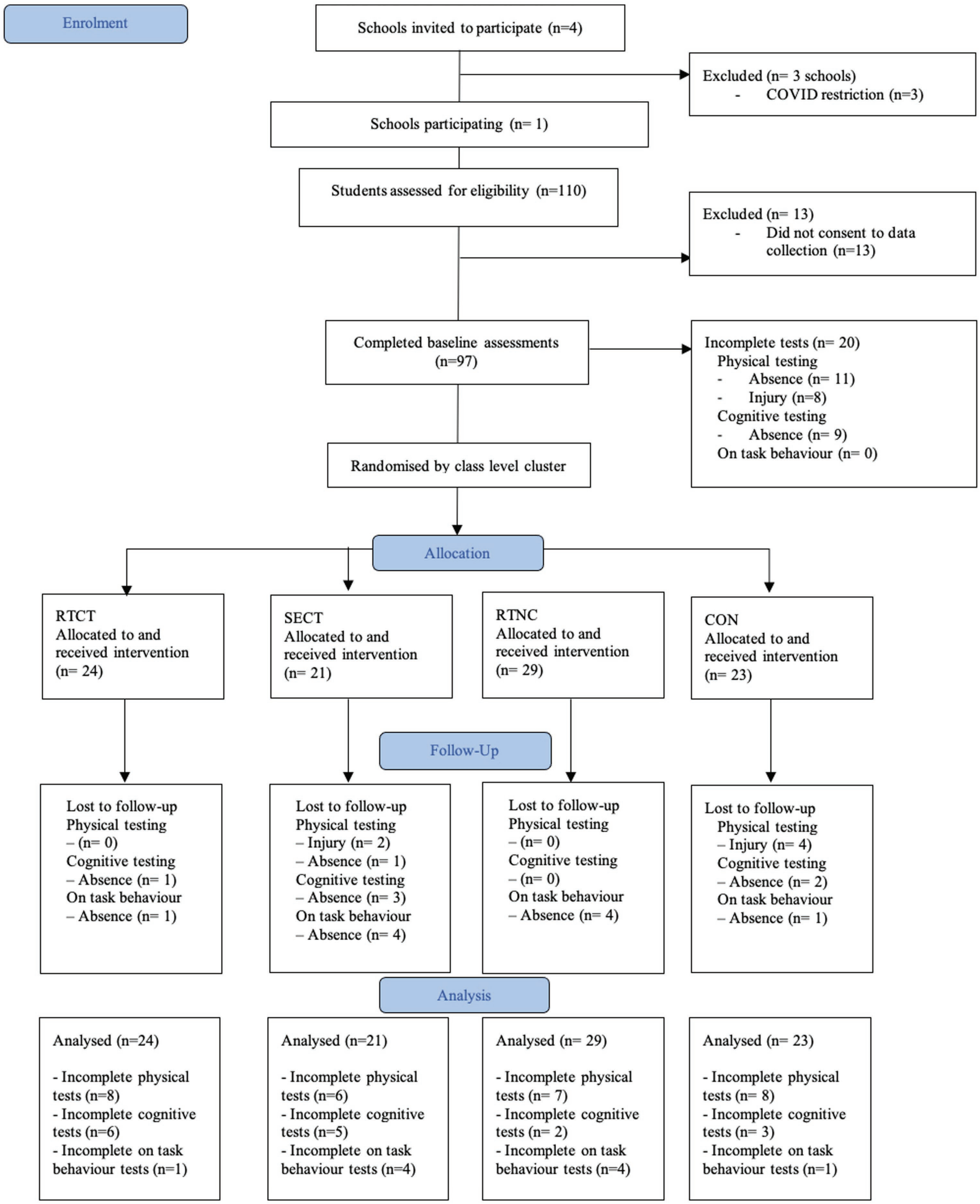
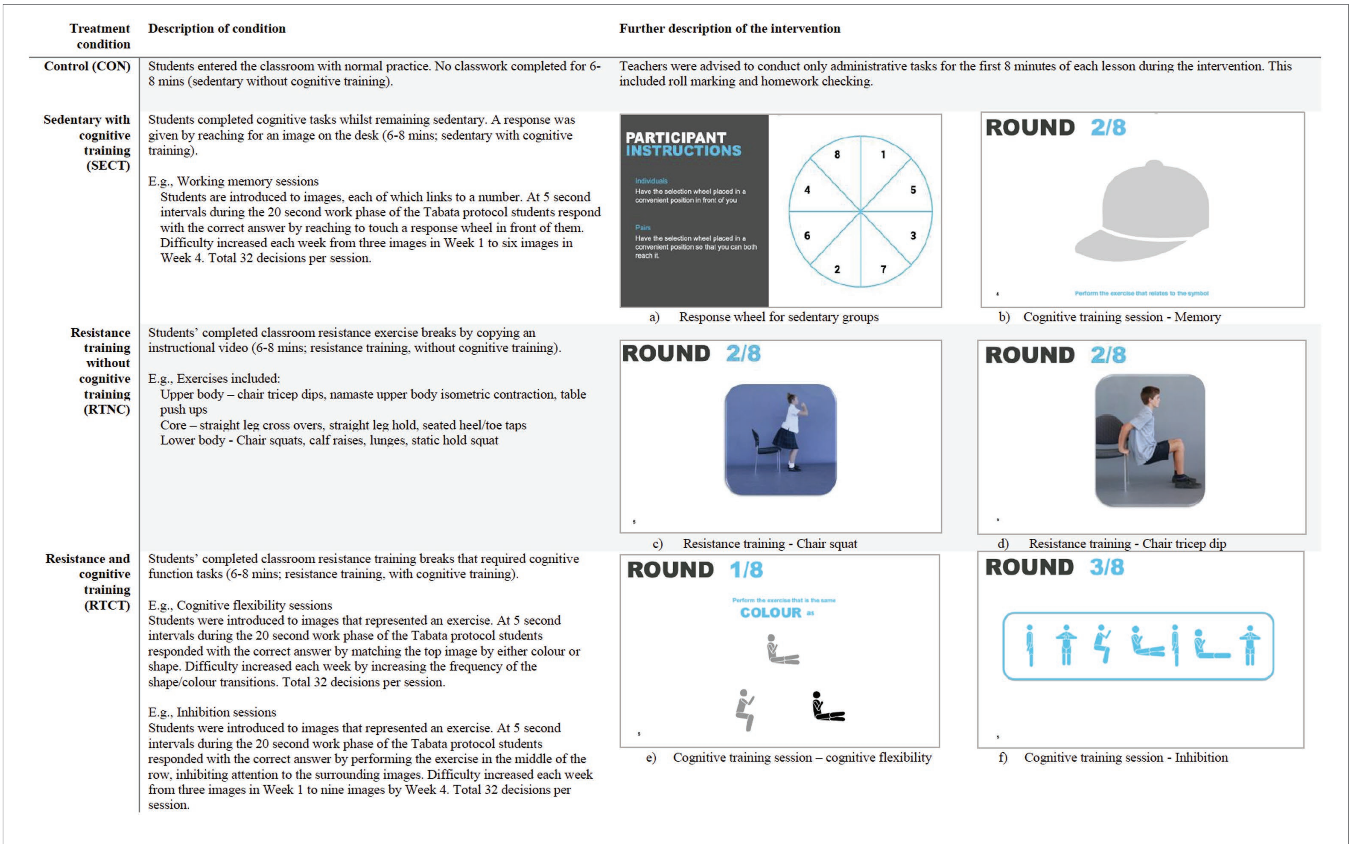


FIGURE 1 | Consort flow diagram of participants.



Treatment condition	Description of condition	Further description of the intervention
Control (CON)	Students entered the classroom with normal practice. No classwork completed for 6-8 mins (sedentary without cognitive training).	Teachers were advised to conduct only administrative tasks for the first 8 minutes of each lesson during the intervention. This included roll marking and homework checking.
Sedentary with cognitive training (SECT)	Students completed cognitive tasks whilst remaining sedentary. A response was given by reaching for an image on the desk (6-8 mins; sedentary with cognitive training). E.g., Working memory sessions Students are introduced to images, each of which links to a number. At 5 second intervals during the 20 second work phase of the Tabata protocol students respond with the correct answer by reaching to touch a response wheel in front of them. Difficulty increased each week from three images in Week 1 to six images in Week 4. Total 32 decisions per session.	a) Response wheel for sedentary groups b) Cognitive training session - Memory
Resistance training without cognitive training (RTNC)	Students' completed classroom resistance exercise breaks by copying an instructional video (6-8 mins; resistance training, without cognitive training). E.g., Exercises included: Upper body – chair tricep dips, namaste upper body isometric contraction, table push ups Core – straight leg cross overs, straight leg hold, seated heel/toe taps Lower body - Chair squats, calf raises, lunges, static hold squat	c) Resistance training - Chair squat d) Resistance training - Chair tricep dip
Resistance and cognitive training (RTCT)	Students' completed classroom resistance training breaks that required cognitive function tasks (6-8 mins; resistance training, with cognitive training). E.g., Cognitive flexibility sessions Students were introduced to images that represented an exercise. At 5 second intervals during the 20 second work phase of the Tabata protocol students responded with the correct answer by matching the top image by either colour or shape. Difficulty increased each week by increasing the frequency of the shape/colour transitions. Total 32 decisions per session. E.g., Inhibition sessions Students were introduced to images that represented an exercise. At 5 second intervals during the 20 second work phase of the Tabata protocol students responded with the correct answer by performing the exercise in the middle of the row, inhibiting attention to the surrounding images. Difficulty increased each week from three images in Week 1 to nine images by Week 4. Total 32 decisions per session.	e) Cognitive training session – cognitive flexibility f) Cognitive training session - Inhibition

FIGURE 2 | Outline of intervention group activities.

Measures

The collection of baseline data occurred 1 week prior to the beginning of the intervention. On-task behavior was assessed in the first two sessions of the daily school timetable during mathematics lessons. On a separate day, students were assessed for muscular fitness, executive function, and episodic memory. Research assistants were not blinded to the experimental conditions at post-test.

Cognitive Function

Inhibition and cognitive flexibility were assessed using executive function tests provided in the National Institute of Health Toolbox Cognition Battery (Gershon et al., 2013). The measures have acceptable test–retest reliability (ICC = 0.91 and ICC = 0.92, respectively; Bauer and Zelazo, 2013). Each of the tests was administered on an iPad using version 12.4.5 or later. Students sat individually during the test and watched the instruction video, designed by the research team, prior to commencement. The Toolbox Flanker Inhibitory Control and Attention Test Ages 12+ was administered first. The test required the participant to focus on a given stimulus while inhibiting attention to flanking stimuli (i.e., arrows) on both sides of the central target stimulus. In one condition, the middle stimulus points in the same direction as the "flankers" (congruent), and in the other condition, the middle stimulus points in the opposite direction as the flankers (incongruent). The second test in the battery was the Toolbox Dimensional Change Card Sort Test Ages 12+. This measure of cognitive flexibility displays two target pictures on the screen that vary along two dimensions, i.e., shape and color. Participants received a simultaneous verbal and visual cue which required them to match a series of bivalent test pictures (e.g., yellow balls and blue trucks) to the target pictures, first according to one dimension (e.g., color) and then, after a number of trials, according to the other dimension (e.g., shape). A 2-vector scoring method is employed for the first two tests that uses accuracy and reaction time, where each of these "vectors" contribute equally to the final calculation of the uncorrected standard score.

A third test of episodic memory adapted for use with early adolescents was added to the battery (Bauer et al., 2013). Episodic memory processes require the use of some prefrontal areas of the brain that are also associated with working memory (Van der Linden et al., 2000). The Toolbox Picture Sequence Memory Test Ages 8+ involves sequences of pictured objects and activities of the theme "playing in the park." The pictures are presented in a specific order which the participant must attempt to reproduce. A sequence of four pictures was used as a practice and on successful completion participants could begin the test. The test involved three trials with six pictures, 15 pictures, and 18 pictures. The number of adjacent pairs placed correctly provides a representation of the participant's estimated ability in this episodic memory task. For all three tasks, the uncorrected standard scores, with normative mean equal to 100 and 15 as SD, provided an accurate gauge of improvement or decline from Time 1 to Time 2, representing an absolute change in the level of performance since the previous assessment (National Institutes of Health, 2021).

On-task Behavior

On-task behavior observations were conducted using the momentary time sampling procedure adapted from the Behavior Observation of Students in Schools and the Applied Behavior Analysis for Teachers (Alberto and Troutman, 2006). On-task behavior includes times when a child is actively engaged in an academic activity (e.g., reading, writing, discussing assigned work, or performing the designated task) or passively engaged (e.g., sitting quietly listening to the teacher but is not actively participating in a set task). Off-task behavior is related to behavior not associated with the task such as off-task motor (e.g., walking around the classroom), off-task verbal (e.g., talking), and off-task passive (e.g., staring out the window). Two research assistants (blinded at baseline) entered the classroom with the class, using the first 10 min to determine student attendance for the six individuals who had been selected at random using random statistical number tables. In the case where a student was absent at baseline, they were replaced with the next student on the list. The same individuals were measured at baseline and post-test. After 10 min, which accounts for time to complete the intervention at post-test, students were observed at 15-s intervals on a rotational basis over a 30-min period. Synchronized stopwatches indicated to the research assistants the time points at which to code participants as on task active, on-task passive, off-task motor, off-task passive, or off-task verbal. Final scores were reported as a percentage of time spent on-task or off-task. Our research team has previously established the inter-rater reliability for the same on-task behavior assessment (ICC = 0.84; Mavilidi et al., 2021).

Muscular Fitness

Muscular fitness testing began with an introductory video, designed by the research team, which was shown to each group upon entering the testing room. During fitness testing, a rule of three was used as a protocol to warm up for fitness tests, e.g., three push-ups, three squats, or 3 s plank hold for familiarity. Three trained research assistants were each assigned to a fitness test to ensure consistency of testing protocols and students progressed between tests in the order outlined. Muscular fitness outcomes were assessed for three regions of the body—*upper body* was assessed using the 90° push-up test (Meredith and Welk, 2010). Participants started in the push-up position (males on toes and females on knees) with their hands and arms at shoulder distance apart. Keeping their back straight, participants then lowered themselves to the ground until there was 90° angle at the elbows, with upper arms parallel to the floor (Meredith and Welk, 2010). The push-ups were completed in time to a metronome set at 40 beats per minute with one complete push-up every 3 s. The participant continued until they could do no more in rhythm (e.g., did not complete the last three efforts in rhythm). This test was found to have acceptable test–retest reliability in adolescents over a period of 7 days (ICC = 0.90; Lubans et al., 2011). *Lower body* muscular fitness was assessed using the 30 s maximal repetition squat to chair test that has a test–retest coefficient of (ICC = 0.73; Bohannon, 1995). Although commonly used in older adults, this test was selected over the standing long jump to examine muscular strength rather than explosive power which is not a focus during the resistance training exercises. The 30 s sit to stand test on a bench height of 44 cm utilizes standardized protocol to assess the adolescent population (Różańska-Kirschke et al., 2006). *Core* strength was assessed using the plank hold test that required students to start with the upper body supported off the ground by the elbows and forearms, and the legs straight with the weight taken by the toes. The test is over when the subject is unable to hold their back straight and the hip is lowered to the ground. This test has acceptable test–retest reliability (ICC = 0.63; Boyer et al., 2013).

Rating of Perceived Exertion

A uniquely designed smartphone application was downloaded by participants and used to collect *ratings of perceived exertion* (RPE) scores before and after each session. The app displayed Borg's modified CR10 RPE scale, represented with scores of 0, nothing at all to 10, very hard (Williams, 2017). Students reported their perceived physical exertion after completing each intervention video. Reliability and validity of the Borg scale has been reported by Lamb (Lamb, 1996) to be feasible in pre-adolescents.

Statistical Analysis

Outcomes were analyzed using linear mixed models in IBM SPSS Statistics, version 23.0 (SPSS Inc., IBM Company Armonk, NY, United States). This statistical approach is consistent with the intention-to-treat principle because missing data, assumed to be missing at random, are modeled using a likelihood-based analysis (Mallinckrodt et al., 2004; White et al., 2012). Mixed models were used to assess the impact of group, time, and the group-by-time interaction, using random intercepts to account for the clustered nature of the data (i.e., students nested in classes). Alpha levels were set at $p < 0.05$ and Cohen's d was calculated to provide a measure of effect size. Outliers that were >3 *SD* from the mean were identified as strong indications of implausible post-test data and were excluded from the analysis.

RESULTS

Intervention completion rates per group were: CON 83%, SECT 92%, RTNC 83%, and RTCT 92%. Reasons for incompletion were public holidays (four sessions) and whole school events (two sessions).

Participants

Participants' mean age was 15.78 ± 0.44, and all demographics are presented in **Table 1**. There were no significant differences between groups, although gender imbalance can be noted in the SECT and RTCT groups. Most of the participants reported having an Australian cultural background (94%), and 6% of students identified as Aboriginal or Torres Strait Islander. A summary of findings per variable is portrayed in **Tables 2**, **3**.

Cognitive Function

No significant group-by-time effects were observed for inhibition or cognitive flexibility. A significant group-by-time effect was observed for participants' episodic memory between the CON and RTNC groups (−9.87 units, 95% CI: −17.71 to −2.03, $p = 0.014$, $d = 0.72$).

On-task Behavior

Significant group-by-time effects were observed for participants' on-task behavior between the CON and SECT groups (mean change = 28, 95% CI: 0.48 to 56.03, $p = 0.046$, $d = 0.84$), between CON and RTCT (mean change = −45.26, 95% CI: −71.50 to −19.03, $p = 0.001$, $d = 1.23$), between SECT and RTNC (mean change = −36.44, 95% CI: −65.26 to −7.61, $p = 0.015$, $d = 1.48$), between SECT and RTCT (mean change = −73.51, 95% CI: −101.29 to −45.74, $p = 0.001$, $d = 2.52$), and RTNC and RTCT (mean change = −37.09, 95% CI: −64.42 to −9.75, $p = 0.009$, $d = 1.34$).

Muscular Fitness

Significant group-by-time effects were shown for participants' upper body muscular fitness as measured using the 90° push-up test, with the SECT group outperforming the RTNC group (mean change = 3.37 repetitions, 95% CI: 0.20–6.54, $p = 0.038$, $d = 0.73$). In addition, the CON group outperformed the RTNC group in core muscular fitness as measured using the plank hold test (mean change = 21.90 s, 95% CI: 1.31–42.50, $p = 0.037$, $d = 0.90$). There were no significant findings for lower body muscular endurance.

Rate of Perceived Exertion

RPE for the sedentary groups of CON ($M = 1.3$) and SECT ($M = 1.7$) reflect scores on the scale that indicate very light to light intensity of physical activity (**Table 4**). RPE scores for RTNC ($M = 2.25$) and RTCT ($M = 2.16$) indicate an exertion rate between light and moderate physical activity.

DISCUSSION

This study was designed to investigate the impact of classroom activity breaks involving body weight resistance exercise with and without additional cognitive demand on adolescents' cognitive function, on-task behavior, and muscular fitness. We hypothesized that participants assigned to the RTCT group would experience larger improvements in cognitive functions than participants in the RTNC, SECT, and CON groups. We also predicted that participants in the RTNC and SECT groups would experience larger improvements in cognitive function than participants in the CON group. We hypothesized that participants in the RTCT and the RTNC group would spend more time on task compared to participants in the SECT and CON groups. Finally, we hypothesized that participants in both resistance training groups would experience improvements in muscular fitness. The resistance training group without cognitive demand significantly improved their episodic memory in comparison with the control group. However, no group-by-time effects were observed for inhibition or cognitive flexibility. Both resistance training groups improved their on-task behavior in comparison with the control group.

Classroom-based resistance training with and without cognitive training did not lead to improvements in adolescents' inhibition and cognitive flexibility. Our findings align with a meta-analysis that reported chronic physical exercise to have a non-significant effect ($d = 0.14$) on executive functions (Verburgh et al., 2014). Our findings align with a meta-analysis that reported chronic physical exercise to have a non-significant effect ($d = 0.14$) on executive functions (Verburgh et al., 2014). More recently, a meta-analysis, focused on adolescents and young adults found conflicting results. In the analysis by Haverkamp et al. (2020), chronic interventions were shown to improve cognitive flexibility (ES = 0.19) and attention (ES = 0.50), with improvements to working memory also evident (Haverkamp et al., 2020). Chronic exercise programs typically include multiple training sessions per week for a longer period (typically spanning between 6 and 30 weeks). Largely, most chronic studies are conducted outside of the classroom or if inside the classroom, the intervention is run as an active classroom, with students simultaneously moving and learning, rather than during an active break (Kamijo

TABLE 1 | Participant demographics.

Characteristics	Control group	SECT	RTNC	RTCT	Total
Participants	(*n* = 23)	(*n* = 21)	(*n* = 29)	(*n* = 24)	(*n* = 97)
Age (years)					
Mean (standard deviation)	15.78 (0.42)	15.65 (0.49)	15.90 (0.41)	15.81 (0.40)	15.78 (0.44)
Sex, *n* (%)					
Male	15 (65)	8 (38)	12 (41)	18 (75)	53 (54.6)
Female	8 (35)	13 (62)	17 (59)	6 (25)	44 (45.4)
Aboriginal or Torres Strait Islander, *n* (%)					
Yes, *n* (%)	3 (13)	2 (10)	0 (0)	1 (4)	6 (6)
No, *n* (%)	20 (87)	19 (90)	29 (100)	23 (96)	91 (94)

CON, control condition; SECT, sedentary with cognitive training; RTNC, resistance training without cognitive training; and RTCT, resistance and cognitive training.

TABLE 2 | Summary of outcome measures.

Variable	Control group		SECT		RTNC		RTCT	
	Baseline Mean (95% CI)	Post-test Mean (95% CI)	Baseline Mean (95% CI)	Post-test Mean (95% CI)	Baseline Mean (95% CI)	Post-test Mean (95% CI)	Baseline Mean (95% CI)	Post-test mean (95% CI)
Cognitive function								
Flanker test (inhibition)	103.18 (99.73, 106.63)	104.15 (100.58, 107.72)	106.55 (102.98, 110.11)	109.44 (105.73, 113.15)	105.79 (102.74, 108.85)	108.07 (105.06, 111.07)	107.90 (104.28, 111.52)	112.00 (108.25, 115.66)
Card sort change test (cognitive flexibility)	103.91 (98.85, 108.97)	103.65 (98.46, 108.84)	104.09 (98.87, 109.31)	106.21 (100.68, 111.73)	111.36 (106.90, 115.82)	110.21 (105.80, 114.61)	111.20 (105.90, 116.50)	113.99 (108.59, 119.39)
Picture sequence memory test (episodic memory)	106.41 (100.67, 112.15)	99.41 (93.46, 105.35)	108.93 (102.95, 114.91)	105.13 (98.77, 111.49)	108.82 (103.69, 113.95)	111.69 (106.69, 116.69)	114.35 (108.33, 120.367)	113.94 (107.68, 120.20)
On-task behavior								
On-task behavior	61.67 (46.54, 76.80)	45.95 (30.23, 61.68)	63.63 (48.51, 78.77)	19.66 (1.47, 37.86)	65.15 (50.08, 80.21)	57.61 (40.42, 74.79)	50.42 (35.29, 65.55)	79.97 (64.24, 95.70)
Off-task behavior	38.33 (23.27, 53.39)	54.05 (38.40, 69.71)	36.37 (21.24, 51.50)	80.34 (62.14, 98.53)	34.83 (19.83, 49.83)	42.38 (25.27, 59.50)	49.58 (34.52, 64.64)	20.04 (4.38, 35.69)
Muscular fitness								
90° Push up test	14.10 (10.57, 17.63)	15.54 (11.97, 19.10)	17.06 (13.05, 21.07)	21.72 (17.67, 25.77)	16.23 (13.04, 19.41)	17.52 (14.36, 20.69)	15.66 (11.96, 19.36)	17.47 (13.83, 21.10)
Squat to chair test	18.91 (16.59, 21.23)	23.28 (20.96, 25.60)	21.94 (19.41, 24.47)	24.60 (22.02, 27.17)	21.91 (19.84, 23.97)	24.47 (22.43, 26.50)	19.99 (17.67, 22.30)	24.14 (21.89, 26.39)
Plank hold test	78.06 (59.32, 96.79)	83.38 (63.90, 102.85)	85.18 (64.10, 106.26)	78.37 (56.99, 99.76)	81.56 (64.68, 98.44)	64.98 (48.26, 81.69)	85.41 (66.45, 104.37)	87.48 (68.75, 106.22)

CON, control condition; SECT, sedentary with cognitive training, RTNC, resistance training without cognitive training, and RTCT, resistance training with cognitive training.

et al., 2011; van der Niet et al., 2016). Interestingly, another study reporting a significant positive effect of chronic exercise on executive functions was a study of overweight children. Compared with adolescents of normal weight, obese individuals present lower cognitive indices (Smith et al., 2011) particularly in tests of executive function (Verburgh et al., 2014). Interventions designed to improve executive functions will find the greatest improvements in participants with initially poorer executive functions (Diamond and Lee, 2011) emphasizing the need for future research to focus investigations on a healthy adolescent population.

Effects were observed for episodic memory, as evidenced by significant improvements in the resistance training with no cognitive training group compared to the control group. Episodic memory relies on a set of mental processes involving encoding, storage, and retrieval of internal or external information (Squire, 2004). Research has demonstrated that prefrontal areas of the brain involved in working memory are also involved in a wide range of tasks including episodic memory (Van der Linden et al., 2000). To the best of our knowledge, this is the first study of its kind to examine the effects of resistance training on episodic memory in adolescents. Chronic training studies involved in a systematic review did not provide compelling evidence for a positive effect of resistance exercise on memory function and of the studies included, only one worked with a population younger than 50 years of age (Loprinzi et al., 2018). One example of the effectiveness of body weight resistance training was evidenced in a 52-week program delivered to a healthy older adult population (Best et al., 2015). Improvements to episodic memory function at the 1-year post intervention period were achieved but only by the group that engaged in twice-weekly resistance training sessions as opposed to once-weekly resistance training. It may be, that for the adolescent population a shorter (4 week) and more condensed (three times per week) exposure to resistance training promotes short-term improvements to episodic memory and longer interventions would be required to explore sustained improvements.

Although we did not find evidence for the chronic effect of resistance training on executive functions, improvements in on-task behavior reflect a potential acute effect for inhibition. Our measure of on-task behavior reflects an individual's ability to ignore distractions and maintain focus on the intended task, which is a key characteristic of inhibition (Diamond, 2013). The effects for on-task behavior aligned with our hypotheses. While both resistance training groups improved, the resistance training with cognitive training group significantly outperformed all other groups. On-task behavior has been shown to contribute to academic outcomes and is displayed as behaviors that may promote learning in the classroom, e.g., concentrating on tasks assigned by the teacher (Riley et al., 2016).

TABLE 3 | Adjusted difference between groups (post-test—baseline).

Variable	CON—SECT			CON—RTNC			CON—RTCT			SECT—RTNC			SECT—RTCT			RTNC—RTCT		
	Mean change (95% CI)	***p***	**Cohen's *d***	**Mean change (95% CI)**	***p***	**Cohen's *d***	**Mean change (95% CI)**	***p***	**Cohen's *d***	**Mean change (95% CI)**	***p***	**Cohen's *d***	**Mean change (95% CI)**	***p***	**Cohen's *d***	**Mean change (95% CI)**	***p***	**Cohen's *d***
Cognitive function																		
Flanker test (inhibition)	−1.93 (−5.86, 2.00)	0.332	0.49	−1.31 (−4.81, 2.19)	0.458	0.06	−3.09 (−6.93, 0.75)	0.113	0.43	0.62 (−3.04, 4.28)	0.737	0.38	−1.16 (−5.15, 2.83)	0.563	0.03	−1.78 (−5.34, 1.78)	0.322	0.33
Card sort change test (cognitive flexibility)	−2.27 (−7.54, 2.81)	0.365	0.00	0.90 (−3.55, 5.34)	0.688	0.20	−3.04 (−7.92, 1.83)	0.217	0.39	3.27 (−1.58, 8.11)	0.183	0.17	−0.68 (−5.92, 4.56)	0.797	0.34	−3.94 (−8.46, 0.58)	0.086	0.66
Picture sequence memory test (episodic memory)	−3.20 (−11.99, 5.58)	0.470	0.18	−9.87 (−17.71, −2.03)	**0.014**	0.72	−6.60 (−15.21, 2.02)	0.132	0.35	−6.67 (−14.92, 1.59)	0.112	0.56	−3.39 (−12.39, 5.61)	0.456	0.24	3.28 (−4.80, 11.36)	0.422	0.26
On-task behavior																		
On-task behavior	28.25 (0.48, 56.03)	**0.046**	0.84	−8.18 (−35.52, 19.16)	0.548	0.24	−45.26 (−71.50, −19.03)	**0.001**	1.23	−36.44 (−65.26, −7.61)	**0.015**	1.48	−73.51 (−101.29, −45.74)	**<0.001**	2.52	−37.09 (−64.42, −9.75)	**0.009**	1.34
Off-task behavior	−30.18 (−57.92, 2.44)	**0.034**	0.84	8.17 (−19.13, 35.47)	0.548	0.24	45.26 (19.05, 71.47)	**0.001**	1.23	38.35 (9.57, 67.13)	**0.010**	1.48	75.44 (47.71, 103.19)	**<0.001**	2.53	37.09 (9.79, 64.40)	**0.009**	1.34
Muscular fitness																		
90° Push up test	−3.23 (−6.65, 0.20)	0.064	0.51	0.14 (−3.00, 3.30)	0.931	0.26	−0.37 (−3.73, 2.99)	0.826	0.06	3.37 (0.20, 6.54)	**0.038**	0.73	32.85 (−0.53, 6.24)	0.097	0.39	−0.51 (−3.61, 2.59)	0.744	0.26
Squat to chair test	1.71 (−1.36, 4.79)	0.269	0.46	1.80 (−1.04, 4.65)	0.210	0.33	0.22 (−2.75, 3.18)	0.884	0.06	0.09 (−2.80, 2.98)	0.950	0.40	−1.50 (−4.50, 1.51)	0.324	0.37	−1.59 (−4.36, 1.19)	0.258	0.34
Plank hold test	12.12 (−10.44, 34.68)	0.288	0.59	21.90 (1.31, 42.50)	**0.037**	0.90	3.24 (−18.30, 24.78)	0.765	0.11	0.78 (−11.37, 30.93)	0.359	0.57	−8.88 (−30.96, 13.20)	0.359	0.26	−18.66 (−38.72, 1.39)	0.068	0.62

CON, control condition; SECT, sedentary with cognitive training; RTNC, resistance training without cognitive training; and RTCT, resistance training with cognitive training. Significant values have been marked as bold. Four outliers (three outliers in tests of cognitive flexibility, one outliers in tests of inhibition) were outside three standard deviations of the mean and were removed from the data set.

TABLE 4 | Rate of perceived exertion scores measured using Borg's modified CR10 RPE scale.

Characteristics	Control group	SECT	RTNC	RTCT	Total
RPE scores					
Mean (standard deviation)	1.3 (2.58)	1.7 (1.25)	2.25 (2.11)	2.16 (2.00)	1.9 (1.89)

CON, control condition; SECT, sedentary with cognitive training; RTNC, resistance training without cognitive training; and RTCT, resistance training with cognitive training. Scores range from 0 = nothing at all, to 10 = very hard.

The positive effect of classroom activity breaks on children's on-task behavior has been well established. For example, results of a meta-analyses showed classroom-based physical activity have a positive effect on improving students' on-task behavior in the classroom ($d = 0.60$; Watson et al., 2017). Previous research from those involved in this study report similar improvements in on-task behavior evoked by physical activity breaks (Mavilidi et al., 2020, 2021). In particular, the Burn 2 Learn study (Leahy et al., 2019), conducted with senior school students aged 16–18 reported students being more actively engaged during classroom-based lessons after participation in HIIT sessions ($p = 0.042$, $d = 0.43$; Mavilidi et al., 2021). Students in the Burn 2 Learn program participated in two high-intensity interval training (HIIT) sessions per week that were delivered using a specifically designed phone application (Kennedy et al., 2020; Mavilidi et al., 2021). Similar to the current study, the Burn 2 Learn sessions included a high percentage of resistance training exercises (combined with aerobic activity). It is important to note the majority of Burn 2 Learn sessions were not explicitly designed to include additional demand (although the intervention did include an option for cognitively demanding high intensity exercise known as Brain HIIT). Consistent with our findings, the Burn 2 Learn program did not have a chronic effect on participants' executive functions (i.e., working memory and inhibition) at the primary end-point of the study (6 months; Lubans et al., 2021).

Contrary to our hypotheses, the sedentary groups outperformed the resistance training groups in terms of changes in muscular fitness. As noted by Stricker et al. in their recent Clinical Report on Resistance Training for Children and Adolescents, strength gains can be achieved with different types of resistance training (including body weight exercises) for a minimum duration of 8 weeks with a frequency of 2–3 times per week. While studies involving shorter durations (e.g., 6 weeks) have reported improvements in adolescents' muscular fitness, these studies have involved higher levels of training intensity (Gorostiaga et al., 1999) or an increased frequency of sessions (Myer et al., 2005). As such, the training load prescribed in the current study was insufficient to induce gains in muscular fitness in the study population.

Strengths and Limitations

Overall, this study offers a unique contribution to the field by combining resistance training and cognitive training using a Latin square study design. The four groups were required to separate the effects often seen when examining physical activity delivered with and without cognitive demand. To our knowledge, this is the first study to examine the effects of cognitively engaging physical activity with adolescents.

Despite these study strengths, there are some limitations that should be noted. First, we were unable to conduct regular face-to-face fidelity checks due to COVID-19 restrictions. The infrequent fidelity checks might also have impacted the RPE scores that showed the resistance training exercises did not meet the target of moderate-to-vigorous intensity. Second, participants were randomized by class to the four study groups. Future studies are encouraged to include a larger number of classes (i.e., clusters) or randomize students at the individual levels. Third, we did not include a measure of working memory in our battery of cognitive tests. We were unable to include the working memory measure from the NIH Toolbox as it requires the use of Bluetooth keyboards connected with devices, which was problematic in a small classroom setting. Fourth, without a measure of height and weight to determine body composition we were unable to determine if weight status moderated the effect of the intervention. Finally, we assessed participants' muscular fitness using three field-based tests (i.e., push-up, sit-to-stand, and plank tests). These tests were selected based on their existing reliability and validity and their alignment with our body weight resistance training protocols. It is important to note that these measures assess muscular endurance not strength, and test performance is influenced by participants' motivation. For example, it was noted by the assessment team that a number of students dropped out of the plank hold test due to boredom rather than fatigue. The push-up test had its own limitations as students regularly could not complete a single push-up making small improvements difficult to calculate.

CONCLUSION

In conclusion, our findings suggest that resistance training without cognitive training can improve adolescents' episodic memory but not inhibition and cognitive flexibility. Alternatively, activity breaks both with and without cognitive demand improved adolescents' on-task behavior. This finding is particularly important as on-task behavior is a key predictor of academic success (Mahar et al., 2006). Using resistance training as a classroom-based exercise break is novel and has been underutilized. We are wary of making definitive statements based on our initial research findings, but we believe evidence from the current study promotes further use of resistance training breaks in the classroom if particular attention is paid to the intensity of the exercise.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Newcastle Human Research Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s) for the publication of any identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

DL, MM, SV, DB, CH, and NR secured funding for the project. KR, DL, MM, and NR designed the intervention, designed and contributed to the administration of the cognitive and muscular fitness assessments, and were responsible for drafting the manuscript. KR and NR designed the RPE measurement protocol and phone application and were responsible for project management, school recruitment, and data collection. DL guided the statistical analysis. All authors contributed intellectually to the study design and research methodology. All authors contributed to the article and approved the submitted version.

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The Role of Physical Activity Behavior in the Mental Wellbeing of Vocational Education and Training Students: The PHIT2LEARN Study

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A positive association has been found between physical activity (PA) and student mental wellbeing (SMW). This association has been mainly explored in secondary school and university students. Studies in vocational education and training (VET) are lacking, while VET students could especially benefit from exploring this association since research shows that VET students, who often come from low socioeconomic status (SES) households, are prone to low SMW. Low SMW can result in higher school dropout rates and long-term negative effects, such as unemployment, social exclusion, and impoverishment. The aim of the current study was to explore the association between total PA and different physical activity behaviors {PABs, i.e., moderate to vigorous physical activity (MVPA), light physical activity (LPA), and sedentary behavior (SB)}, and SMW in the VET setting. In this cross-sectional observational study, students wore an ActivPAL3^{TM} accelerometer for 7 consecutive days to measure PAB. SMW was assessed using the Center for Epidemiologic Studies Depression Scale (CES-D) and the Rosenberg self-esteem questionnaire (RSE). Complete data for the analyses were obtained from 85 students. Multiple regression analyses showed a significant positive association between total PA and self-esteem and a significant negative association between total PA and depressive symptoms. Taking different PA intensities into account, there was a significant positive association between LPA and self-esteem and a significant negative association between LPA and depressive symptoms. No significant associations were found between MVPA and the outcome measures, although the associations were aligned with the findings for LPA. High levels of SB were significantly associated with low self-esteem; however, the association between SB and depressive symptoms was not significant. The significant positive associations between LPA and SMW and the negative association between SB and self-esteem indicate that decreasing SB and increasing LPA could contribute to improve SMW. Future research should determine if these are causal relationships.

Keywords: vocational education and training, physical activity behavior, sedentary behavior, student mental wellbeing, self-esteem, depressive symptoms, observational design

INTRODUCTION

Student mental wellbeing (SMW) is receiving increasing research attention (Dopmeijer et al., 2018; Doornwaard et al., 2021; UNICEF, 2021; Van der Maden et al., 2021). SMW is defined as: "a sustainable state characterized by predominantly positive feelings and attitude, positive relationships at school, resilience, self-optimization, and a high level of satisfaction with learning experiences" (Noble et al., 2008, p. 30). SMW encompasses among others, the absence of depressive symptoms and having high levels of self-esteem (Noble et al., 2008; Schoemaker et al., 2019). Developing depression is a major problem among students, the point prevalence of increased depressive symptoms is globally 37% for 10–19 year olds (Shorey et al., 2021). While prevalence rates for low self-esteem are scarcer, Nguyen et al. (2019) measured self-esteem using the Rosenberg self-esteem questionnaire (RSE) and found that 19% of secondary school students in their sample had low self-esteem (i.e., a score lower than 15). Having low SMW is associated with less academic success and significantly higher school dropout rates, which can eventually result in unemployment, social exclusion, and impoverishment (Andrews and Wilding, 2004; Amholt et al., 2020; European Commission, 2020). It has been suggested that SMW can be improved by increasing physical activity behavior (PAB; Hoare et al., 2016; Korczak et al., 2017). While several studies in primary school, secondary school, and university students indicate that higher PAB is associated with higher SMW (Hoare et al., 2016; Korczak et al., 2017; Zayed et al., 2018; Tamminen et al., 2020), within the vocational education and training (VET) setting this association has not yet been established.

Physical activity behavior is defined by Caspersen et al. (1985) as "any bodily movement produced by skeletal muscles that result in energy expenditure" (p. 126) and can be measured in Metabolic Equivalent of Task (MET), which is the amount of oxygen the body uses for an activity (Jetté et al., 1990). It is often categorized into four intensity levels, namely, vigorous physical activity (VPA), such as running and competitive sports, moderate physical activity (MPA), such as brisk walking or light effort cycling, light physical activity (LPA), for example, desk work and standing, and sedentary behaviors (SB), such as sitting, reclining, or lying (Haskell et al., 2007). In PAB guidelines, MPA and VPA are often combined into one category: moderate to vigorous intensity physical activity (MVPA; Nakagawa et al., 2020).

The relationship between PAB and the sub-concepts of SMW, (lack of) depressive symptoms and self-esteem, has been investigated in several studies (Hoare et al., 2016; Korczak et al., 2017; Biddle et al., 2019; Costigan et al., 2019). There are several studies that report the relationship between total physical activity (PA) (i.e., MVPA and LPA combined) and depressive symptoms and self-esteem (Tremblay et al., 2000; McKercher et al., 2009; Salmon et al., 2011; Gunnell et al., 2016; Van Dijk et al., 2016; Gianfredi et al., 2020; Kandola et al., 2020). However, because PA can be divided into separate intensities that might differently affect SMW, we also analyzed the separate PAB intensities.

Korczak et al. (2017) reviewed 28 cross-sectional studies on the relation between MVPA and depressive feelings and concluded that there appears to be a negative association between MVPA and depressive symptoms. Kandola et al. (2020) found a similar negative significant association in their longitudinal study. Additionally, in several studies in primary and secondary school students and adults, a positive significant association between MVPA and self-esteem was found (Tremblay et al., 2000; Parfitt and Eston, 2007; Fedewa and Ahn, 2011; Zamani Sani et al., 2016).

The relationship between LPA and depressive symptoms is studied less extensively, and the results of the studies in which this relationship is investigated are equivocal (Costigan et al., 2019; Xiang et al., 2020; Hagemann et al., 2021). For example, no significant association was found between LPA and depressive symptoms among 1,223 and 934 secondary school students (Costigan et al., 2019; Hagemann et al., 2021), whereas Xiang et al. (2020) found a significant negative correlation between LPA and depressive symptoms in 428 secondary school students. Moreover, in a longitudinal study, depression scores were significantly decreased with every 60 min of increase in LPA (Kandola et al., 2020). To our knowledge, there is only one study in which the association between LPA and self-esteem is investigated (Goding and Petzén, 2018). In this study, no significant association between LPA and self-esteem was shown among 268 university students.

The relationship between SB and both depressive symptoms and self-esteem has been summarized in a review by Hoare et al. (2016). They included 32 studies in their review and described that there seems to be a positive association between SB and depressive symptoms and a negative association between SB and self-esteem in the adolescent population. Moreover, longitudinal studies by Gunnell et al. (2016) and Kandola et al. (2020) report that high levels of SB and consistently low levels of LPA are significantly associated with more depressive symptoms.

Many of the studies on the association between PAB and SMW used questionnaires to measure different types of PAB (Hoare et al., 2016; Korczak et al., 2017; Goding and Petzén, 2018) and questionnaires on screen time as a proxy for SB (Hoare et al., 2016). This could lead to an over or under representation of the amount of time spent in these behaviors (Schilling et al., 2018).

In the current study, we measured total PA and all different PAB intensities separately by accelerometry using a 24-h measurement protocol, allowing us to capture all time spent in MVPA, LPA, and SB and to determine how these are associated with SMW. Additionally, many of the studies on PAB and SMW have been carried out in secondary schools (Eddolls et al., 2018; Costigan et al., 2019), colleges (Adams et al., 2005; Zhang et al., 2020), or universities (Joseph et al., 2014; Schultchen et al., 2019). Thus, to our knowledge, the relation between PAB and SMW has never been explored within the VET setting. Advanced insights in this population are of added value to the current knowledge base since, for example, a substantial part (40%) of the Dutch tertiary school-going population is enrolled in VET (CBS, 2020) and many VET students are from low socioeconomic status (SES) households (Kennisplatform onderwijs, 2018). Being from low SES households makes VET students more prone to SMW problems, due to a higher exposure to stressful life events [e.g., divorce, financial crises, and (mental) illness within the family] than students from households with a higher SES (Stevens et al., 2018; Reiss et al., 2019). As a result, VET students are more susceptible to dropping out of school (Hjorth et al., 2016; Stevens et al., 2018; European Commission, 2020). In addition, low SES groups, such as VET students, are vulnerable to engage in insufficient PA (Rijpstra and Bernaards, 2011; Grüne et al., 2020), therefore, exploring this relationship could be of importance. Furthermore, besides possible mental wellbeing benefits, PA has also health benefits (Bull et al., 2020). Therefore, the aim of the current study was to explore the association between total PA and SMW and PAB of different intensities (i.e., MVPA, LPA, and SB) and SMW in the VET setting. It is expected that high levels of PA are associated with higher levels of SMW, the same is expected for the association between MVPA and SMW, and high levels of SB are associated with lower levels of SMW. Previous research shows that the relationship between LPA and SMW is less clear, thus, there is no expectation regarding the association between LPA and SMW.

MATERIALS AND METHODS

Study Design

The current cross-sectional observational study is a part of the "PHysical activity InTerventions to enhance LEARNing in VET" (PHIT2LEARN) study. The PAB of students was measured, students executed a number of cognitive tests, and they filled out a number of questionnaires. In the current study, the associations between objectively measured PAB and SMW in VET students are reported, the results regarding the cognitive measures have been reported elsewhere (Golsteijn et al., 2021).

Participants

Participants were recruited using a purposive sampling method (Ritchie et al., 2013) at a VET school in the south of the Netherlands that offers the full range of VET education. In consultation with the management of the school, 374 students (19 classes) were approached. Some of these students were going to school and following internships, while others did not have their internships yet. There were no exclusion criteria formulated, however, students who indicated that they took medication that could influence their SMW were excluded from the data analyses.

The sample size calculation was performed using G*Power for linear multiple regression (fixed model, R^2 increase) (Universität Düsseldorf, Düsseldorf, Germany). The power analysis was based on the results of the study of Zhang et al. (2020) who utilized the positive and negative affect scale to measure positive and negative affect. However, as both, the Center for Epidemiologic Studies Depression Scale (CES-D, i.e., the scale utilized in the current study) and the positive and negative affect scale, include positive and negative affect, we utilized the results of the study of Zhang et al. (2020) to execute the sample size calculation. To calculate the effect size f^2, the Pearson correlations between MVPA and the outcomes positive and negative affect (0.15 and −0.05) and the Pearson correlations between VPA and positive and negative affect (0.21 and −0.17) were transformed to R^2 using an online effect size converter (Effect Size Converter, n.d.), which led to an R^2 of 0.03, 0.003, 0.04, and 0.02. These R^2 were added up leading to an R^2 of 0.098. This R^2 was then entered into G*Power (variance explained by a special effect) and the f^2 was calculated, this led to an f^2 of 0.11, which is approximately a medium effect size. Using an f^2 of 0.11 and an alpha of 0.05, 75 participants were needed to achieve a power of 0.8.

Procedure

The study was approved by the Research Ethics Committee (cETO) of the Open University of the Netherlands (U2017/00519/FRO) and has been registered in the Dutch Trial Register (NTR6358), which is connected to clinicaltrials.gov. After approval from the cETO, for each participating class, three research sessions were planned in three consecutive weeks (March to July 2017) in agreement with the management of the school. During the first session, the researchers held a presentation to inform all students on the procedure of the study. The presentation emphasized that participation was voluntary, that all data would be coded and stored securely, and that students could opt out at any given moment. Afterward, all potential participants received an information letter and informed consent form, which they returned before the start of the second session 1 week later. According to Dutch ethical regulations (National Ethics Council for Social and Behavioural Science, 2018), 16–18 years olds had to inform their parents but could decide and sign the informed consent themselves. Participants aged 18 years or older decided themselves.

During the second session, the participants who gave consent were instructed to attach an accelerometer to the middle anterior part of their right thigh in a private room. Participants (optionally) shaved the middle of the anterior part of their right thigh and taped a waterproofed ActivPAL3^{TM} (PAL Technologies Ltd., Glasgow, United Kingdom) accelerometer on their thigh using Tegaderm^{TM} (3M, Saint Paul, MN, United States) transparent film roll. Participants were asked to wear the accelerometers until the third session (1 week later). After attaching the ActivPAL3^{TM}, the height and weight of the participant were measured to determine their body mass index (BMI). Additionally, all participants filled out a questionnaire regarding general information (i.e., sex, age, current education level, education level of their parents/caregiver, health, and pubertal status).

The third session started with a presentation on what to expect during that session, after which all participants filled out questionnaires regarding their depressive feelings and self-esteem. While students filled out the questionnaires, they were asked to leave the room one by one to remove the accelerometer they had worn and hand it over to the researchers.

Measurements

Physical Activity Behavior

To objectively measure PAB, participants were asked to wear an ActivPAL3^{TM} accelerometer. The ActivPAL3^{TM} is a uni-axial wearable device (53 mm × 35 mm × 7 mm) that detects limb position on three axis (x-, y-, and z axis) and accordingly identifies the wearer's posture. The ActivPAL3 was worn continuously without taking it off for water activities (e.g., showering or swimming). Data were recorded at 20 Hz and summarized in 10-s epochs. In a free-living situation, the inter-device reliability ranged between 0.79 and 0.99 (Grant et al., 2006), and the overall agreement between observer and ActivPAL3 was 95.9% (Sellers et al., 2016).

The students that had regular classes and internships were asked to wear the accelerometers for 10 consecutive days, and students that were not doing internships were asked to wear the accelerometers for 7 consecutive days. This was to make sure that the same number of schooldays was recorded. Afterward all data were downloaded from the ActivPAL3. Processing PAL (Edwardson and Ette, 2019) was then used to process the data.

Based on METs, PAB is in this study classified into three intensity levels, namely, MVPA (>3 MET), LPA (1.6–2.9 MET), and SB (≤1.5 MET) (Haskell et al., 2007; Nakagawa et al., 2020).

Data were considered valid if 2 valid week- and 2 valid weekend days were recorded (Trost et al., 2005). From all valid days, the average hour per day per outcome [i.e., MVPA stepping, LPA stepping, standing (LPA), time spent sedentary (sitting/lying), and time in bed] was calculated. Thereafter, average hours per day of total PA (i.e., MVPA and LPA combined), MVPA, LPA, and SB were calculated per participant.

In addition, the SB ratio was calculated. This SB ratio is an indication of interrupted sitting behavior and is obtained by calculating the ratio between time spent sedentary in bouts shorter than 30 min and the total average SB per day. A high ratio indicates that SB is interrupted more often. This 30 min cutoff is based on the recommendation to interrupt SB every 30 min (Rutten et al., 2013).

Student Mental Wellbeing

As in this study, SMW was operationalized as the absence of depressive symptoms and the presence of self-esteem; two well-validated questionnaires were used to measure these concepts. The absence of depressive symptoms was measured using the Dutch version of the CES-D (Radloff, 1977). The CES-D consists of 20 questions. Students indicated how often they felt a certain way in the previous week on a 4-point scale ranging from rarely to all the time [i.e., 0 = rarely or never (i.e., less than 1 day), 1 = some or a little of the time (i.e., 1–2 days), 2 = occasionally or a moderate amount of the time (i.e., 3–4 days), or 3 = all of the time (i.e., 5–7 days)]. An example of a question is "I felt depressed." Four items are worded positively and thus scored reversely. Thereafter all items were summed to calculate a total score that ranged from 0 (not depressed/absence of depressive symptoms) to 60 (depressed/high number of depressive symptoms). A score of ≥16 is an indication for depression (Beekman et al., 1997) and a score of ≥22 indicates severe to major depression (Cuijpers et al., 2008). The scale has very good internal consistency (alpha 0.85), satisfactory test-retest reliability (0.51–0.67 over 2- to 8-week period, 0.32–0.54 over 3–12 months), and good convergent and construct validity (Radloff, 1977).

Self-esteem was measured using the Dutch version of the Rosenberg self-esteem scale (RSE; Rosenberg, 1979), which consists of 10 statements dealing with general feelings about how students feel about themselves. The participants had to indicate whether they agreed with the statement on a four-point Likert scale ranging from strongly agree to strongly disagree (i.e., 0 = strongly agree, 1 = agree, 2 = disagree, or 3 = strongly disagree). An example of such a statement is "On the whole, I am satisfied with myself." Five positive items were scored reversely. All items were summed to calculate a total score that ranged between 0 and 30, a higher score indicates a higher global self-esteem. The scale has been reported to have a satisfactory reliability of 0.72–0.88 (Gray-Little et al., 1997).

Body Mass Index

Body mass index was calculated for each participant by the formula $\frac{\textit{weight in kilograms}}{\textit{height in } m^2}$. All students were weighed using a body composition monitor (Karada Scan, Omron, BF511) after emptying their pockets and undressing as much as possible (e.g., removal of caps, shoes, and jackets). Afterward, students' height was measured by a member of the research team using a measuring tape.

Other Variables

The students had to fill out several questionnaires regarding background variables that could act as covariates, such as SES, smoking, alcohol intake, and questions on physical disabilities that could influence their PAB or medication that could influence SMW. SES was measured by asking students what the highest education level of their father, mother, and/or caregiver(s) was. Students were asked to estimate how many cigarettes they smoked a week and how many days a week they drank alcohol and to give an estimation on how many units of alcohol on average they drank on the days they consumed alcohol. Regarding physical disabilities that could influence PAB, students were asked if they were diagnosed with something that could influence their PAB, thereafter students were asked what the disability was and who diagnosed it. The same questions were asked regarding medication that could influence SMW.

Statistical Analyses

Analyses were performed using SPSS, version 26 (SPSS Inc., Chicago, IL, United States). Descriptive statistics were obtained using means and standard deviations (SD) for continuous variables and in numbers (N) and percentages for categorical variables and median for the score on the CES-D and RSE. To see if there were significant differences between the group included in the data analyses and the group excluded from the data analysis ANOVA's were performed for BMI, age, RSE score, and CES-D score and a chi-square was performed for sex. Prior to executing the multiple regressions, an assumption check indicated that all assumptions were met. The relationship between PAB and SMW was assessed using multiple linear regression with the ENTER method, forcing all variables at once in the model. The independent variable being total PA, MVPA, LPA, or SB and the dependent variables being total score on the CES-D (depressive symptoms) or total score on the RSE (self-esteem), followed by all covariates: BMI, sex (female/male), age, smoking, and alcohol use. These covariates were added since previous research has shown that these were associated with PAB and SMW (Eddolls et al., 2018; Costigan et al., 2019; Tamminen et al., 2020). Additionally, the categorical covariate "disabilities that could influence PAB" (yes/no) was added to the model. The regression models do not control for the different PAB intensities. As the students used the accelerometer with a 24-h wearing protocol, time spent in different PABs is intrinsically collinear and PABs are codependent, even when they are uncorrelated according to correlation analysis (Pedišić, 2014; Chastin et al., 2015). Therefore, entering several PABs in one model would violate the assumption of no multicollinearity for executing regression analyses. For each independent variable, a separate multiple regression was carried out, with a total of five independent variables (i.e., average hours of total PA, MVPA, LPA, SB, and the SB ratio), thus resulting in a total of ten multiple regression analyses. All analyses with values of $p < 0.05$ were considered significant.

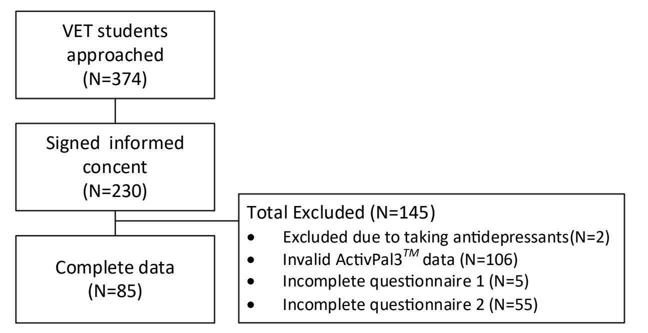

FIGURE 1 | Flowchart of participants. In the total excluded overlap is possible (e.g., a student could have incomplete questionnaire data and invalid ActivPAL3 data simultaneously).

TABLE 1 | Participants' characteristics.

	N	Mean or N (%)	*SD*
Age (years)	85	18.8	2.8
Female/Male	85	60/25 (70.6/29.4%)	–
BMI	85	22.64	3.29
Smoking yes/no	84	12/73 (14.1/85.9%)	–
1–70 cigarettes per week		11 (12.9%)	
>70 cigarettes per week		1 (1.2%)	
Alcohol yes/no	85	54/31 (63.5/36.5%)	
Alcohol units per week	85	4.9	10.2
Physical activity disability yes/no	85	7/78 (8.2/91.8%)	–
Score on CES-D symptoms	85	12.5 *Mdn* 10	8.8
Score on RSE	85	19.8 *Mdn* 20	3.8
Total PA	85	6.3	1.6
MVPA	85	1.4	0.5
LPA	85	4.9	1.5
SB	85	8.4	1.6
Time in bed	85	9.3	0.9

Cigarettes smoked categories obtained from Pierce et al. (1987). BMI, Body mass index; CES-D, Center for Epidemiologic Studies Depression Scale; RSE, Rosenberg self-esteem scale; Total PA, total physical activity; MVPA, moderate to vigorous physical activity; LPA, light physical activity; SB, sedentary behavior. Time in bed does not equal sleeping time, it could also be time awake that is spent lying down.

RESULTS

Participants

A total of 374 VET students were asked to participate in the current study, of whom 230 provided informed consent. Two students used depression medication and were excluded (**Figure 1**). A total of 225 students completed the first questionnaire, 175 completed the second questionnaire, and for 124 students, sufficient ActivPAL3 data were collected; some overlap in excluded data is possible. Thus, this resulted in valid data (e.g., filled out questionnaires and sufficient ActivPAL3 data) for 85 students. The characteristics of the included participants are presented in **Table 1**.

Of the 85 students, 60 (70.6%) were women and the mean age was 18.8 ± 2.8 years. For 13 (15.3%) students, there was an indication for depression (CES-D score between 16 and 21), 11 (12.9%) students were classified as having severe to major depression (CES-D ≥ 22). The mean score on CES-D was 12.4 ± 8.83 (median = 10) and the mean on the RSE was 19.79 ± 3.84 (median = 20). Total PA has a mean of 6.3 ± 1.6 h per day, MVPA has a mean of 1.4 ± 0.5 h per day, the mean of LPA was 4.9 ± 1.5 h a day, and the mean for SB was 8.3 ± 1.6 h per day. All other descriptive data are described in **Table 1**.

The group included in the data analysis differed significantly from the group excluded from the data analysis. Regarding BMI (23.9 ± 4.2; $p = 0.02$) and score on the RSE (21.5 ± 4.6; $p = 0.01$), statistically significant differences were found between the two groups. In addition, the distribution of women/men in the group included in the data analyses was significantly different from the distribution in the group excluded from the data analyses (50.7/49.3%; $p = 0.002$).

Association Between Total Physical Activity and Student Mental Wellbeing

The regression analysis for total PA and depressive symptoms (**Table 2**) revealed a significant negative association between total PA and depressive symptoms (β = −0.25, 95% CI = [−2.58, −0.16], $p = 0.03$). This indicates that with every hour increase in PA, students score 1.37 points lower on the CES-D questionnaire, thus having less depressive symptoms. Smoking and alcohol use were not included as covariates to this and all other multiple regression models, since these two variables had no significant contributions (all $p \geq 0.14$). Moreover, the two variables never significantly improved the regression model.

For self-esteem, the regression analyses revealed a significant positive association between total PA and self-esteem (β = 0.29, 95% CI = [0.19, 1.17], $p = 0.01$). This indicates that with every hour increase in total PA, students score 0.68 points higher on the RSE questionnaire, thus having higher self-esteem.

TABLE 2 | Regression analyses of total PA on depressive symptoms and self-esteem.

	Depressive symptoms R^2 = 0.10; adj. R^2 = 0.05				Self-esteem R^2 = 0.22; adj. R^2 = 0.17			
Variable	**B [95% CI]**	**SE B**	**β**	***p***	**B [95% CI]**	**SE B**	**β**	***p***
(Constant)	6.66 [−13.81, 27.14]	10.29		0.52	23.29 [14.98, 31.60]	4.17		<0.001
Total PA	−1.37 [−2.58, −0.16]	0.61	−0.25	0.03	0.68 [0.19, 1.17]	0.25	0.29	0.01
BMI	0.43 [−0.16, 1.02]	0.30	0.16	0.15	−0.27 [−0.51, −0.03]	0.12	−0.23	0.03
Sex	3.61 [−0.71, 7.94]	2.17	0.19	0.10	−3.35 [−5.11, −1.61]	0.88	−0.40	<0.001
Age	0.11 [−0.58, 0.80]	0.35	0.04	0.75	0.03 [−0.25, 0.31]	0.14	0.02	0.84
Physical disabilities	0.24 [−6.98, 7.46]	3.62	0.01	0.95	2.86 [−0.07, 5.79]	1.47	0.21	0.06

Total PA, Total physical activity; BMI, body mass index.

TABLE 3 | Regression analyses of MVPA on depressive symptoms and self-esteem.

	Depressive symptoms R^2 = 0.09; adj. R^2 = 0.03				Self-esteem R^2 = 0.17; adj. R^2 = 0.12			
Variable	**B [95% CI]**	**SE B**	**β**	***p***	**B [95% CI]**	**SE B**	**β**	***P***
(Constant)	6.35 [−14.65, 27.35]	10.55		0.55	24.18 [15.51, 32.86]	4.36		<0.001
MVPA	−4.12 [−8.58, 0.35]	2.24	−0.24	0.07	1.57 [−0.27, 3.41]	0.93	0.20	0.09
BMI	0.42 [−0.18, 1.02]	0.30	0.16	0.16	−0.26 [−0.51, −0.02]	0.12	−0.23	0.04
Sex	0.87 [−3.78, 5.51]	2.33	0.05	0.72	−2.19 [−4.10, −0.27]	0.96	−0.26	0.03
Age	0.07 [−0.63, 0.77]	0.35	0.02	0.84	0.44 [−0.24, 0.33]	0.15	0.03	0.76
Physical disabilities	1.11 [−6.07, 8.28]	3.60	0.04	0.76	2.30 [−0.67, 5.26]	1.49	0.17	0.13

MVPA, Moderate to vigorous physical activity; BMI, body mass index.

Association Between Moderate to Vigorous Physical Activity and Student Mental Wellbeing

Non-significant associations (**Table 3**) were found for MVPA and depressive symptoms (β = −0.24, 95% CI = [−8.58, 0.35], *p* = 0.07), and for MVPA and self-esteem (β = 0.20, 95% CI = [−0.27, 3.41], *p* = 0.09).

Association Between Light Physical Activity and Student Mental Wellbeing

The regression analysis for LPA and depressive symptoms (**Table 4**) revealed a significant negative association between LPA and depressive symptoms (β = −0.24, 95% CI = [−2.84, −0.01], *p* = 0.048). This indicates that with every hour increase in LPA, students score 1.43 points lower on the CES-D questionnaire, thus having less depressive symptoms.

For self-esteem, the regression analyses revealed a significant positive association between LPA and self-esteem (β = 0.29, 95% CI = [0.18, 1.33], *p* = 0.010). This indicates that with every hour increase in LPA, students score 0.75 points higher on the RSE questionnaire, thus having higher self-esteem.

Association Between Sedentary Behavior and Student Mental Wellbeing

The regression analysis regarding SB and depressive symptoms (**Table 5**) revealed a non-significant association between SB and depressive symptoms (β = 0.20, 95% CI = [−0.13, 2.39], *p* = 0.08).

For self-esteem, however, the regression analysis revealed a significant positive association between SB and self-esteem (β = −0.24, 95% CI = [−1.09, −0.06], *p* = 0.03). This indicates that with every hour increase in SB, students score 0.58 points lower on the RSE questionnaire, thus having lower self-esteem.

Association Between Sedentary Behavior Ratio and Student Mental Wellbeing

The regression analyses regarding SB ratio and depressive symptoms (**Table 6**) revealed no significant association between SB ratio and depressive symptoms (β = −0.18, 95% CI = [−32.98, 3.56], *p* = 0.11), a significant association was not found between SB ratio and self-esteem (β = 0.14, 95% CI = [−2.58, 12.55], *p* = 0.19). This indicates that an increase in SB ratio is not associated with an increase in SMW.

DISCUSSION

The aim of this study was to explore the association between total PA and SMW and PAB of different intensities (i.e., MVPA, LPA, and SB) and SMW in the VET setting. A significant negative association was found for total PA and depressive symptoms and a significant positive association for total PA and self-esteem. This indicates that every hourly increase in PA is associated with scoring 1.37 points lower on the CES-D questionnaire, thus having fewer depressive symptoms and 0.68 points higher on the RSE questionnaire, thus having higher self-esteem, respectively. This is in line with earlier research on total PA and depressive symptoms and self-esteem (Tremblay et al., 2000; McKercher et al., 2009; Salmon et al., 2011; Gunnell et al., 2016;

TABLE 4 | Regression analyses of LPA on depressive symptoms and self-esteem.

	Depressive symptoms R^2 = 0.09; adj. R^2 = 0.03				Self-esteem R^2 = 0.21; adj. R^2 = 0.16			
Variable	**B [95% CI]**	**SE B**	**β**	***p***	**B [95% CI]**	**SE B**	**β**	***p***
(Constant)	4.687 [−15.59, 24.96]	10.18		0.65	24.11 [15.90, 32.31]	4.12		<0.001
LPA	−1.43 [−2.84, −0.01]	0.71	−0.24	0.048	0.75 [0.18, 1.33]	0.29	0.20	0.010
BMI	0.41 [−0.18, 1.01]	0.30	0.16	0.17	−0.27 [−0.51, −0.03]	0.12	−0.23	0.03
Sex	4.25 [−0.32, 8.81]	2.29	0.22	0.07	−3.72 [−5.57, −1.88]	0.93	−0.26	<0.001
Age	0.12 [−0.58, 0.82]	0.35	0.04	0.73	0.02 [−0.26, 0.30]	0.14	0.03	0.87
Physical disabilities	0.57 [−6.66, 7.80]	3.63	0.02	0.88	2.76 [−0.17, 5.69]	1.47	0.17	0.07

LPA, Light physical activity; BMI, body mass index.

TABLE 5 | Regression analyses of SB on depressive symptoms and self-esteem.

	Depressive symptoms R^2 = 0.08; adj. R^2 = 0.02				Self-esteem R^2 = 0.19; adj. R^2 = 0.14			
Variable	**B [95% CI]**	**SE B**	**β**	***p***	**B [95% CI]**	**SE B**	**β**	***p***
(Constant)	−9.75 [−32.28, 12.78]	11.32		0.39	31.57 [22.37, 40.74]	4.61		<0.001
SB	1.13 [−0.13, 2.39]	0.63	0.20	0.08	−0.58 [−1.09, −0.06]	0.26	−0.24	0.03
BMI	0.41 [−0.18, 1.01]	0.30	0.15	0.17	−0.27 [−0.51, −0.02]	0.12	−0.23	0.03
Sex	3.27 [−1.07, 7.61]	2.18	0.17	0.14	−3.19 [−4.96, −1.42]	0.88	−0.38	0.001
Age	0.05 [−0.65, 0.75]	0.35	0.02	0.88	0.58 [−0.23, 0.34]	0.14	0.04	0.69
Physical disabilities	0.40 [−6.98, 7.78]	3.71	0.01	0.91	2.81 [−019, 5.82]	1.51	0.20	0.07

SB, Sedentary behavior; BMI, body mass index.

TABLE 6 | Regression analyses of SB ratio on depressive symptoms and self-esteem.

	Depressive symptoms R^2 = 0.08; adj. R^2 = 0.02				Self-esteem R^2 = 0.16; adj. R^2 = 0.11			
Variable	**B [95% CI]**	**SE B**	**β**	***p***	**B [95% CI]**	**SE B**	**β**	***p***
(Constant)	6.81 [−14.86, 28.49]	10.89		0.53	24.30 [15.33, 33.28]	4.51		<0.001
SB-ratio	−14.71 [−32.98, 3.56]	9.18	−0.18	0.11	4.99 [−2.58, 12.55]	3.80	0.14	0.19
BMI	0.43 [−0.17, 1.03]	0.30	0.16	0.16	−0.27 [−0.51, −0.02]	0.13	−0.23	0.04
Sex	2.85 [−1.45, 7.14]	2.16	0.15	0.19	−2.93 [−4.71, −1.15]	0.89	−0.35	0.002
Age	0.07 [−0.64, 0.77]	0.35	0.02	0.85	0.04 [−0.25, 0.34]	0.15	0.03	0.76
Physical disabilities	1.43 [−5.75, 8.60]	3.60	0.05	0.69	2.14 [−0.83, 5.11]	1.49	0.16	0.16

SB ratio, Sedentary behavior ratio; BMI, body mass index.

Van Dijk et al., 2016; Gianfredi et al., 2020; Kandola et al., 2020). Similar significant negative and positive associations were found for LPA and depressive symptoms and LPA and self-esteem, respectively. Every hour increase in LPA was associated with a 1.43 points lower score on the CES-D questionnaire, and 0.75 points higher on the RSE questionnaire. Additionally, a significant negative association was found for SB and self-esteem indicating that more sitting was associated with lower self-esteem. Even though we did not find significant associations between MVPA and the SMW outcomes, their directions were in line with our expectations, namely, that higher MVPA is negatively associated with depressive symptoms and positively with self-esteem. The same is the case for a positive association between SB and depressive symptoms.

Even though our findings are not consistent with the findings of the longitudinal study of Kandola et al. (2020) and the review of Korczak et al. (2017) who report a significant negative association between MVPA and depressive symptoms, they do largely concur with the findings of Tremblay et al. (2000), Parfitt and Eston (2007), Fedewa and Ahn (2011), and Zamani Sani et al. (2016) who reported a significant positive association between MVPA and self-esteem and the findings of Gunnell et al. (2016); Hoare et al. (2016), and Kandola et al. (2020) who state that there is a positive association between SB and depressive symptoms. The discrepancies in results could possibly be ascribed to a difference in how PAB is measured [e.g., questions on screen time (a proxy for self-reported SB) or self-reported PAB]. For instance, in the 28 cross-sectional studies included by Korczak et al. (2017), MVPA was mostly measured using self-report measurements (n = 26). The same is true for MVPA in the studies of Tremblay et al. (2000), Fedewa and Ahn (2011), and Zamani Sani et al. (2016), and in 16 out of 17 articles in the review of Hoare et al. (2016) on the association between SB and depression. Self-report measurements are susceptible to over- or underestimation of PAB behavior due to social desirable answers (Schilling et al., 2018). This notion is supported by the fact that the two studies in the review of Korczak that assessed MVPA using accelerometers and the study of Hume et al. (2011) that measured SB using an accelerometer, similar to our study, did not show a significant association between MVPA/SB and depressive symptoms. Moreover, a possible reason why Parfitt and Eston (2007) reported a significant positive association between objectively measured MVPA and self-esteem is that they used a different type of self-esteem questionnaire (i.e., the Children and Youth Physical Self-Perception Profile) which measures a broad range of self-esteem concepts, while the RSE is correlated only with global self-esteem (Hagborg, 1993). This could be a possible explanation for finding different results.

The current study showed a significant association between LPA and SMW, meaning that higher LPA is associated with fewer depressive symptoms and higher feelings of self-esteem. Previous research on the relationship between LPA and SMW was inconclusive. Both Costigan et al. (2019) and Hagemann et al. (2021) found no significant association between LPA and depressive symptoms while Kandola et al. (2020) and Xiang et al. (2020), similar to our study, did find a significant association. A possible reason for Costigan et al. (2019) did not find a significant association could be that they included children in their study instead of adolescents, and since feelings of depression often emerge during adolescence (World Health Organization, 2020) it is likely that there were not many children with depressive feelings and it is thus harder to find a significant association. The difference between the results of the current study and that of Hagemann et al. (2021) could be explained by the accelerometer protocol they used. Hagemann et al. (2021) had participants who wear a Fitbit 2 for only 8 h a day, which might lead to an underestimation of LPA. To the best of our knowledge, only one other study (Goding and Petzén, 2018) examined the association between LPA and self-esteem in adolescents. Contrary to Goding and Petzén (2018), the current research showed a significant positive association between LPA and self-esteem, which could possibly be explained by the fact that the participants in the study of Goding and Petzén (2018) over or underestimated their self-reported PAB (Schilling et al., 2018).

The significant association found here for total PA, and more specifically LPA, and the different mental wellbeing outcomes could be explained by several mechanisms, namely, physiological, psychosocial, and behavioral mechanisms. Proposed physiological mechanisms of the relation between PAB and SMW are that increased PAB leads to an increased blood flow, which in turn activates different brain regions and therefore the release of different endorphins and monoamines, resulting in higher SMW (DeVries, 1981; Craft and Perna, 2004; Portugal et al., 2013; Lubans et al., 2016). It is also the case that the increase of body temperature caused by more PAB could lead to feelings of relaxation and reduction of muscular tension which in turn leads to higher SMW (Craft and Perna, 2004). Psychosocial mechanisms suggested to be involved include the fact that PAB can increase SMW by social reward [i.e., doing activities that increase PAB together with other people, such as walking (LPA)] and self-efficacy (i.e., feelings of competence, for instance, being able to complete a certain activity) (Lubans et al., 2016; Szabo et al., 2018). It also has been suggested that a change in appearance due to increased PAB could lead to feelings of autonomy (e.g., by following through on changing your PAB pattern) and contentment with body appearance (Craft and Perna, 2004). Lastly, it has been proposed that behavioral mechanisms are involved in positive SMW due to an increase of PAB, for instance, more PAB, such as walking or standing (LPA), could lead to improvement in sleep quality which in turn could improve SMW (Ellingson et al., 2018).

Moreover, we did find a significant negative association between SB and self-esteem. The significant negative association between SB and self-esteem mentioned in the systematic review by Hoare et al. (2016) is in line with the results of the current study, though the four studies included in their review utilized self-report. To our knowledge, the current study is unique in finding an association between objectively measured SB and self-esteem (Hoare et al., 2016).

Lastly, we explored the association between SB ratio and SMW, based on the recommendation by Rutten et al. (2013) that SB should be interrupted every 30 min. To our knowledge, the association between the SB ratio and SMW has not been explored before. We did not show a significant association between SB ratio and SMW. This indicates that it possibly does not matter if the time spent sedentary is all at once or interrupted by PAB.

Within the current study, all waking wear-time per student was measured with the ActivPAL3 and divided into total PA, MVPA, LPA, and SB. This provides us with comprehensive insights into PAB since decreasing one behavior, for example, SB, should automatically result in increasing one of the other behaviors (i.e., LPA or MVPA). The significant positive associations between higher LPA and SMW and the negative association between SB and SMW indicate that decreasing SB and increasing LPA could contribute to improved SMW. A possible way to reduce SB could be to exchange time spent in sitting for time spent in standing, in LPA or MVPA. Standing has a MET value of 1.59–1.71 (Mansoubi et al., 2015) and can therefore be classified as LPA. Replacing sitting for LPA, such as standing or movement breaks, is especially useful in the educational setting, as studies have shown that students are sedentary most of their time in school (Morton et al., 2016; Golsteijn et al., 2021). To promote standing in the educational setting, replacing traditional desks with standing desks or introducing movement breaks could be options. The current study could be used as starting point to explore the causal relationship between different PABs and SMW in the VET setting by conducting randomized controlled trials (RCT) to explore the effects of, for instance, the use of standing desks or movement breaks on SMW. In the long run, such interventions might lead to lower school dropout and fewer adverse long-term effects, such as unemployment, social exclusion, and impoverishment (Andrews and Wilding, 2004; Amholt et al., 2020; European Commission, 2020).

Strengths and Limitations

To our knowledge, this study is the first study in which the association between PAB and SMW in the VET setting is explored. The findings can be used as a starting point to set up an RCT. Another strength of this study is that PAB was measured using an accelerometer. In comparison to other observational studies, the current study looked at the total waking wear-time divided over SB, LPA, and MVPA by using an accelerometer instead of questionnaires on PAB and screen time, in which PAB is often over or underestimated due to socially desirable answering (Schilling et al., 2018).

Although we experienced a relatively large dropout in the current study, it can be considered as a well-powered study as the number of students who were included was sufficient to achieve a power >80%. Because of the high amount of dropouts due to insufficient data, we considered multiple imputations, however, due to the amount of missing data (i.e., more than 5%), this would not be reliable (Jakobsen et al., 2017). There were some significant differences between the group included in the data analyses and the group excluded from the data analyses, however, it should be noted that for the score on the RSE, this is not a clinical difference but a statistical difference. When considering BMI, it should be noted that students with a higher BMI tend to dropout of studies earlier (Kaiser et al., 2014), however, within the group excluded from the data analysis, BMI is still within the healthy range. Furthermore, we omitted SES from the analyses because we obtained this variable by asking students what the highest level of education of their parents or caregivers was. As some students did not know the educational level of their parents or caregivers, some students had several caretakers (e.g., due to divorces), and others no longer lived with a parent or caregiver, this resulted in a large amount of missing data. Altogether, as the obtained data on SES were of questionable reliability, SES was not added as a covariate in the multiple linear regression model. Therefore, for future research, it is recommended that SES information is provided by parents or caregivers or by the students themselves, when they live independently. It is also important to mention that the current study is an observational cross-sectional study. It is thus is impossible to draw causal conclusions, however, the results of this study can be used as a starting point to explore the presence of a causal relationship. Due to performing multiple regression analyses, it is possible that our results are at risk for a type I error. Although this could have been tackled by correcting for multiple testing, we decided not to do this, since applying such corrections is subject to debate (Bender and Lange, 2001).

Conclusion

The main results of this study indicate that there is a significant association between total PA and SMW. When taking different PABs into account, it seems that this association is strongest for LPA. This study makes a major contribution to the limited amount of research regarding the association between different PAB intensities and SMW. Additionally, a significant negative association between SB and self-esteem was found. Although no significant associations between MVPA and SMW and between SB and depressive symptoms were found, they were in the same line of expectations. Future research should focus on the possible causal relationships between changes in PAB and SMW by setting up RCTs by, for instance, introducing standing desks or movement breaks.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors on request, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee (cETO) of the Open University of the Netherlands (U2017/00519/FRO) and has been registered in the Dutch Trial Register (NTR6358), which is connected to clinicaltrials.gov. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

MK, RGo, RGr, and HS contributed to the conception and design of the study. MK organized the database, performed the statistical analysis, and wrote the first draft of the manuscript. IW, RGo, RGr, and HS supervised and reviewed the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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The Multivariate Physical Activity Signatures Associated With Self-Regulation, Executive Function, and Early Academic Learning in 3–5-Year-Old Children

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The evidence regarding associations between intensity-specific physical activity and cognitive and learning outcomes in preschoolers is inconsistent and limited by low sample sizes and analytical approaches that cannot handle the multicollinearity among multiple physical activity intensity variables. We aimed to determine the multivariate physical activity intensity signatures associated with self-regulation, executive function, and early academic learning in preschool children aged 3–5 years. A 711 Norwegian preschool children (mean age 4.6 years, 52% boys) provided valid data on physical activity (ActiGraph GT3X+), self-regulation, executive function, and early academic learning during 2019–2020. Multivariate pattern analysis was used to determine associations between uniaxial and triaxial intensity spectra (time spent in intensities from 0–99 to ≥15,000 counts per minute) and the outcomes in the total sample and in subgroups split by sex and age (median split). Uniaxial data led to the highest explained variances (R^2) and were reported as the primary findings. We found significant association patterns between physical activity and numeracy ($R^2 = 4.28\%$) and inhibition ($R^2 = 1.48\%$) in the total sample. The associations with numeracy were negative for time spent sedentary (0–99 counts per minute) and positive for time spent in moderate to vigorous intensities (≥ 1,000 counts per minute). The associations with inhibition were positive for time spent sedentary (0–99 counts per minute) and in vigorous intensities (≥ 8,500 counts per minute) and negative for time spent in low to moderate intensities (100–3,499 counts per minute). Associations with numeracy were stronger in boys ($R^2 = 5.58\%$) and older children ($R^2 = 7.27\%$), and associations with inhibition were stronger in girls ($R^2 = 3.12\%$) and older children ($R^2 = 3.33\%$). In conclusion, we found weak associations with numeracy and inhibition across the physical activity intensity spectrum in preschool children.

Keywords: cognition, preschool (kindergarten), accelerometer, self-regulation, executive function, learning

INTRODUCTION

Cognitive function, defined as the set of mental processes that contribute to perception, memory, intellect, and action, is considered to be a key health indicator at early age (Khan and Hillman, 2014; Donnelly et al., 2016; Poitras et al., 2016; Carson et al., 2017) and an early marker for later life success (Moffitt et al., 2011). In recent years, research within psychology, neuroscience, and education has focused on how the processes of self-regulation and executive function relate to reasoning, problem solving, and goal-directed behaviors (Zelazo et al., 2016). Self-regulation is generally defined as the capability to control or direct one's attention, thoughts, and emotions, despite competing impulses or distractions (McClelland and Cameron, 2012). Self-regulation depends on executive function, which is often understood as three related, but distinct fundamental components: inhibition, working memory, and cognitive flexibility (Miyake et al., 2000; Best, 2010; Diamond, 2013; Zelazo et al., 2016). Both self-regulation and executive function seem to impact the development of early academic learning skills such as vocabulary and initial mathematical concepts in young children (Zelazo et al., 2003; Blair and Razza, 2007; McClelland et al., 2007).

There is evidence of positive associations between physical activity (PA) and cognitive function in school-aged children and youth; however, evidence on associations for PA with academic achievement is inconsistent (Rasberry et al., 2011; Donnelly et al., 2016). In younger children, the evidence on associations for PA with cognition and learning is weaker and overall less consistent (Timmons et al., 2012; Carson et al., 2016, 2017; Wood et al., 2020; St. Laurent et al., 2021). Yet, the preschool years are crucial with respect to developing cognitive skills (Thompson and Nelson, 2001; Diamond, 2006; Calkins, 2007; Eisenberg and Zhou, 2016). As the brain is notably susceptible to stimuli in this period (Zelazo et al., 2016), there is a need to further investigate the relationship between PA and cognitive development in this age group. A recently published systematic review by St. Laurent et al. (2021) reports that few studies have explored cross-sectional associations between objectively determined PA and cognitive and academic outcomes in children younger than 6 years old. Relevant studies show a tendency for positive associations between PA and self-regulation (Becker et al., 2014; Bai et al., 2021), while associations between PA and executive function are mixed (McNeill et al., 2018; Willoughby et al., 2018; Cook et al., 2019; Bezerra et al., 2021), and associations between PA and early academic learning are positive (Bai et al., 2021) or non-existent (Becker et al., 2014; St. Laurent et al., 2018).

Previous studies exploring associations for PA with cognition and academic achievement in children vary methodologically and generally have low sample sizes (Howie and Pate, 2012; St. Laurent et al., 2021), which may lead to confusion and lack of generalizability of their results (Kim et al., 2012; Cain et al., 2013). PA as measured by accelerometry is usually reported as time spent along the intensity spectrum, including sedentary time (SED) and one or more PA intensities light-intensity PA (LPA), moderate-intensity PA (MPA), vigorous-intensity PA (VPA), and/or moderate to vigorous-intensity PA (MVPA). However, intensity cut points have only been validated for a certain combination of axes and epoch lengths (Migueles et al., 2017). Thus, there is a lack of agreement on the most appropriate cut points for preschool-aged children (Kim et al., 2012). Moreover, all studies using accelerometry in the systematic review by St. Laurent et al. (2021) used a 15-s epoch length. As children have a natural sporadic PA pattern characterized by intermittent bursts of PA generally lasting less than 10 s (Bailey et al., 1995; Vale et al., 2009), a summation of PA over longer periods will misclassify time spent in the lower and higher end of the PA intensity spectrum. A short epoch length (1 s) has been shown to better capture information about PA of relevance for cardiometabolic health than longer epoch lengths in schoolchildren (Aadland et al., 2020a). A 1-s epoch length has also been suitable to determine associations between the PA intensity spectrum and body mass index (BMI; Aadland et al., 2021) and fundamental motor skills (Nilsen et al., 2020) in preschool children.

Multiple linear regression is commonly used to determine associations between PA intensities and outcomes. However, since different PA intensity variables derived from accelerometry are strongly correlated, novel approaches are needed to model the joint contribution of multiple intensity variables. Multivariate pattern analysis can handle multiple multicollinear PA intensity variables and makes it possible to study associations for the uniaxial (i.e., vertical axis only) or the entire triaxial intensity spectrum with outcomes (Aadland et al., 2018, 2019b, 2021; Nilsen et al., 2020). The inclusion of full intensity spectra from triaxial accelerometry has been shown to be a more powerful approach than uniaxial accelerometry and traditional intensity variables to capture PA of relevance for cardiometabolic health and BMI in children (Aadland et al., 2019b, 2021). Multivariate pattern analysis has been used to determine association patterns between the PA spectrum and fundamental motor skills (Nilsen et al., 2020) and BMI (Aadland et al., 2021) in preschoolers but has not been applied to determine associations of the PA intensity spectrum with self-regulation, executive function, and early academic learning.

The aim of this study was to determine multivariate association patterns of both uniaxial and triaxial PA intensity spectra (including SED) with self-regulation, executive function, and early academic learning in a large sample of preschool-aged children. Based on the available literature, we hypothesized to find weak associations patterns with the outcomes across the PA intensity spectrum, with results showing favorable associations for moderate and vigorous intensities and unfavorable associations for SED.

MATERIALS AND METHODS

Study Design, Recruitment, and Participants

The present study has a cross-sectional design and used baseline data obtained from preschoolers in the Active Learning

Norwegian Preschool(er)s (ACTNOW) cluster randomized controlled trial. A total of 56 preschools were invited to participate, of which 46 preschools (82.1%), encompassing 1,532 children (3–5-year-olds), agreed to participate. At baseline, 1,263 (658 boys and 605 girls) children were recruited and agreed to participate (participation rate, 82.4%). Of these, 711 children (369 boys and 342 girls) provided valid data on all variables relevant to the present study. The main reasons for missing data were that children had insufficient accelerometry wear time, did not want to participate on one or more tasks, or the trained assessor considered the task(s) to be unsuitable for the children due to their young age, language barriers, and/or other mental/physical disabilities (**Figure 1**).

Procedures

We have previously published a detailed description of the study protocol (Aadland et al., 2020c) and therefore provide only a brief overview of the relevant procedures herein.

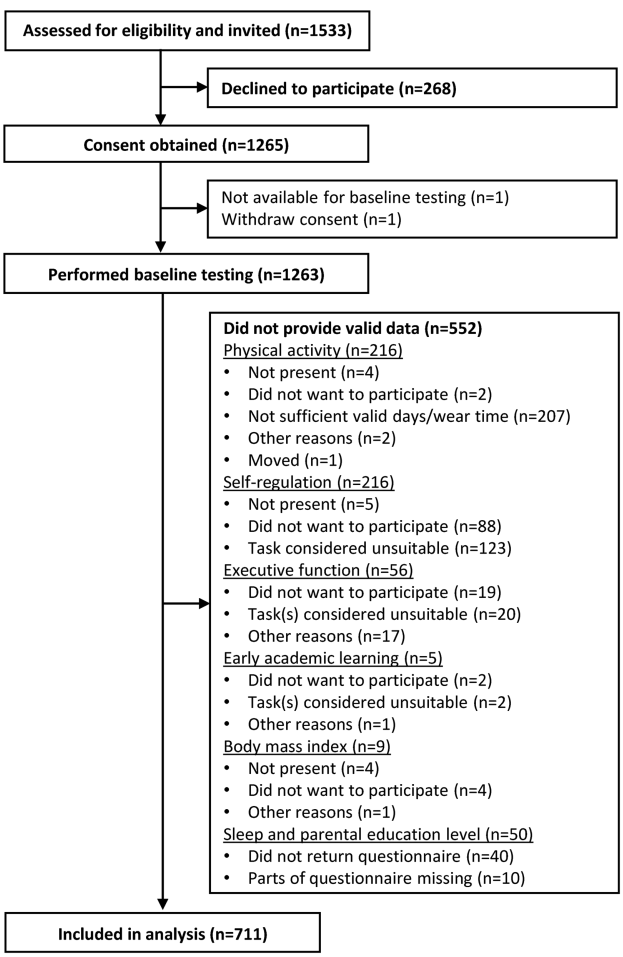

FIGURE 1 | Flow chart of recruitment and the missing data (*n* = children). Other reasons include accelerometer not returned (PA), technical errors, automatically removed data (The Go/No-Go task), and unknown reasons.

Physical Activity and Sedentary Time

PA and SED were measured using ActiGraph GT3X+ accelerometers (ActiGraph, LLC, Pensacola, Florida, United States; John and Freedson, 2012). Children were instructed to wear the accelerometer on their right hip 24 h a day for seven consecutive days, included while sleeping, but except during water activities (i.e., swimming and showering). Accelerometers were initialized at a sampling rate of 30 Hz and analyzed at a 1-s epoch length using MATLAB. Consecutive periods of ≥ 20 min of zero counts were defined as non-wear time (Esliger et al., 2005). Children having ≥ 480 min/day of wear time accumulated between 06:00 and 22:00 for ≥ 3 weekdays and ≥ 1 weekend day were included in the analysis (Aadland et al., 2020b).

For the descriptive statistics and bivariate correlation analysis, we reported SED (≤ 100 cpm), total PA [TPA, counts per minute (cpm)], and time (min/day) spent in intensity-specific PA, LPA (101–2,295 cpm), MPA (2296–4,011 cpm), VPA (≥ 4,012 cpm), and MVPA (≥ 2,296 cpm), as proposed by Evenson et al. (2008) (vertical axis only). Further, to capture movement in narrow intensity intervals, we included the whole PA spectrum from all axes (vertical, antero-posterior, and medio-lateral) and created 33 PA variables of total time (min/day) for each axis; 0–99, 100–249, 250–499, 500–999, 1,000–1,499, 1,500–1,999, …, 14,500–14,999, and ≥ 15,000 cpm. For comparability with previous studies, we interpreted PA intensities along the intensity spectrum of the vertical axis according to the cut points suggested by Evenson et al. (2008).

Cognition

Testing of all cognitive and early academic learning measures was performed individually in a room without disturbances. A trained assessor was present and provided instructions, and, if the child preferred, a preschool staff member could join the child in the room, without influencing test procedures. Testing was divided into two blocks of three tests, with a (minimum) 15-min break after the first block, performed in a standardized order (Block 1: Early Years Toolbox (EYT) Go/No-Go, EYT Numbers, and Head-Toes-Knees-Shoulders (HTKS) task and Block 2: EYT Mr. Ant, EYT Card Sorting, and EYT Expressive Vocabulary). All tasks were translated into Norwegian. As some of the tasks lasted longer the better the children performed, the total test duration varied from 30 to 45 min. After completing the measurements, children received a sticker of physically active cartoon figures. Prior to the data collection, all assessors were thoroughly trained in the test procedures, including practice with children. The trained assessor also considered the validity of each task regarding children's understanding of the task instructions.

Self-Regulation

Self-regulation was assessed by a structured, direct measure: The Head-Toes-Knees-Shoulders (HTKS) task. The HTKS assesses the ability of a child to integrate and apply executive function skills to control and direct actions despite instructions that generate contrary impulses. Children were asked to pay attention to and remember instructions, inhibit the automatic responses generated, and instead execute gross motor movements in line with the task goals (Cameron Ponitz et al., 2008). During three blocks of 10 trials each, children were instructed to perform the opposite of the dominant response, such as "touch your head" when instructed to "touch your toes." Rules increased in complexity with each new block. A correct response (opposite of the instruction) was awarded 2 points and self-correction to the correct response (after commencing or completing the incorrect response) was awarded 1 point. If children got ≥4 points on a block, they moved on to the next block. All three blocks started with brief practice with feedback. Possible scores ranged from 0 to 60, such that a higher score indicated better self-regulation.

The HTKS has shown construct validity in measuring children's behavioral self-regulation in European samples (Cameron Ponitz et al., 2009; von Suchodoletz et al., 2013). As this task involved scoring by a trained assessor, we performed an inter-rater reliability test based on video scoring of 18 children prior to the data collection, which showed an intra-class correlation of 1.00.

Executive Function

To measure the three fundamental constructs of executive function—inhibition, working memory, and cognitive flexibility (Miyake et al., 2000; Best, 2010; Diamond, 2013; Zelazo et al., 2016)—we used the iPad-based Early Years Toolbox (EYT), which has shown strong reliability, convergent validity with existing measures, and developmental sensitivity (Howard and Melhuish, 2017).

Inhibition was measured using the EYT Go/No-Go task, which asked children to catch the fish (Go trial, 80%) by tapping the screen when they saw a fish and to avoid the shark (No-Go trial, 20%) by not tapping the screen when they saw a shark. After instructions and a practice round, the task proceeded with 75 stimuli divided evenly into three 1-min test blocks, separated by a short break with repetition of instructions. The animated stimulus (fish or shark) was visible for 1.5 s and separated by a 1 s interstimulus interval. Responses (children tapping the screen) <0.3 s were removed, as this indicates a response that was unlikely to be initiated in response to the stimulus. The outcome measure of inhibition was an impulse control score (product of proportional Go and No-Go accuracy), representing the strength of the prepotent response in relation to children's ability to inhibit this response. Possible scores ranged from 0 to 1, where a higher score indicated better inhibitory control.

Visual–spatial working memory was measured using the EYT Mr. Ant task, which asked the children to remember spatial locations of an increasing number of "sticker(s)" located on Mr. Ant's body. After instructions and a practice round, the task proceeded with three trials (or two trials if correct on the first two) at level one (remembering the location of one sticker), with each subsequent level increasing in difficulty by adding one sticker. The task lasted until the children completed level eight or, in all cases in the current sample, until failure on all three trials at the current level. The outcome measure was a score calculated as one point for each passed level (at least two of the three trials on one level performed accurately) in a row, starting from the first, plus 1/3 of a point for all correct trials thereafter. Possible scores ranged from 0 to 8, where a higher score indicated better working memory.

Cognitive flexibility was measured using the EYT Card Sorting task, asking the children to sort cards of red and blue rabbits and boats by either color or shape, into two locations (identified by a blue rabbit and a red boat). As the card sorting rules alternate, the children must switch between rules. After instructions and a practice round, the task proceeded with three levels of six trials each. On level one, children were asked to sort cards by color and on level two by shape. At least 5 out of 6 correct trials on both levels were required to proceed to level three, where children were asked to sort cards by color if they were surrounded by a black border or by shape if there were no black border. The outcome was the accuracy (number of correct sorts) on levels two and three (when the switch trials began). If accuracy on level two was higher than on level one, values from level one replaced values from level two. Possible scores ranged from 0 to 12, where a higher score indicated better cognitive flexibility.

Early Academic Learning

Early academic learning was assessed as early expressive vocabulary and early mathematical skills, referred to as "vocabulary" and "numeracy," respectively, hereafter. These were also measured using the EYT (Howard and Melhuish, 2017; Howard et al., 2021).

Vocabulary was measured using the EYT Expressive Vocabulary task, consisting of 54 items with increasing difficulty, asking the children to verbally produce a correct label for the depicted nouns and verbs. The task continued until the child completed all items or was automatically stopped because they answered six items in a row incorrectly. We only accepted words pronounced in Norwegian. Vocabulary was scored as the number of correct items. Possible scores ranged from 0 to 54, where a higher score indicated better vocabulary.

Numeracy was measured using the EYT Early Numeracy task, consisting of 79 items of increasing difficulty that pertain to numerical concepts, spatial and measurement concepts, counting subset, matching digits and quantities, number, ordinality, cardinality, subitizing, patterning, numerical word problems, and equations. The starting point varied from item 1, 11, and 21 for children aged 3, 4, and 5 years, respectively. If the child provided three consecutive incorrect answers to begin with (on item 11 or 21), the app returned to the prior starting point. After five consecutive incorrect responses, the task was automatically stopped. Numeracy was scored as number of trials correct across the entire task. Possible scores ranged from 0 to 79, where a higher score indicated better numeracy skills.

Anthropometry, Parental Education, and Sleep

Body mass was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany) with children wearing light clothing. Height was measured to the nearest 0.1 cm using a transportable Seca 217 (SECA GmbH, Hamburg, Germany). Body mass index (BMI; kg·m^{-2}) was calculated. Children were categorized as normal weight (including underweight), overweight, or obese according to the age- and sex-specific BMI cut points by Cole et al. (2000) for descriptive purposes. Parental education level (highest education of mother or father) and children's sleep time were reported by parent(s) or guardian(s) by questionnaire. Sleep was included as a covariate in our analyses due to its important role for learning, memory, and cognitive processing (Deak and Stickgold, 2010).

Ethics Statement

The procedures and methods used in the ACTNOW study are conform to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study was approved by the institutional ethics committee and the Norwegian Centre for Research Data (reference number 248220). ACTNOW is registered in clinicaltrials.gov 7 August 2019, with identifier NCT04048967.[1]

Prior to all testing, each child's parent(s) or guardian(s) provided written informed consent. Children were informed about the study and testing procedures prior to and during measurements according to their level of understanding.

Statistical Methods

Children's characteristics are provided as frequencies, means, and standard deviations (SD). Differences between boys and girls, age groups (younger/older), and included and excluded children were tested using linear mixed models including random intercepts for preschools. PA data were adjusted for wear time. Bivariate associations between explanatory (using SED, LPA, MPA, VPA, MVPA, and TPA as proxies for the intensity spectrum) and outcome variables were determined using linear mixed models on variables adjusted for wear time (PA), sex, and age.

The multivariate PA intensity signatures associated with self-regulation, executive function, and early academic learning were determined using multivariate pattern analysis applied to the uniaxial and triaxial intensity spectra, equivalent to its previous application to accelerometer data (Aadland et al., 2018, 2021; Nilsen et al., 2020). Partial least squares (PLS) regression analyses (Wold et al., 1984) were used to determine the association patterns between self-regulation, executive function, and early academic learning (outcome variables) and both uniaxial (33 intensity variables from the vertical axis) and triaxial intensity spectra (99 intensity variables) included as explanatory variables in separate models. Briefly, PLS regression decomposes the explanatory variables into orthogonal linear combinations (PLS components), while simultaneously maximizing the covariance with the outcome variable. Thus, PLS regression is able to handle completely collinear variables through the use of latent variable modeling (Wold et al., 1984). Models were validated using Monte Carlo resampling (Kvalheim et al., 2018) with 1,000 repetitions by repeatedly and randomly keeping 50% of the subjects as an external validation set. For each model, we used target projection (Kvalheim and Karstang, 1989; Rajalahti and Kvalheim, 2011) followed by reporting of explained variance (R^2) and multivariate correlation coefficients with 95% confidence intervals (CIs) to show the importance of each PA intensity variable in the multivariate space (Rajalahti et al., 2009a,b; Aadland et al., 2019a). To adjust for sources of variation and confounding, we obtained residuals from linear regression models using self-regulation, executive function, and early academic learning (model 1 adjusted for sex age, model 2 additionally adjusted for BMI, sleep, and parental education level) and PA variables (model 1 adjusted for sex, age, and wear time, model 2 additionally adjusted for BMI, sleep, and parental education level) as outcomes, prior to performing the multivariate pattern analysis. In secondary analyses, we determined association patterns separately in boys and girls and younger and older children (defined by median split). A value of $p \leq 0.05$ was considered statistically significant. Multivariate pattern analyses were performed using the commercial software Sirius version 11.0 (Pattern Recognition Systems AS, Bergen, Norway), while all other analyses were performed using the SPSS software, version 28.0 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., United States).

RESULTS

Children's Characteristics

Characteristics of the 711 included children are shown in **Table 1**. Girls performed significantly better than boys on all tests of self-regulation and executive function ($p < 0.002$), whereas early academic learning outcomes were similar for boys and girls ($p = 0.456$ for vocabulary and $p = 0.052$ for numeracy). Boys had significantly higher TPA (cpm) and spent more time (min/day) in all PA intensities, including SED, than girls ($p < 0.001$). The older children (4.6–6.5 years old) performed significantly better than the younger children (2.7–4.6 years old) on all tests of self-regulation, executive function, and early academic learning ($p < 0.001$) and had higher TPA and spent more time in VPA, MVPA, and SED ($p < 0.040$) and had less time in LPA ($p < 0.001$), than the younger children. MPA did not differ among younger and older children ($p = 0.421$).

The included children performed significantly better on all measures of self-regulation, executive function, and early academic learning ($p < 0.001$) than the excluded children. The included children also had significantly higher TPA and spent more time in MPA, VPA, and MVPA ($p < 0.001$) and had less time in LPA ($p = 0.017$) than the excluded children. SED did not differ between the groups ($p = 0.208$).

Association Patterns

Bivariate associations between (proxy) explanatory and outcome variables are shown in **Table 2**. We found significant negative

[1]https://clinicaltrials.gov/ct2/show/NCT04048967?term=actnowandrank=1

TABLE 1 | Children's characteristics.

	Total sample	Boys	Girls	Younger	Older
	***n*=711**	***n*=369**	***n*=342**	***n*=355**	***n*=356**
Age (years)	4.6 (0.8)	4.5 (0.8)	4.6 (0.8)	3.9 (0.5)	5.2 (0.3)
BMI (kg/m^2)	16.2 (1.5)	16.2 (1.4)	16.2 (1.6)	16.3 (1.5)	16.1 (1.5)
Weight status (%)					
Normal	84.5	89.2	79.5	86.2	82.9
Overweight	12.8	8.9	17.0	11.8	13.8
Obese	2.7	1.9	3.5	2.0	3.4
Sleep (min/day)	657 (44)	657 (44)	658 (43)	668 (41)	646 (44)*
Parental education level (%)					
≤Upper secondary school	23.2	23.3	23.1	21.4	25.0
University/college <4 years	29.1	30.1	28.1	30.7	27.5
University/college ≥4 years	47.7	46.6	48.8	47.9	47.5
Physical activity					
Wear time (min/day)	765 (69)	767 (70)	763 (67)	761 (67)	769 (70)
Total PA (cpm)	696 (153)	729 (151)	659 (147)*	676 (144)	715 (159)*
SED (min/day)	540 (64)	531 (63)	549 (64)*	534 (64)	545 (64)*
LPA (min/day)	149 (21)	155 (21)	143 (19)*	153 (21)	145 (21)*
MPA (min/day)	38 (7)	41 (8)	35 (6)*	38 (7)	38 (8)
VPA (min/day)	38 (10)	40 (11)	36 (10)*	36 (10)	40 (11)*
MVPA (min/day)	76 (17)	81 (17)	71 (15)*	74 (16)	79 (17)*
≥60 min MVPA/day (%)	85.4	90.8	79.5*	83.1	87.6
Self-regulation (score)	15.2 (18.0)	13.3 (16.9)	17.4 (18.8)*	6.8 (11.9)	23.7 (19.0)*
Executive function (score)					
Inhibition	0.60 (0.24)	0.56 (0.24)	0.65 (0.24)*	0.49 (0.23)	0.71 (0.19)*
Working memory	1.53 (0.97)	1.42 (0.99)	1.65 (0.93)*	1.11 (0.91)	1.95 (0.82)*
Cognitive flexibility	6.85 (3.05)	6.49 (3.03)	7.24 (3.01)*	5.95 (3.00)	7.74 (2.87)*
Early academic learning (score)					
Vocabulary	26.3 (9.6)	26.1 (9.6)	26.6 (9.5)	21.6 (8.5)	31.0 (8.2)*
Numeracy	31.5 (15.1)	30.5 (15.2)	32.0 (14.9)	22.5 (11.4)	40.4 (12.8)*

*All values are mean (SD) if not otherwise stated. BMI, body mass index; SED, sedentary time; LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity; and MVPA, moderate to vigorous physical activity. Weight status defined by the Cole et al. (2000) criteria. Physical activity level defined by the Evenson et al. (2008) cut points applied to the vertical axis. All data adjusted for physical activity valid days = ≥3 weekdays and 1 weekend day. Only subjects with valid data on all variables were included in analysis. *Significant difference between boys and girls, and between younger and older children, p ≤ 0.05.*

associations between LPA and inhibition ($r = -0.10$) and between SED and numeracy ($r = -0.08$). Associations with numeracy were significant and positive for MPA, VPA, MVPA, and TPA ($r = 0.08$–0.10). Also, we found positive associations between self-regulation, executive function, and early academic learning ($r = 0.21$–0.32).

In multivariate pattern analyses, we found a significant association between PA and inhibition ($R^2 = 1.48\%$, 2 PLS components; **Figure 2**), but no associations with working memory or cognitive flexibility, when using uniaxial data. The associations with inhibition were positive for time spent in 0–99 cpm and intensities ≥8,500 cpm, and negative for time spent in intensities between 100 and 3,499 cpm. Also, we found a significant association between PA and numeracy ($R^2 = 4.28\%$, 4 PLS components; **Figure 3**), but no association with vocabulary, when using uniaxial data. The associations with numeracy were positive for time spent in intensities between 1,000 and 7,499 cpm and ≥13,000 cpm, and negative for time spent in 0–99 cpm. We found no significant association between PA and self-regulation.

For triaxial spectra, we found a significant association between PA and numeracy ($R^2 = 1.12\%$, 1 PLS component, **Supplementary Figure 1**). No other associations were significant. As associations for the triaxial PA spectra were weaker than for the uniaxial spectrum, we used the uniaxial spectrum for the subgroup analyses.

In subgroup analyses, we found a significant association between PA and self-regulation in boys ($R^2 = 1.70\%$, 1 PLS component, **Supplementary Figure 2**), but not in girls, younger children, or older children. The associations with self-regulation in boys were positive for time spent in intensities ≥500 cpm, and negative for time spent in 0–99 cpm. Further, we found significant associations between PA and inhibition in girls ($R^2 = 3.12\%$, 2 PLS components) and older children ($R^2 = 3.33\%$, 2 PLS components; **Supplementary Figures 3A,B**), but not in boys and younger children. The associations with inhibition in girls were positive for time spent in 0–99 cpm and intensities ≥5,500 cpm, and negative for time spent in intensities between 100 and 2,499 cpm. The associations with inhibition in older children were positive for time spent in 0–99 cpm and time spent in intensities ≥10,000 cpm, and negative for time spent in intensities between 100 and 3,499 cpm. We also found significant associations between PA and numeracy in boys ($R^2 = 5.58\%$, 3 PLS components) and older children ($R^2 = 7.27\%$, 4 PLS components; **Supplementary Figures 4A,B**), but not in girls and younger

TABLE 2 | Bivariate associations (standardized regression coefficient) among and between independent and dependent variables.

S. No.	Variables	1	2	3	4	5	6	7	8	9	10	11	12
1.	Sedentary time	–											
2.	Light PA	**−0.90**	–										
3.	Moderate PA	**−0.91**	**0.72**	–									
4.	Vigorous PA	**−0.73**	**0.38**	**0.73**	–								
5.	MVPA	**−0.86**	**0.56**	**0.90**	**0.95**	–							
6.	Total PA	**−0.80**	**0.51**	**0.77**	**0.96**	**0.94**	–						
7.	Inhibition	0.06	**−0.10**	−0.03	0.03	0.00	0.01	–					
8.	Working memory	−0.03	0.04	0.01	0.02	0.01	0.03	**0.27**	–				
9.	Cognitive flexibility	0.06	−0.05	−0.05	−0.05	−0.06	−0.07	**0.13**	**0.14**	–			
10.	Language	−0.02	0.01	0.02	0.04	0.04	0.04	**0.21**	**0.27**	**0.21**	–		
11.	Numeracy	**−0.08**	0.04	**0.10**	**0.09**	**0.10**	**0.08**	**0.28**	**0.32**	**0.26**	**0.55**	–	
12.	Self-regulation	−0.01	−0.01	0.02	0.04	0.03	0.04	**0.18**	**0.24**	**0.24**	**0.36**	**0.47**	–

PA variables (1–6) adjusted for sex, age, and wear time; cognitive and learning variables (7–12) adjusted for sex and age. PA, physical activity; MVPA, moderate to vigorous physical activity. Significant associations at p ≤ 0.05 are highlighted in boldface.

children. The associations with numeracy in boys were positive for time spent in intensities ≥1,500 cpm, and negative for time spent in 0–99 cpm. The associations with numeracy in older children were positive for time spent in intensities between 1,500 and 7,499 cpm and ≥ 12,500 cpm, and negative for time spent in 0–99 cpm.

DISCUSSION

Using the novel approach of multivariate pattern analysis, we investigated association patterns for both uniaxial and triaxial PA intensity spectra with self-regulation, executive function, and early academic learning in 3–5-year-old children. For the triaxial PA spectra, we found a weak association pattern with numeracy, but no significant associations with other outcome variables. For the uniaxial PA spectrum, we found weak positive association patterns with numeracy and inhibition. Subgroup analyses for the uniaxial PA spectrum showed that the association between PA and numeracy only was evident in boys and older children, while the association between PA and inhibition only was evident in girls and older children. In addition, we found a weak positive association between PA and self-regulation in boys. We did not find any significant associations between PA and working memory, cognitive flexibility, or vocabulary.

Our finding of weak positive associations between moderate and vigorous PA intensities and numeracy are consistent with the findings of Bai et al. (2021) who found a positive association for both total PA and MVPA with cognitive school readiness (which also included colors, sizes, shape recognition, and comparison ability) in preschoolers. However, other studies in preschoolers have reported no associations between MVPA and numeracy-related outcomes (Becker et al., 2014; St. Laurent et al., 2018). Yet, since the assessment of outcomes differs with our study and across these studies math achievement by Becker et al. (2014), number recognition by St. Laurent et al. (2018), and school readiness by Bai et al. (2021), the findings may not be directly comparable. Also, Becker et al. (2014) only included assessment of PA during outdoor recess sessions, and thus excluded indoor activities and activities after preschool hours. Moreover, the previous studies (Becker et al., 2014; St. Laurent et al., 2018; Bai et al., 2021) had small sample sizes, used 15-s epoch length, and did not include the entire PA intensity spectrum in their analyses. Since including a high-resolution PA intensity spectrum can capture more information of movement behaviors of relevance for the outcomes than traditionally applied descriptors of PA (Aadland et al., 2019a, 2021; Nilsen et al., 2020), findings of Becker et al. (2014), St. Laurent et al. (2018) and Bai et al. (2021) are limited by relying on only a few gross intensity categories. Inclusion of the whole intensity spectrum has been called for in several previous studies (Poitras et al., 2016; van der Ploeg and Hillsdon, 2017).

Our findings showing an association between PA and numeracy but not between PA and vocabulary are consistent

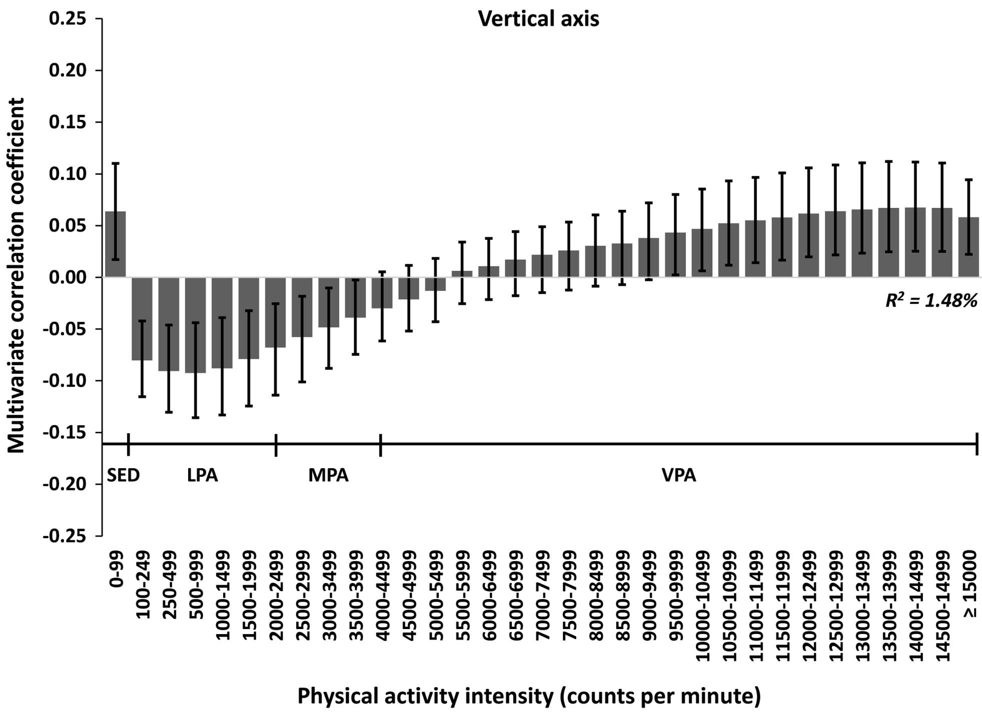

FIGURE 2 | The multivariate physical activity signature for the uniaxial spectrum associated with inhibition in preschoolers. Results are reported as multivariate correlation coefficients. The model (PLS regression) is adjusted for sex, age, wear time (only PA variables), BMI, parental education level, and sleep (model 2).

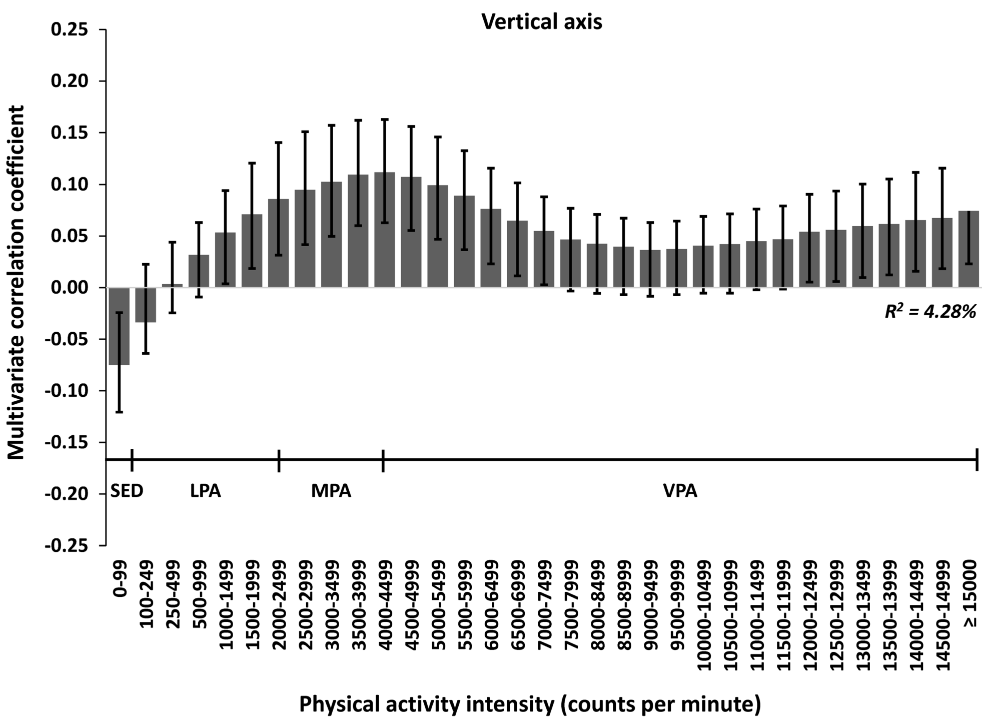

FIGURE 3 | The multivariate physical activity signature for the uniaxial spectrum associated with numeracy in preschoolers. Results are reported as multivariate correlation coefficients. The model (PLS regression) is adjusted for sex, age, wear time (only PA variables), BMI, parental education level, and sleep (model 2).

with findings from intervention studies in children and youth, showing beneficial effects of PA on math performance, while evidence regarding language-related outcomes are inconclusive (Donnelly et al., 2016; Singh et al., 2018). However, in line with the present study, previous observational studies examining associations between PA and academic achievement in school-aged children and youth show weak positive associations for some academic areas but no associations for others, though findings are inconsistent across studies (Rasberry et al., 2011; Donnelly et al., 2016). Limited evidence exists for associations with intensity-specific PA (Donnelly et al., 2016). Nonetheless, based on the present study findings, and the prevailing evidence on the relationships between PA and academic achievement irrespective of study design, PA appears to influence numeracy to a larger extent than vocabulary/literacy. With respect to intervention studies, such findings could derive from physically active lessons being more easily implemented with numbers, counting, and the use of mathematical concepts than with vocabulary/literacy (Donnelly et al., 2016; Singh et al., 2018). At the same time, vocabulary and literacy may have a greater focus and higher quality learning practices than numeracy-related practices in typical preschool settings where children are not necessarily physically active, possibly resulting in language learning being more ubiquitous than numeracy learning. However, information regarding PA content and context is needed to further address these hypotheses. We further speculate that the lack of inter-relationships between PA and vocabulary in the present study could relate to the lack of associations found between PA and both self-regulation and executive function since these cognitive functions play an essential role in learning processes (Barenberg et al., 2011; Donnelly et al., 2016; St. Laurent et al., 2018). However, bivariate associations in the present study showed that all constructs of self-regulation and executive function were correlated with both measures of early academic learning. Thus, there is no obvious reasons to expect that such inter-relationships could differently affect the associations for numeracy and vocabulary.

We found a weak association between PA and inhibition. However, it is difficult to interpret this association pattern showing that associations for both SED and VPA were positive, while associations for LPA and MPA were negative. A positive association between VPA and inhibition is different from findings by Cook et al. (2019), showing no associations for total PA or MVPA with inhibition. Furthermore, Cook et al. (2019) found no associations between PA and cognitive flexibility, but a negative association between PA and working memory, and suggested that free play does not enhance development of executive function. The positive association between SED and inhibition in the present study indicates that SED might facilitate inhibition in preschoolers and underlines the need to explore the influence of various sedentary behaviors. Findings of previous studies indicate that reading and/or being read to are associated with beneficial cognitive development while screen time, and in particular TV-viewing, is not or negatively associated with cognitive development in preschool-aged children (Carson et al., 2015). Importantly, the findings of Carson et al. (2015) are based on a small number of studies with low sample sizes. However, as the present study did not include information on types of sedentary behaviors, we can only speculate on the cognitive benefits of participating in activities typically characterized as sedentary, such as reading books/being read to, solving puzzles, playing with Lego, learning activities during group time or watching/using various screens. Therefore, future studies should include observation of PA and SED content and context to improve knowledge on associations between accelerometry data and executive function.

Even if individual variation in executive function development is present already in the preschool years (Liebermann et al., 2007; Garon et al., 2008), evidence suggests that brain structures that support executive function mature into adolescence and early adulthood (Tamnes et al., 2010). Therefore, we recognize that the process of executive function differentiation in children is slow and that particular tasks may be more or less sensitive to developmental improvements (Diamond, 2006; Lee et al., 2013). However, the present study found that girls and older children scored better on self-regulation and all three executive function components compared to boys and younger children, which may support that our assessments have captured individual differences in cognitive development. Also, our subgroup analyses revealed that PA was associated with inhibition among girls and older children only, which might be explained by differences in cognitive developmental status, supported by previous studies showing more consistent positive associations between PA and cognitive outcomes in school-aged children (Donnelly et al., 2016).

Previous studies have shown positive associations between PA and self-regulation (Becker et al., 2014; Bai et al., 2021) using the HTKS task, as also used herein. Because HTKS has an inherent motor component requiring children to perform bodily movements, our finding showing no association between PA and self-regulation was somewhat unexpected. However, this finding might be consistent with the weak or non-existent associations between PA and executive function. Indeed, HTKS is dependent on involvement of all executive functions in requiring children to inhibit prepotent cognitive responses and bodily movements by focusing and remembering specific rules (Cameron Ponitz et al., 2008, 2009). Also, as cognitively engaging and complex exercise is hypothesized to have a stronger impact on cognitive development than non-engaging and simpler exercises (Best, 2010; Diamond, 2015; Schmidt et al., 2015; Tomporowski et al., 2015), the lack of associations found between PA and both executive function and self-regulation in the present study might relate to insufficient cognitive demands embedded in PA. Notably, our subgroup analyses showed a weak positive association between PA and self-regulation among boys. We have no good explanation for a possible different association for boys and girls. Given the very weak association in boys, it could be a chance finding. We may also speculate whether poorer self-regulation (Gestsdottir et al., 2014) but higher PA levels in boys than in girls mean that boys inherently need more movement than girls and that this stimulus to a larger extent in boys than in girls positively affect self-regulation. This hypothesis is consistent with greater benefit of physically active learning in school-aged boys than in girls (Resaland et al., 2018).

Our finding of lower explained variances when using triaxial as compared to uniaxial PA intensity spectra, contrasts previous studies with children and preschoolers showing higher explained variances using triaxial data (Aadland et al., 2019b, 2021). The previous findings show that triaxial data can capture information about PA that uniaxial data cannot and that this information is relevant for the outcome. Nilsen et al. (2020), however, found that uniaxial and triaxial accelerometry provided rather similar information in relation to fundamental motor skills in preschoolers. A possible reason for our result is inclusion of many variables with little or no relevant information for the outcome (i.e., "noise"). This may alter the covariance structure and number of valid PLS components and thus lead to poorer model fit and weaker associations as expressed by the target projected component (Kvalheim, 1985).

Strengths and Limitations

First, the main strength of this study was the inclusion of the whole PA intensity spectrum (based on a 1-s epoch length) from both uniaxial and triaxial accelerometry and the use of multivariate pattern analysis for determination of joint associations for the PA intensity variables with the outcomes. Second, the relatively large sample size facilitated generalizability of findings and allowed for us to explore sex- and age-specific associations. Third, we adjusted for sex, age, wear time, BMI, parental education level, and sleep. Further adjustment for preschool did not affect findings (results not shown). Therefore, we argue that the present study provides unique and nuanced evidence of association patterns between PA and key aspects of cognitive and learning outcomes in 3–5-year-old children.

Accelerometers are not without limitations and are not able to correctly capture certain activities that may characterize young children's movement behaviors, such as rolling, crawling, climbing, cycling, and other non-load bearing activities. Moreover, accelerometers are not able to provide information on type or context of PA or sedentary behaviors. In addition, the cross-sectional design lacks a temporal relation between the exposure and outcome, meaning that we cannot demonstrate causal relationships. We recommend that future studies seek to determine longitudinal associations and pathways between PA and cognitive and learning outcomes in preschoolers. Finally, the present study did not investigate associations between PA and motor skills. Since motor skills have been shown to associate with cognitive and learning outcomes in children (Diamond, 2000; Cameron et al., 2012; Aadland et al., 2017), future studies should explore associations between PA, motor skills, and cognition.

CONCLUSION

The purpose of the present study was to investigate associations between PA and cognitive and learning outcomes in children aged 3–5 years old. We included a large sample of preschoolers and explored PA association patterns by using the novel approach of multivariate pattern analyses. Our findings revealed weak association patterns between the PA intensity spectrum and numeracy and inhibition. Subgroup analyses showed stronger associations between PA and numeracy in boys and older children and stronger associations between PA and inhibition in girls and older children than in their peers, respectively. We recommend that future studies include observation of PA and SED content and context to help interpret associations with accelerometry data. Future studies should also determine longitudinal and causal relationships to further address the role of PA in promoting child cognitive development and learning.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because Privacy protection regulations restrict sharing of data. Requests to access the datasets should be directed to kbva@hvl.no.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The institutional ethics committee and the Norwegian Centre for Research Data. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

EA, KA, and SH contributed to conception and design of the study. KV, EA, and KA organized the database and wrote sections of the manuscript. KV and EA performed the statistical analysis. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.842271/full#supplementary-material

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Indoor Pool Game and Substance Abuse as Trajectories to Students' Academic Procrastination: The Mediation Role of Self-Regulation

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Background: Over the last decade, indoor pool games (IPGs) and substance abuse (SA) became a remarkable emerging addictive behavior among adolescent university students. With the failure of educational quality and retention of learners, boomerangs around the university local environment in line with the students' learning culture were not considered in many countries including Ethiopia. Thus, this study aimed to examine the trajectory and contribution of an IPG and SA to students' academic procrastination (AP) as determinants of quality education.

Methods: A sequential explanatory mixed-methods design was employed. Self-reporting questionnaires, interview guides, and an observation checklist were used to collect data. All self-reporting items were adapted from previous scales. By using simple random sampling techniques, 237 undergraduate university students were selected for obtaining the quantitative data, and using purposive sampling, 12 interviewees were selected to collect the qualitative data. The SPSS AMOS version 25 was used to compute the multiple mediation path analysis. The Hayes PROCESS macro model was used. Furthermore, the thematic content analysis method was employed for the qualitative data.

Results: A direct path analysis was established between IPG, SA, and AP. The path analysis model indicated that IPG did not significantly predict AP. Moreover, SA significantly predicted AP. In addition, SR had a partial mediating effect on the relationship between IPG, SA, and AP.

Conclusion: The study concluded that IPG and substances available around the university local environment found trajectories to students' AP, which in turn affects the quality of education.

Keywords: academic procrastination, indoor pool game, mediation, substance abuse, university students

INTRODUCTION

In meeting the demand of a rapidly changing world, every country needs a well-educated citizen that has competencies to upgrade and form a decisive alignment to future social development (United Nations Educational, Scientific and Cultural Organization [UNESCO], 1998, 2015a,b; Educational, Scientific and Cultural Organization [UNESCO], 2017; American Association of Colleges of Teacher Education [AACTE], 2010; Granados-Sánchez, 2011; Kromydas, 2017). This can be achieved through the quality culture of higher education that preserves the societal standards of welfare (Vilcea, 2014; Sattler and Sonntag, 2018) and an interactive and mutually supportive relationship that helps learners progress toward their valued goals (Organization for Economic Co-operation and Development [OECD], 2019).

Moreover, to produce learners that best fit the growing demand of the 21st century, it is vital to redesign a system that aligns with educational goals and sustainable development (Scott, 2015); and it needs to be supported by different contributors and educational partners (Idrisa et al., 2012; Gross et al., 2015; Gurlui, 2015; Chantia, 2017; Chakraborty et al., 2018; O'Connor and Daniello, 2019; Pandey, 2020; Levitt, n.d.). Equally important, the university's local environment may have roles in capitalizing on learner's retention and academic performance. A university's local environment is contextually defined as the social and physical availability of factors contributing to the students' academic procrastination (AP).

In addition, educational institutions strong relationship with the educational ecosystem and this ecosystem in turn (pedagogic dimension, schools, homes, and localities) are a protective factor that enables the learners to reach their full potential (Ellis and Goodyear, 2019). Moreover, success in the education system and learners' holistic well-being is secreted in both the university's contribution to the community's demand and the community's partnership in education (Puckett, 2017).

In support of this, previous studies revealed that a conducive and supportive school environment has a vital role in the engagement of learners and learning outcomes (Cohen et al., 2009; Puckett, 2017). Thus, a mutual understanding of the goal of education between the university and external bodies, such as locally authorized professionals, communities, business owners, and voluntary groups, has a chief contribution to the positive stimulation of effective education. Having a common goals and purposes of education among the contributors put grace in the educational destination (The University of Edinburgh, 2017).

On the other hand, when educational contributors and stakeholders have different corners of concentration, failure of academic wisdom is possible. For instance, Hossein Mardi and Hossein (2015) revealed that the university students' academic culture is largely driven by the social environment, featuring a longstanding culture of alcohol, khat, hashish, and behavioral addiction. Promotions, sponsorships of concerts, and the marketing of alcohol and other substances on and near campuses add immediacy to the pressure of the popular culture of consumption (Substance Abuse and Mental Health Services Administration, 2019).

Similarly, gambling practice is widely taking place around universities, targeting university students. Many studies reported that as governments legalized gambling and substance use as entertainment, they have become public health concerns, especially for the youth (LaPlante et al., 2009; Afifi et al., 2010; Abbott, 2017; Binde et al., 2017; Calado et al., 2017; Oksanen et al., 2019; Substance Abuse and Mental Health Services Administration, 2019; Lelonek-Kuleta et al., 2020; Mazar et al., 2020). The availability of indoor pool games (IPG; Welte et al., 2009; Tariku et al., 2015; Mehari and Koye, 2019; Anyanwu et al., 2020), personal level factors (self-esteem, false perceptions, and drug abuse), social factors (peer influence and modeling), and environmental influences (availability of gambling places and advertisements) has a strong association with gambling ramifications, such as problematic emotional and mental well-being, fragile relationship pattern, economic instability such as indebtedness, loss of savings, and assets (Tariku et al., 2015), and the wastage of time economy revealed in the form of AP for the student population (Nordby et al., 2019; Akinci, 2021).

Furthermore, Walters (2004) reported that the impact of drug tradition has effectively stayed on campuses from coast to coast. Another in-depth qualitative study conducted by Tekalign (2012) on children and the youth in Arba Minch city of Ethiopia also confirmed that drug houses around schools are one of the various factors that affect children's and youth's positive development. Following the wide availability of substances in the university local environment, the self-regulation (SR) (Senécal et al., 1995; Bernardo et al., 2019; Katana et al., 2019; Natashia, 2020; Valenzuela et al., 2020) and AP of learners (Park and Sperling, 2011; Yi-Chun et al., 2017; AbdiZarrin et al., 2020; Najma and Sultan, 2021; Solyst et al., 2021; Yang, 2021) are factors that need due consideration. In this regard, even though the notions of gambling and AP are emerging as topics of studies in recent decades, these studies focused on their prevalence. For instance, an in-depth phenomenological study conducted with six participants selected using snow-ball sampling in Bahir Dar city of Ethiopia indicated that a pool game is one of the most common types of problematic gambling activities (Mehari and Koye, 2019). Similarly, Getu (2018) assured that pool games were the most prevalent form of gambling that was practiced by adolescent students. Moreover, a study conducted by Tariku et al. (2015) on students (N = 422) ranging from 12 to 21 years of age stated that the pool game was one of the gambling activities played for money in Ethiopia. Thus, despite taking a glance at the availability of this game in the school environment, none of the previous studies clearly presented its contribution to the students' learning from an AP aspect.

Moreover, substance abuse (SA) among college students is a growing social and health problem. A study conducted among European University students indicated that about 73% of the study participants took alcohol alone or together with cannabis/hashish and/or other illicit drugs (Colomer-Pérez et al., 2019). SA has also a relationship with AP (Wormington et al., 2012; Moes, 2016; Westgate et al., 2017; Ahmadi et al., 2020). In addition, a cross-sectional survey of a stratified random sample of 4,734 high school students aged 12–23 years in Hong Kong has found out that gambling significantly correlated with a high occurrence of alcohol and substance use (Cheung, 2014). However, to our knowledge, the contributions of an IPG and SA on the AP of university students have never been addressed, especially in similar contexts of the study area.

In the context of this study, as education institutions, specifically colleges and universities, have become more accessible, significant problems that affect the future of education appear together. In this case, no matter how the universities' local communities support the learners and the universities' teaching-learning processes, physiologically and psychologically addictive substances (khat and IPG- as an emerging sort of recreation) in recent days could have indirect boomerang effects on students' learning through AP. Many previous studies focused on students' SA. Nevertheless, these studies have not considered the mediating role of the learner's SR in the relationship between IPG, SA, and AP of university students. To address this gap, we tried to check whether SR has a mediating role in the relationship between the above-mentioned study variables. Accordingly, the following research questions were forwarded:

1. To what extents do IPG and SA contributed to the students' AP?
2. Does SR mediate the contribution of an IPG and SA to the university students' AP?

MATERIALS AND METHODS

Research Design

The study employed a sequential explanatory mixed methods design. Quantitative research was mainly the leading research approach. A qualitative approach was employed to support the quantitative part and was used in the mediation studies to identify the possible mediators and explain the causative mechanisms and the contextual factors in which they function (Behrens and Smith, 1996; Davidson, 2000; MacKinnon, 2008). The qualitative mediation study is poorly documented (Bate et al., 2012). We, therefore, gathered more in-depth information on the causal processes that can also complement the quantitative findings.

Population and Sampling

The population of the present study was university students. A total of 507 students were randomly selected at game zones and a mini-house where they play pool games. Of the total 507 selected university students, 394 university students who had both substance use and IPG practice were identified. A total of 237 students were randomly selected from those who had a practice of both substance use and IPG. Perhaps the most important advantage of choosing a random sample is that researchers can rely on the assumptions of statistical theory to conclude from what is observed (Moore and McCabe, 2003). In the simplest random sample, all units in the population are equally likely to be selected. As a result, researchers are convinced to use simple random sampling from those who had an experience of both SA and IPG. Moreover, a total of 12 participants, five from the students and seven from local business owners, were selected purposively for the qualitative study. Students who had a practice of either SA or IPG were excluded from the study.

Tools of Data Collection

Overusing or using a substance in a manner other than it is intended to use is a sign of SA. Taking substances more often than required or in higher doses is a sign of SA (Parikh, 2021). Moreover, Bresheares et al. (2009) reported that substance use can be considered abuse when its recurrence results in a failure to fulfill obligations at work, home, or school. Similar to these findings, this study was treated in the circumstance when university students use substances or engage in IPG more often or in a manner that puts them at academic, social, psychological, and any other negative costs that make them disadvantageous.

Thus, data were collected using an adapted self-reporting questionnaire. A European School Survey Project on Alcohol and Other Drugs (European School Survey Project on Alcohol and Other Drugs, 2015) five-point alternative Likert scale ranging from "Never" = 1 to "Always" = 5 was adapted to assess the SA and IPG. For example, "When I am not playing a pool, I often think about it, 'I play a pool longer than originally planned"' were few sample questions used for an IPG.

The academic procrastination questionnaire was adapted from Yockey's (2016) short-scale five-point alternative Likert scale ranging from "Strongly disagree" = 1 to "Strongly Agree" = 5, whereas SR items were adapted from Chen and Lin (2018). Few of these questions were, "I put off projects (assignments, home works, studying) until the last minute"; "I know I should work on schoolwork, but I just don't do it" were examples of questions used for AP. These questionnaires were translated to two local languages (Afaan Oromo and Amharic languages) in addition to the English language. Forward-backward translation was done and expert evaluation was made after the questionnaire was translated to the two local languages. Semi-structured items and observation checklists were also rigorously evaluated by experts.

Data Analysis

A pilot study was conducted with 33 sampled individuals. Pilot study participants were sampled using simple random sampling from Jimma University Institute of Technology and were not included in the main research. At alpha reliability coefficients of the pilot study participants $\alpha = 0.871$ for IPG, $\alpha = 0.721$ for SA, $\alpha = 0.745$ for SR, and $\alpha = 0.741$ for AP, the final administration of the questionnaire was done. Throughout the study, a 95% CI and a 5% margin of error were used. Mediation analysis assumptions were checked and all assumptions were met. The data were computed with the Statistical Package of Social Science (SPSS, AMOS, version 25, United States). The contribution of SA and IPG to AP through SR was examined using the Structural Equation Model (SEM) path analysis. Moreover, the qualitative data obtained through interviews were transcribed and coded by the researchers and data collection assistants. Referring to Allen (1998) that stated (i) the core category which all others events related to, (ii) the processes leading to the core category that guide the action to the core category, and (iii) the causal conditions that allude to the occurrences that lead to the development of the marvel which is the main category were applied, and a content analysis was done. Thus, the theme categorizes transcribed data into a core category, process, and causal conditions.

Ethical considerations got due attention since the study was conducted on humans and community wisdom. All ethical, legal, regulatory norms, and standards that care for human subjects were also considered. After, the rigorous evaluation and the comments of Institutional Review Boards (IRB) of the College of Education and Behavioral Sciences, a letter to conduct the study was taken from the Jimma University College of Education and the Behavioral Science Research and Post Graduate Coordinating Office after careful evaluation and comment on the research protocol. The privacy and confidentiality of the respondents were ensured. Informed consent was taken from participants.

RESULTS

Socio-Demographic Variables of the Study

The mean age of the participants was 22.87 (SD = 1.79). The minimum age was 17, while the maximum was 30 years of age. Regarding the gender of the participants, 231 (97.5%) were male, whereas 6 (2.5%) were female. This indicates that a large number of the participants were male (see **Table 1**).

Regression Analysis Predicting Academic Procrastination

As revealed in **Table 2**, in the first stage (Regression Equation 1), a direct path (H1) was established between IPG and AP and SA and AP as the first condition of the mediation analysis. The independent variable (IPG) did not predict the dependent variable (AP) significantly ($\beta = 0.08$, $t = 0.554$, $p = 0.260$). In the second stage (Regression Equation 2), another predictor (SA) was significantly and positively predicted by AP ($\beta = 0.33$, $t = 5.941$, $p < 0.05$). According to these findings, H2 was confirmed and 24.6% of the variance AP was explained by substance abuse. As **Table 3** indicates, in the third stage (Regression Equation 3), after the inclusion of the mediator variable (SR) in the model, IPG and SA predicted AP significantly but there was a decrease in the impact coefficient of SA and a change in the direction ($\beta = -0.283$, $t = -4.929$, $p < 0.001$). According to these findings, SR had a partial mediating effect on the relationship between IPG, SA, and AP. Mediator variable analysis is shown in **Figure 1** below.

In **Figure 1**, above the indirect effect of IPG and SA on students' AP through SR [0.14 (−27) × 0.30 = 0.123] corresponds to 26% (0.123/0.473 = 0.65) of the total effect (0.123 + 0.08 + 0.27 = 0.473). With the inclusion of the mediator variable in the model, there was a decrease of 0.143 in the variance explained in the dependent variable. When the mediator variable (SR) is not included in the model, this rate increases to 33%, and the direction changes. However, qualitative data indicate that IPG had a significant impact on the students' academic behavior and mental well-being.

TABLE 1 | Demographic characteristics of the participants.

Variables	
Age (in years)	
Mean	22.87
Standard deviation	1.79
Minimum	17
Maximum	30
Gender	
Male	231 (97.5%)
Female	6 (2.5%)

Interviewee 1

> *. . . I consider gaming as a part of life. But, when I think of the time and money I spend in indoor pool gaming and gambling, I felt guilt, and hate my existence. My family hates gambling; if they know that I am gambling they surely refuse sending me the money even for copying a handout. Moreover, I couldn't study with my full conscience after coming back from the game.*

> *I have tried to stop gaming many times, yet I couldn't do that. What is most boring in this gaming is the regression and revenge I experience after playing. The amount of money I pay for a table when I am defeated is not weigh [sic] up before and during gambling and gaming. But, if defeated, I perceive myself as I am worthless since my thought was with the money I paid followed by excessive stress, and over-anxiety to study.*

Another Interviewee 2

> *I am a third-year economics student. The reason I go to the pool game zone is to take a rest for a while. After I start gaming if I win, I decide to play till I defeated one. If I am a winner for a long round, I perceive myself as a hero and star player. So, I never stop gaming. If I am defeated, I develop I sense of revenge that says "it is my humiliation to go until I defeat it again." So that, I have to wait until my turn gets to and I stay for a long time. Thus, most of the time, I spent a long time at least triple of the time I planned to stay at an indoor pool game. But when I turn back, I am in intrapersonal conflicts; consider myself as I am worthless, upset, and resentful about the many I paid and the time I wasted without studying.*

Another Interviewee Also Suggested

> *I am a psychology student at Gambella University, Ethiopia. It is not my interest to spend a long time on gaming. At the preliminary phase, whenever I plan to go to the game zones, I decide to play only two rounds. But after I get into the room unknowingly, I stay a long time. This is not a day or 2 days experience. I experience this all the time. Financial loss, academic score deterioration, and moral guilt are at the center of this practice.*

> *The result from observation also revealed that participants felt restless and were eager to engage in the game. But after they played, those who were defeated in the game had intense psychological dissatisfaction behavioral and emotional disturbance, guilt feeling, and worthlessness intensively manifested after being defeated once [sic] or more rounds of in-door pool game. Wreak, pessimism, self-criticism, and emotional discomfort were also repeatedly noticed.*

TABLE 2 | Hierarchical regression analysis predicting academic procrastination.

Reg. equal	Dependent variable	Independent variables	*B*	β	*t*	Adjusted R^2	*F*
1	Academic procrastinate	In-door PG	0.041	0.08	0.554	0.246	681.023
		Subs. Abuse	0.196	0.33	5.941		
		Self-Reg.	−0.126	−0.283	−4.929		

B, Beta; β, standardized beta; t, t-score; R^2, Coefficient of determination; F, critical value, $P < 0.05$.

TABLE 3 | The direct and indirect path effect for the mediation model ($N = 237$).

	Model paths	Estimates	SPC	SE	CI		
					Lower	Upper	*p*
Standardized direct	IPG→AP	0.081	0.08	0.072	−0.049	0.241	0.260
	IPG→SR	0.141	0.14	0.087	−0.033	0.316	0.108
	SA→AP	0.332	0.33	0.061	0.202	0.467	0.010
	SA→SR	−0.268	−0.27	0.068	−0.429	−0.138	0.010
Standardized indirect	IPG + SA→SR→AP		−0.30	0.072	−0.109	0.009	0.010

IPG, Indoor Pool Game; AP, Academic Procrastination; SA, Substance Abuse; SR, Self-Regulation; SPC, Standardized Path Coefficient; SE, Standard Error; CI, confidence interval.

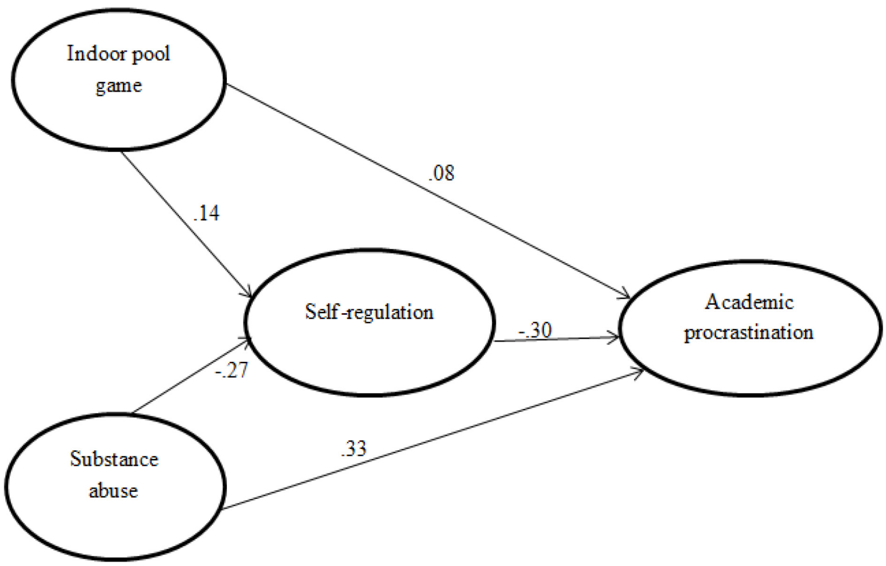

FIGURE 1 | The conceptual framework of the mediation role of self-regulation in the relationship between indoor pool game, substance abuse, and academic procrastination.

On the other hand, the local business owners' perception of IPG on the students' academic culture was revealed as positive. Local business owners perceived game zones and IPG around the university as a means of supporting the students' teaching-learning process.

Most of the Interviewees Reported

We feel as we are partners of education and also supporting the teaching-learning process. We support this through availing what makes students free whenever they want to be. In this case, indoor pool games are the main source of refreshment for university students. For instance, students who have little money which is not enough to use something at the cafeteria can play a pool game with 5 (five birr) coming to the game zone. But when they got to the cafeteria, it is inevitable to pay twofold or threefold for this. Hence, the financial cost of the encounter is not as greater as the benefit they gain.

Moreover, students develop alternative thinking behavior and problem-solving skills. When they play a pool, they can develop self-confidence, interpersonal skills and friendship bonds, and related psychological assets as they grow to the best player. But if they go to the cafeteria, they may intake something and make communications on a certain topic(s). So, gaming has a paramount role in youths' mental wellbeing.

However, most students may not come to the star player within a short period. For these individuals, the frequency of paying table, the value may be high. As a result, these individuals feel bored, angry, and also may feel guilt feeling since most of the university students are family-dependent.

All of the effects of the path were reported. A direct path was established between IPG and AP and also between SA and AP. Of the independent variables, SA predicted the dependent variable (AP) significantly and positively ($\beta = 0.33$, $t = 5.941$, $p = 0.010$). According to these findings, 24.6% of the variance in AP was explained by SA. In the second regression equation, IPG predicted AP insignificantly ($\beta = 0.08$, $t = 0.554$, $p = 0.260$), whereas SR was accounted for IPG positively but weakly. In the third stage, after the inclusion of the mediator variable (SR) in the model, IPG and SA predicted AP significantly, but there was a decrease in the impact and change in direction of the coefficient of IPG, SA, and AP ($\beta = -0.30$, $t = 5.982$, $p < 0.001$). According to these findings, SR had a partial mediating effect on the relationship between IPG, SA, and AP.

Direct and Indirect Effects: The Causal Conditions, Process, and Core Category

A qualitative study obtained from the interview also revealed that IPG and SA had a direct and indirect effect on the students' academic performance. University students reported that IPG and substance use had a reasonable effect on academic success. Participants of the study reported that they had AP which has been presented as the core category that all other categories relate to. On the other hand, a key mediating variable in this study was the students' SR. We believed that the university students' AP is lessened when students master SR skills based on the study variables.

As the interview transcription indicated, the ultimate aim of why students go to IPG is to restore one's mental energy after study or to start their study with a fresh mind. As interviewees report, students who are aiming at taking a recreation after class or after study in the case of an IPG prefer the game zone. In the beginning, when they went there, they had no plan to stay in both pool game zones and substance use houses for a limited time. As a result of poor SR, students develop either a sense of inferiority and revenge when they get defeated or a sense of pride and being a star player. For instance, in IPG, if they are a winner in gaming, they are led by a sense of winning, so they never stop gaming until they get defeated.

On the other hand, if they get defeated from the very beginning, they develop a spitfire emotion, so that to clean their own moral from the inferiority complex against the winner, they counter for the second, third, or even fourth round. Even, if there are other referees, it is necessary to wait for two to three gaming rounds. After all these rounds, the defeated student starts gaming again. He waits for two-three rounds if he gets defeated again. In this case, if one round of the game takes 10 min on average, a student who waits for a game after three or four players wastes plenty of time.

. . ..This is common whether it is at an examination season or not. Even, when we develop test anxiety, we think we can compensate for a consumed time at gaming in the nighttime. When we turn back to study is in this mood, we have a sense of urgency in which we get insisted to address all the contents but very few things internalized. Moreover, there is a circumstance in which we encounter relive about the game and also a nightmare when we are not there physically.

DISCUSSION

Unrestrained ways of life in the university are being considered potential risk factors for the adoption of unhealthy behaviors. A self-regulatory problematic behavior manifested in the form of not starting or finishing tasks on time (Argiropoulou and Kalantzi-Azizi, 2016). A study conducted by Rabin et al. (2011) on college students ($n = 212$) affirmed that AP negatively impacted learning, achievement, academic self-efficacy, and quality of life; it was also considered a problem of executive dysfunction. A similar pattern of results was obtained in this study revealing that university students who had procrastination experience also had poor academic performance and poor psychological well-being. Moreover, a study conducted by Akinci (2021) on problematic smartphone use, SR, AP, and academic stress of 632 university students reported that AP negatively accounted for SR. Our study result is also consistent with the findings of Eissa and Khalifa (2020) and Saad (2020) who reported that SR learning and AP had a relationship.

Nowadays, many university students are spending their time on IPG either in the form of gambling or without gambling. Also, this study revealed that SA and IPG are contributing factors to the students' AP. In this regard, in the literature, even though there is a significant lack of evidence regarding the students' experience of IPG, this study agrees with a study conducted by Hossein Mardi and Hossein (2015) that reported university student's academic culture is largely driven by the social environment, featuring a longstanding culture of alcohol, khat, hashish, and behavioral addiction. Moreover, a study conducted by the Molinaro et al. (2020) revealed that gaming and gambling are emerging risk behaviors with a tendency of a high degree of normalization in societies and the culture of gambling within the family environment. Similarly, the Substance Abuse and Mental Health Services Administration (2019) reported that promotion, making sponsorship of concerts, and marketing of alcohol and other substances on and near campuses add immediacy to the pressure of students' consumption of popular culture (Substance Abuse and Mental Health Services Administration, 2019).

A cross-sectional study conducted on 250 Medical Science students also showed that students with high AP experience high difficulties in emotion regulation (Bytamar et al., 2020a,b). Moreover, experimental research revealed that the SR had the power to capitalize the learners' ability to overcome AP (Motiea et al., 2012a,b). In our study, we found that the university students' AP was lowered when students mastered the SR skill. In line with this, very little literature explained the relationship between alcohol use and AP (Moes, 2016; Tesfa et al., 2017; Westgate et al., 2017; Ahmadi et al., 2020). So, this is in agreement with previous studies. However, no study to date has examined the contribution of IPG to the students' AP and also the mediation role of SR on the relationship between the study variables.

On the other hand, SR is a notion that gets consideration together with the incidence of students' AP. As a study on a sample of 503 Chinese college students indicated, SR moderated the students' AP and learners' procrastination was negatively correlated with time usage character and self-control (Zhao et al., 2019). Similarly, in this study, SR mediated the students' AP. Furthermore, procrastination behavior has an impact not only on learners' academic achievement but also on their mental and psychological well-being (Sirois, 2007; Smolets, 2019). For instance, in the study conducted on a sample of 140 Chinese medical students (Khalid et al., 2019), procrastination induced stress among students. Muliani et al. (2020) also confirmed that there was a significant relationship between procrastination and stress. This finding is in total agreement with our study.

CONCLUSION

Over the last decade, IPG and drug abuse became a remarkable emerging addictive behavior among adolescents, especially among university students as important target groups. This study disclosed that university students had IPG and drug abuse practices. There was also a reasonable positive relationship between the students' IPG practice and AP. On the other hand, there was a moderate and positive relationship between drug abuse and AP. Conclusively, despite the levels of variation among students, IPG and drugs such as khat, alcohol, and hashish around the university's local environment had a significant impact on the students' AP.

Limitations

The study attempted to identify the students' culture of an IPG, drug use, and AP. The time which students spent may be different from individual to individual and this was not considered. Yet, we have not examined the average time they spent using illicit drugs. Moreover, this study did not identify the time they spent on gaming or gambling based on school days and non-school days.

Implications

Despite the disclosed limitations, this study set forth inferences for practice and contributed to the existing bodies of knowledge in the area. The practical implication of this study is valuable to professionals in the field of education, psychology, sociology, social work, health, policymaking, community studies, and family studies. On this subject, since the practice of IPG, gambling, and SA culture are widely emerging incidents with adolescents at universities becoming accessible, the issue needs to get the necessary attention. Thus, the findings from this study have significant implications for the future of education and the well-being of learners.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board of College of Education and Behavioral Sciences. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DG conceived the study, drafted the proposal, and collected and analyzed the data. AK wrote the manuscript draft. BW contributed to proposal development and proofreading the manuscript. All authors contributed to the article and approved the submitted version.

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The Impact of the Daily Mile^{TM} on School Pupils' Fitness, Cognition, and Wellbeing: Findings From Longer Term Participation

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Background: School based running programmes, such as The Daily Mile^{TM}, positively impact pupils' physical health, however, there is limited evidence on psychological health. Additionally, current evidence is mostly limited to examining the acute impact. The present study examined the longer term impact of running programmes on pupil cognition, wellbeing, and fitness.

Method: Data from 6,908 school pupils (mean age 10.2 ± 0.7 years), who were participating in a citizen science project, was examined. Class teachers provided information about participation in school based running programmes. Participants completed computer-based tasks of inhibition, verbal and visual-spatial working memory, as well as the Children's Feeling scale and Felt arousal scale to determine subjective wellbeing. A multistage 20-m shuttle run test was used to estimate fitness.

Results: From our total sample of 6,908 school pupils, 474 participants had been taking part in a running programme for <2 months (Shorter term participation); 1,004 participants had Longer Term participation (>3 months); and 5,430 did not take part in a running programme. The Longer Term participation group had higher fitness levels than both other groups and this remained significant when adjusted for age, sex and SES. Moderated regression analysis found that for the Shorter Term participation group, higher shuttle distance was associated with better visual-spatial working memory. Effect sizes were small though.

Conclusion: We identified small and selective positive impact of participation in school based running programmes on fitness and cognition. While no long term benefit was identified for cognition or wellbeing, the impact on fitness and short term benefit suggest schools should consider participation.

Keywords: physical activity, wellbeing, schools, children, cognition

INTRODUCTION

Recent reviews have concluded that greater physical activity is associated with improved cognition and academic attainment in young people (Barbosa et al., 2020; Chaput et al., 2020). Previous research has demonstrated positive longitudinal associations between physical activity and both academic attainment (Singh et al., 2012; Booth et al., 2014) and cognition (Booth et al., 2013), however, evidence from acute studies and interventions is equivocal (Daly-Smith et al., 2018; Singh et al., 2018). Fitness is also thought to have a positive role in the relationship between physical activity, cognition and attainment and has been suggested as a possible explanatory mechanism (Donnelly et al., 2016). However, levels of physical activity are low globally (Aubert et al., 2021) and so efforts to support increases are warranted.

Classroom physical activity breaks are increasing in popularity in the United Kingdom (for a discussion see Routen et al., 2017). Generally, classroom activity breaks involve short bouts of physical activity during or between academic lessons (Daly-Smith et al., 2018) which occur in addition to break/recess time and aim to increase physical activity and disrupt sedentary behaviour. A vast number of schools are adopting these programmes, however, there are limitations in the scientific evidence base for their effectiveness with many studies viewed as low quality (Daly-Smith et al., 2018). The health benefits of these breaks are no doubt a key consideration, however, it is also important to determine any impact on academic attainment and underlying cognitive skills as these classroom activity breaks often take time away from academic lessons.

The Daily Mile™[1], is an example of a classroom activity break which is gaining popularity; children run/walk outside for approximately 15 min each school day. Pupils can determine the pace themselves, they can take part in their regular school clothes and should not need to change into sports outfits, and teachers are advised it should take place during curricular time on at least 3 days of the week. It is estimated that over 13,000 schools across 88 countries take part in The Daily Mile™ ("The Daily Mile, 2021, Accessed 21 October 2021"). This differs from other school based running programmes, such as Marathon Kids ([2]Chalkley et al., 2018) and the Golden Mile[3] in that it occurs during class time and is a break from class activity, not an addition to existing break or lunch times (Ryde et al., 2018).

Despite its widespread adoption and positive perception amongst teachers (Malden and Doi, 2019), there is limited quantitative evidence surrounding the impact of The Daily Mile™ on a variety of pupil outcomes. In a quasi-experimental pilot study conducted over 8 months with 391 pupils, The Daily Mile™ was found to lead to increases in moderate-to-vigorous physical activity (MVPA) and fitness, reduction in time spent being sedentary, and improvements in body composition (Chesham et al., 2018). Following this, several studies have examined the impact of The Daily Mile™ on fitness after 3–6 months (Brustio et al., 2019, 2020; de Jonge et al., 2020). To our knowledge, no longer term examination of the impact on pupil fitness has been reported.

It is also vital that the impact that participation in The Daily Mile™ has on pupil cognition and wellbeing be considered, as these are key focusses for pupils, teachers, parents and policy makers. There are inconsistent findings concerning the impact that physical activity breaks or interventions have on pupil cognition (i.e., executive function, IQ) and academic attainment (i.e., results of exams or test performance). While reviews have argued that there is certainly no detrimental impact on academic performance of increasing physical activity in the school setting (Singh et al., 2018), and that there is indeed evidence of beneficial impact (Barbosa et al., 2020), the impact on *cognition* of taking 15 min out of class every day (or 75 min a week) for the school year to complete The Daily Mile™ is not yet known.

In relation to The Daily Mile™, Morris and colleagues examined the acute impact on maths test performance and executive function in a sample of 9 year old children (n = 303) (Morris et al., 2019). They reported no benefit for maths test performance or executive function. However, in a large study with over 5,000 children aged approx. 10 years old, an acute beneficial impact has been found for short physical activity breaks including a Daily Mile like activity for aspects of executive function (Booth et al., 2020). Furthermore, a recent study examined the acute impact of participation in The Daily Mile™ in a sample of 104 children (mean age 10.4 years) and found a trend for a positive impact on children's working memory, but no broad impact on cognition (Hatch et al., 2021). Hatch and colleagues also found that children enjoyed participation and reported a positive impact on social relatedness and autonomy. As studies reported have only examined the acute impact of participation in The Daily Mile™, there is therefore a need to examine these outcomes in relation to longer term participation.

Furthermore, there is widespread evidence demonstrating the positive impact which physical activity has on pupil mental health (Biddle et al., 2019), in particular it is beneficial for reducing the risk of depression (Chaput et al., 2020). In addition, recent research involving 8–12 year olds (n = 1,540) found that self-reported physical activity was positively associated with subjective wellbeing and satisfaction with life (García-Hermoso et al., 2020). However, little evidence exists concerning the impact that Daily Mile participation has on pupil wellbeing, although acute benefits on wellbeing have been reported following participation in a Daily Mile like activity (Booth et al., 2020). Given the number of school pupils participating globally, there is therefore an urgent need to understand the longer term impact that participation may have.

One underlying factor which has been proposed to account for the relationship between physical activity and cognition, is physical fitness (Donnelly et al., 2016). However, not all reviews have found supporting evidence for the fitness-cognition hypothesis (e.g., Etnier et al., 2006). Research has found that longitudinal changes in fitness were associated with changes in school attainment in adolescent boys but not in girls (Kyan et al., 2018). However, other research has reported fitness to

[1]https://thedailymile.co.uk/

[2]https://www.marathonkids.co.uk/

[3]http://www.golden-mile.org/

be positively associated with academic attainment and that the relationship was partially mediated by executive functions (Visier-Alfonso et al., 2020). A review by Ludyga et al. (2016) found that both low and high fit individuals benefit cognitively from an acute bout of physical activity. Despite this, a recent large study on the acute impact of physical activity breaks found that fitness did not mediate the relationship between physical activity and cognition in children (Booth et al., 2020). In addition, fitness has been reported to have an impact on wellbeing in childhood and adolescence (LaVigne et al., 2016; Marques et al., 2017). While taking part in The Daily Mile™ has been found to improve pupils fitness (Chesham et al., 2018; Brustio et al., 2019, 2020; de Jonge et al., 2020) it is important to consider to what extent fitness has an impact on cognition and wellbeing in this context.

The present study will compare groups of pupils who have taken part in The Daily Mile™ for a short time (i.e., 2 months or less) and longer term (i.e., more than 3 months), compared to those who have not participated. The aim is to address gaps in the knowledge base and understand the longer term impact that taking part in The Daily Mile™ has on pupil cognition, wellbeing and fitness, and the relationship between these factors.

MATERIALS AND METHODS

The Present Study

BBC Terrific Scientific[4] is a project aiming to support young people learning about science through citizen science. Briefly, citizen science characterises generally large scale research studies which involve members of the public in data collection (e.g., Brestovitsky and Ezer, 2019). The BBC Terrific Scientific programme encourages mass participation of school pupils in real world academic research in the United Kingdom. Teachers lead pupils through data collection for research studies employing online resources and lesson plans linked with a United Kingdom University. The pupils involved learn about a range of aspects of research as well as about scientific enquiry. The present study was developed and administered as part of Terrific Scientific and was known as the Exercise Investigation[5].

Participants

Participants were volunteers in the BBC Terrific Scientific Programme. 503 class teachers registered their class to take part in the study. **Table 1** shows demographic information about the sample. In total, 7,337 children from the registered classes (mean age 10.2 ± 0.7 years; 50% female) provided information on at least one key outcome measurement. Participants were from all parts of the United Kingdom, with 78.1% (n = 5,728) being from England, 14% (n = 1,024) from Scotland, 7.3% (n = 536) from Wales and 0.5% (n = 40) from Northern Ireland. Furthermore, according to postcode data, the majority of schools were in the least deprived areas of the country with 14.5% of the sample from Index Multiple Deprivation/Scottish Index Multiple Deprivation 10.

[4]https://www.bbc.co.uk/terrificscientific

[5]https://www.bbc.com/teach/terrific-scientific/KS2/zmtxy9q

Measures

Teacher Reported Information

Class teachers provided demographic information when registering their class for the project. They provided information about school postcode which was used to determine IMD/SIMD as an indication of socioeconomic status (SES[6]). Furthermore, they reported pupil year group and whether their class currently took part in a running programme like The Daily Mile™ or something similar. If they responded positively, they were asked the name of the programme, how long they had been participating, and how often their class took part. The core principles of the Daily Mile™ are that participants should take part on at least 3 days of the week and while there is variability reported in schools approach to undertaking this (e.g., Ryde et al., 2018), we used this criteria to clarify participation in line with Brustio et al. (2020).

Pupil Reported Demographic Information

Pupils were asked to specify their age and sex when first completing any measurements.

Cognition

Cognition was measured using three bespoke computer-based tasks which are described in detail in Booth et al. (2020). Briefly, they involved:

Inhibition

Inhibition was measured using an adapted stop-signal task (Logan et al., 1984). Pupils were asked to press a button corresponding to the direction of an arrow. Participants were instructed to suppress their response if the stimuli changed colour (i.e., not press any button). Outcome variables were reaction time (for "go" trials), correct responses, incorrect responses (failure to stop) and an adjusted inhibition score (reaction time for go trials plus number of incorrect responses × 10). Using this method, lower scores equal better performance. The stop-signal task has acceptable reliability and validity in children (Williams et al., 1999) and the use of reaction times adjusted for error rate has been recommended for reaction time tasks (Draheim et al., 2016).

Working Memory

Visual spatial working memory was assessed using a computer based adapted version of the static boxes search task (Diamond et al., 1997). Pupils were tasked with searching for a cartoon face hidden in on-screen boxes. Once a face was located, it would not be presented there until the next round. Scores were based on accuracy with an optimum number of presses for the level reached (i.e., for level 4, optimum number of presses = 10) adjusted for the actual number of presses (actual – optimum) so that a lower score indicates better performance.

Verbal working memory was assessed using a reading span task (Daneman and Carpenter, 1980). Pupils were presented with a series of sentences and asked to judge the veracity of the sentence before remembering the last word. The number of sentences presented together increased (i.e., two sentences, then

[6]https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019

TABLE 1 | Demographic information: n (%); mean (SD) for age.

Variable	Shorter term participation			Longer term participation			No participation		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Age (months)	122.29 (9.29)	122.18 (9.39)	122.24 (9.33)	122.61 (8.18)	123.18 (8.22)	122.90 (8.20)	121.70 (8.53)	121.54 (8.56)	121.62 (8.54)
Sex	242 (51.1)	232 (48.9)	474 (6.86)	495 (49.3)	509 (50.7)	1004 (14.53)	2709 (49.9)	2721 (50.1)	5430 (78.60)
Country									
England	118 (48.8)	128 (55.2)	246 (51.9)	337 (68.1)	336 (66.0)	673 (67.0)	2241 (82.7)	2249 (82.7)	4490 (82.7)
Scotland	85 (35.1)	76 (32.8)	161 (34.0)	124 (25.1)	122 (24.0)	246 (24.5)	266 (9.8)	252 (9.3)	518 (9.5)
Northern Ireland	0	0	0	9 (1.8)	7 (1.4)	16 (1.6)	12 (0.4)	12 (0.4)	24 (0.4)
Wales	39 (16.1)	28 (12.1)	67 (14.1)	25 (5.1)	44 (8.6)	69 (6.9)	190 (7.0)	208 (7.6)	398 (7.3)
SES									
1 (most deprived)	11 (4.5)	11 (4.7)	22 (4.6)	10 (2.0)	9 (1.8)	19 (1.9)	175 (6.5)	143 (5.3)	318 (5.9)
2	49 (20.2)	44 (19.0)	93 (19.6)	46 (9.4)	40 (7.9)	86 (8.6)	203 (7.5)	195 (7.2)	398 (7.3)
3	29 (12.0)	24 (10.3)	53 (11.2)	0	0	0	231 (8.5)	259 (9.5)	490 (9.0)
4	28 (11.6)	28 (12.1)	56 (11.8)	64 (13.1)	50 (9.9)	114 (11.5)	244 (9.0)	217 (8.0)	461 (8.5)
5	29 (12.0)	29 (12.5)	58 (12.2)	100 (20.5)	114 (22.5)	214 (21.5)	176 (6.5)	177 (6.5)	353 (6.5)
6	16 (6.6)	12 (5.2)	28 (5.9)	55 (11.3)	59 (11.6)	114 (11.5)	314 (11.6)	308 (11.3)	622 (11.5)
7	18 (7.4)	15 (6.5)	33 (7.0)	121 (24.8)	112 (22.1)	233 (23.4)	311 (11.5)	292 (10.7)	603 (11.1)
8	20 (8.3)	25 (10.8)	45 (9.5)	4 (0.8)	8 (1.6)	12 (1.2)	320 (11.8)	337 (12.4)	657 (12.1)
9	14 (5.8)	17 (7.3)	31 (6.5)	39 (8.0)	51 (10.1)	90 (9.0)	391 (14.4)	395 (14.5)	786 (14.5)
10 (least deprived)	28 (11.6)	27 (11.6)	55 (11.6)	49 (10.0)	64 (12.6)	113 (11.4)	344 (12.7)	398 (14.6)	742 (13.7)

three sentences, etc.) up to a maximum of eight. Scores were based on the total number of words correctly recalled, with higher scores indicating better working memory. This method of scoring has good reliability in adults and children (Friedman and Miyake, 2005; Towse et al., 2008).

Subjective Wellbeing

The adapted Children's Feeling Scale and Felt Arousal Scale (Hulley et al., 2008) were employed to assess the affective component of subjective wellbeing. Children were presented with a Likert scale and pictures with corresponding facial expressions. They were asked: "How do you feel right now?" on a scale of very bad to very good (scored from −5 to +5) and "How awake do you feel right now?" on a scale of very sleepy to very awake (scored from 1 to 6). A higher score indicates greater feelings of wellbeing. This adapted version has been used widely with children (e.g., Budzynski-Seymour et al., 2019; Vazou et al., 2019) and acceptable validity has been reported for single item measures (Van Landuyt et al., 2000).

Fitness

Pupils completed the bleep test following standard procedure for the maximal multistage 20-m shuttle run test (Léger et al., 1988). Pupils were grouped into pairs taking it in turns to act as runner and distance recorder before repeating the test with roles swapped. A fuller description is given in Booth et al. (2020). Pupils then entered the number of the level and shuttle which they reached in the online form when they returned to class. Age-corrected VO_2 max scores were created using procedure described by Léger et al. (1988) following recommendations by Tomkinson et al. (2019).

Procedure

Ethical permission was granted from the local University ethics committee (UOE ref 1066). Information packs were provided to schools which included health and safety information and information letters for parents. Following British Psychological Society ethical guidance, as Terrific Scientific was deemed an educational activity, parental opt-out consent was employed, in addition to school/teacher consent for class participation. Pupils could, however, choose not to participate in the online measurements. Class teachers were responsible for gathering this information.

Teachers completed an online form to register their class to take part in the BBC Terrific Scientific programme (see text footnote 4). Upon this registration, teachers were given access to a secure website which contained the online measurements. Separate registration information was required from teachers – this ensured that all information held by the research team was independent from information held by the BBC. A set of unique pupil identifiers were computer generated for registered classes and access given to class teachers. Teachers allocated each consenting pupil in their class one of the identifiers and retained this information until the project was complete. Upon completion, teachers were asked to destroy the information linking pupils to identifier information.

Consenting pupils were given access to the online system by their class teacher using the unique identifier. Pupils completed the demographic questions and then tasks of cognition and subjective wellbeing. Lesson plans, videos explaining the tasks and procedure, and downloadable pupil resources were given to class teachers to share with pupils prior to commencing the study (adapted copies accessible from see text footnote 5). Teachers were advised that measurements should not be completed immediately following the pupils arriving in the morning, just after break or lunch time, or just after completing PE (or other PA).

Statistical Analysis

Outliers were excluded using the inter-quartile rule (i.e., if they were < Q1-1.5*IQR or > Q3 + 1.5*IQR) (Jones, 2019) prior to group categorisation. Residuals and probability plots were inspected to ensure assumptions were met. Missing data was removed using pairwise deletion. Between groups ANOVA was performed to explore differences between participants depending on the duration which they had been taking part in a running programme (longer term and shorter term), as well as those who did not, while controlling for age, sex and SES. Eta-squared (η^2) estimates of effect size are included and interpreted as small = 0.01, medium = 0.06, and large = 0.14 (Cohen, 1988).

Regression analysis was used to explore the relationship between fitness and outcomes of cognition and wellbeing. Furthermore, model 1 from the PROCESS macro for SPSS (Hayes, 2018) was employed to determine the moderating impact of duration of Daily Mile participation (coded as Shorter term, Longer term, and no participation) on these relationships. All analysis was performed using SPSS (version 25).

RESULTS

The Daily Mile™ Participation

From our total sample, class teachers reported that 21.8% (n = 1,596) of pupils took part in The Daily Mile™ or similar running programme on at least 3 days of the week, with 799 of these doing it every school day. There were a small number of participants whose teacher reported that they took part in a running programme less than once a week (n = 96), or just once a week (n = 215). For subsequent analysis, and following Brustio et al. (2020), we excluded participants who were taking part once a week or less, with included participants therefore categorised depending on whether they were taking part in a running programme on 3 or more days, or not taking part at all.

In order to categorise duration of participation, we excluded 118 participants whose teachers reported not remembering when they started doing The Daily Mile™. 29.7% of the sample (n = 474) started doing the running programme in the school term in which the study took place, which meant that at the time of data collection, they had been doing it 2 months or less. We categorised this as the Shorter Term participation group. 62.9% (n = 1,004) started in the previous school year or earlier, which we termed the Longer Term participation group for analysis. The No Participation group therefore contained the remaining 5,430 participants. Demographic and descriptive statistics for outcome variables for all 6,908 participants included in the analysis can be found in **Tables 1–3**.

Impact of Duration of Daily Mile Participation

Between groups ANOVA revealed a statistically significant difference in visual spatial working memory (VSWM) scores in the unadjusted models [$F(2,6347) = 6.63$, $p = 0.01$, $\eta^2 = 0.002$]. Inspection of pairwise comparisons illustrated that the Longer Term participation group had significantly higher scores than the participants who did not participate in the Daily Mile (mean

TABLE 2 | Descriptive data from shuttle run test by country.

Variable	Shorter term participation			Longer term participation			No participation		
	Male (n = 242)	Female (n = 232)	Total (n = 474)	Male (n = 495)	Female (n = 509)	Total (n = 1,004)	Male (n = 2,709)	Female (n = 2,721)	Total (n = 5,430)
Age corrected VO_2 max									
England	47.78 (5.32)	45.92 (4.79)	46.76 (5.10)	48.53 (6.05)	47.06 (5.48)	47.83 (5.82)	48.50 (5.08)	46.88 (4.22)	47.68 (4.73)
Scotland	48.96 (5.55)	45.34 (4.66)	47.18 (5.40)	47.98 (4.81)	47.65 (3.96)	47.81 (4.38)	49.35 (5.40)	46.26 (4.94)	47.79 (5.39)
Northern Ireland	–	–	–	51.88 (6.95)	47.40 (4.16)	49.96 (5.97)	45.10 (1.70)	44.78 (1.67)	44.84 (1.59)
Wales	48.27 (4.14)	42.56 (2.59)	46.37 (4.55)	51.83 (4.60)	46.69 (3.54)	47.97 (4.40)	46.69 (4.50)	45.23 (3.33)	45.94 (4.00)
Total	48.15 (5.24)	45.60 (4.70)	46.84 (5.12)	48.62 (5.65)	47.20 (4.70)	47.88 (5.22)	48.39 (5.10)	46.59 (4.24)	47.47 (4.76)
Shuttle distance									
England	608.21 (402.05)	487.06 (369.38)	541.77 (387.64)	724.16 (462.73)	616.09 (432.36)	672.64 (450.61)	699.57 (390.24)	573.48 (312.18)	635.76 (358.37)
Scotland	779.20 (464.56)	537.50 (316.08)	660.82 (413.14)	680.00 (394.51)	633.87 (301.59)	656.17 (348.87)	760.36 (419.01)	537.19 (375.50)	647.79 (412.23)
Northern Ireland	–	–	–	1070.00 (543.20)	760.00 (408.41)	937.14 (480.20)	460.00 (113.14)	464.64 (106.67)	463.64 (101.91)
Wales	722.00 (331.25)	328.00 (142.55)	597.33 (331.13)	948.00 (374.43)	561.33 (229.60)	658.00 (316.71)	584.62 (320.73)	464.00 (245.62)	522.62 (290.29)
Total	667.69 (416.28)	492.37 (348.74)	577.23 (391.86)	730.29 (441.43)	615.51 (363.63)	670.67 (406.40)	693.41 (388.50)	555.32 (314.13)	623.18 (359.25)

TABLE 3 | Descriptive information from outcome measures [mean (sd)].

Outcome	Shorter term participation	Longer term participation	No participation	Effect size adjusted models ($\eta_p{}^2$)
Affect	2.25 (2.03)	2.20 (2.06)	2.21 (2.01)	0.00
Alertness	4.30 (1.23)	4.36 (1.29)	4.32 (1.23)	0.00
Inhibition: RT adjusted for errors	795.01 (132.51)	802.81 (145.51)	795.84 (138.60)	0.001
Inhibition: mean RT (go trials)	647.65 (124.75)	663.69 (156.76)	641.14 (149.01)	0.003
Inhibition: errors	12.09 (8.56)	11.28 (8.46)	11.73 (8.61)	0.00
Verbal working memory: Total number of words	25.86 (14.80)	26.12 (14.81)	26.09 (14.65)	0.00
Visual-spatial working memory: Actual adj optimum	−41.75 (35.14)	−39.37 (35.02) ***	−43.82 (34.93)	0.002

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.*

difference = 4.44, SE = 1.25, $p < 0.001$, 95% CI = 1.99 to 6.89). This remained statistically significant when adjustment was made for age, sex, and SES, although the effect size was small (mean difference = 4.50, SE = 1.24, $p < 0.001$, 95% CI = 2.08 to 6.93, $\eta_p{}^2 = 0.02$).

Furthermore, a statistically significant difference was found between groups for shuttle distance completed [$F(2,2403) = 4.32$, $p = 0.013$, $\eta^2 = 0.004$], and the finding approached conventional levels of statistical significance for Age corrected VO^2 max [$F(2,2403) = 2.86$, $p = 0.058$, $\eta^2 = 0.002$]. Pairwise comparisons revealed that the Longer Term participation group had greater shuttle distance than the group who did not do the Daily Mile^{TM} (mean difference = 47.49, SE = 21.26, $p < 0.05$, 95% CI = 5.79 to 89.19), as well as those who had Shorter Term participation (mean difference = 93.44, SE = 33.29, $p < 0.01$, 95% CI = 28.27 to 158.59). These associations remained statistically significant after adjustment for age, sex and SES: shuttle distance $F(2,2391) = 4.76$, $p = 0.009$, $\eta^2 = 0.004$; age corrected VO^2 max $F(2,2391) = 4.71$, $p = 0.009$, $\eta^2 = 0.004$. No further statistically significant differences were found for any outcomes.

Impact of Fitness on Cognition and Wellbeing and Moderation of Duration

Shuttle distance was entered in a regression model to predict VSWM, as between group differences had been found for this variable. However, no significant model emerged [$F(1,2506) = 1.03$, $p > 0.05$]. Including duration of Daily Mile participation as a moderator of this relationship did lead to a significant model [$F(5,2369) = 3.35$, $p < 0.001$, $R^2 = 0.01$]. Specifically, VSWM scores differed between the Shorter Term participation group in comparison to no participation, and the resulting interaction term approached conventional levels of statistical significance (see **Table 4**).

Figure 1 illustrates that for the Shorter Term participation group, as shuttle distance increased, VSWM scores decreased, which represents an improvement in VSWM. No significant model was found when age corrected VO_2 max scores were used as the predictor variable though.

Shuttle distance was also entered as a predictor of alertness and affect, however, no significant model emerged: $F(1,2537) = 1.01$, $p > 0.05$, and $F(1,2537) = 0.093$, $p > 0.05$, respectively. There was also no significant moderation of duration of Daily Mile participation (all p values > 0.05). The same pattern emerged when age corrected VO_2 max was used as the predictor variable – see **Table 4** for coefficients.

DISCUSSION

Overall, we found a small but positive impact of longer term participation in The Daily Mile^{TM} on participants' fitness. Participants in the present study who had been taking part for 3 months or more, had significantly greater fitness levels than participants who had been taking part for a short term, or who did not participate at all. This was true even when adjusting for confounders. In terms of cognition, we found that the Longer Term participation group had worse performance on the visual-spatial working memory task than participants who were not taking part in the Daily Mile, although the effect size was very small. However, examination of the impact of fitness found that for those who had been participating in The Daily Mile^{TM} for a short term, there was a positive association between fitness levels and visual-spatial working memory performance, whereby increased fitness was associated with better working memory performance. This pattern was not found in the other participant groups though. Furthermore, we found no significant impact of participation on other cognitive outcomes, or on pupils' wellbeing. Overall findings therefore demonstrate small and selective benefits of taking part in The Daily Mile^{TM}.

Relation to Previous Literature

We found no substantial differences in cognition and wellbeing between those participants who were participating in a running programme at school compared to those who were not. This finding is inconsistent with research demonstrating an acute impact of a Daily Mile like activity (Booth et al., 2020), as well as studies demonstrating long term associations between physical activity and cognition in young people (Booth et al., 2013). Interestingly in Booth et al. (2020) there was no acute impact on visual-spatial working memory but there was a positive impact on other measures of cognition and wellbeing. Similarly, the two other studies which have explored the acute impact of The Daily Mile^{TM} (Morris et al., 2019; Hatch et al., 2021) found varied pattern of results in terms of the acute impact on cognition, although the scale of both of these studies was much smaller. Differential impact of physical activity on tasks of cognition, including working memory, has

TABLE 4 | Coefficients from analysis of fitness predicting outcomes, with duration of Daily Mile participation as moderator.

	Affect			Alertness			VSWM		
	Beta	SE	95% CI	Beta	SE	95% CI	Beta	SE	95% CI
Shuttle distance	0.00	0.00	−0.00 to 0.00	0.00	0.00	−0.00 to 0.00	−0.00	0.00	−0.01 to 0.00
Longer term vs. No participation	−0.07	0.21	−0.47 to 0.34	0.04	0.12	−0.20 to 0.28	−3.19	3.65	−10.35 to 3.97
Shorter term vs. No participation	−0.18	0.25	−0.68 to 0.32	0.09	0.15	−0.20 to 0.39	**14.44****	**4.57**	**5.48 to 23.39**
Shuttle distance × Longer term	0.00	0.00	−0.001 to 0.001	0.00	0.00	−0.00 to 0.00	0.01	0.01	−0.00 to 0.02
Shuttle distance × shorter term	0.00	0.00	−0.00 to 0.001	−0.00	0.00	−0.001 to 0.00	**−0.01⁺**	**0.01**	**−0.02 to 0.001**
Age corrected VO_2 max	0.01	0.01	−0.01 to 0.03	0.01	0.01	−0.00 to 0.02	−0.09	0.16	−0.41 to 0.22
Longer term vs. No participation	−0.39	0.99	−2.34 to 1.56	−0.13	0.59	−1.28 to 1.03	−21.68	17.63	−56.26 to 12.89
Shorter term vs. No participation	−1.30	1.31	−3.87 to 1.28	0.41	0.78	−1.11 to 1.93	38.14	23.40	−7.75 to 84.02
VO_2 max × Longer term	0.01	0.02	−0.03 to 0.05	0.00	0.01	−0.02 to 0.03	0.47	0.37	−0.25 to 1.19
VO_2 max × shorter term	0.03	0.03	−0.03 to 0.08	−0.01	0.02	−0.04 to 0.02	−0.65	0.50	−1.63 to 0.32

*Bold indicates associations of interest. *p < 0.05; **p < 0.01; ***p < 0.001; ⁺p = 0.07.*

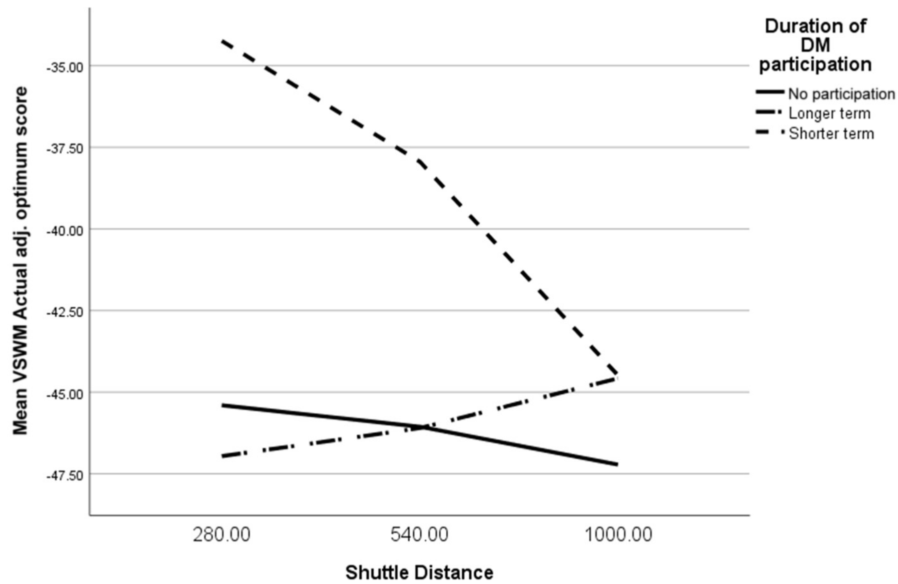

FIGURE 1 | Moderation of Daily Mile™ duration on relationship between shuttle distance and Visual Spatial Working Memory.

been reported in previous reviews (Smith et al., 2010) and as the effect size detected in the present study is small, it is worth conducting further research with a range of measures of visual-spatial working memory before strong conclusions are drawn. Our finding adds to the wider evidence base about the impact of classroom activity breaks (Daly-Smith et al., 2018) and suggests that due consideration should be given by researchers to the tasks they use to assess cognition. This aligns with a recent review of the impact of physical education on cognition and academic performance which reported positive associations but cautioned that there were a large number of assessment instruments of varying reliability (García-Hermoso et al., 2021). Thus the extent to which the differential impact of physical activity on cognition is related to the variety of assessment tasks should be considered in future work in this area.

We did find small but statistically significant differences in fitness levels between those who had been taking part in the Daily Mile™ in the longer term, compared to those who did not participate, as well as compared with the Shorter Term participation group. Interestingly, it was the Shorter Term participation group who had the lowest fitness levels from all participants. We were not able to determine whether there were differences in habitual levels of physical activity though and it is possible that pupils who were not taking part in school running programmes were actually doing more MVPA than pupils who were and so their fitness levels were comparable. Participation of pupils in The Daily Mile™ and other running programmes is decided by class teachers and school management and it may be that a needs analysis informs school participation. That is, only where need is perceived to be greatest, do schools choose to participate. Potentially teachers recognised that pupils' fitness levels were low in the Shorter Term group and so introduced The Daily Mile™ as a mechanism to improve this. This is conjecture, although does align with previous reports (Malden and Doi, 2019).

This possibility is also consistent with evidence showing that uptake of The Daily Mile™ is greater in schools with higher numbers of pupils from disadvantaged backgrounds in England (Venkatraman et al., 2021), where it may be perceived that pupils have less access to other avenues for structured physical activity. Evidence concerning associations of physical activity and SES is inconsistent in primary school aged pupils though (O'Donoghue et al., 2018). Further research should aim to understand factors which influence uptake of running programmes, as well as the longer term impact on pupils.

Study Strengths and Limitations

The present study has several strengths and provides a unique contribution to our knowledge of this area. This is the first study to consider the longer term impact that taking part in running programmes has on school pupils' cognitive ability and wellbeing. However, it is important to consider what "longer term" means in the context of the present study. Teachers reported that their class had started doing a running programme in the term of data collection (2 months or less) or in the academic year before or earlier (more than 3 months). We were not able to determine the exact period of participation though. We excluded participants if their teacher could not remember when they started taking part and it is entirely possible that these were pupils who had been taking part for longer periods of time; as we could not verify this, we removed these participants from analysis. As the popularity and duration of uptake of such running programmes increases, it will be important to consider longer term participation in a more refined manner.

Data collection for the present study took place from the middle of August (when schools in Scotland return from summer holiday) until October. As such, some participants took part immediately after the summer holidays. We did not collect data concerning participation in physical activity during the school holidays, and it cannot be ruled out that fitness levels may have been impacted by the break from participation in the Daily Mile, even for those who had been taking part longer term. Unfortunately the citizen science nature of the present study meant we were not able to be flexible with the data collection period. It is important to acknowledge that time of year may have had an impact on the findings of the present study.

One further limitation of the citizen science approach to data collection is that fidelity of measurement for the bleep test is unclear, although the resulting figures for shuttle distance are very similar to those found in a sample of children when collected by trained researchers (e.g., Chesham et al., 2018). This was not an issue for other measurements due to the computerised assessment. We also employed the Léger et al. (1988) equations for estimating VO_2 max and it must be acknowledged that alternative methods do exist.

Overall, we believe that the benefits of citizen science outweigh the limitations (Den Broeder et al., 2016), however, the variation in running experience between participants must also be acknowledged as a possible limitation.

Conclusion

We found a positive relationship between longer term participating in The Daily Mile™ and school pupils' fitness levels. While longer term benefits for cognition and wellbeing were not apparent in this study, the health benefits of physical activity coupled with the acute benefit, which is likely to support learning, makes such physical activity breaks worthwhile and should be considered by class teachers and school management, as well as education policy makers.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of ethical restrictions. Requests to access the datasets should be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Edinburgh Ethics Committee. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

JB and CM were responsible for data analysis. JB was responsible for interpretation of analysis and for drafted the manuscript and is accountable for all aspects of the work. All authors were responsible for conceptualisation, gaining funding for this research, contributed to critically revising the manuscript, and approved the final version.

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The Relationship Between Empowering Motivational Climate in Physical Education and Social Adaptation of Senior High School Students: An Analysis of Chain Mediating Effect

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This study aims to contribute to understanding the mechanisms underlying the association between empowering motivational climate in physical education and social adaptation among senior high school students, and has important implications for interventions that aim at improving social adaptation among senior high school students. Through the quota sampling, 1,526 students (average age = 17 years, SD = 0.714 years) who came from Anhui Province and met the requirements participated and completed the Empowering Motivational Climate Questionnaire in Physical Education (EMCQ-PE), the Physical Education Engagement Scale (PEES-S), the Emotional Intelligence Scale (EIS) (Chinese version), and the Adolescent Social Adaptation Assessment Questionnaire (ASAAQ). For data analysis, Pearson's correlation analysis, structural equation model test, and bias-corrected percentile Bootstrap method were carried out in turn. The results showed that empowering motivational climate in physical education positively predicted social adaptation ($\beta = 0.282$, $p < 0.01$), empowering motivational climate in physical education positively predicted physical education engagement and emotional intelligence ($\beta = 0.169$, $p < 0.01$; $\beta = 0.690$, $p < 0.01$), physical education engagement positively predicted emotional intelligence and social adaptation ($\beta = 0.591$, $p < 0.01$; $\beta = 0.058$, $p < 0.05$), and emotional intelligence positively predicted social adaptation ($\beta = 0.365$, $p < 0.01$). Physical education engagement and emotional intelligence played a mediating role in empowering motivational climate in physical education and social adaptation, with a total mediating effect value of 0.251. This study shows that empowering motivational climate in physical education not only directly predicts social adaptation but also indirectly predicts social adaptation through the chain mediating effect of physical education engagement and emotional intelligence.

Keywords: empowering motivational climate in physical education, social adaptation, physical education engagement, emotional intelligence, senior high school students

INTRODUCTION

Social adaptation is the ability of an individual to effectively adapt to the social environment, to be able to independently deal with daily life, and to shoulder social responsibilities (Jingjing et al., 2020). Social adaptation is not only an important index to evaluate individual mental health but also a key factor to determine the degree of individual socialization. It plays an important role in individual academic development, career planning, and future social behavior (Hualing et al., 2021). In December 2016, the National Health Commission of the People's Republic of China and other government departments issued the "Guiding Opinions on Strengthening Mental Health Services," stating that: adolescents are the key group of mental health services. Primary and secondary schools should pay attention to students' mental health education, improve adolescents' psychological adjustment ability, and maintain good adaptability. Improving students' social adaptation is also the practical development goal of the school's physical education curriculum. "General High School Physical Education and Health Curriculum Standards (2017 Edition)" points out that the cultivation of high school students' health behavior literacy focuses on exercise habits, emotional regulation, and adaptability (Ministry of Education of the People's Republic of China, 2018). The high school period is a special period in which individual physiology and psychology change rapidly. Due to age characteristics and various reasons, they are also prone to various psychological and behavioral problems in the process of social adaptation (Xinbo et al., 2021). Studies have shown that the development of social adaptation in Chinese adolescents is not ideal, and the proportion of poor social adaptation is higher than the theoretical distribution (Yangang et al., 2008). Based on this, this study intends to focus on the influencing factors and mechanism of social adaptation of high school students, so as to provide a theoretical and empirical basis for promoting their social adaptation.

The social adaptability of adolescents is mainly affected by internal psychological factors (e.g., intelligence level, self-awareness, and personality characteristics) and external objective factors (e.g., school environment, social environment, and family environment), among which the role of school education cannot be ignored. Recent studies have found that school atmosphere (i.e., teacher support, peer support, and autonomy opportunities) is closely related to adolescents' adaptability, and school atmosphere can directly affect adolescents' social adaptation (Feilong et al., 2019). Therefore, schools must establish the awareness of cultivating social adaptability, and teachers should create an atmosphere for cultivating social adaptability.

Duda (2013) and Appleton et al. (2016) suggested a hierarchical and multidimensional conceptualization of the coach-created motivational climate that integrates the major social environmental dimensions emphasized within achievement goal theory (AGT) (Nicholls, 1989; Ames, 1992) and self-determination theory (SDT) (Deci and Ryan, 1985, 2000). Duda's conceptualization suggests that the motivational climate created is multidimensional and can be more or less "empowering" and "disempowering." The motivational climate created by teachers in physical education has received considerable attention in previous research from an AGT or SDT perspective and holds important pedagogical implications for students' motivation (Braithwaite et al., 2011), the quality and quantity of their engagement and learning (Reeve, 2012), levels of moderate-to-vigorous physical activity, and psychological responses in physical education (Van den Berghe et al., 2014). The research shows that the empowering motivational climate in physical education is favorable to the development of middle school students' moral responsibility (Mouratidou et al., 2007). However, the influence of the empowering motivational climate in physical education on high school students' social adaptation needs to be further confirmed.

Empowering Motivational Climate in Physical Education and Social Adaptation

The reasons leading to adolescents' social adaptation disorder may be closely related to the influences of school, family, and society. Among these influencing factors, which factors play a key role in recent years? Some scholars have discussed the relationship between school education and adolescents' social adaptation, especially focusing on the role of teachers. Previous studies have shown that social adaptation was correlated with specific external factors such as school bonding (Haowen et al., 2021), and the three dimensions of school bonding (i.e., teacher support, peer support, and school belonging) are positively correlated with social adaptation. One study (Ntoumanis, 2001) showed that cultivating intrinsic motivation and providing positive social factors in physical education (e.g., promoting cooperative learning, emphasizing personal progress, and task selection) can produce positive results. Existing studies have shown that compared with other types of support, students who benefit from teachers' support are more likely to broaden their personal ideological resources and behaviors, which is favorable to adapting to the school environment (Fredrickson and Branigan, 2005). Binrong and Mei (2021) believed that a good teacher–student relationship is conducive to children's positive emotion toward school, positive behavior, and improvement of individual adaptation. The teacher–student relationship can significantly predict different adaptation types, and the higher the satisfaction of the student–teacher relationship, the less likely it is to become a high-risk or vulnerable type (Yibing, 2018). Therefore, hypothesis 1 is put forward: The empowering motivational climate in physical education can positively predict the social adaptation of senior high school students.

Mediating Effect of Physical Education Engagement

One of the mediating mechanisms in this study is the mediating effect of physical education engagement. Learning engagement is the superordinate concept of physical education engagement. Learning engagement is a positive cognition and emotional psychological state related to employment and learning. It includes three dimensions, namely, concentration, dedication, and vitality (Schaufeli et al., 2002a). Previous studies have found that school, society, family, and students themselves are the four factors that affect young students' learning engagement; the school atmosphere has a significant positive correlation with learning engagement (Jingang and Jinze, 2011; Yongzhan, 2016), and teachers' support has a positive impact on students' learning engagement (Feng et al., 2017). Research shows that when the teaching environment meets students' basic psychological needs such as competence, autonomy, and sense of relationship, students' learning motivation, the sense of well-being, and achievement will be significantly improved, and it also has a promoting effect on students' learning (Gairns et al., 2015). By creating positive situational stimulation, physical education teachers can improve the students' motivation level for physical education learning and produce positive results in the improvement of students' physical health and sports skills, the mastery and application of physical education, and health knowledge, as well as attitude recognition and other learning behaviors (Ntoumanis, 2001). Other studies have confirmed that as a positive psychological index related to students' learning, physical education engagement reflects the positive psychological state of students in the learning process and plays a very important role in stimulating students' positive psychological qualities such as social adaptation, optimism, anti-frustration ability, and self-regulation ability (Laitan et al., 2008). Cross-cultural studies show that the more positive adolescents perceive the school atmosphere (i.e., teacher support, peer support, and autonomy opportunities), stronger learning initiative, higher degree of learning engagement, and higher levels of adaptability indicators such as school learning and life satisfaction (Eccles and Roeser, 2011). Therefore, hypothesis 2 is put forward: Physical education engagement plays a mediating role between empowering motivational climate in physical education and senior high school students' social adaptation.

The Mediating Effect of Emotional Intelligence

Another mediating mechanism that this study focuses on is the mediating effect of emotional intelligence. Emotional intelligence refers to an individual's adaptive ability to understand the perceptual utilization and regulation of others' and their own emotions (Salovey and Mayer, 1990; Schutte and Malouff, 1999). It can also be regarded as both a cognitive ability (Mayer et al., 1999) and a personality trait (Ciarrochi et al., 2001). Studies have shown that school atmosphere (i.e., teacher support, peer support, etc.) has a significant impact on adolescents' social emotional regulation and problem behaviors (Mingte and Thomas, 2012). There is a significant positive correlation between perceived teacher emotional support and emotional intelligence of high school students (Romano et al., 2020). Other studies have shown that emotional intelligence training programs have a significant impact on college students' social adaptation (Nimisha and Anoop, 2019). Accurate perception of others' emotions is associated with good social adaptation, and emotional perception is an antecedent variable of social adjustment. Positive emotion regulation can reduce adolescents' anxiety level, thus improving individuals' ability to adapt to the environment (Berking et al., 2008). Studies indicate that adolescent emotional intelligence can not only directly predict social adaptation but also indirectly predict social adaptation through other variables (e.g., shyness, self-esteem, and peer relationship) (Cancan et al., 2011; Qingsong et al., 2016; Zewen et al., 2021). An intervention study shows that while the emotional intelligence of high school students is improved, so is their social adaptation (Lili, 2013; Wenyuan, 2020). Therefore, hypothesis 3 is proposed: Emotional intelligence plays a mediating role between empowering motivational climate in physical education and social adaptation.

The Chain Mediating Effect of Physical Education Engagement and Emotional Intelligence

As for the physical education engagement and emotional intelligence in this study, some studies have shown that there is a significant positive correlation between high school students' engagement and emotional intelligence (Hongmei and Lin, 2012; Binghuang and Liang, 2020). Learning engagement is a kind of positive and lasting psychological characteristic of students in the process of learning (Schaufeli et al., 2002b). It reflects the degree of students' learning engagement and the positive degree of learning psychology. It is conducive to stimulate the positive psychological quality of individuals and promote their development and maturity. Emotional intelligence, which is the ability to properly express, correctly identify, and evaluate emotions, and to regulate one's own words, actions, and thoughts by using this information, has a significant impact on individuals' timely self-recognition, positive attitude, and academic learning (Bar-On et al., 2000). Therefore, the two (learning engagement and emotional intelligence) have a collaborative relationship. The support provided by teachers can mobilize students' learning enthusiasm and improve individual learning engagement, which is conducive to stimulating individual emotional intelligence and improving social adaptation ability. Therefore, hypothesis 4 is proposed: Physical education engagement and emotional intelligence play a chain mediating effect between empowering motivational climate in physical education and social adaptation.

To sum up, this study further deepens and expands previous studies and has theoretical and practical value. On the one hand, this study not only helps to investigate the direct effect of empowering motivational climate in physical education on high school students' social adaptation but also helps to examine the indirect effect of empowering motivational climate in physical education on high school students' social adaptation, that is, the independent and chain mediating effects of physical education engagement and emotional intelligence (**Figure 1**), so as to enrich the research on social adaptation. On the other hand, this study sheds light on why the empowering motivational climate in physical education has an impact on high school students' social adaptation and how to intervene and cultivate high school students' social adaptation. It provides a theoretical and empirical basis of psychology for preventing and diagnosing adolescents' adaptation disorders, improving their social adaptation level, and promoting the better implementation of quality education.

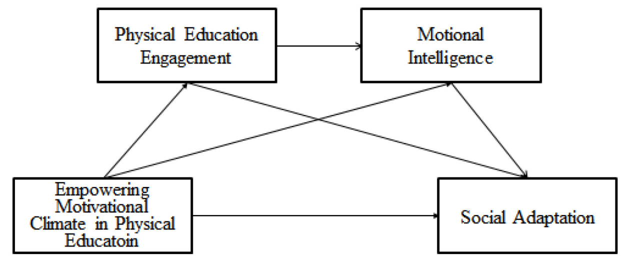

FIGURE 1 | Conceptual framework.

MATERIALS AND METHODS

Participants and Procedure

Using stratified cluster sampling, six high schools were selected from urban and rural areas in the southern, central, and northern Anhui Province, and two classes were randomly selected from each grade of each high school. The questionnaires were distributed to a total of 1,879 students from 36 classes. The main test is for all college students majoring in sports psychology who have received professional training. The consent of the school leaders, teachers, and the test subjects was obtained when the test was administered. The group test was adopted, and the principles of voluntary filling, data confidentiality, and anonymous filling were emphasized, and variables such as gender and grade of the subjects were controlled. Being in accordance with the Declaration of Helsinki, this study has been approved by the Institutional Review Board of the School of Physical Education and Health at Zhaoqing University. In this process, all invited participants are voluntary and confidential.

Notably, 353 invalid questionnaires were excluded due to regular answers, lack of data, and other reasons, and 1,526 questionnaires were considered in this study. The recovery rate was 81.2%. Each questionnaire took about 7–10 min to complete. The average age of the 825 male participants and 701 female participants was 17.00 ± 0.714 years. There were 421 students in the first grade, 589 students in the second grade, and 516 students in the third grade. There was no significant difference in the variables of different genders and grades.

Measures

Empowering Motivational Climate in Physical Education

The empowering motivational climate in physical education was evaluated by the Empowering Motivational Climate Questionnaire in Physical Education (EMCQ-PE), which was a sub-questionnaire of the Empowering and Disempowering Motivational Climate Questionnaire in Physical Education (EDMCQ-PE), and was modified by Pengyu and Jianing (2020) based on Duda's (2013) EMCQ-PE. The questionnaire has one dimension and 17 questions (e.g., "in PE class, teachers encourage students to cooperate fully in class."). The Likert's 7-point evaluation is used, in which 1 represents strongly disagree and 7 represents strongly agree. The higher the score, the higher the level of empowering motivational climate in physical education. A previous study showed that this questionnaire is suitable for high school students (Pengyu and Jianing, 2020). In this study, the internal consistency coefficient α of the questionnaire was 0.89, and the confirmatory factor analysis fit indices were as follows: $\chi^2/df = 2.176$, SRMR = 0.044, NFI = 0.921, RFI = 0.917, IFI = 0.907, and CFI = 0.929.

Physical Education Engagement

The physical education engagement was assessed by the Physical Education Engagement Scale-Student (PEES-S), which was modified by Baogen et al. (2020) based on Laitan et al. (2008) Utrecht Work Engagement Scale-Student (UWES-S). The scale contains a total of 17 items (e. g., "I am full of energy and motivation when learning physical education."), which is divided into three dimensions: concentration (e.g., "I am immersed in physical education class learning."), dedication (e.g., "I am passionate about physical education in the classroom."), and energy (e.g., "I can go on a long time in a physical education class without a break."). The Likert's 5-point evaluation is adopted, in which 1 represents very inconsistent and 5 represents very consistent. The higher the score, the higher the level of physical education engagement. Additionally, a previous study demonstrated that this scale was conducted well in a sample of senior high school students (Baogen et al., 2020). In this study, the internal consistency coefficient α of the scale was 0.88, and the confirmatory factor analysis fit indices were as follows: $\chi^2/df = 2.245$, SRMR = 0.024, NFI = 0.933, RFI = 0.940, IFI = 0.930, and CFI = 0.957.

Emotional Intelligence

Compiled by Schutte et al. (1998) and revised by Caikang (2002), the Emotional Intelligence Scale (EIS) (Chinese version) was used to measure the emotional intelligence. The research shows that the scale is suitable for the measurement of emotional intelligence of middle school students in China (Caikang and Zhiwen, 2002; Qiuyan et al., 2004). The scale consists of 33 items (e.g., "I can see new hope when I am in a good mood."), among which questions 5, 28, and 33 are reverse scoring. This scale contains four dimensions, which includes self-emotion regulation (e.g., "When I'm in a good mood, I know how to prolong it."), emotional perception (e.g., "I find it difficult to read other people's body language."), others' emotional regulation (e.g., "I try to make a good impression on others."), and emotional use (e.g., "I can control my emotions."). The Likert's 5-point evaluation is used, in which 1 means very inconsistent, and 5 means very consistent. The higher the score, the higher the level of emotional intelligence. In this study, the internal consistency coefficient α of the scale was 0.82, and the confirmatory factor analysis fit indices were as follows: $\chi^2/df = 2.509$, SRMR = 0.031, NFI = 0.915, RFI = 0.904, IFI = 0.927, and CFI = 0.938.

Social Adaptation

Social adaptation was assessed by the Adolescent Social Adaptation Assessment Questionnaire (ASAAQ), which was compiled by Jianwen and Xiting (2004). The ASAAQ consists of 70 questions (e.g., "I am seen as active") and contains four dimensions: psychological energy (e.g., "I am a very competitive person."), psychological dominance (e.g., "I feel I have many strengths."), psychological resilience (e.g., "I bounce back from bad emotions fairly quickly."), and interpersonal adaptation (e.g., "I enjoy helping people."). The Likert's 5-point evaluation is adopted, in which 1 represents very inconsistent and 5 represents very consistent. The higher the score, the better the social adaptation. The scale has good reliability and validity, and the retest reliability and internal consistency coefficient α are greater than 0.60. Studies have shown that this scale is widely applicable to the measurement of social adaptation of middle school students in China (Xiaohui, 2011; Na, 2015). The internal consistency coefficient α of the scale was 0.86, and the confirmatory factor analysis fit indices were as follows: $\chi^2/df = 2.047$, SRMR = 0.040, NFI = 0.931, RFI = 0.911, IFI = 0.920, and CFI = 0.940.

Statistical Analyses

All statistical analyses were performed with IBM SPSS statistical software (version 23.0) and process plug-in by Hayes (2013); confirmatory factor analysis was performed on all questionnaires using Amos 21.0. First, IBM SPSS statistical software version 23.0 was used to test the data for Harman common method deviation; second, Pearson's correlation analysis was carried out to calculate the relationship among empowering motivational climate in physical education, physical education engagement, emotional intelligence, and social adaptation. Continuous variables of normal distribution are expressed as mean ± standard deviation (SD). Finally, in order to verify the independent and chain mediating effects of physical education learning engagement and emotional intelligence on the relationship between empowering motivation climate in physical education and social adaptation of high school students, model 4 in SPSS macro program compiled by Hayes (2013) was used to test the mediating effect, and model 6 was used to test the chain mediating effect. There is not any missing data in the collected data. There was no significant difference in age and gender of the subjects, so they were not included in the control variable. According to previous experience, the goodness-of-fit index χ^2/df less than 3, RMSEA less than 0.08, NNFI and CFI greater than 0.9, and SRMR less than 0.05 are acceptable. In this study, the significance level is set as $p < 0.05$.

RESULTS

Common Method Deviation Test

Since all of the data in this study were collected from the self-presentation questionnaire survey, and there may be a problem of common method deviation, the questionnaires were filled anonymously, and the purpose of data collection was mainly used for scientific research (Hao and Lirong, 2004). Furthermore, Harman's single factor method was used to conduct a common method deviation test on the collected data. The results showed that the variance of the first-factor explanation was only 24.53%, which was less than the critical value of 40%. The confirmatory factor analysis method was used to extract a common factor from multiple variables involved in the study, and all items were loaded on this factor. The results showed that the model had a poor data fitting effect: $\chi^2/df = 13.67$, CFI = 0.51, TLI = 0.46, RMESA = 0.17, SRMR = 0.14, indicating that there is no factor that can explain most of the variation in this study. Therefore, there is no serious problem of common method deviation in this study.

Descriptive Statistics and Correlation Coefficients for Each Variable

As shown in **Table 1**, the correlation coefficients of social adaptation, emotional intelligence, physical education engagement, and empowering motivational climate in physical education are all statistically significant. The correlation analysis shows that social adaptation is positively correlated with empowering motivational climate in physical education, emotional intelligence, and physical education engagement.

Mediating Effect of Physical Education Engagement and Emotional Intelligence

The correlation analysis results met the statistical requirements for further testing the mediating effect of physical education engagement and emotional intelligence (Zhonglin and Baojuan, 2014). Next, the SPSS macro program compiled by Hayes (2013) was made to perform the mediation effect test based on Bootstrap, and the test model 6 was used to conduct the chain mediation model.

Table 2 shows that empowering motivational climate in physical education significantly positively predicts social adaptation ($\beta = 0.282$, $p < 0.01$), and hypothesis 1 is established. Next, after incorporating physical education engagement and emotional intelligence into the regression equation, empowering motivational climate in physical education significantly positively predicts the physical education engagement ($\beta = 0.690$, $p < 0.01$) and emotional intelligence ($\beta = 0.169$, $p < 0.01$). Physical education engagement is significantly positive for emotional intelligence ($\beta = 0.591$, $p < 0.01$) and social adaptation ($\beta = 0.058$, $p < 0.05$). Emotional intelligence significantly positively predicts social adaptation ($\beta = 0.365$, $p < 0.01$). At this time, empowering motivational climate in physical education can still predict social adaptation ($\beta = 0.031$, $p < 0.01$). The mediating effect size analysis results show that (see **Table 3** and **Figure 2**) physical education engagement and emotional intelligence are used in empowering motivational climate in physical education and social adaptation. There is a significant mediating effect between adaptation, and the total standardized mediating effect value is 0.251. Mediating effect is specifically composed of indirect effects generated by three pathways: empowering motivational climate → physical education engagement → social indirect effect of adaptation path formation 1 (effect value 0.040); the indirect effect formed by the path of empowering motivational climate → emotional intelligence → social adaptation 2 (effect value 0.062); and empowering motivational climate → physical education engagement → emotional intelligence → social indirect effect 3 of adaptation path (effect value 0.149). The ratios of the three indirect effects to the total effect are 14.18, 21.98, and 52.84%, respectively, and the 95% confidence interval

TABLE 1 | Average, standard deviation, and correlation coefficient of each variable.

	M	SD	1	2	3	4
1. Social adaptation	44.454	6.952	1			
2. Emotional intelligence	4.168	0.615	0.388**	1		
3. Physical education engagement	4.224	0.841	0.295**	0.708**	1	
4. Empowering motivational climate in physical education	6.153	1.074	0.220**	0.577**	0.690**	1

*N = 1,526. **p < 0.01.*

of the above indirect effects does not contain the number 0, indicating that the three indirect effects have reached a significant level, and hypothesis 2, hypothesis 3, and hypothesis 4 are all true. The indirect effect comparison option in model 6 was selected to compare the indirect effects of different paths in pairs to investigate whether there was a significant path difference. Comparison 1 showed that the Bootstrap 95% confidence interval for the difference between indirect effect 1 and indirect effect 2 did not contain 0 value, indicating that indirect effect 1 was significantly different from indirect effect 2. Using the same idea, there is no significant difference between indirect effect 1 and indirect effect 3, indirect effect 2 and indirect effect 3.

DISCUSSION

Empowering Motivational Climate and Social Adaptation

This study focuses on the mechanism of empowering motivational climate in physical education on social adaptation of high school students. The results show that empowering motivational climate in physical education significantly positively predicts school adaptation, and the independent and chain mediating effects of physical education engagement and emotional intelligence are verified. This study verifies that empowering motivational climate in physical education is a significantly positive predictor of social adaptation, which is consistent with previous studies (Lim and Wang, 2009), and verified hypothesis 1. Physical education teachers can build a positive psychological environment to meet the basic needs of students and further produce adaptive behavior results through physical exercise motivation (Lim and Wang, 2009). Research by Jose et al. (2020) shows that teachers are more closely related to school adaptation among the social support perceived by adolescent students from family, teachers, and friends. Other studies have shown that teacher caring behavior can significantly positively predict the social adaptation of ethnic minority students (Yaqiong et al., 2019). There is a significant positive correlation between social support (teachers, classmates, and relatives) and social adaptation, and the reduction of adolescents' perceived social support will lead to a decrease in their social adaptation (Yan et al., 2017). One possible reason is that students who can positively perceive emotional support from teachers are better able to resist adjustment barriers and school burnout than other students (Reschly et al., 2008). Other studies have confirmed that positive social factors provided by physical education teachers (e.g., teachers encouraging students to try new sports skills and encouraging students to cooperate fully in sports) can satisfy students' sense of relationship, competence and autonomy and then produce more positive behaviors through motivation (Deci and Ryan, 1985, 2000; Lim and Wang, 2009). Therefore, empowering motivational climate in physical education plays an important role in promoting high school student association adaptation. In physical education class, teachers' care and encouragement, appreciation, and trust, as well as various teaching organizations and teaching methods, may promote the cultivation of high school students' social adaptation ability.

Independent Mediating Effect of Physical Education Engagement and Emotional Intelligence

This study not only investigates the direct relationship between empowering motivational climate in physical education and high school students' social adaptation but also builds a mediation model between them using physical education engagement and emotional intelligence as the mediating variables. It is found that physical education engagement plays a partial mediating role between empowering motivational climate and social adaptation. Hypothesis 2 is verified. This is related to the previous research evidence about which empowering motivational climate has a positive effect on physical education engagement (Reeve, 2012) which contributes to social adaptation (Tao and Zheng, 2006; Wenhua et al., 2013). This study investigates the relationship among the above three variables simultaneously, revealing that empowering motivational climate in physical education is an important factor to improve the learning input of physical education. It is also an important factor for social adaptation. The possible reason is that senior high school students who perceive sufficient support from physical education teachers show a high level of physical education engagement and enhance the communication among classmates in the process of high-quality physical education learning. The psychological compatibility among students is improved, and the self-confidence and anti-frustration ability are enhanced. The psychological quality of students is improved, so is their social adaptation. It is worth mentioning that, as a positive emotional state, physical education engagement enables individuals to correctly deal with the challenges they encounter in the learning process. This is not only conducive to the improvement of high school students' optimism and self-esteem but also helpful to buffer external pressure. In other words, physical education engagement can enable individuals to maintain a good physical and mental state.

TABLE 2 | Analysis of regression relationship among variables.

Effect	Item	Effect	SE	*t*	*p*	LLCI	ULCI
Direct effect	Empowering motivational climate → social adaptation	0.031	0.040	0.760	0.008	0.011	0.049
Indirect effect process	Empowering motivational climate → physical education engagement	0.690	0.023	30.444	<0.001	0.645	0.734
	Empowering motivational climate → emotional intelligence	0.169	0.030	5.623	<0.001	0.110	0.228
	Physical education engagement → emotional intelligence	0.591	0.030	19.639	<0.001	0.532	0.650
	Physical education engagement → social adaptation	0.058	0.047	1.230	0.019	0.034	0.149
	Emotional intelligence → social adaptation	0.365	0.041	8.817	<0.001	0.284	0.447
Total effect	Empowering motivational climate → social adaptation	0.282	0.031	9.097	<0.001	0.160	0.280

All variables in the model have been standardized, the same as below; LLCI is the lower limit of 95% interval of estimated value, and ULCI is the upper limit of 95% interval of estimated value.

TABLE 3 | Mediating effect analysis of empowering motivational climate and school adaptation.

Item	Effect	Boot SE	Boot LLCI	Boot ULCI	*p*
Empowering motivational climate → physical education engagement → social adaptation	0.040	0.003	0.068	0.077	<0.001
Empowering motivational climate → emotional intelligence → social adaptation	0.062	0.014	0.037	0.09	<0.001
Empowering motivational climate → physical education engagement → emotional intelligence → social adaptation	0.149	0.010	0.132	0.172	<0.001

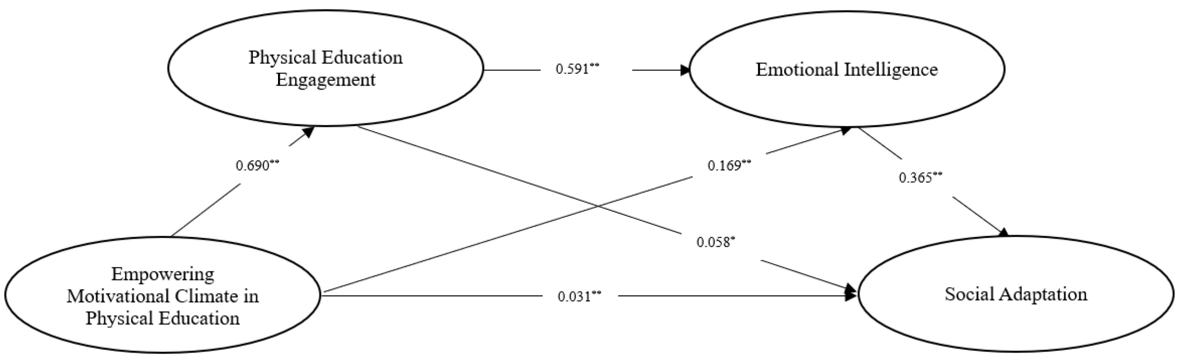

FIGURE 2 | The chain mediation model of empowering motivational climate and school adaptation. $^{*}p < 0.05$ and $^{**}p < 0.01$.

Individuals with physical education engagement have higher levels of physical and mental health (Steele and Fullagar, 2009).

It is also found that emotional intelligence plays a partial mediating role between empowering motivational climate in physical education and social adaptation, which was consistent with existing research results and verified hypothesis 3. Empowering motivational climate in physical education plays an important role in promoting emotional intelligence (Sergio et al., 2020). The possible reason is that perceived teacher emotional support by high school students is more closely associated with lower levels of emotional exhaustion and higher subjective well-being than other sources of support (Hughes et al., 2001, 2008). Studies have shown that emotional intelligence can positively predict social adaptation (Engelberg and Sjöberg, 2004; Jiajun et al., 2016); individuals with high emotional intelligence are better able to adjust their emotions, perceive their own and others' emotions more accurately, better cope with the pressure and confusion brought by adverse environments, keep an optimistic attitude in difficult situations, and better adapt to the society (Yu and Peng, 2017). The results of this study confirm that the motivation climate of PE empowerment is an important factor in promoting not only emotional intelligence but also social adaptation of high school students. According to the stress coping model, high school students with sufficient support from teachers can acquire emotional management ability related to emotional disclosure, which will help them regulate anxiety, depression, and other negative emotions more effectively, and then improve social adaptation. In terms of the influence of emotional intelligence on individual life, the important role of emotional intelligence is characterized by two aspects: on the one hand, emotional intelligence should be embodied in the areas of emotional activities, such as dealing with setbacks and challenges encountered in our daily life, and on the other hand, emotional intelligence should deal with things and individual efficiency and the ability to combine.

Chain Mediating Effect of Physical Education Engagement and Emotional Intelligence

This study further found that physical education learning engagement and emotional intelligence had a chain-mediated effect on the relationship between empowering motivational climate and social adaptation, which verified hypothesis 4. This is consistent with the existing research results that physical education engagement contributes to emotional intelligence (Hongmei and Lin, 2012). Previous studies have shown that emotional intelligence and physical education engagement have a significant positive correlation, but most studies have confirmed that emotional intelligence can significantly and positively predict physical education engagement (Binghuang and Liang, 2020). This study found that physical education engagement also significantly positively predicted emotional intelligence. Learning engagement is a continuous, full, positive, and perfect mood and state of employees, which is characterized by vitality, dedication, and concentration (Schaufeli et al., 2002a). The higher the degree of learning involvement, the more persistent efforts in the face of difficulties, full of enthusiasm for learning, and dare to face the challenges in learning. Such positive and healthy emotions and cognition can help individuals to timely understand themselves, maintain a positive attitude, deal with various pressures and difficulties in the environment, monitor their own and others' emotions, and then promote the development of their own emotional intelligence. Through the chain mediation effect test, this study found that adequate physical education teacher support can promote students to fully engage in learning, which will lead to a healthier development of emotional intelligence, and then promote social adaptation. Therefore, in physical education teaching, teachers should create a good learning environment through a variety of teaching methods or teaching modes, improve the level of the students' physical education engagement, which in turn raises the student good emotional intelligence, in order to better cope with problems and challenges brought about by the pressure, maintains an optimistic attitude in the difficult situation, and finally improve the social adaptability of high school students.

Empowering motivation climate can stimulate senior high school students' learning motivation and then promote physical education engagement, and physical education learning engagement and emotional intelligence are significantly positive correlation. Therefore, the chain mediation of physical education engagement → emotional intelligence in this study is feasible and has a partial mediating effect between the empowering motivation climate and social adaptation. To a certain extent, the mediating effect model reveals the mechanisms underlying the association between empowering motivational climate and social adaptation. It is suggested that on the premise of giving full play to the role of empowering motivation climate, physical education educators can further improve the social adaptability of senior high school students by improving their physical education investment and emotional intelligence.

Practical Significance

First, the empowering motivational climate in physical education is an important variable to predict social adaptation. Adolescence is a critical period for a person's development, and it is the period with the most changes in the life cycle. It keeps growing in physical and psychological aspects, and the individual's mentality and social relations are constantly changing. Due to age characteristics and other reasons, they are prone to adaptive disorders and problematic behaviors. School education is an effective process to accelerate, guide, and standardize individual socialization, and the cultivation of adolescents' good social adaptability should be an important part of school education. Teachers have to shoulder the heavy responsibility of not only spreading cultural skills but also instilling new social role norms, and also creating an atmosphere of social adaptation, and teaching students to adjust themselves with social rules. Second, physical education engagement and emotional intelligence are the important factors that affect the social adaptation of high school students. Schools should take practical and effective measures to cultivate emotional intelligence. On the one hand, schools should establish a new teacher–student relationship, build an emotional classroom teaching model, set emotional intelligence education content in standardized courses, and adopt a scientific teaching evaluation system. On the other hand, they should carry out humanities education, social practice activities, quality development training, and professional school psychological consultation. In addition, schools should also organize a variety of extracurricular sports activities and sports competitions. Teachers can use a variety of teaching content, teaching methods, teaching organization, and teaching evaluation to improve the endogenous motivation of physical education courses and then increase students' level of physical education engagement.

Limitations and Future Directions

This study explores the relationship between empowering motivational climate in physical education and senior high school students' social adaptation and constructs a chain mediation model. It reveals the mechanisms underlying the association between empowering motivational climate and social adaptation. It has important theoretical and practical value to understand the causes of senior high school students' social adaptation, and at the same time, it also provides a basis for studying the causal relationship between the variables. However, this study has not been able to draw a causal inference between the variables. Longitudinal tracking or experimental intervention design can be used in the future, so as to more effectively explain the impact of empowering motivational climate in physical education on senior high school students' social adaptation. In addition, in this study only physical education engagement and emotional intelligence are considered in empowering motivational climate. In fact, there may still be other intermediary variables such as personality, self-esteem, and so on, which need to be further explored in the future. In the future research, we will adhere to the education concept of "health first" and explore the multiple mechanisms of physical education on adolescent physical and mental health.

CONCLUSION

Empowering motivational climate in physical education can significantly positively predict social adaptation. Physical education engagement and emotional intelligence play a significant mediating role between empowering motivational climate in physical education and social adaptation. There are three mediating paths, namely, the separate mediating effect of physical education engagement, the separate mediating effect of emotional intelligence, and the chain mediating effect of physical education engagement and emotional intelligence.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

KG designed the study, collected and analyzed the data, and wrote the manuscript. QM, SY, HC, ZH, CL, and PW revised the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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