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ARTICLE

Effects of Vigorous Intensity Physical Activity on Mathematics Test Performance

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The effect of an acute bout of physical activity on academic performance in school-based settings is under researched. The purpose of this study was to examine associations between a single, vigorous (70–85%) bout of physical activity completed during physical education on standardized mathematics test performance among 72, eighth grade students at a school in the Southwestern United States. Students received both a physical activity and nonactive condition, in a repeated measures design. Academic performance measures were collected at 30 and 45-minutes post condition. It was hypothesized that students would have greater gains in mathematics test scores post physical activity condition compared with post nonactive condition. Results reported students achieved 11–22% higher math scores at 30 minutes post physical activity condition compared with other time points (45 minutes post PA, 30 and 45 minutes post sedentary) ($F(1, 68) = 14.42$, $p < .001$, $d = .90$). Findings suggest that physical activity may facilitate academic performance in math.

Keywords: physical education, academic achievement

Current literature supports the notion that physically active and physically fit students academically outperform inactive and unfit classmates (Castelli et al., 2011; Coe, Pivarnik & Malina, 2006; Donnelly et al., 2009; Grissom, 2005; Howie & Pate, 2012, Welk et al., 2010). Even though the effect of physical activity (PA) (bodily movement that increases energy expenditure, Darst, & Pangrazi, 2009) on academic performance (AP) is a well-documented line of inquiry, findings have historically

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been associated with bouts of chronic PA (exercise over a period of several weeks) (Barenberg, Berse, & Dutke, 2011). Positive results from the chronic physical activity/cognition literature have directly led to a line of study that has considered whether a single acute bout of PA (Dishman, Washburn & Heath, 2004) can affect AP. A small number of school-based researchers are continuing to attempt to translate controlled laboratory-based child-aged acute research (which uses a plethora of differing cognitive tests as measurement instruments) by changing the setting to the gymnasium. These acute school-based studies frequently use mathematics tests as the measurement instrument of AP, reporting higher mean score gains, and larger ES than in studies using other types of academic tests (Fedewa, & Ahn, 2011). Historically, the acute school-based literature has neglected to accommodate for the dose-response relationship (Van Dusen, Kelder, Khol, Ranjit, & Perry, 2011) that considers how intensity, duration and effect time are integral to eliciting a cognitive response. The current study, compared with previous literature intends to use a more scientifically rigorous methodology when considering the PA-AP relationship in a school setting. In a world where the place of Physical Education in the school curriculum is becoming more critically observed, it would seem salient to consider the growing line of research that suggests PA may enhance academics. Essentially, researching the dose response of an acute bout of PA on academic performance can help to inform Physical Education (PE) recommendations.

Consequently, to understand the plausible effects of an acute bout of PA on AP, it is necessary to review experimental research with high ecological validity, to justify the need and design of this present study. In seminal work, Tomporowski (2003) conducted a meta-analysis that examined all of the known research on an acute steady state bout of PA in relation to information processing (brain processes that subserve academic performance through sensory and decision making functions). His research confirmed the idea that, within the laboratory, acute PA maybe related to cognitive performance in an inverted U shape (i.e., physical fatigue equates to decreased cognition), aligning with literature that suggests that over-arousal (a physiological response to input, Pribram, & McGuinness, 1975) can also be detrimental to performance (Yerkes, & Dodson, 1908). In contrast, other researchers have suggested that exercise intensity of PA is paramount when antecedent to the cognitive task—that low intensity PA facilitates cognitive processes immediately after exercise, yet high intensity work facilitates fatigue and consequent cognitive degrade, but improves cognitive performance after a physiological recovery (Chang, Labban, Gapin, & Etnier, 2012).

The few acute PA studies focused on children are normally conducted in laboratory settings using within subjects and controlled experimental designs. It is common for the research participants to complete prescribed doses of exercise on treadmills or stationary cycles, and then test them with a variety of cognitive based measurement instruments at different time points postcondition (Hillman, 2009; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Hillman, Castelli, & Buck, 2005). Many of these studies have used brain-imaging resources such as electroencephelograms (EEGs) or magnetic resonance imaging (MRIs) to measure neural activation as a representation of learning. The findings of these controlled studies are generally positive. Although the cognitive tests used were not strictly ‘academic’ in nature, the results suggested improvements in information processing, response time, accuracy of answers and inhibitory control (Barenberg et al., 2011).

Yet these findings have implications for education, as a child's ability to perform these cognitive processes (particularly the information processing and inhibitory control) are attributes associated with learning.

It is therefore necessary within the conceptual framework of the current study, to consider how mathematics performance is a function of cognitive processes to help establish a link between PA and AP. Core cognitive processes collectively termed executive control (EC) include the three elements of, working memory, inhibition, and cognitive flexibility—processes that are mediated by networks that rely upon the prefrontal cortex (Chan, Shum, Toulopoulou, & Chen, 2008; Diamond, 2008;). Once information has been received by sensory memory, an individual must rehearse the information as a means to transfer the information from the short-to long-term memory or else the information will be forgotten. In adults, recognizable tasks such as remembering a phone number or driving directions are common occurrences. Children use this strategy to remember math facts such as multiplication tables. Regardless of the tasks, it is important to note that such steps engage working memory. Unlike working memory, inhibition is the ability to resist a response. As humans, we have developed expectancies in our behaviors, like the societal norm that a green traffic light means go and a red light means stop. Such expectancy for children would be to complete a math problem beginning from the left and moving to the right. However, once we introduce algebraic functions such as solving for X, which can be located anywhere with the problem, such expectancies require inhibitory control and a reframing to find a solution. A third and final element of EC is cognitive flexibility. Although it is widely believed that humans have the ability to multitask, this phenomenon is a myth (Rosen, 2008; Rubinstein, Meyer, & Evans, 2001). What humans are actually experiencing when they quickly move their focus between tasks is called cognitive flexibility. Such processes allow us to refocus our attention within milliseconds and also help us to navigate situations that violate our expectancies.

Specific to mathematics, the cognitive core concepts of EC that subserve and underpin concepts of learning include resisting and inhibiting a response, prioritizing of information, and sequencing a task (Blair, & Razza, 2007; Bull, & Scerif, 2001; St-Clair Thompson, & Gathercole, 2006). These components are particularly appropriate when solving for 'X' in an algebraic equation. Examples from the mathematics test questions in the current study are included in Figure 1.

According to the Cognitive Energetic model (Sanders, 1983), the efficiency of the EC processes of working memory, inhibition, and cognitive flexibility are influenced by arousal, effort, and activation (See Figure 2). It is important to note that the brain is always active, but when presented with a stimulus, or in the case of children a learning task, we perceive, decide, and act on the information. Such underlying processes are integral to scholastic success in the classroom (Hillman et al., 2012; St-Clair Thompson, & Gathercole, 2006) and therefore it is appropriate to consider the findings of previous PA-EC and PA-AP literature as intrarelated.

In addition to the controlled laboratory studies, there have been a small number of authentic field-based studies that have considered the PA-EC association in a school setting using mathematics test as the measurement instrument. Seminal work reported a linear relationship between duration of PA and an improvement in math computation scores (Gabbard, & Barton, 1979). A replication of that study suggested a similar linear relationship (McNaughten, & Gabbard, 1993). Recently, in

Question: Simplify the expression below.

$(3x^3 + 2x^2 - 5x) + (-8x^3 + 3x)$

A $-11x^3 + 2x^2 - 2x$

B $11x^3 - 2x^2 + 8x$

C $-5x^3 + 2x^2 - 2x$

D $5x^3 - 2x^2 - 8x$

Question**:** What value of x makes the equation below true?

$$\frac{x + 3}{2} = 8$$

A 1

B 5

C 13

D 19

Figure 1 — Sample of mathematics questions from math tests administered to study participants

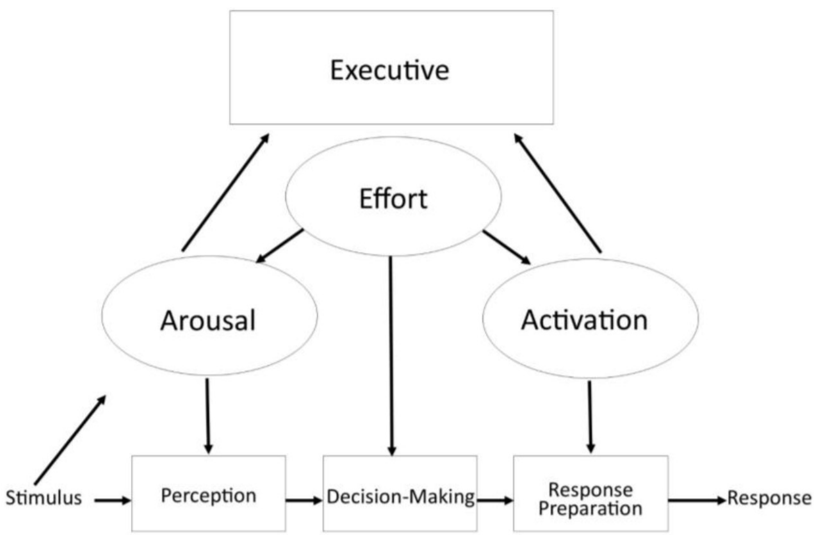

Figure 2 — Cognitive Energetic Model, taken from Sanders, A.F. (1983). Toward a model of stress and performance. *Acta Psychologica, 53,*61–97.

a small-scale, nonexperimental study, middle school aged children increased their response time and accuracy of math computation scores related to the intensity of a bout of PA (Travlos, 2010).

As mentioned previously, these studies did not fully consider the dose-response relationship (Van Dusen et al., 2011) between a bout of PA and mathematics performance. The dose-response relationship seems to be an integral component in aiming to address how PA may aid AP and inevitably affects a proposed design in any school-based study. It would be salient to suggest, again from the designs and results expounded within the controlled experimental literature, that to gain EC benefits, participants need to be engaged in moderate intensity aerobic exercise for a minimum of 20 minutes. Positive effects may last for up to 48 minutes post-condition (Davis et al., 2007; Hillman et al. 2005), although responses to a bout of PA may be individualistic in nature (Tomporowski, 2003). Part of this individual response may be due to cognitive maturation, although a wide range of child-aged participants have been used in experimental designs, including both preschool and preadolescent children (Drollette, Shishido, Pontifex, & Hillman, 2012; Hillman, 2009), children with ADHD (Pontifex, Saliba, Raine, Pichietti, & Hillman, 2013), and children who have been tested as either low cognitive or high cognitive functioning (Drollette et al., 2013).

It is also apparent from previous studies that possible moderating variables within a PA-AP construct include physical fitness (PF) levels and gender. PF levels were reported as a moderating variable and positively related to cognitive functioning and AP in 20 published studies considering the PA-EC relationship (Fedewa, & Ahn, 2011). The effect of gender as a moderating variable has been reported as most significant within mixed-gender studies (Davis et al., 2007; Fedewa, & Ahn, 2011) yet other studies have suggested that vigorous PA is more beneficial (with regard to EC), for females as opposed to males (Carlson et al., 2008; Coe et al., 2006). Hence, these potential moderators were included in the study design for secondary analyses.

Therefore the purpose of this translational study was to examine the effect of PA, and non-PA on AP in a school-based setting, by considering the effect of vigorous intensity acute exercise on mathematics test performance given at 30 and 45 minutes post condition. A secondary analysis considered the effect of PF and gender as moderating variables. It was anticipated that mathematics test performance would be facilitated after a bout of PA as opposed to after a bout of sedentary activity. The findings from this study are valuable because they could help to guide the development of delivery and scheduling of PA across the school day.

Methods

Study Design and Conditions

Adolescent students enrolled in eighth-grade PE classes from a middle school in the Southwestern United States were recruited for participation in this study. Before the familiarization visits, and using a within-subjects design, intact classes were randomly assigned to an order condition of either a PE class involving vigorous PA (i.e., physically active condition), or sitting and watching a video related to PE content (i.e., sedentary condition). Math tests were administered to the students at 30 minutes and 45 minutes post condition. Familiarization to research procedures was conducted during two school visits before data collection, where baseline data for cardiorespiratory fitness were also collected for use as a possible moderating variable.

Participants and Setting

Participants were students enrolled in two eighth-grade PE classes in an urban middle school located in the Southwestern United States. Based on the results of an a priori power analysis sample size was set at $N = 72$ (originally the $N = 80$, but was lower at the time of data collection due to absences/injury) across the two groups of students, ($n = 36$) in each of two PE classes. The participants were aged 14 ($n = 71$, 98.6%), and 15 ($n = 1$, 1.4%). Males totaled ($n = 44$, 61.1%) and females ($n = 28$, 38.9%). Effect size was set at .25, to align with the meta-analysis effect size by Etnier et al. (1997) relating physical fitness, exercise and cognitive function.

Students who scored 100% on their Criterion Referenced state math tests (as a perfect score in math ability could be viewed as a confounding variable) were excluded from the study. As anticipated, none of the students had received such a score. Those who were unable to participate in PE lessons without modifications were also excluded from this study. Permission to conduct the study was obtained from the University Institutional Review Board, the school district, the school administration, and the teacher before the start of data collection. The students provided written informed assent and parents provided written informed consent before data collection.

The setting for the data collection was a middle school located in an urban city in the southwestern United States. The school has an enrollment of 610 students from 7th and 8th-grades, of which 67% are proficient at math for their grade level, according to the 2009–2010 Annual Yearly Progress District Report (SLC K-12 2010). The school employs only licensed teachers, with 52% of them holding an advanced degree. The head of department for PE holds a bachelor's degree in PE and over 20 years' PE teaching experience. There were two other teachers in the department, one of which had a full-time PE schedule, whereas the other taught PE and Health. Both teachers held PE degrees and were licensed teachers. The students had 40-minute PE classes, on alternate days for one semester during the school year, within a curriculum framework that offered the students a variety of activities such as skiing, fitness, dance, and traditional ball games.

Instruments

Within this study there was one primary measure of academic performance and several measures of intensity and fidelity to condition. These included an aerobics activity circuit, a sedentary activity DVD, mathematics tests, heart-rate monitors, and the FITNESSGRAM PACER test.

Aerobic Activity Circuit. To elicit vigorous PA within the PE lesson, an aerobics circuit was designed, based on previous fitness literature (Brown, & Ferrigno, 2005). Aerobic circuits are used as part of normal PE lessons at the research site, and the exercises were familiar to the participants. The circuit included nine different aerobic stations that were spread out in a gymnasium (see Table 1), over a 20-minute total duration. The stations were organized as to be able to accommodate four participants at one time, working for a one-minute period, with a trained assigned research assistant at each station overseeing each activity. The students then rotated to the next station within a 7 s transfer time.

Sedentary Activity DVD. A twenty minute section of the DVD 'Dare to Dream—The story of US Women's Soccer' explaining how the US National Women's Soccer team was chosen for the World Cup, with interviews with key players and snippets of game play, made up the content for the sedentary setting. This video was used because the content relates to a normal sporting activity taught in PE classes.

Mathematics Tests. The New York State Testing Program (8th Grade Math tests, with scores represented from 1–100) was selected for use in this study as the measure of AP. Each of the tests were previous exams used from 2006–2010 administered to eighth-grade students in the State of New York. These tests were selected for use in this study because not only are they current and authentic for use in the school setting, but come available with technical manuals that verified the multiple choice content with Cronbach's Alpha coefficient scores ranging between $r = .83$ to $r = .89$. Reliability data were not available for the State Math tests where the data were collected, and it was for this reason that out of state

Table 1 Aerobics Circuit

Name of Exercise	Description
Line Jumps	The participants will jump sideways across and back over a line with both feet together.
Ladder Run	Running through an agility ladder/ set of cones, and then run down the side of the ladder/cones to repeat the process.
Hurdles	The participant will hurdle over small 6–12 inch hurdles and then run down the side of the hurdles to repeat the process.
Step Ups	The participant will step up and down on 18 inch high aerobic steps.
High Knees	The participant will lift alternate knees high into the air on the spot.
Shuttle Drills	The participant will sprint to cones and back, 3, 5 and 10 yards away.
Z Pattern Run	The participant will run through a set of cones arranged in a zig zag pattern 5 yards away from each other, and then run down the side of the cones to repeat the process.
Jump Rope	The participant will jump rope on the spot.
Jumping Jacks	The participants will complete jumping jacks on the spot.

(Adapted from Brown, L.E., & Ferrigno, V. (2005), *Training for speed, agility and quickness*. Champaign, IL: Human Kinetics) previous exams were used as the measurement instrument. The State Department of Education also confirmed that both curriculums were aligned across the grade levels. Four math tests (titled math test 1,2,3 and 4), with 10 different questions in each test, were assembled from the previous exams by a National Board Certified math teacher with a Master's degree in Mathematics Education and over 15 years of junior high teaching experience. The type of math questions that were extracted from the exams included: a) number sense and operations, b) algebra, c) geometry and d) measurement, evenly spread across the four tests. Each of the tests were assigned to be completed with a 5-minute time limitation (therefore concentrating on speed of answers within the speed-power test continuum) to align with the reported advantages a dose of acute PA can give to the respondent—an increase in answer response time and accuracy.

Heart Rate Monitors. As a measure of intensity, E600 Polar Heart Rate monitors (specifically designed for use with school-aged children, Polar, 2013) were used to measure PA. The monitors were preprogrammed at a calculated 70–85% age predicted maximum heart rate to measure vigorous intensity activity, as per CDC guidelines (Center for Disease Control, 2011). Each participant was instructed to maintain their heart rate within the target zone while working physically at each station of the aerobic circuit for one minute—the heart-rate monitor was set to beep when the participant was not within the target zone. Research has suggested that Polar Heart Rate Monitors yield energy expenditure estimates more accurately than in calibrated devices (Crouter, Albright, & Bassett, 2004). The polar heart rate monitor has shown high test-retest reliability (.94 to .99) in school-based research (Treiber et al., 1989), with similar results (.86 to .99) in a similar study (Bar-Or, Bar-Or, Waters, Hirji, & Russell, 1996).

FITNESSGRAM PACER Test. To collect baseline data of PF levels within the two groups, cardiorespiratory fitness was measured through the administration of the FITNESSGRAM Progressive Aerobic Cardiovascular Endurance Run (PACER) to all students enrolled in the physical education class. The PACER test, a 20-m shuttle run, was taken from the FITNESSGRAM battery of tests, which is used across schools world-wide to measure components of health-related fitness. The number of laps completed marks whether the participants were within the healthy fitness zone for their age and gender. Tests were administered following the protocol as outlined by FITNESSGRAM guidelines (Meredith, & Welk, 2007). The data were calculated for later use in the statistical analyses.

Protocol

Two initial visits (to both randomized groups) were made to the research site before the study. The primary reason for the first visit was to separately familiarize both groups of students to the protocols of wearing heart rate monitors during PE lessons. In addition, during the first visit, baseline measures of math ability via Math Criterion Reference Test scores from the previous academic year (i.e., data that were a year old) were collected. In addition, a measure of cardiorespiratory fitness (via the PACER test) was collected given the potential influence as a covariate. During the second visit, both groups of students were separately taught the aerobic circuit that would be used as the physical activity condition to enhance fidelity of the condition. Students were also taught ways to increase or decrease his/ her heart rate as a means of remaining within the target heart rate zone. There was no familiarization with the sedentary condition within these visits.

The physically active condition included the students attaching the heart rate monitors as practiced in previous visits, and participating in twenty minutes of vigorous intensity PA via the aerobics circuit during PE class. At the end of the twenty minutes aerobic circuit, the PA group returned their heart rate monitors to the researcher so the data could be downloaded confirming that the participants remained within the target heart rate training zone. The students then dressed out in the locker room, and walked to a classroom, imitating normal practice after a PE class. The active condition group sat in silence, with no communication allowed between peers, researcher and research assistants and completed math test 1, in total, at 30 minutes post the completion of the PA condition. They then sat quietly, reading condition. At the conclusion of test 2, the students were dismissed and returned to class.

The sedentary condition, (which happened during the next class period in the school-day) included the group assigned to the nonactive condition being taken, by the researcher, to a classroom. During the sedentary condition the students watched a video in silence for 20 minutes, with no communication with the researchers, teachers or peers allowed. The video was then turned off at 20 minutes, and the students sat in silence for a further 10 minutes (i.e., a total of 30 minutes sedentary behavior). The students then completed math test 3 (as opposed to the PA group who took math test 1 first). The math tests were taken in a different order per group to reduce learning effects through participants relaying test questions to each other. After math test 3, the students sat quietly, reading sports related magazines. The process was then repeated with math test 4, administered (after a total of 45 minutes sedentary behavior). At the end of test 4 the students were dismissed and returned to class. Essentially the protocol involved the groups taking math tests at 30 and 45 minutes post a bout of 20 minutes vigorous PA, and taking different math tests at 30 and 45 minutes of sedentary activity.

Overall, the protocol was very similar to regularly scheduled PE class. It is common practice within the school for some students to be sitting in an academic classroom taking a test, while some students are in the gym being physically active. This authenticity was compounded and repeated during the second visit (after a passage of two weeks of time, again to prevent learning effects through student conversation) where the researcher collected data using the same protocol as the first visit, except with the two classes switching conditions, (and therefore taking different math tests).

Data Analysis

Statistical methodology used was based on a 2 × 2 mixed factor repeated-measures ANOVA crossover construct. Two cohorts of students (n = 36 in both cohorts), were randomly assigned to two different order groups, each group receiving each experimental condition. Repeated-measures ANOVA was used to interpret the three-way interaction of condition by activity type (either PA or sedentary) by time period (30 minutes and 45 minutes post-condition) using math test performance as the outcome variable. Descriptive statistics were used to determine the outcomes of the repeated measure ANOVA. Secondary analyses (exploratory data analyses) were run to consider possible gender differences, and the importance of fitness as a moderating variable. Statistical significance for all tests was set at .05. Data analysis was conducted using SPSS version 19.0 (SPSS, Inc., Chicago, IL).

Results

Primary Analysis

The final number of students, the reported baseline mathematics ability and cardiorespiratory fitness baseline data are shown in Table 2. Baseline mathematics ability, founded on prior Criterion Referenced Test scores were reported at ($N = 72$, M = 72.33), with scores at ($n = 36$, $m = 75.02$) for group 1, and ($n = 36$, $m = 69.57$), for group 2. The baseline data for cardiovascular fitness levels were measured by whether the students were within the Healthy Fitness Zone for the FITNESSGRAM PACER test, which is specific to age and gender. Overall scores were reported at ($N = 72$, $M = 68.05\%$), for group 1 at ($n = 36$, $m = 75\%$) and for group 2 at ($n = 36$, $m = 66.6\%$) (See Table 2). These data show that the group 1 math ability was consistent across both genders, yet the females were more aerobically fit than the males. The group 2 data shows that the females were, again, more aerobically fit than the males, but weaker in their math ability.

The total math test mean scores for both order groups, by time for the math test taken at 30 minutes post PA were 11–22% higher, irrespective of gender or fitness level compared with other time points. Therefore, the results for each gender by time revealed significant differences in mean math scores again, at 30 minutes post PA when compared with the other 3 math tests (see Table 3).

The ANOVA revealed a main effects interaction of math test scores by condition, for the total sample, significant at ($F(1, 68) = 14.42$, $p < .001$, with a large effect size of $d = .90$, as displayed in Table 3.

Table 2 Baseline Data by Group, Gender, Math Criterion Reference Test Scores (CRT) and Healthy Fitness Zone (HFZ)

Group	n	Male	Female	Mixed
1	36	21	15	
Math CRT		75%	74%	75.02%
Within HFZ		61.9%	93.3%	75%
2	36	23	13	
Math CRT		74.5%	62%	69.57%
Within HFZ		47.8%	84.6%	66.6%
Total	*N* = 72	44	28	
Math CRT M				72.33%
Within HFZ M				68.05%

Table 3 Grand Mean Score Differences by Gender, Time Point and Activity Type

	Time	Post Physical Activity (PA)				Post Sedentary Activity (SA)			
		30 min		45 min		30 min		45 min	
VAR	N	M	*SD*	M	*SD*	M	*SD*	M	*SD*
Total	72	5.75*	2.38	4.30	1.88	4.21	2.12	4.04	1.81
Gender									
Male	44	6.11*	2.2	4.57	1.9	4.70	1.92	4.34	1.92
Female	28	5.18*	2.52	3.89	1.81	3.43	2.21	3.57	1.52

$p \leq .001$

Note. For total sample, and for males and females, Post PA 30> Post PA 45, Post SA 30 and Post SA 45 *p<.001.

Secondary Analysis. Mean math scores were higher after 30 minutes post PA for males (m = 6.11, sd = 2.24) as opposed to females (m = 5.17, sd =2.52). The math test scores by condition data reported significance by gender, for males at $F(1, 42) = 6.68$, $p = .013$, $d = 0.8$, and for females at $F(1, 26) = 6.68$, $p = .013$, $d = 1.2$. When PF levels were analyzed, there was an interaction between mean math scores, PF and the condition at $p = .046$. After further decomposition results reported statistical significance for males only, at $p = .014$.

Discussion

Findings from this study suggest that brief bouts of vigorous physical activity throughout the school day can be beneficial in a school-setting, where children spend the majority of their time learning while in a sedentary position. This small yet important study was an attempt in examining the association between PA and AP in an authentic setting, using as much of a scientifically rigorous design as one would expect within field-based research. The results suggest that vigorous physical activity may be a cause of increased mathematic academic performance test scores up to at least 30 minutes after condition. This conclusion aligns with current literature that suggests (although the mechanisms that explain the association of PA-EC are unknown) that the enhancing cognitive effects of an acute bout of PA persist for at least half an hour (Barenberg et al., 2011).

However, to fully demonstrate the nature of the data, the results of the study need to be compared with both the laboratory setting and school-based setting literature, due to methodological limitations in some previous authentic setting studies. The findings of this research study can be aligned with the growing laboratory-based body of literature that suggests that PA may aid EC in children. Findings of this research demonstrate that an acute bout of PA may increase the AP on math tests of adolescents. Results reported an acute effect of 20 minutes of vigorous PA on mathematics test performance, but only at 30 minutes post PA. A previous laboratory-based study (where children mildly increased EC function after moderate PA via a treadmill) had suggested that the 'optimal' time for an increase in cognitive function post PA was between 16–48 minutes (Hillman et al., 2005). This research was compounded in a quasi-controlled acute effects experimental design in an after-school PA program that suggested 20 minutes post exercise as the most favorable time for facilitated EC, after a dose of vigorous intensity PA (Davis et al., 2007). Data from the current research study suggest that there are significant increases in math scores at 30 minutes post PA, therefore falling in line with current findings (Barenberg et al., 2011).

As intensity and duration of exercise are important variables closely linked to one another in terms of dosage, yet also highly individualized in relating to an increase in AP, one should be guarded with the results of the current study. Specifically, the duration of PA was fixed in the current study at 20 minutes and intensity of PA data were not individually analyzed. Nevertheless, as previous authentic setting literature reports an increase in math scores, both after a dose of 20 minutes of PA (Gabbard, & Barton, 1979), and 16 minutes of PA, (Travlos, 2010) and after high intensity PA (Castelli et al., 2011), one could suggest that the current condition of 20 minutes vigorous intensity PA leading to an increase in math scores does fall in line with existent research. Conversely, only one study (Castelli et al., 2011), linked intensity levels of PA with cognitive function benefits within children in an authentic setting. In that particular study, the researcher found a relationship between increase in cognitive tests and time spent above the target heart rate zone, which was set at a vigorous intensity level (55–80% max heart rate). Therefore, heart rate was not a predictor of cognitive benefits, but time spent above 80% of the participants maximum heart rate was. However, this intervention measured the chronic effects of PA on cognition using tests such as the K-BIT, Stroop Test, and the Trails Making Tests, which are more intellectual tests by nature, and measure different components of EC as opposed to being stringently academic and authentic for schoolchildren. In the current study, there were no data collected on duration of time that heart-rate stayed elevated after PA, although data confirmed that both genders stayed within the vigorous intensity HR zone during the aerobic circuit.

There were gender differences reported within the data, but variance may be somewhat explained by fitness levels of the participants. Certainly the data did reveal a larger effect size for the females, who had lower math ability, yet were more aerobically fit than the males. High-fit females with lower math ability made fewer gains than the low-fit males with the higher math ability and high-fit females with high math ability. Results however, did show statistical significance and large effect sizes for both genders in the condition irrespective of math ability and fitness levels. Previous research suggests that males perform better on math tests than females (Frost, Hyde, & Fennema, 1994) but essentially the condition was more effective for those students with most to gain academically, which is consistent with existent PA-EC literature (Drollette et al., 2013).

However, when HFZ data were entered as a covariate in the analysis, there was a three-way interaction between aerobic fitness, the 20 minutes of vigorous intensity PA and math test mean scores. This suggests that PF levels acted as a moderating variable in the current study—yet as this statistic was only significant for the males (who were less fit than the females), the author is suggesting that PA thresholds and the intensity of activity required to elicit an EC response may differ from the low-fit to the high-fit. Essentially the difference in mean scores and significance between the genders was due to PF levels, not to gender in isolation.

Research also suggests that school-aged children may react in a complex fashion in cognitive areas such as accuracy, attention, and working memory (Hillman et al., 2005). From the laboratory-based literature, it is apparent that school-aged children have different EC levels and abilities. It is also plausible to argue that as children are at dissimilar fitness levels they therefore have dissimilar fitness thresholds. It is reasonable to suggest that a section of the participants, such as the high-fit females, needed to be working at a higher intensity level to illicit academic benefits. One can posit that the condition was likely aided by other variables which are chronic by nature however as PA and PF levels may be part of a number of variables aiding an increase in AP, one can still see the importance of PA throughout the school day in terms of assisting learning.

This information poses questions on the differing implications of PA on AP in school-aged children, as there seems to be dissimilar individualistic responses in EC components. Research from the current child-age literature suggests that the dose-response PA-EC relationship is not linear, is multifactorial, so therefore different reactions in terms of cognitive benefits from PA should be expected. This seems likely related to diverse rates of pre frontal cortex development, especially in terms of plasticity and change in cortical thickness (Shaw et al. 2006), and hippocampus growth (Pfluger et al., 1999) within children. Not enough is known, within the literature, regarding recommended levels of intensity, dosage of PA, and its consequent task dependent response effects on AP within children, especially in a school-based environment.

Future education practice implications, based on the findings of the study, are multifaceted and may manifest in terms of PE lesson content, structure and advocacy. The current AP-EC literature proposes that the most advantageous mode of PA to gain a cognitive response is aerobic exercise. The author is not advocating for a fitness-model only curriculum, but for teachers to be aware of the academic ramifications of short, vigorous bouts of PA. As most PE classes are at least 40 minutes long for middle school, and with many high school classes organized around a block schedule, it is not unrealistic to suggest that there is time for specific aerobic-based PA within class-time (preferably toward the end of the lesson to have maximum effects). In addition, it would seem beneficial within a traditional PE lesson to include not only the advancement of sports-type skills, but for aerobic PA to be a fundamental part of the lesson objectives. These two elements of a lesson objective should not be viewed as mutually exclusive.

If future research continues to report that aerobic PA in the gymnasium filters through to assist AP in the classroom, then the place of PE becomes more fixed within the school curriculum. As the association between PA and mathematics becomes clearer, the positioning of PE within the school day may become strategic. The scheduling of PE may take place before mathematics, especially as math is a major area for standardized testing (Lee, 2008). In turn, students (especially who have the most to gain) may find themselves more appropriately positioned to succeed within the classroom environment.

However, as of now, recommendations targeting obesity, diabetes, and physical inactivity in schools have largely been ignored as teachers strive to meet the demands for student AP (therefore, school districts have not been able to find enough curriculum time for PE) (United States Department of Education 2002, United States Department of Health and Human Services, 2010). Yet the landscape of school-based PA is progressively becoming more comprehensive and multicomponent in nature (Kulinna, Brusseau, Cothran, & Tudor Locke, 2012; Webster et al., 2013). The results from the current study indicate how important these PA opportunities can be in the potential development of the student in an educational setting.

Strengths, Limitations and Conclusions

The current study attempts to add to the literature from differing perspectives. Theoretically, much is known from the literature about the enhanced EC benefits from PA. However, animal science and older-adult population studies have dominated the research landscape. So much is known about the developed brain, yet little is known about the developing brain, especially in field-based settings. The results of this research have added to that knowledge base by considering an under-researched population in a field-based setting.

From a methodological perspective, the authors have authenticated a controlled paradigm into the school setting—yet the very nature of the design (when a laboratory-based design is translated to a field-based setting) logically increases the influence of issues associated with scientific rigor. However, the current study is more solid in both its methodology and conceptual nature (by considering the 'dose' i.e., 20 minutes of vigorous PA, and the 'response' i.e., at 30 minutes and 45 minutes post condition), compared with previous field-based literature (which has not enough data about the dose-response to help expand on, or compare results with, on this topic). Essentially the authors had to align and compare field-based results with experimental designs studies that: a) did not use protocols that are explicit to the school setting, and b) did not ask the specific questions that educators are asking within the field.

It was not possible to cover all the questions within the dose-response relationship within the current study—therefore so many questions go unanswered (e.g., different modes of PA, differing duration of PA, use of other time points in terms of effect). Future research therefore requires continued focus on the dose-response relationship of PA-EC in authentic field-based settings to add perspective to the current educational climate. The current study should be considered as adding to, and agreeing with the ever-increasing volume of existent literature that suggests that PA may be academically beneficial to the sedentary world of K-12 education.

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