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Abstract

Background: The current study evaluated the reciprocal longitudinal relationship between physical activity (PA) and motor competence (MC) and the potential mediation of cardiorespiratory endurance across seven years. **Methods:** This was a seven-year longitudinal study with three measuring points (mean ages [in years] and respective sample size: 6.75 ±0.37, n=696; 9.59 ±1.07, n=617; 13.35 ±0.34, n=513) – the Copenhagen School Child Intervention Study (CoSCIS). PA was assessed using accelerometers. MC by the *Körperkoordinationstest für Kinder* (KTK) test battery. Cardiorespiratory fitness (VO_{2peak}) was evaluated using a continuous running protocol until exhaustion. Structural equation modeling was performed to evaluate the longitudinal associations. **Results:** Vigorous PA (VPA) and MC presented reciprocal longitudinal association during the seven-year follow-up (VPA → MC; β=0.18; 95%CI: 0.10, 0.26; MC → VPA; β=0.14; 95%CI: 0.08, 0.21). In addition, VO_{2peak} mediated the relationship in both directions (VPA → MC; β=0.09; 95%CI: 0.06, 0.12; MC → VPA; β=0.06; 95%CI: 0.03, 0.09). **Conclusions:** PA and MC presented a positive reciprocal relationship across childhood through early adolescence and VO_{2peak} mediated the association in both directions. Interventions targeting to increase PA in children and adolescents should also address the development of MC skills because of the clear positive feedback loop between PA and MC.

Introduction

The health benefits of physical activity are well established as physical activity is associated with protection from lifestyle diseases[1-4]. Additionally, physically active children are protected of developing cardiovascular risk factors[5]. Furthermore, reviews noted evidence for associations between several psychological and social-emotional health benefits of physical activity including mental well-being, higher self-esteem and social skills, self-efficacy, perceived competence, goal orientation, motivation and sports participation[4, 6, 7].

There also is strong cross-sectional evidence noting the positive association between physical activity and motor competence in children and adolescents[8, 9]. However, only a few longitudinal studies with these variables have been conducted[10-12]. Barnett, et al. [11] followed 276 Australian children during five years and observed that object control proficiency in childhood was positively associated with moderate-to-vigorous physical activity (MVPA) time during adolescence. In addition, children with good object control proficiency were more likely to participate in at least some vigorous physical activity during adolescence[11]. Lopes, et al. [12] observed a decrease in physical activity level in Portuguese children followed between six and 10 years of age. Importantly, children with high motor competence at six years of age exhibited lower decrease in physical activity levels at the age of 10, compared to children with low and average motor competence levels at six years of age[12].

Understanding how physical activity and motor competence influence each other across childhood and adolescence is not well established, as researchers generally attempt to establish a unidirectional pathway with one variable causally determining the outcome of the other. However, Stodden, et al. [13] published a theoretical framework where the direction of causation is hypothesized to change from early to middle childhood. In early childhood, physical activity is suggested to promote motor competence via a variety of exploratory as well as context-specific (i.e., structured activities, games and sports) movement experiences. As a child ages, the relationship is hypothesized to become more reciprocal and is driven by the development of a child's ability to perceive and understand that they are competent in various movement contexts, which promotes success and enjoyment in a variety of activities. Thus, higher levels of motor competence foster more physical activity and, reciprocally, more physical activity fosters greater motor competence, which creates a positive spiral of engagement in physical activity across childhood and into adolescence.

Few studies evaluated the theorized reciprocal relationship of physical activity and motor competence[13]. Independent investigations have shown the reciprocal relationship between object control[14] and locomotor control[15] with physical activity. Barnett, et al. [14], in a cross-sectional study, observed a positive feedback association between object control and moderate-to-vigorous physical activity in 215 Australian adolescents. Additionally, perceived sports competence mediated the association in both directions[14]. Larsen, et al. [15] monitored 768 children during three years and observed a reciprocal relationship between shuttle run test which is a measure of agility, speed and cardiorespiratory capacity, and physical activity.

Fitness is hypothesized to mediate the reciprocal association between physical activity and motor competence as demonstrating higher fitness allows an individual to sustain physical activity for longer periods of time[16]. Concomitantly, increased physical activity and increased motor competence likely function to assist in the development of cardiorespiratory fitness as physical activity and motor competence demonstrate consistent positive associations with fitness across childhood. Finally, the strength of associations between these three health-related variables is hypothesized to increase across childhood and into adolescence as their synergistic and reciprocal interactions will be mutually beneficial, or mutually detrimental (i.e., negative trajectory of physical activity, motor competence and fitness)[8]. Unfortunately, few studies have evaluated this possible mediation component of physical fitness in the physical activity-motor competence relationship. Khodaverdi, et al. [17] observed that cardiorespiratory fitness mediated the relationship between motor competence and physical activity as hypothesized by the Stodden, et al. [13] theoretical framework. However, the authors only evaluated the association of motor competence with physical activity, not vice and versa. In summary, there is evidence of the reciprocal relationship between physical activity and motor competence and the mediation role of physical fitness in this relationship; however, this evidence has not been summarized in a long-term longitudinal study.

To the best of our knowledge, no longitudinal study has tested the possible reciprocal association of objectively measured physical activity and motor competence, and whether cardiorespiratory fitness mediates the relationship in both directions. Therefore, the primary aim of this study was to evaluate, in both directions, the longitudinal relationship (seven-year follow-up) between motor competence and physical activity. The secondary aim of this study was to analyze the possible mediating effect of cardiorespiratory fitness in this relationship.

Methods

This study was based on longitudinal analysis of data from the Copenhagen School Child Intervention Study, a quasi-experimental study which began in 2001. Because the complete methodology has been previously published[18-20], the methodology here presents only those variables of interest. Children were recruited from preschools in two communities in the area of Copenhagen (46 preschool classes in 18 schools). Informed consent was obtained from the parents/guardians of 706 children (69% of the population), and 696 actually participated in the study at baseline (409 children attending intervention schools and 287 enrolled in the control schools). Following the intervention, which lasted three years, 613 children were retested at nine years of age and 441 children followed up again in 2008 at 13 years, seven years after the beginning of the study. The study was approved by the ethical committee, University of Copenhagen.

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 Tanner's criteria[21]. Cardiorespiratory fitness was assessed using a continuous running protocol on a treadmill until exhaustion. Cardiorespiratory fitness was measured directly on an AMIS 2001 Cardiopulmonary Function Test System (Innovision, Odense, Denmark) at ages six and nine years, and using a COSMED K4b^2 portable metabolic system (COSMED, Rome, Italy) at 13 years. Both systems provide valid measures of cardiorespiratory fitness when validated against the Douglas bag method[19, 22, 23]. Cardiorespiratory fitness was standardized for all statistical analyses. Biceps, triceps, subscapular, and suprailiac skinfolds were measured on the self-reported non-dominant side of the body by the same two skilled researchers with a Harpenden skinfold caliper (Harpender, West Sussex, UK), and the body fatness was computed as the sum of the four skinfolds in millimeters (mm).

Motor competence was assessed using the "Körperkoordinationstest für Kinder" (KTK), which is a standardized normative German test battery[24, 25]. The KTK has high test-retest reliability (0.90 to 0.97)[24, 25]. The KTK consists of four independent tests: (1) walking backwards on balance beams of decreasing width: 6.0, 4.5, and 3.0 cm, (2) moving sideways on wooden boards for 20s, (3) one-legged hopping over a foam obstacle with increasing height in consecutive steps of 5cm and (4) two-legged jumping from side to side for 15s. The KTK battery has been used in numerous studies to evaluate motor competence levels in normally developing children and adolescents up to 15 years-of-age[26-29]. The raw performance score on each item was summed and standardized in z-scores.

Physical activity was measured using Actigraph 7164 accelerometers (ActiGraph LLC, Pensacola, FL) in epochs of 10 seconds. All devices were calibrated in a motor driven vertical acceleration machine before use. Due to reactivity, the first day the participants wore the device was excluded from the analysis. The participants wore an elastic belt with the accelerometer on the right side of the waist close to the center of gravity. The device was only supposed to be removed while sleeping and during activities involving water. Periods with 30 or more minutes with consecutives zeros counts were considered as non-wear periods. A valid day had to have at least 10 valid hours of monitoring. Children with four or more valid days were included in the analysis. At baseline, 322 children presented four or more valid days whereas, 298 children were monitored four or more days at nine years of age and 300 children exhibited four or more valid days at 13 years of age. Therefore, 398 children were excluded from the analyses due to lack of valid physical activity data. To calculate the minutes spent in moderate to vigorous physical activity (MVPA) and vigorous physical activity (VPA) we used Evenson's cut-points[30] because of its valid estimation for the age range of the participants in the present study[31]. For analysis purposes, MVPA and VPA were standardized.

Statistical analysis

In all analyses, we used STATA version 14.0 (StataCorp LP, College Station, TX, USA). We based our analysis on the theoretical framework first proposed by Stodden, et al. [13], which hypothesized reciprocal associations between physical activity and motor competence that is mediated by current cardiorespiratory fitness levels. Therefore, structured equation modeling was performed to test the reciprocal longitudinal relationship between physical activity (MVPA and VPA) and motor competence, and; additionally, if the longitudinal association between physical activity and motor competence was mediated by cardiorespiratory fitness (VO_{2peak}).

Figure 1 presents the pathways examined in the analysis. The arrows indicate the directionality between variables which the model was built to evaluate the reciprocal relationship between physical activity and motor competence during the seven-year follow-up and the mediation component of VO_{2peak} on the reciprocal relationship between physical activity and motor competence. Sex, valid PA weekend days (valid PA weekend day monitored – yes and no), pubertal status, follow-ups (age at the measurements – six, nine and 13 years of age) and intervention (enrolled in the intervention schools – yes and no) controlled all the analyses. The exact same diagram was built for MVPA and VPA as the physical activity outcome. Independent of the physical activity outcome used (vigorous or moderate-to-vigorous physical activity), the model fitted the data: CFI = 1.00, TLI = 1.00, RMSEA < 0.01, SRMR = 0.01. In the analyses, 793 observations were included which represents an average of 264 participants for each of the three measuring points in the current study.

Results

Almost all of the children were born in Denmark (98.1%). At baseline, the annual family income (parents combined) was lower than 200,000 Danish Kroner (DKK) (approximately 30,000 U.S. Dollars) in 5.6% of the families in our study (14.5% between 200,000-400,000 DKK; 44.5% between 400,000-600,000 DKK; 35.5% more than 600,000 DKK). Less than 1% of the children's mothers had less than 7 years of education (0.5%: 7-8 years of education; 98.7%: 9+ years of education). There were no statistical differences in age or other demographic characteristics between those children with complete or incomplete data[29]. Boys spent more time in MVPA and VPA, and exhibited higher VO_{2peak} than girls at any age. On the other hand, girls presented higher body fatness than boys at six, nine and 13 years of age (Table 1).

Physical activity longitudinally associated with motor competence

During the seven-year follow-up, VPA presented direct association with the development of motor competence (β_{VPA}=0.095; 95% CI: 0.021:0.169 – Black coefficients). Nevertheless, MVPA only presented association with motor competence via fitness mediation. No direct association between MVPA and motor competence was observed. Moreover, MVPA and VPA exhibited indirect association with motor competence via fitness mediation (β_{MVPA}=0.071; 95% CI: 0.040:0.101; β_{VPA}=0.087; 95% CI: 0.055:0.117 – Green coefficients). Finally, MVPA and VPA presented similar total association with motor competence (β_{MVPA}=0.139; 95% CI: 0.062:0.217; β_{VPA}=0.181; 95% CI: 0.104:0.257 – Red coefficients) (Figure 2).

Motor competence longitudinally associated with physical activity

Motor competence was longitudinally associated with both MVPA and VPA during childhood until early adolescence. In particular, motor competence was directly associated with VPA (β_{VPA}=0.084; 95% CI: 0.018:0.149 – Black coefficients). The direct association between motor competence and MVPA was not significant (β_{MVPA}=0.061; 95% CI: -0.005:0.126 – Black coefficients). Additionally, fitness mediated the association between motor competence and physical activity (β_{MVPA}=0.049; 95% CI: 0.023:0.075; β_{VPA}=0.061; 95% CI: 0.034:0.087 – Green coefficients). Finally, the total association between motor competence and MVPA and VPA were analogous (β_{MVPA}=0.111; 95% CI: 0.049:0.171; β_{VPA}=0.144; 95% CI: 0.083:0.206 – Red coefficients) (Figure 3).

Discussion

Results of this study indicated a reciprocal longitudinal relationship occurred between physical activity and motor competence across seven years. In summary, for each additional standard deviation (SD) in MVPA or VPA, motor competence increased by 0.139 SD and 0.181 SD during the seven-year follow-up, respectively. On the other hand, a standard deviation increment in motor competence would increase MVPA and VPA time by 0.111 SD and 0.144 SD, respectively. Additionally, cardiorespiratory fitness mediated the relationship in both directions. Both results have been predicted by the heuristic model proposed by Stodden, et al. [13]. Monitoring 768 children during three years, Larsen, et al. [10] observed a reciprocal relationship between physical activity and the shuttle run test which measures cardiorespiratory fitness, agility and speed. In particular, children who improved their time in the shuttle run test by one standard deviation increased their time spent in moderate-to-vigorous physical activity in 42 minutes a week. The authors also analyzed the influence of time in moderate-to-vigorous physical activity on the shuttle run test. According to their results, children with more time spent in moderate-to-vigorous physical activity had better performance in the shuttle run test[10]. Similarly, Barnett, et al. [14] also observed a reciprocal relationship between physical activity and motor competence in a cross-sectional investigation. However, Barnett, et al. [14] observed a reciprocal positive relationship between object control and moderate-to-vigorous physical activity, and only a one-way relationship from moderate-to-vigorous physical activity to locomotor control which contradicts the findings observed in the present study and the investigation conducted by Larsen, et al. [10].

The KTK battery used in the current study and the shuttle run test used at Larsen, et al. [10] investigation are primarily locomotor measures of motor performance. The different results observed in both investigations and Barnett, et al. [14] can be due to the self-reported measure of physical activity[14], different batteries to assess motor competence and the study design, cross-sectional[14]. In addition, Barnett, et al. [14] monitored adolescents (mean age of 16 years) whereas the current study and Larsen, et al. [15] evaluated children until early adolescence. Nevertheless, there are some contradictory results, the reciprocal influence between physical activity and motor competence seems real from the results presented in both longitudinal investigations.

It seems clear that physical activity and motor competence interact synergistically during childhood. Possibly, children who are more physically active have more opportunities to better develop their motor competence skills. Concomitantly, motor competent children experience greater success and enjoyment during many developmentally appropriate activities (e.g., sports and games) and are more likely to continue to participate and further develop their motor competence and be more physically active[13]. According to our results, cardiorespiratory fitness was impacted by both physical activity and motor competence and consequently mediated the relationship between physical activity and motor competence in both directions. Khodaverdi, et al. [17] also observed cardiorespiratory fitness mediating the associations between locomotor skill competence and physical activity; however, the authors only analyzed locomotor skill competence influencing physical activity[17]. Moreover, the reciprocal association between MVPA and motor competence was only via physical fitness mediation, highlighting the importance of higher physical activity intensity and the role of physical fitness during childhood development. Physical fitness is a key element in the theoretical framework proposed by Stodden, et al. [13]. The authors believed that the acquisition of motor competence in the preschool age would serve to promote physical fitness by also promoting physical activity and neuromotor development. In addition, children with good levels of motor competence during middle childhood would present higher physical activity level and physical fitness. From the middle to late childhood, fit children would be more likely to continue physically active for longer periods, increasing their physical activity and motor competence levels. Children with low physical fitness level would be less physically active because of their lower ability to persist in activities which require higher levels of physical fitness and consequently have compromised physical activity and motor competence development[13].

It should also be noted that this is the first longitudinal study to test the theoretical framework first proposed by Stodden, et al. [13] which intended to describe how physical activity and motor competence are associated across childhood and adolescence. Importantly, we were able to follow children for seven years during their childhood until early adolscence, which represents a period where the foundation of physical activity behaviors are formed and tend to track until adulthood[32]. Additionally, the analyses were controlled for pubertal status which is a pivotal element on children's development. In summary, physical activity and motor competence exhibited reciprocal longitudinal relationship throughout childhood and early adolescence, and; additionally, physical fitness mediated their relationship in both directions. Both results were correctly predicted by the Stodden, et al. [13] model. However, future investigations can investigate additional components of the Stodden, et al. [13] model: 1) whether the strength of the association between physical activity and motor competence changes during childhood and adolescence; 2) whether other aspects of health-related fitness (strength, flexibility, speed, agility), or perceived motor competence can mediate the relationship between physical activity and motor competence, and; 3) whether the synergic relationship among physical activity, motor competence and health-related fitness are longitudinally associated with the risk of obesity in children and adolescents.

Our study has limitations to be considered in the interpretation of the results. While accelerometry is considered the gold standard measure for physical activity in epidemiological studies, physical activity presents a relatively high measurement error which could have influenced the strength of association between physical activity and motor competence. In addition, the current study only tested the participants' locomotor competence, thus other aspects related to motor competence, i.e. control movement skills could have been monitored and included in the analyses. The two first measurements of VO_{2peak} were performed in a camper where we had stationary analyzers. These are more stable and give less error variation in the measurements. In the last test round we used a portable system, because we did not have access to the original analyzers. In all tests we used direct measurement of VO_{2peak} during a progressive treadmill test, which is the highest quality of cardiorespiratory fitness assessment seen in any school based study. Importantly, both systems exhibited valid measures of cardiorespiratory fitness when validated against the Douglas bag method[19, 22, 23]. No other epidemiological study reached this quality of assessment and we therefore believe the change in analyzers did not impact the results. This is a longitudinal study that was part of an intervention project which aimed to increased the ammount of physical activity in the intervention schools; however, compared to participants in the control arm of the original intervention study, the intervention demonstrated no significant impact on physical activity, motor competence or cardiorespiratory fitness[18] and the longitudinal results presented in this study were adjusted for the intervention factor. Unfortunately, we only have three time points of monitoring, which makes it less clear how the longitudinal associations developed than if we had more time points.

Practitioners should stimulate activities related to whole body movements that influence the success of engagement in sports which is one of the major ways of being physically active. Complementarily, more physically active children will probably engage more in whole body movement activities and consequently improve their locomotor skills by practice.

In conclusion, physical activity and motor competence were positivily reciprocally related across childhood until early adolescence and cardiorespiratory fitness mediated the association in both directions. Interventions with the goal of increasing physical activity in children and adolescents should also address the development of motor competence skills in order to optimize the results because of the clear positive feedback loop between physical activity and motor competence.

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References

1. Andersen LB, Riddoch C, Kriemler S, et al. Physical activity and cardiovascular risk factors in children. *Br J Sports Med.* 2011; 45(11):871-876.
2. Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act.* 2010; 7:1-16.
3. Voss MW, Chaddock L, Kim JS, et al. Aerobic fitness is associated with greater efficiency of the network underlying cognitive control in preadolescent children. *Neuroscience.* 2011; 199:166-176.
4. Biddle SJ, Gorely T, Stensel DJ. Health-enhancing physical activity and sedentary behaviour in children and adolescents. *J Sports Sci.* 2004; 22(8):679-701.

5. Andersen LB, Harro M, Sardinha LB, et al. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet.* 2006; 368(9532):299-304.

6. Van Der Horst KP, MJCA.; Twisk, JWR.; Van Mechelen, W.;. A Brief Review on Correlates of Physical Activity and Sedentariness in Youth. *Med Sci Sports Exerc.* 2007; 39((8):):1241-1250.

7. Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. *Med Sci Sports Exerc.* 2000; 32(5):963-975.

8. Robinson LE, Stodden DF, Barnett LM, et al. Motor Competence and its Effect on Positive Developmental Trajectories of Health. *Sports Med.* 2015; 45(9):1273-1284.

9. Lubans DR, Morgan PJ, Cliff DP, et al. Fundamental movement skills in children and adolescents: review of associated health benefits. *Sports Med.* 2010; 40(12):1019-1035.

10. Larsen LR, Kristensen PL, Junge T, et al. Motor Performance as Predictor of Physical Activity in Children: The CHAMPS Study-DK. *Med Sci Sports Exerc.* 2014.

11. Barnett LM, van Beurden E, Morgan PJ, et al. Childhood motor skill proficiency as a predictor of adolescent physical activity. *J Adolesc Health.* 2009; 44(3):252-259.

12. Lopes VP, Rodrigues LP, Maia JA, et al. Motor coordination as predictor of physical activity in childhood. *Scand J Med Sci Sports.* 2011; 21(5):663-669.

13. Stodden DF, Goodway JD, Langendorfer SJ, et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest.* 2008; 60:290-306.

14. Barnett LM, Morgan PJ, Van Beurden E, et al. A reverse pathway? Actual and perceived skill proficiency and physical activity. *Med Sci Sports Exerc.* 2011; 43(5):898-904.

15. Larsen LR, Kristensen PL, Junge T, et al. Motor Performance as Predictor of Physical Activity in Children: The CHAMPS Study-DK. *Med Sci Sports Exerc.* 2015; 47(9):1849-1856.

16. Ré AHN, Cattuzzo MT, Henrique RS, et al. Physical characteristics that predict involvement with the ball in recreational youth soccer. *J Sports Sci.* 2016; 34(18):1716-1722.

17. Khodaverdi Z, Bahram A, Stodden D, et al. The relationship between actual motor competence and physical activity in children: mediating roles of perceived motor competence and health-related physical fitness. *J Sports Sci.* 2015:1-7.

18. Bugge A, El-Naaman B, Dencker M, et al. Effects of a three-year intervention: The Copenhagen school child intervention study. *Med Sci Sports Exerc.* 2012; 44(7):1310-1317.

19. Eiberg S, Hasselstrom H, Gronfeldt V, et al. Maximum oxygen uptake and objectively measured physical activity in Danish children 6-7 years of age: The Copenhagen school child intervention study. *Br J Sports Med.* 2005; 39(10):725-730.

20. Hasselstrom HA, Karlsson MK, Hansen SE, et al. A 3-year physical activity intervention program increases the gain in bone mineral and bone width in prepubertal girls but not boys: The prospective Copenhagen school child interventions study (CoSCIS). *Calcif Tissue Int.* 2008; 83(4):243-250.

21. Tanner JM. Normal growth and techniques of growth assessment. *Clin Endocrinol Metab.* 1986; 15(3):411-451.

22. Jensen K, Jorgensen S, Johansen L. A metabolic cart for measurement of oxygen uptake during human exercise using inspiratory flow rate. *Eur J Appl Physiol.* 2002; 87(3):202-206.

23. McLaughlin JE, King GA, Howley ET, et al. Validation of the COSMED K4 b2 portable metabolic system. *Int J Sports Med.* 2001; 22(4):280-284.

24. Kiphard E, Schilling F. *The whole body coordination test for children. Manual*, Weinheim, Germany, Beltz Test GmbH; 1974.

25. Kiphard E, Schilling F. *The whole body coordination test for children*, Göttingen. Germany, Überarbeitete und ergänzte Auflage. Beltz Test GmbH; 2007.

26. D'Hondt E, Deforche B, Gentier I, et al. A longitudinal analysis of gross motor coordination in overweight and obese children versus normal-weight peers. *Int J Obes (Lond).* 2013; 37(1):61-67.

27. Graf C, Koch B, Kretschmann-Kandel E, et al. Correlation between BMI, leisure habits and motor abilities in childhood (CHILT-project). *Int J Obes Relat Metab Disord.* 2004; 28(1):22-26.

28. Laukkanen A, Pesola A, Havu M, et al. Relationship between habitual physical activity and gross motor skills is multifaceted in 5- to 8-year-old children. *Scand J Med Sci Sports.* 2014; 24(2):e102-110.

29. Morrison KM, Bugge A, El-Naaman B, et al. Inter-relationships among physical activity, body fat, and motor performance in 6- to 8-year-old Danish children. *Pediatr Exerc Sci.* 2012; 24(2):199-209.

30. Evenson KR, Catellier DJ, Gill K, et al. Calibration of two objective measures of physical activity for children. *J Sports Sci.* 2008; 26(14):1557-1565.

31. Trost SG, Loprinzi PD, Moore R, et al. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc.* 2011; 43(7):1360-1368.

32. Malina RM. Tracking of physical activity and physical fitness across the lifespan. *Res Q Exerc Sport.* 1996; 67(3 Suppl):S48-57.

Table 1 Mean (SD) physical and motor characteristics of participants by age and sex.

	All			Boys				
	6 years	9 years	13 years	6 years	9 years	13 years	6 years	9
Age (years)	6.75 (0.37)	9.59 (1.07)	13.35 (0.34)	6.81 (0.37)	9.59 (1.31)	13.39 (0.34)	6.67 (0.35)	(
MVPA* (min/day)	76.50 (26.97)	72.97 (25.53)	53.20 (24.62)	82.65 (29.57)	78.05 (25.84)	59.85 (26.49)	69.66 (21.83)	6 (2
VPA* (min/day)	28.28 (13.99)	29.94 (15.09)	20.75 (13.28)	31.09 (15.56)	32.57 (15.78)	23.34 (14.09)	25.15 (11.24)	2 (1
KTK score	119.18 (27.66)	195.17 (34.64)	249.40 (29.41)	120.07 (28.42)	194.77 (34.89)	251.37 (29.88)	118.18 (26.79)	1 (3
VO_{2peak}* ($ml.kg^{-1}.min^{-1}$)	46.71 (5.97)	49.06 (7.14)	49.27 (8.69)	48.45 (5.93)	51.80 (6.81)	53.18 (8.37)	44.75 (5.38)	4 (
Body fatness* (mm)	26.62 (9.97)	33.56 (16.46)	34.93 (16.83)	24.35 (8.95)	30.13 (14.52)	31.63 (16.96)	29.18 (10.43)	3 (1

* $p < 0.05$ significant difference between boys and girls in all ages

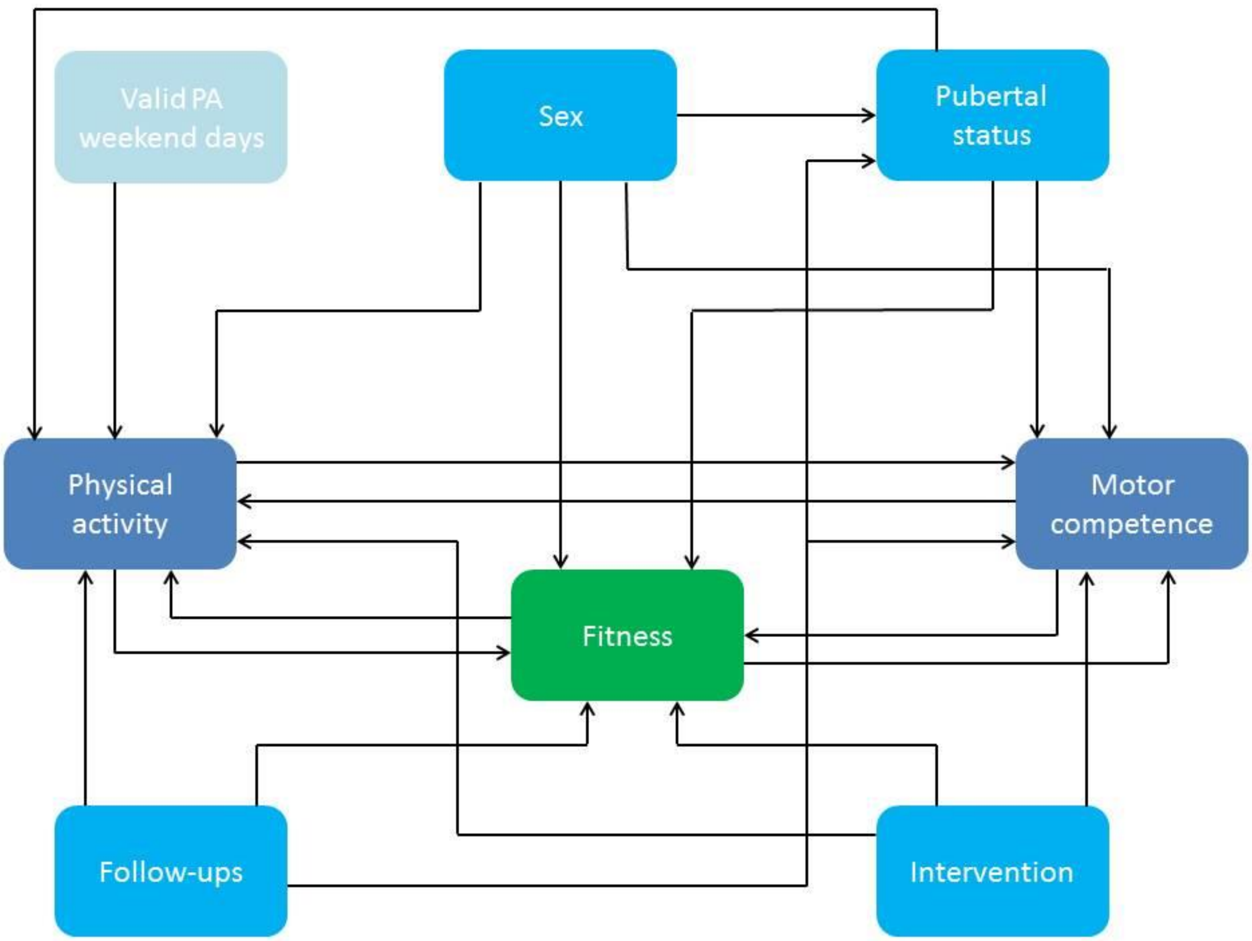

Figure 1. Diagram with the pathways used in the SEM analyses.
Legend: Intervention refers to assignment to control or intervention school physical education program; Fitness refers to cardiorespiratory fitness; Follow-ups refers to each of the time points monitored (six, nine and 13 years of age).

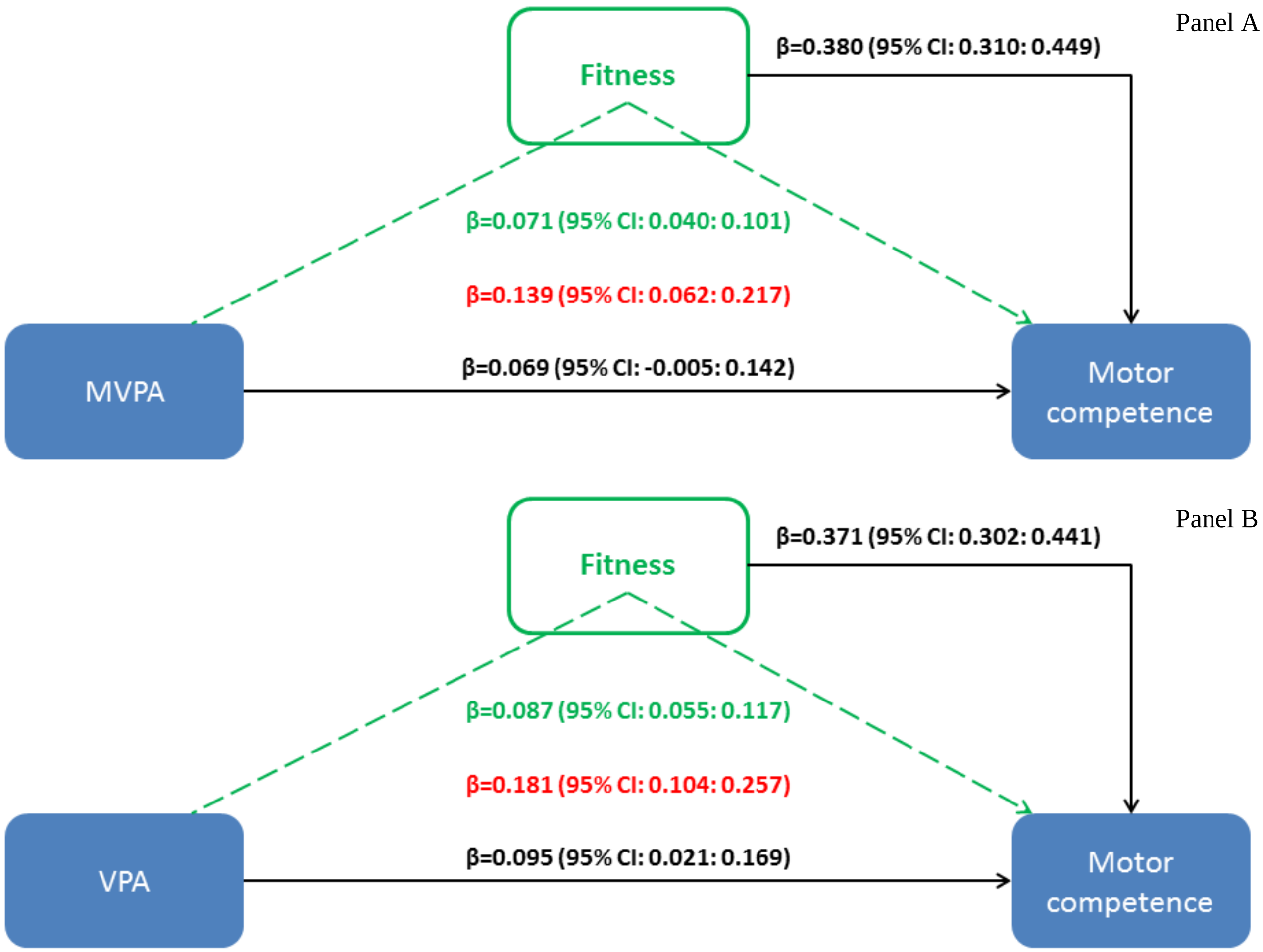

Figure 2. Standardized parameter estimates of the slope for the total, direct and indirect association between physical activity (Panel A: MVPA; Panel B: VPA) and motor competence mediated by cardiorespiratory fitness. Legend: a) Black solid line and coefficients: direct association between the exposures and motor competence; b) Green dotted line and coefficients: the association between physical activity and motor competence mediated by cardiorespiratory fitness c) Red coefficients: Direct and indirect association combined (total association) between physical activity and motor competence.

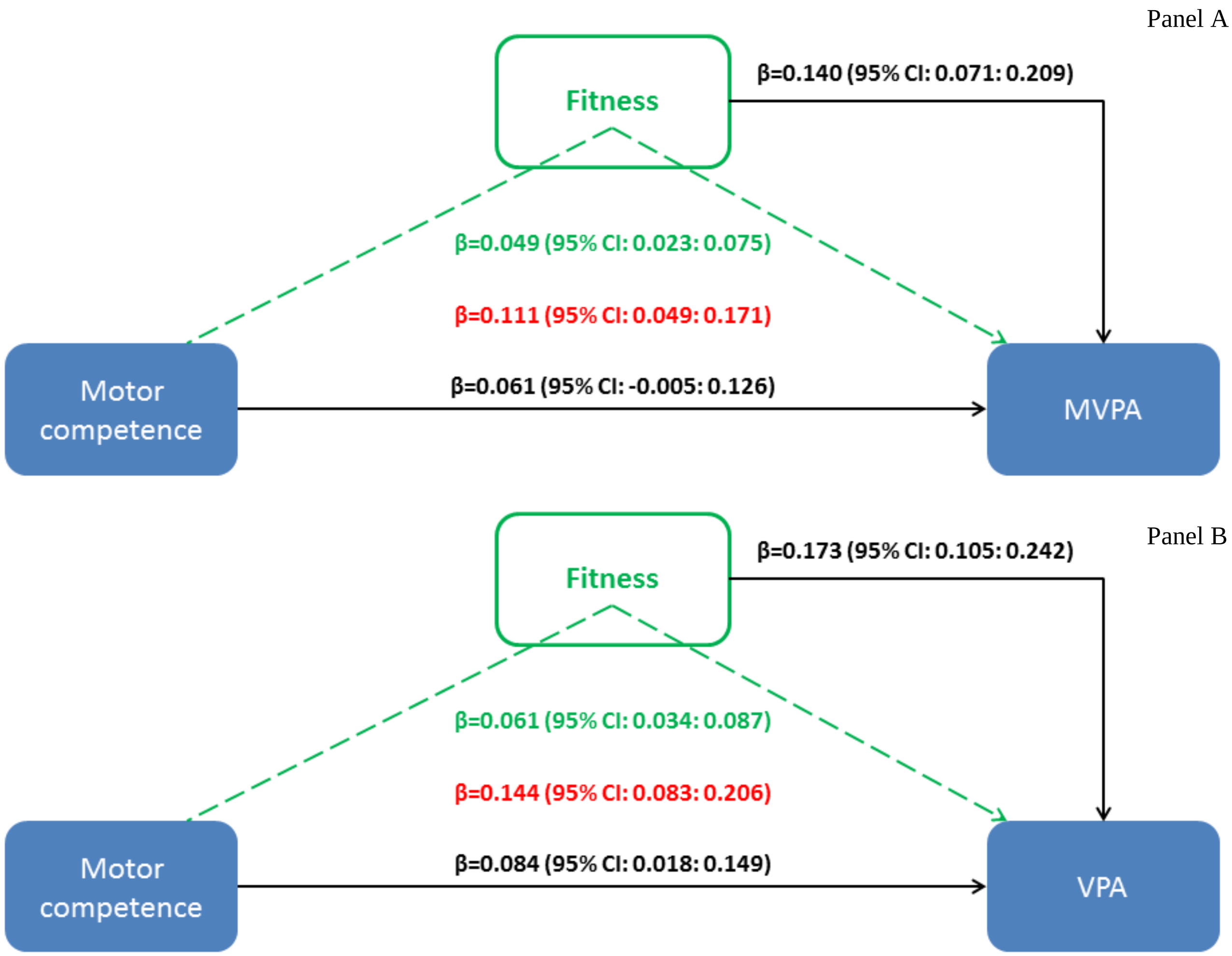

Figure 3. Standardized parameter estimates of the slope for the total, direct and indirect association between motor competence and physical activity mediated by cardiorespiratory fitness (Panel A: MVPA; Panel B: VPA). Legend: a) Black solid line and coefficients: direct association between the exposures and physical activity; b) Green dotted line and coefficients: the association between motor competence and physical activity mediated by cardiorespiratory fitness c) Red coefficients: Direct and indirect association combined (total association) between motor competence and physical activity.