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Title: School Physical Activity Intervention Effect on Adolescents' Performance in Mathematics

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ABSTRACT

Purpose The primary aim of this study was to test the effect of a school-based physical activity intervention on adolescents' performance in mathematics. A secondary aim was to explore potential mechanisms that might explain the intervention effect.

Methods: The Activity and Motivation in Physical EDucation (AMPED) intervention was evaluated using a two-arm cluster randomized controlled trial in 14 secondary schools located in low socioeconomic areas of Western Sydney, Australia. Study participants (n=1,173) were Grade 8 students (mean age = 12.94 years, SD = .54). The multi-component intervention was designed to help teachers maximize students' opportunities for moderate-to-vigorous physical activity (MVPA) during physical education (PE) and enhance students' motivation towards PE. Mathematics performance was assessed as part of national testing in Grade 7, which was the year before the trial began and then again in Grade 9. Potential mediators were: (i) proportion of PE lesson time that students spent in MVPA and leisure-time MVPA (%), measured using Actigraph GT3X+ accelerometers, and (ii) students' self-reported engagement (behavioral, emotional, and cognitive) during mathematics lessons. Mediators were assessed at baseline (Grade 8) and follow-up (Grade 9, 14-15 months after baseline).

Results: The effect of the intervention on mathematics performance was small-to-medium ($\beta = .16$, $p < .001$). An intervention effect was observed for MVPA% in PE ($\beta = .59$, $p < .001$), but not for leisure-time MVPA or any of the engagement mediators. There were no significant associations between changes in potential mediators and mathematics performance.

Conclusions: The AMPED intervention had a significant positive effect on mathematics performance in adolescents. However, findings should be interpreted with caution as the effect was small and not associated with changes in hypothesized mediators.

Trial registration: Australian New Zealand Clinical Trials Registry No: ACTRN12614000184673.

Key words: academic performance; physical education; mediation analysis; mechanism; standardized testing

INTRODUCTION

Participation in regular moderate-to-vigorous physical activity (MVPA) can help children and adolescents improve cardiorespiratory fitness, build strong bones and muscles, maintain a healthy weight, reduce symptoms of anxiety and depression, and minimize the risk of developing lifestyle diseases such as heart disease and cancer (1, 2). It has also been suggested that time spent in physical activity might enhance academic performance (i.e., extent to which students achieve their educational goals) (3, 4). A recent systematic review and meta-analysis (5) found effect sizes ranging from $d = .13$ (for reading) to $d = .21$ (for mathematics). However, the review included just two interventions involving adolescents (6, 7) and the findings from studies involving children cannot be generalized to adolescent populations due to differences in maturation and appropriate intervention strategies (8).

The EDUcation for FITness (EDUFIT) study (mean age: 13.0 years) (6) tested the effects of increasing the volume and intensity of physical education (PE) in a small-scale group randomized controlled trial. The researchers found that increasing the intensity and volume, but not the volume alone, improved academic performance in adolescents over the 4-month study period. In the second study involving adolescents, the Learning, Cognition and Motion (LCoMotion) intervention (mean age: 12.9 years) (7) produced improvements in fitness and adiposity, but participants did not improve their performance in mathematics, relative to those in the control group. Based on the limited available evidence it is not possible to determine if physical activity interventions can improve adolescents' academic performance and further study of mediating mechanisms might help to strengthen the evidence base.

A range of behavioral (e.g., on-task behavior in the classroom, sleep volume and quality) and psychosocial (e.g., motivation, interest and perceptions of novelty) factors have been posited as potential mechanisms responsible for the positive effects of physical activity on academic performance (9). There is compelling evidence that activity breaks (often called energizer breaks) can increase children's concentration and focus in the classroom (10). In this example, energizer breaks are thought to improve academic performance via the mechanism of on-task behavior in subsequent lessons in the classroom. Alternatively, integrating physical activity into other key learning areas (e.g., mathematics and English) may improve academic performance via a range of psychosocial mechanisms (9). For example, evidence suggests that students enjoy learning mathematical concepts through movement, which is likely to have a positive effect on their motivation and interest in class (11, 12). To date, the vast majority of the studies linking physical activity to academic outcomes have been conducted with children in elementary schools (5). Moreover, it is not known if increasing physical activity in other areas of the school day, such as PE can also increase on-task behavior in subsequent lessons and performance on standardized academic tests.

The Activity and Motivation in Physical EDucation (AMPED) trial was a school-based physical activity intervention for adolescents in Grade 8 (mean age = 12.9 years, SD = .5) at baseline (17). We previously reported that the intervention successfully increased physical activity during PE lessons at posttest (5.58% of lesson in MVPA) and follow-up (2.64%), but had no effect on overall physical activity (i.e., inclusive of leisure-time physical activity) at either time point (18). The primary aim of the current study was to test the effect of AMPED on adolescents' performance in mathematics using a standardized test. A secondary aim was to explore potential behavioral and psychosocial mechanisms that might explain the effect of the intervention. We hypothesized that, compared with students in the control condition, students whose PE teachers participated in the intervention would achieve more favorable results on a standardized mathematics test and that the effects would not differ by sex or baseline MVPA level. We also hypothesized that quality PE would act as an 'energizer break' enabling students to focus more effectively in subsequent mathematics lessons. However, it was not possible to observe students' behavior in subsequent lessons, therefore MVPA in PE and perceived engagement (i.e., behavioral, emotional, and cognitive) during mathematics lessons were tested as potential mediators of the intervention effect.

METHODS

Study design

Ethics approval for this study was obtained from the human research ethics committees of the University of Newcastle, Australia and New South Wales Department of Education (NSW). The AMPED intervention was evaluated using a cluster randomized controlled trial and conducted in accordance with CONSORT guidelines (13). The trial was registered with the Australian and New Zealand Clinical Trials Registry (ACTRN12614000184673). The methods and major outcomes from the AMPED trial have been described in detail previously (14, 15). The trial was conducted in Australia over two school years. In Australia, school years run from the end of January to the middle of December, with a summer break from mid-December to late January. Mathematics performance was assessed as part of the National Assessment Program- Literacy and Numeracy (NAPLAN) in Grade 7, which was the year before the trial began (i.e., May 2013) and then again in Grade 9 (May 2015) at the completion of the intervention. Potential mechanisms tested in this study were: (i) MVPA% (PE lesson time and total leisure-time), and (ii) students' self-reported engagement (behavioral, emotional, and cognitive) during mathematics lessons. Potential mechanisms were assessed at baseline when students were in Grade 8 (February-April 2014) and follow-up (May-July 2015: 14-15 months after baseline).

Setting and participants

The AMPED trial was conducted in government-funded secondary schools in the Western Sydney region of Australia. Of note, the Western Sydney region has a large proportion of students who come from low socio-economic status (SES) and immigrant backgrounds (16). Eligibility criteria for schools were as follows: (i) secondary school with students in Years 8 and 9; (ii) funded by the NSW Department of Education; (iii) located in Western Sydney or South Western Sydney regions; (iv) located in a postcode with low socioeconomic status, as defined by a decile rank of ≤ 5 according the Australian Bureau of Statistics' Index of Relative Socioeconomic Disadvantage; and (v) permission granted by the Principal, the Head Teacher of PE and at least one Year 8 PE teacher. Parents provided written informed consent and students provided their assent to participate. Study participants (n=1,173) were Grade 8 students (mean age = 12.94 years, SD = .54).

Sample size

The original study power calculation was conducted to determine the sample size needed to detect a moderate effect (*d* =.6) in the trial primary outcome (i.e., percentage of PE lesson time spent in MVPA)(14, 15). Assuming class sizes of 22 students participating and an intraclass correlation of 0.63, a total sample of 1,280 students was required to achieve 80% power. To achieve this number, the goal was to recruit 14 schools and 4.5 classes per school (i.e., 1,386 students). Posteriori power estimates were computed using simulated-based method along with Wald test in Mplus. The resulting power estimates were .992 for the intervention effect on mathematic performance at time 2 and .234 for the mediation effect (Intervention, MVPA time 2, mathematics performance time 2).

Intervention

A detailed description of the AMPED intervention methods and results can be found elsewhere (14, 15). The intervention was underpinned by self-determination theory (17) and had two main aims: (i) to help teachers maximize opportunities for MVPA in PE lessons; and

(ii) to help teachers enhance their students' motivation towards PE (18). To achieve the first aim (i.e., maximize MVPA opportunities), teachers' learnt to implement a number of PE-based teaching strategies that were organized into the following four categories: (i) 'Maximizing Movement and Skill Development' (e.g., using small-sided games) and (ii) 'Reducing Transition Time' (e.g., taking the class roll while students are active). Strategies to enhance student motivation were organized under the following headings: (iii) 'Building Competence' (e.g., providing effective positive feedback) and (iv) 'Supporting Students' (e.g., providing students with opportunities to make choices). Consistent with the tenets of SDT, increasing motivation in PE was hypothesized to have a positive effect on students' motivation to be physically active in their leisure-time.

In the first phase of the intervention (five months: Terms 2 and 3 of 2014), teachers participated in two days of face-to-face workshops at a local university and completed two implementation tasks at their school. These implementation tasks involved a video-based self-reflection task via the project's Web 2.0 platform and an individualized feedback meeting with PE mentors from the research team. Intervention schools were also asked to complete two group peer-mentoring (i.e., teachers observed each other) sessions at their school to discuss strategy implementation. In the booster phase (four months), teachers participated in a half-day workshop at their school and completed one online implementation task, and a group mentoring session at their school.

Assessment and blinding

Assessment of mathematics performance was conducted independently in schools by the Australian Curriculum Assessment and Reporting Authority. Trained research assistants conducted all assessments of the potential mechanisms at baseline and posttest. Randomization occurred after baseline assessments and research assistants were blinded to school allocation. Schools were match paired according to their level of socioeconomic disadvantage, school size, sex composition of PE classes and the duration of PE lessons. A blinded statistician randomized schools to the control or intervention conditions using a computer-based randomization procedure. Students participating in the study were blinded to the study hypotheses and treatment allocation.

Measures

Students reported their country of birth and language spoken at home. Students also indicated if they were of Indigenous origin (i.e., Aboriginal and Torres Strait Islander Australians) and socioeconomic status was assessed using the Family Affluence Scale (19). Students' height to the nearest 0.1 cm was assessed by trained research assistants using a portable stadiometer (Surgical and Medical Products No. 26SM, Medtone Education Supplies, Melbourne, Australia) and weight was determined using digital scales (UC-321, A&D Company LTD, Tokyo, Japan). Height and weight were used to calculate students' body mass index (BMI) and BMI z-scores were used to define weight status (20). Participants' maturity status was determined using years from/to peak height velocity. Maturity offset values were calculated using the following regression equations: $-7.999994 + (0.0036124 \times (\text{age} \times \text{height}))$ for boys and $-7.709133 + (0.0042232 \times (\text{age} \times \text{height}))$ for girls (21).

Students' academic performance in mathematics was measured using the National Assessment Program-Literacy and Numeracy (NAPLAN) scores and provided to the research team by the NSW Department of Education. NAPLAN is a national standardized test given to all students in Australia in Grades 3, 5, 7, and 9. The median score is 500 across all year groups with approximately two thirds of students' scores falling within 100 points of the average score. The numeracy tests (including multiple-choice and constructed response) assess students' proficiency in understanding, fluency, problem-solving, and reasoning across the three content strands of mathematics: (i) number and algebra; (ii) measurement and geometry; and (iii) statistics and probability. Students completed the tests in Grade 7 (first year of secondary school) and Grade 9 (third year of secondary school). As the assessment of mathematics performance was external to the research project, the research team were required to gain parental consent and student assent to gain access to this data.

Physical activity levels in PE were assessed using Actigraph accelerometers (GT3X+ models; Fort Walton Beach, FL) attached at the right hip using 1-second epochs to capture sporadic bouts of activity. Vertical axis data were used to classify activity intensity using an MVPA cut point of ≥38.27 counts/ 1-second (derived from a cut point of ≥574 counts/15 seconds)(22). Research assistants recorded the start and finish times of each lesson and this information was used to filter the accelerometer data. Leisure-time physical activity was also assessed using Actigraph accelerometers. Students were asked to wear their accelerometer for five weekdays and two weekend days at each time point (baseline, post-intervention, and maintenance). Periods of 30 minutes or more of consecutive ‘0’ counts were considered non-wear time and removed from the dataset. To be included in the analyses, the students were required to provide valid data for at least three days, including at least two weekdays (valid days defined as days with ≥ 8h of wear time).

Students' self-reported engagement during mathematics lessons was measured using the School Engagement Scale adapted for mathematic lessons (23). The questionnaire included three subscales that assessed students' typical behavioral (e.g., behavior in the classroom), emotional (e.g., enjoyment of lessons), and cognitive (e.g., problem solving) engagement during mathematics lessons. Cronbach alphas (baseline and follow-up) were all acceptable (range, $\alpha = .74$ to .89).

Data analysis

Statistical analyses were conducted to examine the effect of the AMPED intervention on adolescents' performance in mathematics and explore potential mechanisms (Figure 1). Independent samples t-tests in SPSS were used to compare groups at baseline for the primary outcome. Statistical analyses were estimated using Mplus 8's Full Information Maximum Likelihood (FIML) procedure (24) that utilizes all available information during the estimation process and provides consistent and efficient population parameters (25). Standardized regression coefficients of 0.1, 0.3 and 0.5 were considered small, medium and large, respectively (26). Regressions models with interaction terms were used to determine if the following were significant moderators ($p < .10$) of the intervention on mathematics performance: (i) sex (male or female) and (iii) baseline MVPA level.

The models were tested in the following steps with all models adjusted for baseline values and the following covariates: sex, age, socio-economic status, and weight status at baseline. First, the total effect of the treatment (i.e., intervention versus control) on mathematics performance was examined (C pathway in Figure 1). In the second step, single and multiple mediator models were estimated to explore evidence for mediation effects. These models generated unstandardized regression coefficients for: (i) the effect of the intervention on the mediators (A pathways); (ii) the mediator effects on mathematics performance (B pathways); and (iii) the direct effect of the intervention on academic performance with the inclusion of mediators in the model (C′ pathway). The models also calculated the significance of the product-of-coefficients (A x B), which was used to determine the presence of an indirect effect. The indirect effect was considered statistically significant if the confidence intervals for the product-of-coefficients did not cross zero.

As Mplus does not support bootstrapping with clustered data, single level bootstrap confidence intervals were compared with confidence intervals adjusted for clustering. This modeling accounts for the non-independence of students nested within classes by adjusting the standard errors using a sandwich estimator. Previous school-based studies have shown that school-level clustering is negligible after accounting for clustering at the class level (27).

Similar conclusions were found using the two modelling strategies and the results from both analyses are reported.

RESULTS

Overview

The study sample has been described in detail previously(15) and participants' demographics are provided in Table 1. In summary, the majority of participants were born in Australia and were of English or European ethnicity. Approximately 25% of study participants were overweight or obese. Maturity offset values for the control and intervention groups were .09 (.83) and .24 (.88), respectively. Indicating that on average, participants had reached peak height velocity. Indicating that on average, participants had reached peak height velocity. From the original study sample (N = 1,421), 1,173 students agreed to provide the research team with access to their mathematics test results (Figure 2). Nine students from the control group did not complete the follow-up assessments for mathematics performance. Participants in the control group achieved significantly higher mathematics scores at baseline, in comparison to those in the intervention group. Baseline and follow-up values for intervention and control groups are reported in Table 2.

Intervention effect on mathematics performance and potential moderators

We observed a small-to-medium positive intervention effect on mathematics performance (β = .16, $p < .001$). In the models adjusting for potential mediators, the direct intervention effects remained statistically significant. See Tables 3 and 4 for single and multiple mediator models, respectively. Sex and baseline MVPA level did not moderate the intervention effect on mathematics performance (see Table, SDC 1, interaction estimates and sub-group analyses for mathematics performance).

Intervention effect on potential mechanisms

The intervention effect on the proportion of PE lessons spent in MVPA was statistically significant in both the single (.59, p <.001) and multiple (.52, p<.001) mediator models. The intervention effect on engagement in mathematics was not statistically significant.

Mediator effects on mathematics performance

After adjusting for covariates, there were no significant associations between potential mediators and mathematics performance in the single or multiple mediator models.

Significance of mediated effects

None of the potential mechanisms satisfied the criteria for mediation.

DISCUSSION

The primary aim of this study was to examine the effect of the AMPED intervention on adolescents' performance in mathematics. After adjusting for baseline values and covariates, the intervention effect on mathematics performance was equal to approximately one quarter of the increase in mathematics performance that is typically observed in students from Grade 7 to Grade 9 (typical gain is 48.5 unit over the two year period)(28). It is important to note that this effect reflects greater improvement in the intervention group (who had lower scores at baseline) compared with the control group over the two-year study period. Of note, mathematics performance was assessed using the NAPLAN numeracy tests, which are administered annually to all Australian students; thus, our findings have high ecological validity.

Consistent with our first hypothesis, students in the AMPED intervention group significantly improved their performance in mathematics, in comparison with students in the control schools. This is a notable finding and suggests that high quality PE can have academic benefits for students regardless of their sex or baseline level of MVPA. Cross-sectional and longitudinal studies typically report positive associations between physical activity and academic performance in young people, but evidence from high quality experimental trials is mixed and few studies have involved adolescent populations (3, 4). The Lifestyle Of Our Kids (LOOK) study (29) tested the effects of PE lessons delivered by specialists compared with PE delivered by generalist elementary school teachers. Students who participated in the specialist delivered PE lessons had significantly greater improvements in mathematics (but not reading or writing), compared with those in the control group (effect = 10.9 units, p = .03). Unfortunately, the authors did not assess any potential mechanisms or report the total number of PE lessons delivered in the intervention and control schools over the two-year study period. The failure of classroom teachers to deliver PE lessons in the control group (i.e., poor implementation) (30) compared with the consistent delivery of PE by the specialist teachers, may explain the positive intervention effect. Additionally, physical activities are often cancelled in elementary school settings, while other major barriers to the effective delivery of PE in primary schools include a lack of time and low teacher confidence (31). Poor implementation is also a barrier to the success of interventions delivered in secondary school (30). Of note, Tarp and colleagues (7) found no intervention effects for physical activity or mathematics performance in the 20-week LCoMotion trial. The authors concluded that poor implementation fidelity was a potential explanation for their null findings.

Active Smarter Kids (ASK) was a multi-component school-based physical activity intervention evaluated in 60 Norwegian primary schools (mean age: 10.2 years) (20). While the ASK study found no effect on academic performance in numeracy or literacy in the full sample, a favorable intervention effect was observed among children who performed poorest in numeracy at baseline (lowest tertile). Aadland and colleagues subsequently conducted mediation analyses to determine if changes in executive function, behavioral self-regulation and school-related well-being mediated the intervention effect on numeracy in the subsample of students. Despite a positive intervention effect on executive function in the subscale of students, none of the hypothesized mechanisms satisfied the criteria for mediation. Establishing mediation in large-scale school-based physical activity interventions is challenging for a number of reasons, including the considerable variability between schools, teachers, students and intervention implementation. Moreover, self-report measures of behavioral self-regulation, such as those used in ASK and AMPED studies lack sensitivity to detect change. Alternatively, classroom observational methods have more utility for measuring improvement in context specific behavior.

Providing children with opportunities to be physically active within (i.e., class time) and beyond the classroom (e.g., recess and lunch-time) can have a positive effect on their classroom behavior (10). It is possible that the additional dose of physical activity that students received during PE lessons in the intervention group contributed to improvements in their on-task behavior in the classroom. Although we observed an intervention effect for MVPA in PE, we failed to demonstrate an effect on students' perceived engagement during mathematics lessons. Moreover, changes in self-reported engagement in mathematics were not associated with changes in mathematics performance. These null findings may be due to our failure to measure baseline mediators at the same time as mathematics performance. Although mediators were assessed before the intervention started (in Grade 8), mathematics performance was assessed the year before in Grade 7. Mediation may have occurred, but because Grade 7 measures of physical activity and engagement were not collected, we could not establish mediation.

Cardiorespiratory fitness appears to be more strongly associated with academic outcomes than physical activity behavior in young people (4). Unfortunately, we did not assess fitness and we were unable to test this hypothesis in the current study. The EDUFIT trial (6) was designed to assess the effects of increasing the time and intensity of PE, on adolescents' cognitive performance and academic achievement using a three-arm trial (control, 4 sessions/week of medium intensity PE or 4 sessions/week of high intensity PE). Of note, the higher intensity EDUFIT group (mean and maximum heart rate were 147 and 193 BPM, respectively) experienced the largest improvements in cognitive performance and academic achievement over the 4-month study period, in comparison to the other experimental (mean and maximum heart rate were 129 and 177 BPM, respectively) and control groups (mean and maximum heart rate were 116 and 174 BPM, respectively). In another study (32), children who participated in three physical activity sessions/week for 9-months, improved their cardiorespiratory fitness and their performance on measures of inhibition and cognitive flexibility, compared with those in the control group. While the dose of physical activity delivered in the AMPED intervention was relatively small (i.e., 1 to 2 sessions/week), previous studies have demonstrated that activity levels in PE lessons are typically very low (33, 34) and this is what students in the control group would have received.

Although we sought to examine a range of theoretically, and empirically-supported, mediators in this trial (MVPA in PE and student engagement during mathematics lessons), we acknowledge the possibility of other mechanisms, that we did not assess, that may have explained the effect of the intervention on mathematics performance. These include both intra-individual neurobiological (e.g., greater vascularization and neurogenesis) (4) as well as contextual (e.g., task complexity during PE requiring high exertion plus high cognitive demand) (35) factors; these represent viable targets for examination in future research. In addition, further research is needed to examine the influence of changes in physical activity on performance in other academic subjects.

Strengths and limitations

The strengths of this study include the cluster RCT design that adhered to the CONSORT guidelines. Additional strengths include the blinded assessment of outcomes, objective measurement of physical activity in PE (high level of implementation fidelity), and access to standardized national data pertaining to students' performance in mathematics. There are, however, some limitations that should be noted. First, we did not objectively measure students' engagement in mathematics using classroom observations. Previous studies have demonstrated that students spend more time engaged in the classroom after they have been physically active (10). Second, failure to assess maturity status may be considered a study limitation. However, the maturity offset values suggest that on average, participants had reached peak height velocity. Third, we were not able to obtain measures of the mediators at the same time as the pre-test assessments of mathematics were obtained (the study started in Grade 8, but mathematics performance was assessed in Grade 7). Our failure to assess aerobic fitness and motor competence are also study limitations. Finally, this study did not include measures of cognitive function (working memory, inhibition or task flexibility). Although there is strong evidence regarding the acute and chronic effects of physical activity on cognitive outcomes in young people, the majority of studies have been conducted with children in primary schools and further research is needed with adolescent samples in real world settings (4, 36).

CONCLUSIONS

The AMPED intervention had a significant positive effect on mathematics performance in a large sample of adolescents. However, students in the intervention group were not outperforming those in the control group at the follow-up assessments. Instead they had merely caught up, having lower scores at baseline. Moreover, we were not able to identify any potential mechanisms that might explain the intervention effect on mathematics performance. In summary, the results should be interpreted with caution, but do indicate a positive effect of quality PE lessons on academic performance.

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Supplementary Digital Content 1: Interaction estimates and sub-group analyses for mathematics performance

Figure 1: Conceptual model of potential mechanisms explaining academic performance

Figure 2: Flow of participants through the study