Mental Health and Physical Activity 17 (2019) 100293

Contents lists available at ScienceDirect

Mental Health and Physical Activity

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

Effects of acute physical activity on NIH toolbox-measured cognitive functions among children in authentic education settings

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ARTICLE INFO

Keywords:
Cognition
Physical activity
Classroom
Brain break
Accelerometry

ABSTRACT

Introduction: Identifying a dose of physical activity (PA) that can improve cognitive function in children has important implications for school-day PA recommendations. Researchers and educators have interest in this link as it relates to both health and academic performance. This study examined the dose-response relationship between PA and improvement in cognition in a sample of fifth and sixth grade students.
Methods: Participants (n = 156) from eight classes each completed two of four different cognitive assessments on an iPad, both before and after exposure to one of four randomized, 10-min PA conditions (sedentary, light, moderate, and vigorous). Conditions were standardized through use of videos to lead movement, and participants wore accelerometers to confirm fidelity to PA condition. The four cognitive assessments were selected from the NIH Toolbox Cognition Battery, and included Dimensional Change Card Sort, Flanker, Pattern Comparison, and Picture Sequence Memory tests. Hierarchical linear regression models were used to estimate the effects of condition on each test using an intention to treat analysis.
Results: Fidelity to PA condition was acceptable for sedentary and light conditions, but became less precise for moderate and vigorous conditions. No significant time by condition interaction was observed for any of the cognitive assessment scores.
Conclusions: Results did not substantiate a dose-response link between PA intensity and selected measures of cognitive function. More research is needed to investigate the potentially nuanced effects of short bouts of PA on cognitive functioning in children.

1. Introduction

The use of physical activity (PA) during the school day is increasingly recommended as a low-cost health-enhancing strategy to aid in improving student learning outcomes (Institute of Medicine, 2013; Pate et al., 2006). School leaders and educators have been tasked with identifying feasible ways to increase their students' PA across the school day in order to meet the recommendation of providing 30 min of moderate to vigorous PA during school. The Comprehensive School Physical Activity Program model (CDC, 2013; Society of Health & Physical Educators, 2013) is a framework for increasing school PA, suggesting that children be provided with adequate opportunities for PA before, during, and after school. With many children spending at least 30 h per week specifically in the school classroom (Burns et al., 2015), which may not be traditionally viewed as an "active" environment, the classroom is a prime target for introducing more opportunities for movement. Referred to as classroom physical activity, brain breaks, brain boosters, or active learning, this method of increasing school-day PA includes taking a short pause in the standard lesson to be physically active, or integrating PA into the lesson (Centers for Disease Control and Prevention, 2018).

Classroom physical activity is not universally provided in schools throughout the United States (Centers for Disease Control and Prevention, 2015; Turner & Chaloupka, 2017), despite its popularity in the public health sector. However, research exploring the effects of classroom PA on physical health, classroom behavior, and cognitive and academic outcomes, has surged over the last several decades (Castelli et al., 2014; de Greeff, Bosker, Oosterlaan, Visscher, & Hartman, 2018). Evaluation of classroom PA intervention programs such as TAKE 10! and Physical Activity Across the Curriculum (PAAC), which were among the first randomized controlled trials testing the integration of core curriculum content with bouts of PA, found that PA breaks

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https://doi.org/10.1016/j.mhpa.2019.100293
Received 18 March 2019; Received in revised form 3 June 2019; Accepted 9 June 2019
Available online 10 June 2019

significantly increase students' daily PA levels (Donnelly et al., 2009; Stewart, Dennison, Kohl, & Doyle, 2004). Additional studies have since corroborated this evidence, indicating that classroom PA does significantly increase the volume of PA that students receive during the school day (Calvert, Mahar, Flay, & Turner, 2018; Carlson et al., 2015; Erwin, Beighle, Morgan, & Noland, 2011). Recently, classroom PA delivery has been enhanced through advances in technology, as more internet-based resources – including free YouTube videos and fee-based subscription services– have become more accessible to teachers. Much of the content now available is of high production quality, increasing its relevance to young students, which could bolster engagement in and enjoyment of classroom PA. GoNoodle, an on-line physical activity break tool, has been shown to increase student's aerobic PA across the school day (Fedewa, Fettrow, Erwin, Ahn, & Farook, 2018). Similarly, the combination of video-based classroom PA breaks and PA monitoring through wearable technology has been shown to not only enhanced student's accumulation of moderate to vigorous PA (MVPA), but also reduced their accumulation of sedentary minutes (Buchele Harris & Chen, 2018).

Incorporating PA into the classroom routine has been linked to positive learning outcomes for children aged 6–12 years. Studies have found that short bouts of classroom PA increase on-task behavior (Goh, Hannon, Webster, Podlog, & Newton, 2016; Grieco, Jowers, & Bartholomew, 2009; Grieco, Jowers, Errisuriz, & Bartholomew, 2016; Ma, Le Mare, & Gurd, 2014; Mahar et al., 2006), although it is still unclear whether this translates to improved academic performance in the long term. Indeed, the effects that long-term engagement in PA may have on academic outcomes in school-aged youth are still under study (Singh et al., 2018). In their review, Singh and colleagues noted that results from several rigorous randomized controlled trials which used school PA intervention (Ahamed et al., 2007; Donnelly et al., 2009; Gao, Hannan, Xiang, Stodden, & Valdez, 2013; Resaland et al., 2016; Telford et al., 2012) have shown improvement in 60% of academic performance outcomes, while 40% of outcomes did not improve. However, the causality of the relationship, or the mechanisms underlying improvement in academic achievement with prolonged exercise intervention, remain unknown (Singh et al., 2018).

Although several laboratory-based studies have shown that acute PA can improve both academic and executive control outcomes (Hillman et al., 2009; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013) immediately following exercise, a recent systematic review of studies examining acute bouts of classroom PA on children's cognition found mixed evidence for the effect of acute PA on various cognitive processes. This review found that most classroom-based studies reported null effects, while some showed an increase in cognitive performance (Daly-Smith et al., 2018). Some of this research suggests that the duration of the classroom PA bout may largely dictate its effects on academic outcomes, and that 5 min per day is not enough to elicit a benefit (Howie, Schatz, & Pate, 2015; Kubesch et al., 2009). Specifically, Howie et al. (2015) explored how 5 min, 10 min, and 20 min of classroom PA influenced academic performance and cognitive processing immediately after PA among 9 through 12-year-old children. Their results indicated that 10 and 20-min PA break significantly improved math scores as compared to changes over similar periods of time when students were sedentary (Howie et al., 2015).

As concluded by Daly-Smith et al. (2018) in their review, more high-quality studies which measure intervention fidelity are needed to help identify trends in the effects of acute classroom PA on cognitive functioning. The varied findings in the literature on cognitive function and PA specific to the classroom context leaves much unknown about how length and intensity of PA dose may impact specific cognitive processes in the classroom environment. Continuing to identify these effects may help explain whether and how PA can benefit academic achievement in the long term. Accordingly, this study used an experimental design to evaluate the dose-response effects of short bouts of PA at varying intensities across four cognitive outcomes in 5th and 6th grade children, in the classroom context.

2. Methods

This research was approved by the Institutional Review Board at Boise State University under protocol number 101-SB17-155. Both parental consent and written assent were obtained from each participant prior to their participation in this study. The average parental consent rate among participating classrooms was 72%, while the average student assent rate was 88%. Only students who both assented and had parental consent participated in the study. Data were collected between the months of October 2017 and February 2018.

2.1. Participants

Students (n = 156) from eight classrooms in a one public middle school in southwestern Idaho assented and also had parental consent to participate. All participants were in grade levels five (40%) and six (60%) and 54% were female (typical age range for these grades is 10–12 years). The school has a total attendance of slightly more than 600 students, among whom 55.6% are eligible for free and reduced price lunch, 62.8% are white/non-Latino, and 37.2% are students of color. Teachers agreed to let the research team come into their classrooms in 1-h blocks to conduct the study, and teachers remained in the classroom for the duration of the testing session.

2.2. Instruments

Several assessments from the National Institutes of Health (NIH) Toolbox Cognition Battery version 1.13 were administered via iPad application to measure cognitive functioning (Weintraub et al., 2013). Assessments included: 1) Dimensional Change Card Sort Test (Card Sort) Ages 8–11; 2) Flanker Inhibitory Control and Attention Test (Flanker) Ages 8–11; 3) Pattern Comparison Processing Speed Test (Pattern Comparison) Age 7+; and 4) Picture Sequence Memory Test (Picture Sequence) Age 8+. Respectively, these assessments measure cognitive flexibility, inhibitory control, processing speed, and episodic memory. Cognitive flexibility and inhibitory control are both executive functions, or top-down processes that involve the prefrontal cortex and are key to concentration and goal-directed activity, and as such play an instrumental role in learning and school readiness (Diamond, 2013). Processing speed indicates the speed at which simple cognitive operations are conducted, and episodic memory, or the capacity to store and retrieve information, is critical for knowledge acquisition (Weintraub et al., 2013). Some studies have shown these fluid cognitive abilities to improve as a result of acute exercise, although research findings are mixed (Daly-Smith et al., 2018).

To conduct the assessments, the NIH Toolbox software application was downloaded onto 30 iPads, which allowed every student in a given classroom to have their own iPad for testing. IPads were equipped with folding cases that could be converted to stands which propped up the iPads on top of desks. A brightly colored foam star was glued onto each of the cases to serve as "home base" for finger placement during each of the assessments. Each iPad was programmed with two of the four possible cognitive assessments, with half of the iPads programmed on one testing battery (Flanker and Picture Sequence), and the other half programmed with the alternate test battery (Card Sort and Pattern Comparison). The order of the two tests was counterbalanced across days. Participants were given verbal instructions by the research staff regarding the use of iPads. Participants were also provided headphones to listen to the assessment directions and cues, which were also displayed in text on the iPad screen. Each of the assessments began with a brief practice session, and research staff members were available to answer questions. Participants started the test on their own once they finished the practice round.

The PA conditions used in the experiment were based on video modules selected from GoNoodle, an online platform that provides activity-focused video content targeted at children and youth. GoNoodle was chosen for its prevalence of use among teachers (gonoodle.com cited usage in 14 million classrooms as of early 2019), as well as its availability within the classrooms in this study. Videos were also utilized to standardize the PA intervention conditions across classes. Each PA condition lasted approximately 10 min, and was comprised of two videos shown back-to-back. For the control condition, videos included a social studies lesson and two reading/grammar lessons from the *Blazer Fresh* GoNoodle channel, both set to music. Participants were instructed to view these videos while seated. Exercise videos were selected from the *Fresh Start Fit* GoNoodle channel, and included one low to moderate intensity activity video (directed stretching and low-impact movements) and two high intensity videos (directed fast-paced body weight exercises with jumping). These exercise videos were also set to music. Conditions were created as follows: 1) sedentary control (SED) condition comprised of two control videos; 2) light (LIGHT) condition comprised of one control video followed by the light to moderate intensity video; 3) moderate (MOD) condition comprised of one control video followed by a high intensity video; and 4) vigorous (VIG) condition comprised of two high intensity videos. Each of the participants wore an ActiGraph GT3X-BT accelerometer attached to the waist via elastic band to measure fidelity to PA condition.

2.3. Protocol

Each classroom was randomized to receive two different PA conditions, with sessions occurring on separate days (i.e., the four conditions were randomized across 16 teacher-days, among eight teachers). This also meant that participants were exposed to two different intervention conditions if they were present on both days of testing. However, on the second day of testing, participants were assigned the alternative testing battery to the one they completed on the first day (i.e., they did not repeat the same cognitive assessments across days). At least two research staff members attended each testing session. Testing sessions occurred within the 2 h of the last morning bell and before morning recess. At the beginning of each session, researchers entered the classrooms and distributed an iPad, accelerometer, earphones, an assent form, and a drawing form to each participant. After the research staff read the study briefing and assent script aloud, they instructed participants on how to put on and correctly place their accelerometers. Then, the researchers guided participants through logging into the iPads, and positioning them to stand up on their desks. Researchers had all participants practice returning their index fingers to the home base star when they were not touching the screen. Participants were then instructed to begin the iPad assessments, and were given 15 min to complete them. To provide a filler activity for students who finished the assessments earlier than others—and to avoid possible disruption of students who were still working on the assessments—students were instructed to draw a picture on the provided form after completing the assessments (all students were prompted to draw the same objects). In the 16 testing days, there were three instances where a student did not finish within 15 min. These scores were omitted from analyses as incomplete data.

At the conclusion of 15 min, the intervention condition began. During control videos, participants were instructed to stay seated and attend to the videos, participating in reciting the chorus of the songs when prompted by the videos. For the exercise videos, participants were instructed to find a space in the classroom where they could move around comfortably, and to participate in the PA to the best of their ability. For both the LIGHT and MOD conditions, videos always followed control videos. Research staff performed the exercises in the videos to role model and also verbally encouraged participation during the PA videos. Once both videos were finished, participants returned to their seats and repeated the same cognitive battery that they had completed prior to the intervention condition. Testing started within 1–3 min of the conclusion of the video. Once all participants completed the second round of assessments, the testing session finished.

2.4. Data processing and scoring

All scores for the cognitive assessments were calculated automatically by the NIH Toolbox software. For Flanker and Card Sort, scores were computed using a 2-vector scoring method which utilizes both speed and accuracy outcomes from the tests. The computed scores for these tests range in value from 0 to 10. For Picture Sequence, computed scores represent the outcome of an item response theory calculation utilizing the number of correct adjacent pairings of pictures. For Pattern Comparison, the computed score represents the number of correct responses generated in 85 s. For more information on how scores are calculated, see scoring and interpretation guide for the iPad (National Institutes of Health & Northwestern University, 2016). Each participant's computed scores were exported in a. csv file for statistical analysis.

Accelerometer data processing was done in ActiLife version 6.13.3. Raw data were downloaded in 5 s epochs using the normal filter. A date/time filter was applied to the data from each testing day before scoring. The filter excluded all minutes within the testing session except for the minutes when the intervention condition occurred. Freedson et al. (2005) cut points (sedentary: 0–149 counts per minute; light PA 150–499 counts per minute; moderate PA 500–3999 counts per minute; vigorous PA 4000–7599 counts per minute; very vigorous PA 7600 + counts per minute) were used for data scoring (Freedson, Pober, & Janz, 2005). The Axis 1 activity counts per minute, derived from acceleration of the vertical axis, were used in the analysis, as this outcome represents an average PA intensity across time for each participant.

2.5. Statistical analysis

One classroom was omitted from analysis due to a lockdown drill that occurred during data collection, leaving 15 classroom-days for analysis. Since the cognitive assessment instructions were only provided in English, and the district had a relatively high percentage of Hispanic/Latino families, there was concern that participants who may not have been completely proficient in English for their grade level may have struggled to understand the testing directions, thus confounding the results. To investigate this, students' English-language learner status (yes/no) was obtained from the school district, and baseline cognitive assessment scores for English-language learner students were compared to non- English-language learner students' baseline scores using an independent samples *t*-test. T-test results indicated that there was no significant difference in scores between the two groups on any cognitive assessment (Card Sort [$t\ (130) = 0.583$, $p = 0.561$]; Flanker [$t\ (122) = 1.26$, $p = 0.209$]; Pattern Comparison [$t\ (129) = 0.403$, $p = 0.688$]; Picture Sequence [$t\ (114) = 0.241$, $p = 0.81$]). So, English-language learner status was not used in the subsequent main analyses.

As a check on the fidelity of the experimental manipulation, we examined differences in counts per minute across conditions using a one-way ANOVA with Tukey's post-hoc tests. To assess the necessity of using hierarchical linear modelling for the main analysis, intraclass correlations (ICCs) were estimated for the cognition score for each assessment. The ICCs were non-significant for Card Sort (ICC = 0.0, χ^2 (14) = 13.6, $p > 0.5$) and Pattern Comparison (ICC = 0.03, χ^2 (14) = 20.1, $p > 0.125$), but were significant for Flanker (ICC = 0.09, χ^2 (14) = 29.9, $p = 0.008$) and Picture Sequence (ICC = 0.11, χ^2 (14) = 32.1, $p = 0.002$). Given the magnitude and significance of the variance components at level 3 for two of the four ICCs, hierarchical linear modelling was used (Raudenbush, Bryk, Cheong, Congdon, & du Toit, 2011). We tested the effect of PA condition on cognitive functioning using a 3-level (time, participant, classroom) mixed effects

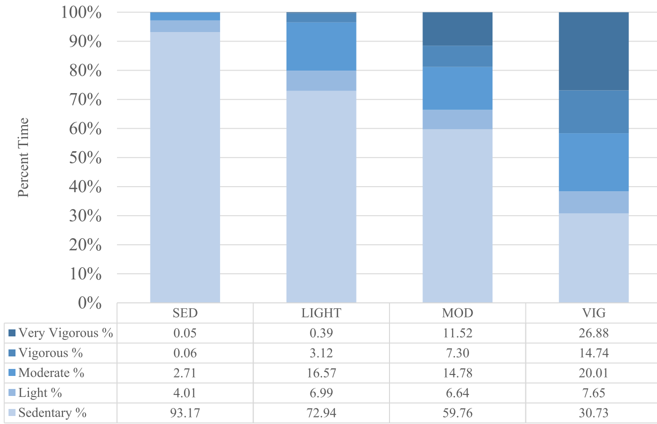

Fig. 1. Percent time in each physical activity intensity by intervention condition.

Fig. 2. Scatterplot of axis 1 counts per minute (CPM) per student by intervention condition.

regression model and an intention to treat analysis. Models used full maximum likelihood estimation, and accounted for the nesting of multiple observations within participant and within classroom. The NIH Toolbox-computed score for each cognitive assessment was the dependent variable in the models. All statistical analyses were conducted using SPSS version 25 and HLM software Version 7.03 (Raudenbush et al., 2011).

3. Results

Percent time spent in each PA intensity, across all conditions, is presented in Fig. 1. The experimental manipulation was mostly successful in eliciting differences in PA level across conditions; ANOVA results (Table 1) confirmed a between-group difference in counts per minute (F (3,190) = 179.64, $p < 0.001$) and post-hoc analyses revealed that average counts per minute differed significantly across all conditions except for the SED and LIGHT conditions. These data are displayed visually across all participant-days in Fig. 2.

Mean increases in scores from baseline to post-test for all assessments across all conditions were non-significant, except for the VIG group on the Pattern Comparison (t (111) = 8.134, $p < 0.001$). The slopes from other conditions were not significantly different from the VIG condition (i.e. the scores on the Pattern Comparison increased from baseline to post-test across all groups). Condition randomization failed for Flanker, as baseline scores between the SED and VIG groups were significantly different (t (107) = 2.98, $p = 0.004$). Omnibus tests for the time by condition interaction effects were non-significant for Card Sort ($\chi 2$ [3, n = 134] = 3.09 p = 0.38), Flanker ($\chi 2$ [3, n = 125] = 4.29 p = 0.23), Pattern Comparison ($\chi 2$ [3, n = 131] = 1.25 $p \geq 0.5$), and Picture Sequence ($\chi 2$ [3, n = 125] = 0.52 $p \geq 0.5$), revealing that there was no effect of condition assignment on performance for any cognitive assessment. Model estimated mean scores for baseline and post-test cognitive assessments for each condition are provided in Table 2.

4. Discussion

The present study did not find that enhancements in cognitive performance were elicited by a high-intensity classroom PA bout when compared to lower intensity classroom PA bouts and sedentary control conditions. Further, participants' scores did not differ significantly from baseline to post-test, except Pattern Comparison. However, this study does add further evidence to the literature base showing that moderate to intense bouts of classroom PA, as well as sedentary, cognitively engaging breaks from traditional instruction, do not pose a threat to the cognitive functioning of children (Ahamed et al., 2007; Howie et al., 2015; Jäger, Schmidt, Conzelmann, & Roebers, 2015; Tandon et al., 2018; Vazou & Smiley-Oyen, 2014).

In this study, participants were randomized across four treatments including 1) SED condition in which students remained seated while watching two educational videos set to music; 2) LIGHT condition in which students were seated and watched one seated video followed by engaging in a light to moderate intensity video; 3) MOD condition in which students watched one seated video followed by engaging in a high intensity video; and 4) VIG condition where students engaged in two high intensity videos. A similar dose-response design was utilized by Grieco et al. (2016), who found that fourth grade students declined in their observed time on task after the completion of a sedentary teacher-delivered lesson (a writing task), and showed no improvement or decline after a game-based lesson (involving peer group competition). They also found benefits for time on task for the low-intensity and moderate to vigorous-intensity physically active competitive game versus both sedentary conditions. These findings suggest a positive effect of adding a novel element to a sedentary lesson (which the authors attribute to the theory of attentional reset [Evans & Pellegrini, 1997]), as well as PA, for subsequent attention to task. Time on task was not measured in the present study. However, all assessments except for Picture Sequence were scored partially based on 'time to completion,' which does involve an attentional component. Thus, it is possible that benefits to attention may have resulted from the intervention

Table 1
Axis 1 counts per minute for each condition.

Condition	n	Mean	Standard Deviation	Lower C.I.	Upper C.I.	Cohen's d	p value
SED	40	64.78	76.98	40.15	89.40	Ref	Ref
LIGHT	62	517.04	228.40	459.04	575.04	2.65	0.216
MOD	48	2576.96	1343.51	2186.84	2967.07	2.64	< 0.001
VIG	46	5014.29	1923.26	4443.16	5585.43	3.64	< 0.001

Note. C.I. = confidence interval, SED = Sedentary, MOD = moderate, VIG = vigorous.

Table 2
Model-estimate mean cognitive functioning scores by condition.

Assessment	Condition	Baseline Mean (SE)	*p* value (baseline differences)	Post-test Mean (SE)	Baseline to Post-test change	*p* value (time by group interaction)
DCCS	SED	6.86 (0.33)	0.317	6.97 (0.25)	0.11	0.74
	LIGHT	7.13 (0.30)	0.841	7.15 (0.23)	0.03	1
	MOD	7.42 (0.27)	0.384	7.14 (0.21)	−0.28	0.145
	VIG^{+}	7.19 (0.21)		7.21 (0.16)	0.02	
Flanker	SED	8.40 (0.24)	0.004**	8.74 (0.18)	0.34	0.665
	LIGHT	7.73 (0.24)	0.865	8.13 (0.18)	0.41	0.119
	MOD	7.87 (0.22)	0.409	8.09 (0.17)	0.22	0.055
	VIG^{+}	7.69 (0.17)		7.74 (0.13)	0.06	
PCT	SED	49.81 (3.52)	0.723	63.68 (2.46)	13.87	0.823
	LIGHT	50.50 (3.32)	0.559	64.43 (2.30)	13.93	0.789
	MOD	52.29 (2.99)	0.215	64.24 (2.08)	11.96	0.514
	VIG^{+}	48.56 (2.34)		61.87 (1.64)	13.32	
PSMT	SED	519.09 (27.65)	0.454	548.08 (21.85)	28.98	0.569
	LIGHT	538.81 (27.42)	0.143	555.41 (21.85)	16.59	0.996
	MOD	539.85 (25.96)	0.112	563.83 (20.81)	23.97	0.72
	VIG^{+}	498.32 (20.54)		514.79 (16.64)	16.48	

Note. $^{+}$ Indicates reference group, SE = standard error, SED = Sedentary, MOD = moderate, VIG = vigorous, DCCS = Dimensional Change Card Sort Test, Flanker = Flanker Inhibitory Control and Attention Test, PCT = Pattern Comparison Test, PSMT = Picture Sequence Memory Test **$p < 0.05$.

conditions, but were not apparent due to the computed scores (which take into account both accuracy and reaction time) used to report Card Sort and Picture Sequence. However, Pattern Comparison, which measures the speed of simple cognitive processes, and is scored solely based on items correct in a fixed time frame, did show improvement across all intervention conditions. Although we cannot rule out the potential of a learning effect from pre to post assessment, it is also possible that the task novelty (viewing GoNoodle videos) in all conditions within our study elicited some improvements in processing speed on the Pattern Comparison.

In a similar study, Schmidt, Jäger, Egger, Roebers, Conzelmann (2015) utilized a 2 × 2 factorial design to examine the effects of classroom breaks which elicited low versus high cognitive engagement, with and without PA, in children 10 and 11 years old. Their results showed that participating in a cognitively engaging break, either while sedentary or while being physically active, was enough to elicit some improvements in attention, but not processing speed or accuracy. The authors attributed this to the partial mediation of positive affect, which was another variable examined in their study. Other work has corroborated, through annotation of video capture, that children in the 9–10 year old age range do enjoy classroom PA (Howie, Newman-Norlund, & Pate, 2014). Thus, mechanisms such as task novelty or positive affect may partially mediate improvements in performance on cognitive assessments and on-task behavior after "non-traditional" classroom experiences. Future work in this area could include a measure of positive affect to elucidate this relationship.

It should be considered that all neuropsychological tests are somewhat limited in their generalizability to academic performance, as they are designed to provide information about very specific cognitive functions. Classrooms are complex environments, with myriad stimuli that children must navigate at any given time (e.g., complex visual and auditory stimuli). Further, building evidence suggests that neuropsychological measures currently accessible may not accurately represent the measured cognitive domains when conducted in authentic settings (Odhuba, Van Den Broek, & Johns, 2005; Parsons & Rizzo, 2008) especially in the classroom context (Obradović, Sulik, Finch, & Tirado-Strayer, 2018). This study utilized the NIH Toolbox Cognition Battery because it contains widely recognized cognitive measures developed by experts in neuropsychological assessment. However, they were developed for use in a one-on-one testing setting. As such, perhaps in this study —as with other studies of a similar design (e.g., Jäger et al., 2015)–- the potential for distraction introduced in the classroom environment may confound any effects that could have resulted from the PA conditions.

There continues to be a lack of consistent evidence demonstrating that classroom PA improves short-term cognitive outcomes in school-age children (Daly-Smith et al., 2018). This information, coupled with strong evidence for behavioral improvements after five or more minutes of MVPA (Daly-Smith et al., 2018) and strong evidence for math performance improvement after chronic exposure to PA (Singh et al., 2018) leaves much to be determined about the "PA-cognitive performance relationship" (Singh et al., 2018, p. 8). Hillman and colleagues note the importance of utilizing neuroelectric techniques and biomarker measures (e.g., brain-derived neurotropic factor, epinephrine), in conjunction with cognitive measures, in future investigations seeking to elucidate mechanisms underlying the effects of acute PA on cognition (Hillman, Logan, & Shigeta, in press). Thus, future work exploring these factors in laboratory settings is also warranted.

4.1. Strengths and limitations

The experimental design of the study is a strength of this work. Many conditions that could have confounded the study results were controlled for in the design, including conducting assessments at the same time of the school day, and using a set of video recordings for intervention. Videos were all cognitively engaging and set to music, thus the conditions only varied in the amount of PA elicited from participants. Additionally, PA was measured via accelerometry to account for treatment fidelity, which is a strength that is absent from many other studies in this area (Daly-Smith et al., 2018). However, not all aspects of research within school classrooms can be controlled, and limitations arose from factors related to real-world classroom measurement. Full participation in PA videos was encouraged, but we could not require students to participate, thus not all students fully complied with their intervention condition. Students were seated in desk pods among their peers, so they could have become distracted by others in the classroom and not performed the assessments to the best of their ability. Other study limitations include potential selection bias, as the population of students who assented and had parental consent to participate may not have been representative of the general school population (though average rates of consent/assent were > 75%), or the general childhood population.

5. Conclusions

The purpose of the study was to further examine the dose-response effect of an acute classroom PA bout on cognitive performance. Although our hypothesized outcomes regarding PA were not substantiated, this study contributes to the broader literature documenting that providing novel cognitive engagement opportunities with and without PA across the school day does not harm subsequent cognitive performance. As previous work demonstrates, students should be provided with routine classroom PA to facilitate their on-task behavior and engagement, and online video resources may be a way for teachers to provide time for PA without the burden of planning an additional element of instructional practice. The underlying mechanisms of classroom PA on academic performance in the short and long term still warrant further research.

Funding

This research was supported an internal grant from Boise State University as well as grant R305A150277 from the Institute of Education Sciences and US Department of Education to Boise State University. The opinions expressed are those of the authors and do not represent views of the institute or the US Department of Education.

Conflicts of interest

Declarations of interest: none.

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