Lima, R. A., Pfeiffer, K. A., Møller, N. C., Andersen, L. B., Bugge, A. (2019). Physical activity and sedentary time are positively associated with academic performance: A 3-year longitudinal study. *Journal of Physical Activity and Health, 16*, 177-183.

Title: Physical activity and sedentary time are positively associated with academic performance: a three-year longitudinal study

Running head: Physical activity and academic performance

Manuscript type: Original research

Key-words: Accelerometry; Adolescent; Body composition; Epidemiology; Pediatrics

Word count: 4,340

Abstract word count: 200

Date of manuscript submission: 20.10.2017

Authors:

Rodrigo Antunes Lima[a,b]; Karin A. Pfeiffer[c]; Niels Christian Møller[b]; Lars Bo Andersen[d,e]; Anna Bugge[b,f].

Affiliations:

[a] CAPES Foundation, Ministry of Education of Brazil, Brasília – DF, 70040-020, Brazil;

[b] Research Unit for Exercise Epidemiology, Centre of Research in Childhood Health, Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark;

[c] Department of Kinesiology, Michigan State University, East Lansing, Michigan;

[d] Faculty of Teacher Education and Sport, Sogn og Fjordane University College, Sogndal, Norway;

[e] Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway.

[f] Department of Physiotherapy and Occupational Therapy, University College Copenhagen, Copenhagen, Denmark.

Corresponding author: Rodrigo Antunes Lima; rodrigoantlima@gmail.com

Abstract

Background: To analyze the longitudinal association between academic performance and moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), and sedentary time (SED) in a three-year longitudinal study. A secondary aim was to determine whether moderate-to-vigorous physical activity and vigorous physical activity were indirectly related with academic performance via waist circumference (WC). **Methods:** Physical activity (PA) and SED were measured by accelerometers. Academic performance was assessed by national tests in Danish and Math. Structural equation modeling was performed to evaluate whether MVPA, VPA and SED were associated with academic performance and the potential indirect relationship between PA and academic performance via WC. **Results:** MVPA and VPA were associated with academic performance, mediated via WC (β=0.036, 95% confidence interval (CI): 0.002: 0.070 and β=0.096, 95%CI: 0.027: 0.164, respectively). SED was directly associated with academic performance (β=0.124, 95%CI: 0.030: 0.217; MVPA model and β=0.132, 95%CI: 0.044: 0.221; VPA model). **Conclusions:** Both PA and SED time were positively associated with academic performance. Based on this, PA should be encouraged in children and youth not only to promote physical health, but also to promote academic performance. Future studies are encouraged to distinguish between school-related SED and other SED activities and their relationship with academic performance.

Introduction

Numerous studies have investigated the relationship between physical activity and academic performance in children and adolescents, and results are summarized in several reviews[1–3]. Despite the considerable number of published studies, a recent systematic review did not find clear evidence regarding the relationship between physical activity and academic performance[3]. One of the important issues that warrants consideration is study design. The vast majority of previous studies have been cross-sectional, and the results are inconsistent[3]. Most of the longitudinal studies that exist report positive relationships between physical activity and academic performance. Booth et al.[4] followed 4,755 children and adolescents from 11 to 16 years-old. More physically active children at 11 years-old exhibited higher academic performance at 13 and 16 years-old, compared to their less active peers[4]. However, others have reported conflicting results[5,6]. Hansen et al.[5] reported no significant linear or nonlinear relationship between physical activity and academic performance in a three-year follow-up study conducted with North American children. Moreover, Haapala et al.[6] observed that total physical activity was related to worse academic performance in Finnish girls, and better academic performance in boys. Therefore, more work is necessary to examine relationships between physical activity and academic performance across time.

In addition, only a few studies have evaluated the relation between sedentary time and academic performance[7–11], and to our knowledge only two studies with a longitudinal design[6,12]. One study found that accelerometry-based sedentary time and academic performance were positively, longitudinally associated, whereas screen time was negatively associated with academic performance[12]. Both longitudinal studies found that time spent studying or reading was positively associated with academic performance[6,12]. Thorough examination is warranted to better characterize the relationship between sedentary time and academic performance.

One issue that further complicates examining these relationships is the fact that body weight has been shown to be negatively related to both physical activity[13] and academic performance[14–16]; however, few studies have investigated the possible synergic relationship among these three factors[17,18]. Telford et al[19] found that children who attended physical education classes conducted by specialists showed smaller increase in percentage of body fat and also greater improvements in academic performance compared to children who attended common-practice physical education classes. A better understanding of the physical activity-academic performance relationship is needed to inform parents, teachers, policy makers and the greater community. Therefore, the current investigation aimed to analyze the longitudinal association between academic performance and moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), and sedentary time (SED) in a three-year longitudinal study. A secondary aim was to determine whether moderate-to-vigorous physical activity and vigorous physical activity were indirectly related with academic performance via waist circumference (WC).

Methods

The current investigation was part of the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS-study DK), which was the research part of a community initiative: the Svendborg Project. Because the complete methodology of the CHAMPS-study DK has been extensively published elsewhere[20], only the variables of interest are described here. The study was conducted in accordance with the Declaration of Helsinki. It was approved by the local scientific ethics committee (ID S20080047) and registered in the Danish Data Protection Agency (J.nr. 2008-41-2240). Parents had to provide written consent before their children were included in the study.

Measurements

Since 2010, the Danish school system has performed a national standardized test to assess academic performance of all the children enrolled in Danish schools. Therefore, the current study was able to evaluate the association between physical activity and academic performance in 902 students from seven-to-12-years of age, starting in 2010 during a three-year period (2010 – 2013). The national test is a standardized computer test, which advances according to the children’s performance. Thus, a question answered correctly would be followed by a more complex question. Similarly, a less complex question would follow an incorrect answer. The children were tested in Danish in the second, fourth, sixth and eighth grades, whereas Math performance was assessed in the third and sixth grades. Both subjects were evaluated in three different domains. In particular, language understanding, decoding and text comprehension were domains evaluated in the Danish tests, and algebra, geometry and basic mathematics skills were domains tested in Math. The total score for each subject could range from 0 to 300 points. A composite academic performance score was calculated by summing scores from both subjects (Danish and Math). In the sixth grade, an average of the performance in Danish and Math was used because participants were tested in both subjects at this school class.

Mother’s education was collected via a questionnaire and categorized into five levels: primary and lower secondary education, general upper secondary education, vocational education and training, bachelor degree and masters or PhD degree. Information on learning difficulties and physical disabilities hindering participation in physical activities were obtained via a questionnaire. Pubertal status was assessed by self-report of sexual maturation using a scale of pictures of breast development for girls and genital development for boys. Numbers were rated 1-5, according to criteria described by Tanner[21]. Pubertal stage was dichotomized into later puberty (stage four and five in the scale) and pre-and early puberty (stages one, two and three).

From 2010 to 2013, all participants were physically examined and tested at least once a year. Height was measured to the nearest 0.5 centimeter (cm) with a portable stadiometer (Seca 214, Seca Corporation, Hanover, MD). Weight was measured to the nearest 0.1 kg on an electronic scale (Tanita BWB-800S; Tanita Corporation, Tokyo, Japan) with the participant wearing light clothes. Waist circumference (WC) was assessed with a measuring tape at umbilicus level to the nearest 0.5 cm. Two measurements were performed, and in cases where the difference between the first and the second measurement was greater than one cm, a third measurement was performed. The average of the two nearest measurements was calculated and used for the analysis.

Physical activity was measured using Actigraph GT3X accelerometer (ActiGraph LLC, Pensacola, FL) four times in the current study (winter 2009/10; summer/fall 2010; summer/fall 2012; spring 2015) using 2 second epochs. GT3X+ accelerometers were also used in the last two measuring points. The accelerometers were delivered personally by the research staff, who explained to the children how to attach the device properly on the right side of the hip using an elastic belt. The device was only supposed to be removed while night sleeping and during activities involving water. Periods with 30 or more minutes with consecutives zeros counts were considered as non-wear periods[22,23]. A valid day was noted at a minimum of 10 hours of wear time[22,23].

Children with four or more valid days in at least two measuring points were included in the analyses. It was not required that children presented valid weekend days to be included in the analyses. Evenson et. al's cut-points[24] were used to calculate the minutes spent in sedentary (SED: ≤100 counts per minute [cpm]), moderate-to-vigorous (MVPA: ≥2296 cpm) and vigorous physical activity (VPA: ≥4012 cpm) because of its valid estimation for the age range of the participants in the present study[25]. Light physical activity was not used in the current study. More details regarding the analysis in the next section.

Data analyses and statistics

STATA version 14.0 (StataCorp LP, College Station, TX, USA) was used for all analyses. For descriptive purposes, means and standard deviations are presented, and ANOVA was performed to test for differences between boys and girls and among grades.

The pathways examined in the analyses are presented in Figure 1. Generalized Structured equation modeling (GSEM) was used to determine whether SED, MVPA or VPA were longitudinally associated with academic performance. In summary, the first model included MVPA and SED in the diagram to evaluate the association between SED, MVPA and academic performance, and the potential indirect association via WC. In the second model MVPA was replaced with VPA, to evaluate the association between SED, VPA and academic performance, besides the potential indirect association via WC. In addition to the co-variates presented in Figure 1 (school type [control and intervention], age, sex, height, school class and mothers' education), pubertal status (later puberty and pre-and early puberty) all analyses were furthermore adjusted for season of accelerometry measurements (fall, winter, spring and summer), accelerometer wear time, learning difficulty of the participants (yes and no), physical disabilities (yes and no) and cluster structure (students nested in classes and classes nested in schools). Note that all follow-up measures were included in one box for each respective variable in Figure 1, because it is difficult to show the complexity of all variables assessed at all time points within one figure, but information from each time point was used in the analyses. In all analyses performed, the term “direct association” refers to the association of physical activity (MVPA and VPA) and sedentary time with academic performance, the term “indirect association” refers to the association of physical activity with academic performance mediated via waist circumference, whereas the term “total association” refers to the sum of the direct and indirect association of physical activity, sedentary time with academic performance.

Results

Older children had higher WC, were taller, heavier, and spent more time in sedentary activities, and less time in MVPA compared to younger children, both when analyzing boys and girls together or independently. However, there were no differences in academic performance or time spent in VPA across different grade levels. Boys spent more time in MVPA and VPA than girls, regardless of grade level. Girls presented higher scores in Danish than boys (see Table 1).

Neither MVPA nor VPA were directly associated with academic performance, whereas SED time exhibited a direct association. MVPA and VPA were associated indirectly with academic performance via WC. Specifically, for each additional minute a day spent in MVPA or VPA activities, academic scores increased 0.036 and 0.096 points, respectively. Furthermore, each additional minute spent in SED activities increased the academic scores 0.129 (MVPA model) and 0.140 points (VPA model). In addition, WC was negatively associated with academic performance. On average, for each centimeter of WC added, academic performance decreased 1.259 points (MVPA model) and 1.223 points (VPA model). Also, each additional minute/day in MVPA and VPA was related to a decrease in WC of 0.029 and 0.078 cm, respectively (see Figure 2).

Discussion

The current study investigated the three-year relationship between objectively measured MVPA and VPA and SED and academic performance in Danish children aged seven-to-twelve-years-old at enrollment of study. MVPA and VPA were indirectly associated with academic performance via WC. Moreover, SED time was directly and positively associated with academic performance.

Longitudinal association between MVPA, VPA and academic performance

In the current investigation, both physical activity and sedentary time were positively associated with academic performance. It is worth mentioning that the interpretation of the MVPA and VPA relationship with academic performance was independent of SED time. In addition, given the mutual adjustments performed in the MVPA and SED model, the interpretation of the MVPA association with academic performance should be considered in the light of substituting light physical activity minutes with MVPA minutes. Whereas, in the VPA and SED model, the interpretation of the VPA association with academic performance should be interpreted by substitution of light or moderate physical activity minutes with VPA minutes.

Previous investigations have reported diverging results regarding the relationship between physical activity and academic performance[3,5,6]. The longitudinal study available with the largest sample size (n=4,755 children evaluated for five years – from 11 to 16 years-old) observed a relationship between MVPA and English and Math grades[4]. The same study evaluated a possible dose-response in the physical activity-academic performance relationship. Booth, et al.[4] found that only children in the highest MVPA quintile presented higher academic performance compared to their lowest quintile peers, whereas no significant difference in academic performance was observed in children in other quintiles of MVPA time[4]. The authors speculated that higher physical activity intensities were more closely related to improvements in academic performance[4].

Indirect association via waist circumference

The results from this study showed that MVPA and VPA were indirectly associated with academic performance via WC mediation. The negative association between weight status and academic performance is relatively well-documented in the literature[14,16,26]. One example is a randomized controlled trial study examining the effect of two types of physical education classes to children - a control condition and enhanced physical education classes with extra two hours a week with skill-based PA and tennis training. Both conditions resulted in improvements in inhibition, but overweight children in the intervention group showed larger improvements in inhibition than their lean peers[27], which indicates the importance of weight status in relation to cognition in children. On the other hand, in a matched-pairs study design, Davis, et al.[28] observed that physically active children who participated in organized physical activity programs exhibited higher cognitive function than their inactive peers, independently of their weight status (normal weight or overweight/obese). Moreover, normal weight children exhibited less distractibility compared to overweight children with similar low- level of physical activity participation and fitness. In summary, Davis, et al.[28] observed that both physical activity and weight status were associated with cognitive function independently of each other. A recent systematic review analyzed how physical activity and obesity individually or combined seems to affect cognitive function[17]. However, the number of studies evaluating the possible synergic association between physical activity, weight status and academic performance was insufficient to draw firm conclusions[17]. Theoretically, weight status may be on the pathway between physical activity and cognition/academic performance, but further investigation is necessary to verify this.

Other possible underlying mechanisms on the physical activity-academic performance relationship

It is not in the scope of the current investigation to analyze the mechanisms that might explain the relationship between physical activity and academic performance. However, it is worth mentioning that physical activity might be related to academic performance via numerous pathways. A recent systematic review reported associations between physical activity level and 1) executive functions (i.e. inhibition, working memory, cognitive flexibility), 2) neurobiological measures (i.e. white matter structure, characteristics of the prefrontal cortex and medial frontal gyrus), 3) psychosocial measures (i.e. physical self-concept, family and friend support, social competence), 4) mental health outcomes (i.e. depression, quality of life, self-esteem), and 5) behavioral mechanisms (i.e. self-control, cognitive self-regulation, affective self-regulation)[29]. Moreover, increased aerobic fitness in children has been found to be associated with decreased regional cortical thickness[30], increased regional white matter integrity[31], increased hippocampus and striatal volumes[32], and better academic performance[16,19]. A relatively well-described association between physical activity and aerobic fitness can be found in the literature[33]. Therefore, it is plausible that higher physical activity level not only relates to academic performance via WC, but also by affecting the aerobic fitness level[4] (although it was not tested in the current investigation).

Longitudinal association between sedentary time and academic performance

The current investigation observed a positive association between SED time and academic performance, which has also been observed in previous studies[6,7,12]. It seems that objective measures of SED time present a positive association or no association with academic performance in children and adolescents[6,7,12], but specific SED activities (e.g. watching TV, surfing on the internet) appear to be negatively associated with academic performance[8,9,12]. For example, one study found that sedentary time measured by accelerometers exhibited positive association with academic performance, yet various components of sedentary time showed different individual relationships. Specifically, screen time was negatively associated with academic performance, and time spent studying and reading was positively associated with academic performance[12]. SED time is a complex behavior to monitor, especially related to academic performance. A considerable amount of time the students are studying would represent SED activities (i.e. lessons, homework). Therefore, it is extremely challenging and important to be able to distinguish between SED activities related to schools, such as community band, as lessons and homework and SED activities related to leisure time, e.g., screen time (watching TV, computer and video games). Because of the aforementioned limitations, investigators from the largest study evaluating the relationship between physical activity and academic performance chose not to evaluate the association between SED time and academic performance, although the authors reported a decrease in the relationship coefficients between MVPA and academic performance when SED time was included as covariate[4]. Unfortunately, the current study did not collect data on the SED time context. It is likely that the combination of direct measures of SED time with self-reported SED time context information is the most appropriate approach to evaluate the relationship between SED time and academic performance.

Study strengths and limitations

The main strengths of the current investigation are the longitudinal design with several measuring points, relative large sample size, the comprehensive data collection that renders it possible for us to adjust for many known confounders, comprehensive assessments of Danish and Math subjects by use of standard national tests and objective measures of different physical activity intensities. Also, the use of statistical modelling capable of examining the potential indirect association of MVPA and VPA with academic performance via WC can be considered a strength. Nevertheless, there are limitations to be taken into account. The CHAMPS-study DK is an intervention that increased the amount of physical education classes in the intervention schools. However, the intervention had no effect on academic performance[34] and all analyses were adjusted for the intervention (intervention and control group). It was not possible to test the psychometric measures of the academic tests, and students were not tested in each academic subject every year. Thus, the amount of information could have been more comprehensive, but the tests followed the national test system in Denmark. The current study did not collect information on the context in which the sedentary activity children were involved. Thus, it was not possible to properly evaluate the relationship between SED and academic performance. It is possible that an appropriate adjustment for sedentary time with and without relation to academics would weaken the observed positive relationship. In addition, while accelerometry is considered the gold standard measure for physical activity in epidemiological studies, between accelerometry and anthropometric measures, the accelerometers present the biggest measurement error which could have weakened the strength of relationships between physical activity and academic performance. Especially in Denmark accelerometry is problematic, because cycling is a major part of total PA that is not well captured by accelerometry[35]. Finally, the results of the current study should be interpreted carefully and cautiously transferred to other cultures. Physical activity level differ across different countries[36] and these differences might influence the physical activity-academic performance relationship.

In conclusion, physical activity was associated with academic performance in children and adolescents. In addition, physical activity (MVPA or VPA) was only indirectly associated with academic performance via waist circumference. It seems that higher physical activity intensities have stronger longitudinal relationship with academic performance[4]. Although the strength of the positive longitudinal association between physical activity and academic performance was weak, the current study does support the growing body of evidence suggesting that greater amounts of time spend in physical activities do not decrease students' academic performance. Regarding the observed positive relationship between sedentary time and academic performance, it is recommended that future studies consider the context of sedentary activity (study-related vs. screen-time related).

Acknowledgments

The authors thank the participants and their families, school teachers and administrations, and research staff for their support and help for this study. Authors wish to acknowledge members of the CHAMPS Study-DK not listed as co-authors of this paper, especially Niels Wedderkopp, who initiated the study.

Funding source

The current study was funded by: TrygFonden; CAPES Scholarship, number: 1361/13-9; The Danish Heart Foundation; The Nordea Foundation; The IMK Foundation; The Region of Southern Denmark; The Egmont Foundation; The A.J. Andersen Foundation; The Danish Rheumatism Association; Østifternes Foundation;

Brd. Hartmanns Foundation; TEAM Denmark; University College Lillebaelt Department of Physiotherapy; University of Southern Denmark; The Danish Chiropractic Research Foundation; and The Municipality of Svendborg.

References

1. Fedewa AL, Ahn S. The effects of physical activity and physical fitness on children's achievement and cognitive outcomes: a meta-analysis. *Res Q Exerc Sport*. 2011;82(3):521-535. doi:10.1080/02701367.2011.10599785

2. Singh A, Uijtdewilligen L, Twisk JWR, van Mechelen W, Chinapaw MJM. Physical Activity and Performance at School. *Arch Pediatr Adolesc Med*. 2012;166(1):49. doi:10.1001/archpediatrics.2011.716

3. Donnelly JE, Hillman CH, Castelli D, et al. Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: a systematic review. *Med Sci Sport Exerc*. 2016;48(6):1197-1222. doi:10.1249/MSS.0000000000000901

4. Booth JN, Leary SD, Joinson C, et al. Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. *Br J Sports Med*. 2014;48(3):265-270. doi:10.1136/bjsports-2013-092334

5. Hansen DM, Herrmann SD, Lambourne K, Lee J, Donnelly JE. Linear/nonlinear relations of activity and fitness with children's academic achievement. *Med Sci Sports Exerc*. 2014;46(12):2279-2285. doi:10.1249/MSS.0000000000000362

6. Haapala EA, Poikkeus A-M, Kukkonen-Harjula K, et al. Associations of physical activity and sedentary behavior with academic skills--a follow-up study among primary school children. Gillison F, ed. *PLoS One*. 2014;9(9):e107031. doi:10.1371/journal.pone.0107031

7. Maher C, Lewis L, Katzmarzyk PT, Dumuid D, Cassidy L, Olds T. The associations between physical activity, sedentary behaviour and academic performance. *J Sci Med Sport*. 2016;19(12):1004-1009. doi:10.1016/j.jsams.2016.02.010

8. Syväoja HJ, Kantomaa MT, Ahonen T, Hakonen H, Kankaanpää A, Tammelin TH. Physical activity, sedentary behavior, and academic performance in Finnish children. *Med Sci Sports Exerc*. 2013;45(11):2098-2104. doi:10.1249/MSS.0b013e318296d7b8

9. da Costa BGG, da Silva KS, George AM, de Assis MAA. Sedentary behavior during school-time: Sociodemographic, weight status, physical education class, and school performance correlates in Brazilian schoolchildren. *J Sci Med Sport*. 2017;20(1):70-74. doi:10.1016/j.jsams.2016.06.004

10. Esteban-Cornejo I, Tejero-González CM, Martinez-Gomez D, et al. Objectively measured physical activity has a negative but weak association with academic performance in children and adolescents. *Acta Paediatr*. 2014;103(11):e501-6. doi:10.1111/apa.12757

11. Lopes L, Santos R, Mota J, Pereira B, Lopes V. Objectively measured sedentary time and academic achievement in schoolchildren. *J Sports Sci*. 2017;35(5):463-469. doi:10.1080/02640414.2016.1172724

12. Corder K, Atkin AJ, Bamber DJ, et al. Revising on the run or studying on the sofa: prospective associations between physical activity, sedentary behaviour, and exam results in British adolescents. *Int J Behav Nutr Phys Act*. 2015;12(1):106. doi:10.1186/s12966-015-0269-2

13. Sahoo K, Sahoo B, Choudhury AK, Sofi NY, Kumar R, Bhadoria AS. Childhood obesity: causes and consequences. *J Fam Med Prim care*. 2015;4(2):187-192. doi:10.4103/2249-4863.154628

14. Booth JN, Tomporowski PD, Boyle JME, et al. Obesity impairs academic attainment in

adolescence: findings from ALSPAC, a UK cohort. *Int J Obes (Lond)*. 2014;38(10):1335-1342. doi:10.1038/ijo.2014.40

15. Telford RD, Cunningham RB, Fitzgerald R, et al. Physical Education, Obesity, and Academic Achievement: A 2-Year Longitudinal Investigation of Australian Elementary School Children. *Am J Public Health*. 2012;102(2):368-374. doi:10.2105/AJPH.2011.300220

16. London RA, Castrechini S. A Longitudinal Examination of the Link Between Youth Physical Fitness and Academic Achievement. *J Sch Health*. 2011;81(7):400-408. doi:10.1111/j.1746-1561.2011.00608.x

17. Chang Y-K, Chu C-H, Chen F-T, Hung T-M, Etnier JL. Combined Effects of Physical Activity and Obesity on Cognitive Function: Independent, Overlapping, Moderator, and Mediator Models. *Sports Med*. 2017;47(3):449-468. doi:10.1007/s40279-016-0589-7

18. Saevarsson ES, Gudmundsdottir SL, Kantomaa M, et al. Above average increases in body fat from 9 to 15 years of age had a negative impact on academic performance, independent of physical activity. *Acta Paediatr*. July 2018. doi:10.1111/apa.14459

19. Telford RD, Cunningham RB, Telford RM, Abhayaratna WP, Abharatna WP. Schools with fitter children achieve better literacy and numeracy results: evidence of a school cultural effect. *Pediatr Exerc Sci*. 2012;24(1):45-57. http://www.ncbi.nlm.nih.gov/pubmed/22433264. Accessed June 26, 2017.

20. Wedderkopp N, Jespersen E, Franz C, et al. Study protocol. The Childhood Health, Activity, and Motor Performance School Study Denmark (The CHAMPS-study DK). *BMC Pediatr*. 2012;12(1):672. doi:10.1186/1471-2431-12-128

21. Tanner JM. Normal growth and techniques of growth assessment. *Clin Endocrinol Metab*. 1986;15(3):411-451. http://www.ncbi.nlm.nih.gov/pubmed/3533329. Accessed June 27, 2017.

22. Lima RA, Storino S, Barros H, et al. Influence of number of days and valid hours using accelerometry on the estimates of physical activity level in preschool children from Recife, Pernambuco, Brazil. *Brazilian J Kinanthropometry Hum Perform*. 2013;16(2):171-181.

23. Møller NC, Tarp J, Kamelarczyk EF, Brønd JC, Klakk H, Wedderkopp N. Do extra compulsory physical education lessons mean more physically active children--findings from the childhood health, activity, and motor performance school study Denmark (The CHAMPS-study DK). *Int J Behav Nutr Phys Act*. 2014;11(1):121. doi:10.1186/s12966-014-0121-0

24. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008;26(14):1557-1565. doi:10.1080/02640410802334196

25. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*. 2011;43(7):1360-1368. doi:10.1249/MSS.0b013e318206476e

26. Chen L-J, Fox KR, Ku P-W, Wang C-H. A longitudinal study of childhood obesity, weight status change, and subsequent academic performance in Taiwanese children. *J Sch Health*. 2012;82(9):424-431. doi:10.1111/j.1746-1561.2012.00718.x

27. Crova C, Struzzolino I, Marchetti R, et al. Cognitively challenging physical activity benefits executive function in overweight children. *J Sports Sci*. 2014;32(3):201-211. doi:10.1080/02640414.2013.828849

28. Davis CL, Tkacz JP, Tomporowski PD, Bustamante EE. Independent Associations of Organized Physical Activity and Weight Status with Children’s Cognitive Functioning: A Matched-Pairs Design. *Pediatr Exerc Sci*. 2015;27(4):477-487. doi:10.1123/pes.2015-0044

29. Lubans D, Richards J, Hillman C, et al. Physical Activity for Cognitive and Mental Health in Youth: A Systematic Review of Mechanisms. *Pediatrics*. 2016;138(3):e20161642-e20161642. doi:10.1542/peds.2016-1642

30. Chaddock-Heyman L, Erickson KI, Kienzler C, et al. The Role of Aerobic Fitness in Cortical Thickness and Mathematics Achievement in Preadolescent Children. *PLoS One*. 2015;10(8):e0134115. doi:10.1371/journal.pone.0134115

31. Chaddock-Heyman L, Erickson KI, Holtrop JL, et al. Aerobic fitness is associated with greater white matter integrity in children. *Front Hum Neurosci*. 2014;8:584. doi:10.3389/fnhum.2014.00584

32. Chaddock L, Erickson KI, Prakash RS, et al. Basal Ganglia Volume Is Associated with Aerobic Fitness in Preadolescent Children. *Dev Neurosci*. 2010;32(3):249-256. doi:10.1159/000316648

33. Kemper HCG, Koppes LLJ. Linking Physical Activity and Aerobic Fitness: Are We Active Because We Are Fit, or Are We Fit Because We Are Active? *Pediatr Exerc Sci*. 2006;18(2):173-181. doi:10.1123/pes.18.2.173

34. Bugge A, Möller S, Tarp J, et al. Influence of a 2- to 6-year physical education intervention on scholastic performance: The CHAMPS study-DK. *Scand J Med Sci Sport*. 2018;28(1). doi:10.1111/sms.12902

35. Tarp J, Andersen LB, Østergaard L. Quantification of Underestimation of Physical Activity during Cycling to School When Using Accelerometry. *J Phys Act Heal*. 2015;12(5):701-707. doi:10.1123/jpah.2013-0212

36. Cooper AR, Goodman A, Page AS, et al. Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD). *Int J Behav Nutr Phys Act*. 2015;12:113. doi:10.1186/s12966-015-0274-5

Table 1. Mean and standard deviation (SD) of the time spent in moderate-to-vigorous, vigorous physical activity, sedentary behavior, waist circumference (WC) and academic achievement scores for the different grade levels in 2010.

All participants	1st grade (n= 189 – 217)		2nd grade (n= 225 – 299)		3rd grade (n= 237 – 313)		4th grade (n= 238 – 313)		5th grade (n= 225 – 264)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age (years)	7.87	(0.34)	8.89	(0.33)	9.86	(0.39)	10.88	(0.32)	11.87	(0.37)
WC (cm)*	57.56	(5.32)	61.03	(6.22)	63.67	(6.90)	65.27	(7.17)	68.55	(8.27)
Weight (kg)*	27.05	(4.23)	30.96	(5.46)	34.13	(6.27)	37.83	(6.85)	42.46	(8.82)
Height (cm)*	129.35	(5.55)	135.72	(5.95)	140.61	(6.79)	146.27	(6.42)	152.26	(7.33)
MVPA (min/day)*	69.46	(7.27)	66.75	(6.52)	65.00	(6.71)	61.30	(6.57)	59.12	(7.19)
VPA (min/day)	23.27	(3.42)	23.07	(3.14)	23.24	(3.15)	22.53	(3.13)	22.51	(3.43)
SED (min/day)*	435.16	(11.32)	460.68	(9.44)	484.03	(11.05)	510.28	(9.73)	534.31	(11.20)
Danish (points)	-	-	162.46	(75.53)	-	-	161.78	(75.39)	-	-

Math (points)	-	-	-	-	166.68	(66.52)	-	-	-	-
Boys	1st grade		2nd grade		3rd grade		4th grade		5th grade	
Age (years)	7.90	(0.36)	8.96	(0.33)	9.94	(0.41)	10.95	(0.32)	11.94	(0.37)
WC (cm)*	57.38	(5.68)	61.24	(5.40)	63.68	(6.53)	65.50	(7.14)	68.93	(8.48)
Weight (kg)*	27.32	(4.28)	31.21	(4.94)	34.55	(6.07)	37.99	(6.93)	42.81	(9.33)
Height (cm)*	130.58	(5.76)	136.40	(5.74)	141.88	(6.97)	146.94	(6.56)	153.21	(7.34)
MVPA (min/day)*¥	77.30	(1.06)	74.41	(1.06)	71.95	(1.27)	69.25	(0.99)	66.66	(1.16)
VPA (min/day)¥	26.99	(0.26)	26.80	(0.25)	26.54	(0.25)	26.35	(0.26)	26.14	(0.28)
SED (min/day)*	428.65	(9.62)	455.76	(9.63)	479.15	(11.56)	504.54	(8.99)	528.95	(10.75)
Danish (points)¥	-	-	166.94	(75.88)	-	-	154.82	(76.70)	-	-
Math (points)	-	-	-	-	168.75	(71.69)	-	-	-	-
Girls	1st grade		2nd grade		3rd grade		4th grade		5th grade	
Age (years)	7.84	(0.33)	8.84	(0.32)	9.78	(0.35)	10.82	(0.32)	11.81	(0.35)

WC (cm)*	57.71	(5.03)	60.84	(6.85)	63.67	(7.31)	65.10	(7.22)	68.20	(8.10)
Weight (kg)*	26.82	(4.19)	30.73	(5.88)	33.66	(6.48)	37.71	(6.81)	42.13	(8.35)
Height (cm)*	128.33	(5.17)	135.14	(6.09)	139.21	(6.32)	145.75	(6.28)	151.38	(7.25)
MVPA (min/day)*	62.88	(1.06)	60.28	(0.97)	57.73	(1.09)	55.00	(1.04)	52.45	(1.02)
VPA (min/day)	20.15	(0.25)	19.95	(0.26)	19.79	(0.24)	19.51	(0.25)	19.30	(0.27)
SED (min/day)*	440.62	(9.65)	465.11	(8.83)	489.12	(9.95)	514.98	(9.45)	539.06	(9.31)
Danish (points)	-	-	170.02	(70.03)	-	-	175.97	(72.28)	-	-
Math (points)	-	-	-	-	164.94	(58.83)	-	-	-	-

*p<0.05 differences among grades; ¥ <0.05 differences between boys and girls.

Table 1. Mean and standard deviation (SD) of the time spent in moderate-to-vigorous, vigorous physical activity, sedentary behavior, waist circumference (WC) and academic achievement scores for the different grade levels in 2010.

	1st grade	2nd grade	3rd grade	4th grade	5th grade
All participants	(n= 189 – 217)	(n= 225 – 299)	(n= 237 – 313)	(n= 238 – 313)	(n= 225 – 264)

	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age (years)	7.87	(0.34)	8.89	(0.33)	9.86	(0.39)	10.88	(0.32)	11.87	(0.37)
WC (cm)*	57.56	(5.32)	61.03	(6.22)	63.67	(6.90)	65.27	(7.17)	68.55	(8.27)
Weight (kg)*	27.05	(4.23)	30.96	(5.46)	34.13	(6.27)	37.83	(6.85)	42.46	(8.82)
Height (cm)*	129.35	(5.55)	135.72	(5.95)	140.61	(6.79)	146.27	(6.42)	152.26	(7.33)
MVPA (min/day)*	69.46	(7.27)	66.75	(6.52)	65.00	(6.71)	61.30	(6.57)	59.12	(7.19)
VPA (min/day)	23.27	(3.42)	23.07	(3.14)	23.24	(3.15)	22.53	(3.13)	22.51	(3.43)
SED (min/day)*	435.16	(11.32)	460.68	(9.44)	484.03	(11.05)	510.28	(9.73)	534.31	(11.20)
Danish (points)	-	-	162.46	(75.53)	-	-	161.78	(75.39)	-	-
Math (points)	-	-	-	-	166.68	(66.52)	-	-	-	-
Boys	1st grade		2nd grade		3rd grade		4th grade		5th grade	
Age (years)	7.90	(0.36)	8.96	(0.33)	9.94	(0.41)	10.95	(0.32)	11.94	(0.37)
WC (cm)*	57.38	(5.68)	61.24	(5.40)	63.68	(6.53)	65.50	(7.14)	68.93	(8.48)

Weight (kg)*	27.32	(4.28)	31.21	(4.94)	34.55	(6.07)	37.99	(6.93)	42.81	(9.33)
Height (cm)*	130.58	(5.76)	136.40	(5.74)	141.88	(6.97)	146.94	(6.56)	153.21	(7.34)
MVPA (min/day)*¥	77.30	(1.06)	74.41	(1.06)	71.95	(1.27)	69.25	(0.99)	66.66	(1.16)
VPA (min/day)¥	26.99	(0.26)	26.80	(0.25)	26.54	(0.25)	26.35	(0.26)	26.14	(0.28)
SED (min/day)*	428.65	(9.62)	455.76	(9.63)	479.15	(11.56)	504.54	(8.99)	528.95	(10.75)
Danish (points)¥	-	-	166.94	(75.88)	-	-	154.82	(76.70)	-	-
Math (points)	-	-	-	-	168.75	(71.69)	-	-	-	-
Girls	1st grade		2nd grade		3rd grade		4th grade		5th grade	
Age (years)	7.84	(0.33)	8.84	(0.32)	9.78	(0.35)	10.82	(0.32)	11.81	(0.35)
WC (cm)*	57.71	(5.03)	60.84	(6.85)	63.67	(7.31)	65.10	(7.22)	68.20	(8.10)
Weight (kg)*	26.82	(4.19)	30.73	(5.88)	33.66	(6.48)	37.71	(6.81)	42.13	(8.35)
Height (cm)*	128.33	(5.17)	135.14	(6.09)	139.21	(6.32)	145.75	(6.28)	151.38	(7.25)
MVPA (min/day)*	62.88	(1.06)	60.28	(0.97)	57.73	(1.09)	55.00	(1.04)	52.45	(1.02)

VPA (min/day)	20.15	(0.25)	19.95	(0.26)	19.79	(0.24)	19.51	(0.25)	19.30	(0.27)
SED (min/day)*	440.62	(9.65)	465.11	(8.83)	489.12	(9.95)	514.98	(9.45)	539.06	(9.31)
Danish (points)	-	-	170.02	(70.03)	-	-	175.97	(72.28)	-	-
Math (points)	-	-	-	-	164.94	(58.83)	-	-	-	-

*p<0.05 differences among grades; ¥ <0.05 differences between boys and girls.

Online version

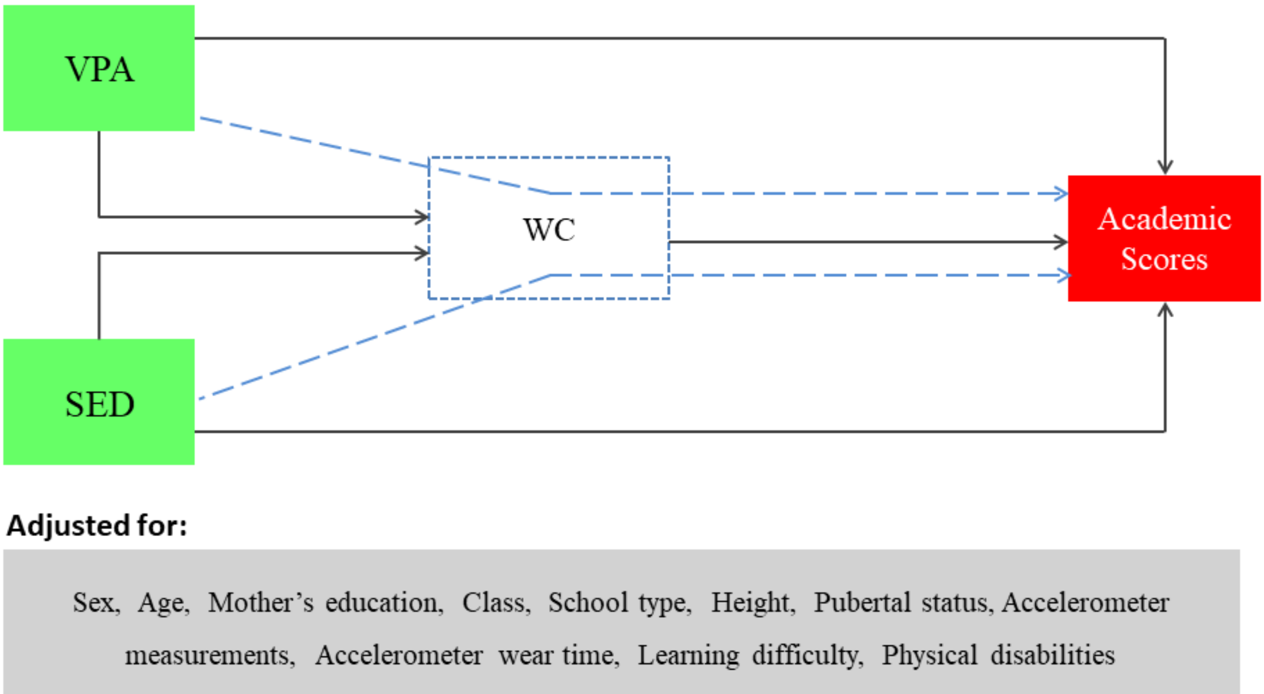

Figure 1. Diagram of the pathways used in the analyses.

Note that all three-time points were used in analysis and this figure is a representation of the vigorous physical activity (VPA) model. Moderate-to-vigorous physical activity (MVPA) model replaced VPA to estimate the relationship between MVPA and academic performance. WC refers to Waist circumference. School type refers to assignment to control or intervention school physical education program. Academic scores refer to the composite academic performance score (Danish and Math combined). Pubertal status refers to later puberty (Tanner's stage four and five) and pre-and early puberty (Tanner's stages one, two and three). Accelerometer measurement refers to the season of accelerometry measurements (fall, winter, spring and summer).

Printed version

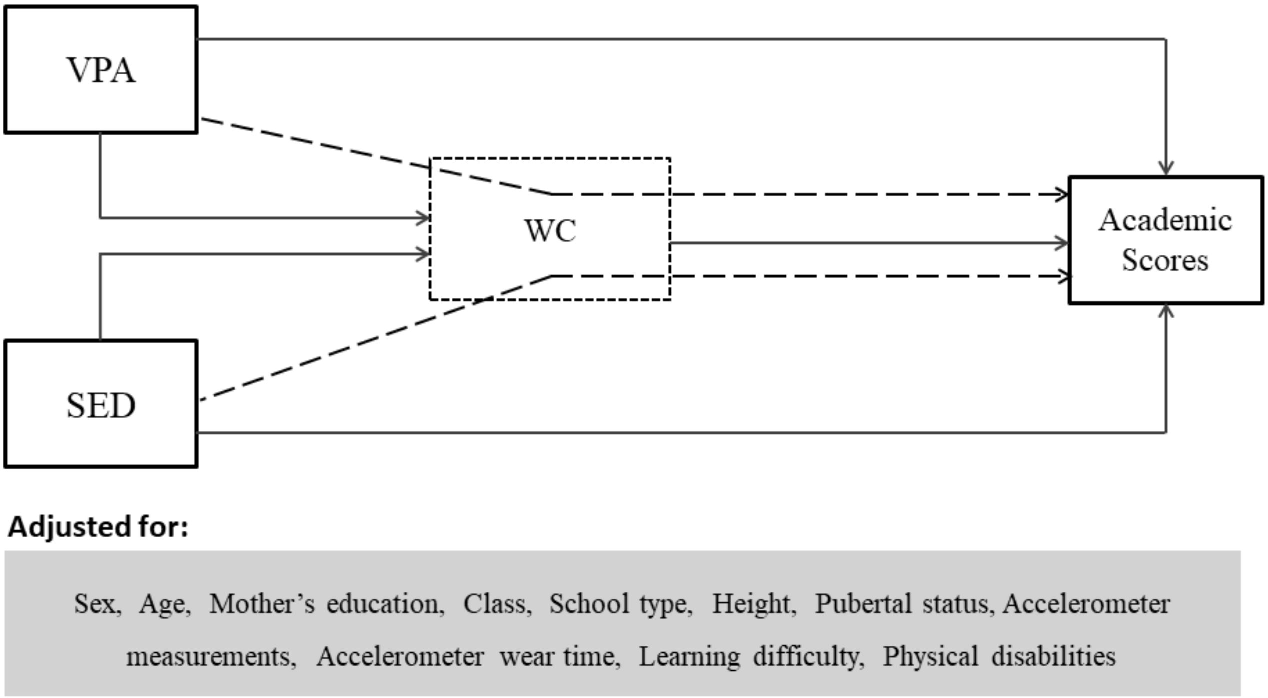

Figure 1. Diagram of the pathways used in the analyses.

Note that all three-time points were used in analysis and this figure is a representation of the vigorous physical activity (VPA) model. Moderate-to-vigorous physical activity (MVPA) model replaced VPA to estimate the relationship between MVPA and academic performance. WC refers to Waist circumference. School type refers to assignment to control or intervention school physical education program. Academic scores refer to the composite academic performance score (Danish and Math combined). Pubertal status refers to later puberty (Tanner's stage four and five) and pre-and early puberty (Tanner's stages one, two and three). Accelerometer measurement refers to the season of accelerometry measurements (fall, winter, spring and summer).

Online version

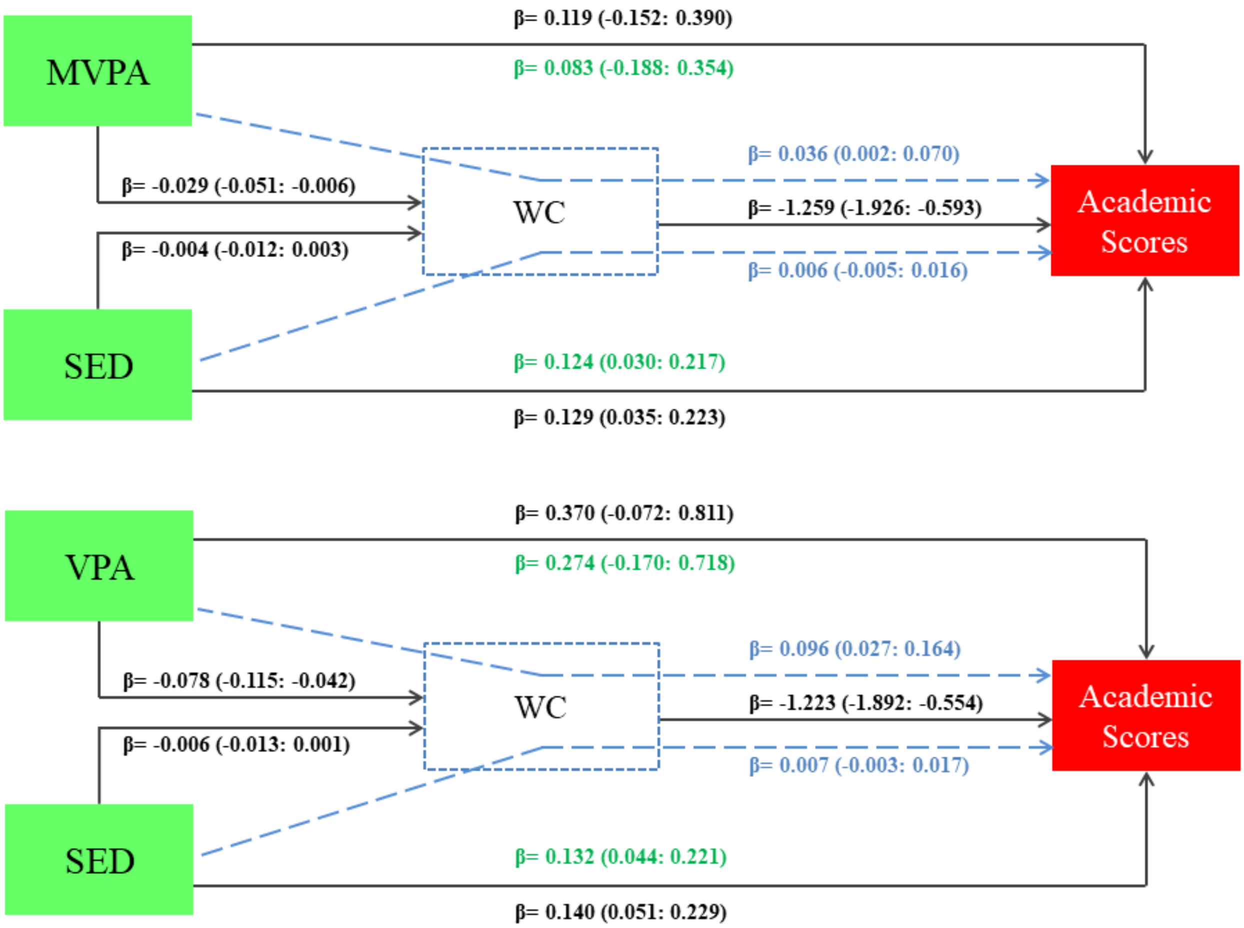

Figure 2. Parameter estimates of the path coefficient (95% CI) of the association between physical activity (SED, MVPA and VPA), waist circumference (WC) and academic performance.

Note – Black coefficients: Total association; Green coefficients: Direct association (remaining association after mediation is removed); Blue coefficients: Indirect association (the part attributed to mediation).

Printed version

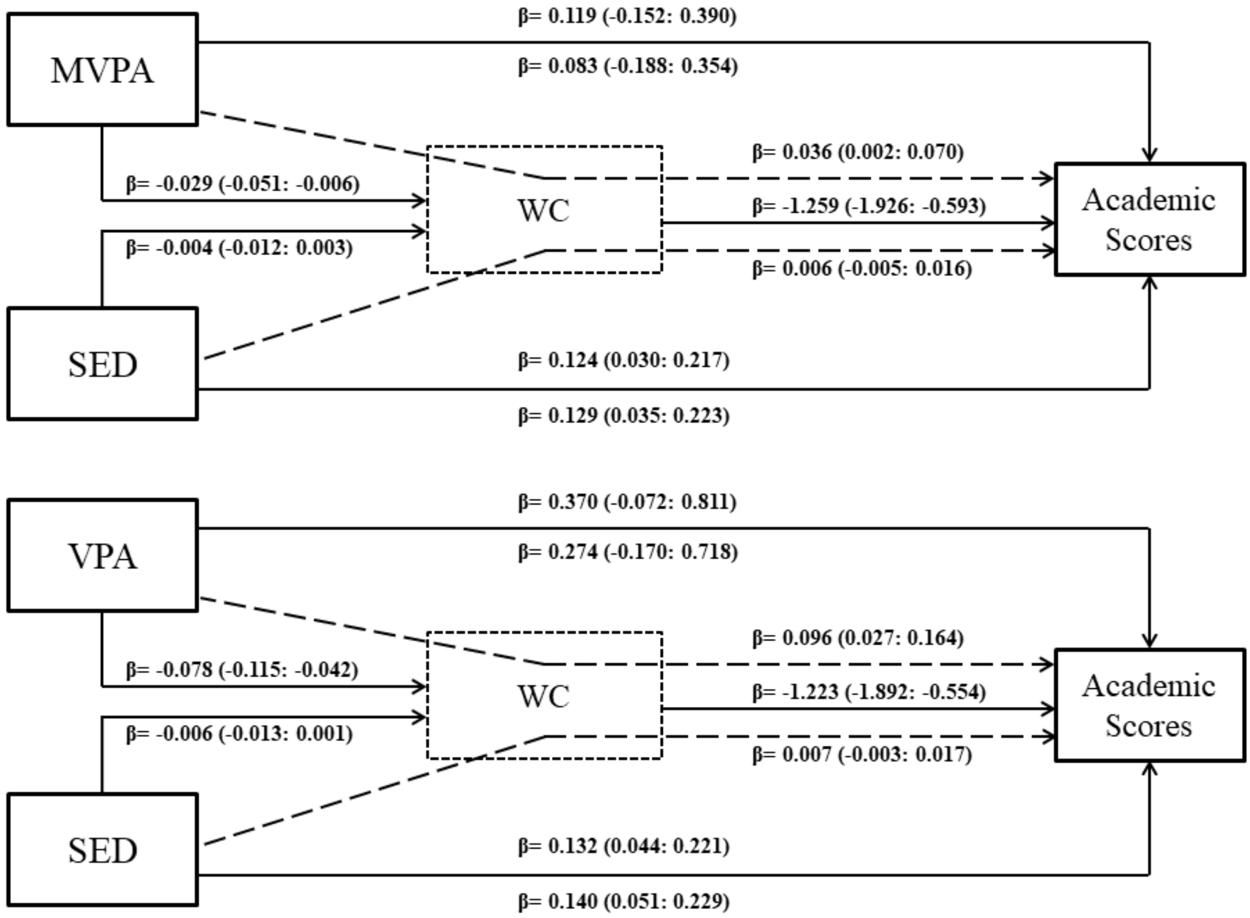

Figure 2. Parameter estimates of the path coefficient (95% CI) of the association between physical activity (SED, MVPA and VPA), waist circumference (WC) and academic performance.

Note – Dotted paths: Indirect association (the part attributed to mediation).