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Associations between gross Motor Coordination and Academic Achievement in elementary school children

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ABSTRACT

We aimed to evaluate the relationship between gross motor coordination (MC) and academic achievement (AA) in a sample of Portuguese children aged 9–12 years. The study took place during the 2009/2010 school year and involved 596 urban children (281 girls) from the north of Portugal. AA was assessed using the Portuguese Language and Mathematics National Exams. Gross MC was evaluated with the Körperkoordination Test für Kinder. Cardiorespiratory fitness was predicted by a maximal multistage 20-m shuttle-run test of the Fitnessgram Test Battery. Body weight and height were measured following standard procedures. Socio-economic status was based on annual family income. Logistic Regression was used to analyze the association of gross MC with AA. 51.6% of the sample exhibited MC disorders or MC insufficiency and none of the participants showed very good MC. In both genders, children with insufficient MC or MC disorders exhibited a higher probability of having low AA, compared with those with normal or good MC ($p < .05$ for trend for both) after adjusting for cardiorespiratory fitness, body mass index and socio-economic status.

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1. Introduction

Mastery of a variety of motor skills is a requisite for children to engage in everyday activities and has important implications for different aspects of development in children and adolescents

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(Piek, Baynam, & Barrett, 2006). Children's motor skill development incorporates many body systems, including sensory, musculoskeletal, cardiorespiratory, and neurological systems (Dwyer, Baur, & Hardy, 2009), as well as the child's ability to interact with the environment (Riethmuller, Jones, & Okely, 2009). Consequently, the study of a child's motor development is a prerequisite for the full understanding of the child's whole development (Payne & Isaacs, 1998).

The importance of promoting the development of MC at younger ages relies on the current and future benefits associated with the acquisition and the maintenance of motor proficiency (Lubans, Morgan, Cliff, Barnett, & Okely, 2010). For instance, it has been suggested that an appropriate acquisition of MC contributes to children's physical, cognitive, and social development (Payne & Isaacs, 1998). Furthermore, a proper MC level is essential for a strong general development, as well as for health, psychosocial development, and well-being (Haga, 2008; Piek et al., 2006). Childhood is a critical period for the development of these skills, which are considered building blocks of more complex movements (Clark & Metcalfe, 2002) and represent a key factor in the promotion of lifelong active lifestyles (Clark, 2005; Stodden et al., 2008). It is also known that motor skills have been observed to track during childhood (Malina, 1996).

Recently, there is a re-emerged debate around the possible relations between physical activity (PA), physical fitness, motor coordination (MC) and cognitive development (Niederer et al., 2011), based on the decrease in children's PA (Knuth & Hallal, 2009), physical fitness (Tomkinson & Olds, 2007), MC (Prätorius & Milani, 2004), and the pressure of schools and parents to improve cognitive performance (Chomitz et al., 2009; Ertl, 2006).

While the relationship between PA and physical fitness with academic achievement (AA) has been thoroughly explored (Ahamed et al., 2007; Carlson et al., 2008; Castelli, Hillman, Buck, & Erwin, 2007; Chomitz et al., 2009; Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Etnier, Nowell, Landers, & Sibley, 2006; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009; Fox, Barr-Anderson, Neumark-Sztainer, & Wall, 2010; Grissom, 2005; Hillman, Erickson, & Kramer, 2008; Kwak et al., 2009; Niederer et al., 2011; Rasberry et al., 2011; Ruiz et al., 2010; Sigfusdottir, Kristjansson, & Allegrante, 2007; Strong et al., 2005; Taras, 2005; Trudeau & Shephard, 2008), is known about the relation between gross MC and AA in elementary school children.

Studies suggest that neuronal structures (in the cerebellum and the frontal lobe) are responsible for coordination as well for cognition (Serrien, Ivry, & Swinnen, 2006). There is also evidence that working memory capacity and visual perceptual ability limit children's AA (Alloway, 2007; Alloway & Alloway, 2010; Sortor & Kulp, 2003). Besides, one cross-sectional and longitudinal study found that higher baseline motor skills (agility and dynamic balance) were related to better spatial working memory and/or baseline attention as well as their future improvements over the following nine months (only no association was found between dynamic balance and attention) (Niederer et al., 2011). Indeed, children with developmental coordination disorders tend to perform poorly in literacy and numeracy assessments (Alloway, 2007), while fine MC was found to positively correlate with AA (Sortor & Kulp, 2003), and children with learning disabilities scored poorer in gross MC test (both locomotor and object-control) (Westendorp, Hartman, Houwen, Smith, & Visscher, 2011). Additionally, other cross-sectional (Knight & Rizzuto, 1993; Nourbakhsh, 2006; Planinsec, 2002) and interventional studies (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Erickson, 2008; Uhrich & Swalm, 2007) have shown that improved motor skill levels may be positively related to improvements in AA or other cognitive variables. Moreover, longitudinal studies in preschool children found a relationship between early motor development and later cognitive function (Piek, Dawson, Smith, & Gasson, 2008; Son & Meisels, 2006), suggesting that early school motor skills assessment may increase the predictability of later achievement and the probability of identifying children at risk for school failure (Son & Meisels, 2006).

It is important to note that the term "motor coordination" used in this study is a general term that encompasses various aspects of movement competency. There are many different test batteries that assess movement in a variety of ways using various movement tests. Specifically, process and product oriented movement assessments are used to examine differences in levels of MC. While it is outside the scope of this study to explain the differences and limitations in how movement and/or movement outcomes are assessed, we used the term "motor coordination" in this study as it specifically aligns with the language used in the assessment implemented for this study (Kiphard-Schilling body coordination test) and with previous literature that has used the same assessment.

Despite these findings, to the best of our knowledge, no study to date has addressed the association between gross MC and direct/objective indicators for AA, namely scores on standardized tests, in elementary school children without intellectual disabilities, accounting for potential confounders such as physical fitness, body composition or socio-economic status (Carlson et al., 2008; Coe et al., 2006; Etnier et al., 2006; Kwak et al., 2009; Rasberry et al., 2011; Trudeau & Shephard, 2008). In this context, understanding whether or not gross MC is related to AA among school age children may provide useful information about how to incorporate PA into daily life, helping to achieve recommended levels of PA and physical fitness and positively impacting academic success or progress. The purpose of the present study was to evaluate the relationship between gross MC and AA in urban Portuguese children aged 9–12 years, accounting for cardiorespiratory fitness, body mass index, and socio-economic status.

2. Methods

2.1. Study design and sampling

Data for the present study are derived from the Bracara Study, which aimed to evaluate the relations between gross MC, PA, physical fitness, body composition, AA and health behaviors among elementary school children. The Bracara Study was conducted in a middle city located in the north of Portugal during the 2009/2010 academic year.

2.2. Participants

All 21 public elementary schools in the city that qualified as urban (according to the Municipal Administration Registry) were considered and invited to participate in this study, corresponding to 846 children enrolling in the fourth grade; two schools decided not to take part in this study, corresponding to 90 children; six schools could not be evaluated on time to take part in this study, corresponding to 130 children; 30 children who failed the inclusion criteria (having a mental and/or physical disability or a health condition that did not allow them to participate in physical education classes) or had missing information on the variables of interest were excluded from this analysis. Therefore, the study included 13 urban public elementary schools, and 596 participants (281 girls) aged 9–12 years old.

2.3. Procedure

The schools' directors and children's parents/guardians received verbal and written description of the study and signed a written informed consent form. The protocol and procedures employed followed the Helsinki Declaration for Investigation in Human Subjects and were approved by the Curricular Development and Innovation Division (Portuguese Ministry of Education) and by the University's Ethics Committee.

Two full-time assessors collected data during regularly scheduled physical education classesby. The assessors were physical education graduates who received specific training, and had already participated in previous KTK data collection. The assessors were helped by the physical education teachers.

2.4. Measures

2.4.1. Academic achievement

AA was assessed using the Portuguese Language and Mathematics *National Exams* that are mandatory for all 4th grade students. The exams were administered in May 2009 by two supervision teachers in the classroom. The Educational Evaluation Office from the Portuguese Ministry of Education performs management, analysis, and maintenance of student data and the National Exams database. The National Exams are criterion-referenced tests that provide scores to students, teachers and parents according to the performance levels: A (very good), B (good), C (fair), D and E (insufficient). For each exam 1, 2, 3, 4, or 5 points were attributed to scores of E, D, C, B, and A, respectively. An AA score was computed by summing the points attained for each of the exams. Participants were then categorized as having high AA (>8 points); middle AA (7–5 points); or lower AA (<4 points), based on the tertile values of this score.

2.4.2. Cardiorespiratory fitness

Health-related components of physical fitness were evaluated using the Fitnessgram Test Battery, version 8.0. The Fitnessgram is included in the physical education curriculum, and the five tests recommended in the Portuguese National Program (curl-up, push-up, trunk lift, shuttle-run, and the modified back saver sit-and-reach) were used in this study. All tests were conducted according to the Fitnessgram measurement procedures (Welk & Meredith, 2008).

For the purpose of the present analysis we only considered the 20-m shuttle-run test as a way to evaluate cardiorespiratory fitness. This test requires participants to run back and forth between two lines set 20 m apart. Running speed started at 8.5 km/h and increased by 0.5 km/h each minute, reaching 18.0 km/h at minute 20. Each level was announced on the tape. The participants were told to keep up with the pacer until exhausted. The test was finished when the participant failed to reach the end lines concurrent with the audio signals on two consecutive occasions. Otherwise, the test ended when the subject stopped because of fatigue. Participants were encouraged to keep running as long as possible throughout the course of the test. The number of shuttles performed was recorded. Age- and sex-adjusted *z*-scores were computed, because the age and sex-specific cut-off points of the Fitnessgram criteria are only developed for children aged 10 years old or older, and most participants in this study were nine years old.

2.4.3. Motor coordination

MC was evaluated with the body coordination test, Körperkoordination Test für Kinder (KTK), developed for German children (aged 5–15 years) (Kiphard & Schiling, 1974). The KTK battery has four items:

Balance: the child walks backward on three balance beams each 3 m in length, 5 cm in height, but with decreasing widths of 6, 4.5 and 3 cm. The child has three attempts at each beam; the number of successful steps is recorded; a maximum of 24 steps (eight per trial) were counted for each balance beam, which comprises a maximum of 72 steps.

Jumping laterally: the child makes consecutive jumps from side to side over a small beam (60 cm × 4 cm × 2 cm) as quickly as possible for 15 s. The child is instructed to keep his/her feet together; the number of correct jumps in two trials was summed.

Hopping on one leg over an obstacle: the child was instructed to hop on one foot at a time over a stack of foam blocks after a short run-up. After a successful hop with each foot (the child clears the block without touching it and continues to hop on the same foot at least two times), the height was increased by adding a block (50 cm × 20 cm × 5 cm). The child had three attempts at each height and on each foot; three, two or one point(s) was/were awarded for a successful performance on the first, second or third trial, respectively; a maximum of 39 points (12 stacks blocks) could be scored for each leg (maximum score 78).

Shifting platforms: the child began by standing with both feet on one platform (25 cm × 25 cm × 2 cm) supported on four legs, 3.7 cm in height and holding a second identical platform in his/her hands; the child was then instructed to place the second platform alongside the first and to step onto it; the first box was then lifted and placed alongside the second and the child stepped onto it; this sequence continued for 20 s. Each successful transfer from one platform to the next earned two points (one for shifting the platform, the other for transferring the body); the number of points in 20 s was recorded and summed for two trials. If the child fell off the platform in the process, he/she simply stepped back onto the platform and continued the test.

Although some of the items in the KTK appear to measure specific components of motor performance, e.g., dynamic balance, speed and agility, balance and power, the four tests were loaded in a single factor when analyzed with other items (Kiphard & Schiling, 1974). Hence, the four items were utilized together as a global indicator of MC, the "motor quotient". Each performance item was scored relative to gender- and age-specific reference values for the population upon which the KTK was established. The sum of the standardized scores for the four items provided the motor quotient. Using the motor quotient children were then categorized as having: MC disorders (<70 motor quotient); MC insufficiency ($71 \leqslant$ motor quotient $\leqslant 85$); normal MC ($86 \leqslant$ motor quotient $\leqslant 115$); good MC ($115 \leqslant$ motor quotient $\leqslant 130$); or very good MC ($131 \leqslant$ motor quotient $\leqslant 145$).

The psychometric characteristics of the KTK have been documented in literature (Kiphard & Schiling, 1974). The test-retest reliability coefficient for the raw score on the total test battery was .97, while corresponding coefficients for individual tests ranged from .80 to .96. Factor analysis of the four individual tests resulted in a single factor labeled gross MC. The percentage of total variance in MC explained by the four tests varied from 81% at 6 years to 98% at 9 years (Kiphard & Schiling, 1974). Inter-correlations among the four tests varied from .60 to .81 for the reference sample of 1228 children. Both the factor analysis and inter-correlations thus indicated acceptable construct validity. Validity was further determined through differentiation of normal from disabled children. The KTK test differentiated 91% of children with brain damage from normal children. Participants were classified as having: MC disorders, MC insufficiency, normal MC, good MC or very good MC, according to the KTK reference values described above. Participants with good MC were recoded and combined with those with normal MC due to their small sample size (1.2%).

2.4.4. Sociodemographics

Each child's date of birth, gender, and socio-economic status was extracted from the schools' administrative record systems. The socio-economic status records used by the Portuguese Ministry of Education are based on annual family income: children may be eligible for benefit A, eligible for benefit B, or not eligible. These categories were used as a proxy measurement of family socio-economic status (Education, 2009). According to the Portuguese Ministry of Education, those eligible for benefit A receive books, school supplies, and meals for free; those eligible for benefit B receive 50% of the books required and a 50% discount on meals.

2.4.5. Anthropometrics

Weight was measured to the nearest 0.1 kg using a regularly calibrated digital scale (Tanita TBF-300), while the child was wearing light clothing without shoes. Height was measured to the nearest millimeter with a field stadiometer (Seca 220). The body mass index (kg m^{-2}) was calculated according to cut-off points defined by Cole, Bellizzi, Flegal, and Dietz (2000).

2.5. Statistical analysis

Two tailed *t*-test compared gender differences in continuous variables. Binary logistic regression was used to analyze the influence of MC on AA, adjusting for cardiorespiratory fitness, body mass index and socio-economic status. In this regression analysis children belonging to the lower and middle tertiles of AA were grouped into one category – models were constructed separately for girls and boys. In each model all variables were tested simultaneously.

Statistics was performed using Predictive Analytics Software (IBM – PASW Statistics 18 – Statistical Program for Windows), formerly known as SPSS (Statistical Package for the Social Sciences). A *p*-value of <.05 denoted statistical significance.

3. Results

Boys had, on average, significantly higher levels of gross MC and fitness compared with girls ($p < .001$ for both), Table 1.

As shown in Table 2, 51.6% of the entire sample exhibited MC disorders or MC insufficiency and none of the participants showed very good MC. In both, Portuguese Language and Mathematics exams, none of the participants scored E, and more boys than girls scored A and D.

Children with MC insufficiency or MC disorders exhibited a higher probability of having low AA, compared with those with normal coordination ($p < .05$ for trend in both genders; see Tables 3 and 4).

Table 1
Participants' characteristics.

	Whole sample ($n = 596$)	Girls ($n = 281$)	Boys ($n = 315$)	p^*
Age (years)	9.7 ± 0.6	9.7 ± 0.5	9.7 ± 0.6	.552
Cardiorespiratory Fitness (number of laps)	19.9 ± 11.3	16.6 ± 8.0	22.8 ± 13.0	.000
Motor Coordination (motor quotient)	85.7 ± 14.4	81.7 ± 14.5	89.3 ± 13.4	.000
Body Mass Index (kg m^{-2})	18.6 ± 3.3	18.6 ± 3.3	18.6 ± 3.3	.934

Portugal, academic year 2009/2010.
* *t*-Test compared gender differences.

4. Discussion

The results of this study indicated that children of both genders with low gross MC had a higher probability of having low AA, after adjusting for cardiorespiratory fitness, body mass index, and socio-economic status.

There are potential biological, psychological, and social mechanisms that may help explain this relationship. Coordinative exercise (exercises strengthening various coordination abilities) involve an activation of the cerebellum, which influences motor functions (Gao et al., 1996) as well as attention (Courchesne et al., 1994), working memory (Klingberg, Kawashima, & Roland, 1996), and verbal learning and memory (Andreasen et al., 1995). Additionally, the frontal lobes play an important role in mediating both MC (Hernandez et al., 2002) and cognitive functions (Miller & Cohen, 2001). An interventional study performed by Budde et al. (2008) aiming to investigate the effect of 10 min of physical exercise (coordination exercises vs. non-specific physical education lessons) on concentration and attention performance in a school setting revealed enhanced attention and concentration performance in both groups, with significantly higher enhancement in the group that performed coordination exercises. Furthermore, they suggest that coordination exercises lead to a facilitation of neuronal networks that results in a pre-activation of cortical activities that are responsible for cognitive functions such as attention (Budde et al., 2008).

Table 2
Prevalence of motor coordination and academic achievement.

	Whole sample ($n = 596$)		Girls ($n = 281$)		Boys ($n = 315$)	
	n	%	*n*	%	*n*	%
Motor coordination						
Motor coordination disorders	86	14.4	63	22.4	23	7.3
Motor coordination insufficiency	222	37.3	107	38.1	115	36.5
Normal motor coordination	281	47.1	110	39.1	171	54.3
Good motor coordination	7	1.2	1	0.4	6	1.9
Very good motor coordination	0	0	0	0	0	0
Portuguese language exam						
A	64	10.7	27	9.6	37	11.8
B	210	35.2	107	38.1	103	32.7
C	255	42.8	121	43.1	134	42.5
D	67	11.3	26	9.2	41	13.0
E	0	0	0	0	0	0
Mathematic exam						
A	114	19.1	48	17.1	66	21.0
B	201	33.7	100	35.6	101	32.0
C	215	36.1	102	36.3	113	35.9
D	66	11.1	31	11.0	35	11.1
E	0	0	0	0	0	0

Portugal, academic year 2009/2010.

Table 3
Odds ratios and 95% confidence Intervals from binary logistic regression model predicting low academic achievement, for girls.

Boys	Low academic achievement							
	Unadjusted model				Adjusted model[a]			
	OR	95% CI	*p*	*p* for trend	OR	95% CI	*p*	*p* for trend
Normal/good motor coordination[b]	1			<.001	1			<.001
Motor coordination insufficiency	1.938	(0.778–4.828)	.155		2.496	(0.941–6.623)	<.066	
Motor coordination disorders	5.150	(2.087–12.711)	<.001		7.861	(2.739–22.559)	<.001	
Body mass index					0.916	(0.816–1.029)	.139	
Cardiorespiratory fitness					1.223	(0.815–1.837)	.331	
Socioeconomic status[b] (not eligible)					1			.698
Socioeconomic status (benefit A)					0.678	(0.246–1.865)	.451	
Socioeconomic status (benefit B)					0.744	(0.330–1.681)	.477	

Portugal, academic year 2009/2010.
OR – Odds Ratio.
CI – Confidence Intervals.
[a] Adjusted for socioeconomic status, body mass index and cardiorespiratory fitness.
[b] Reference category.

Table 4
Odds ratios and 95% confidence Intervals from binary logistic regression model predicting low academic achievement, for boys.

Boys	Low academic achievement							
	Unadjusted model				Adjusted model[a]			
	OR	95% CI	*p*	*p* for trend	OR	95% CI	*p*	*p* for trend
Normal/good motor coordination[b]	1			<.026	1			.006
Motor coordination insufficiency	1.483	(0.769–2.862)	<.240		1.868	(0.902–3.865)	<.092	
Motor coordination disorders	3.758	(1.428–9.886)	.007		6.815	(2.075–22.379)	.002	
Body mass index					0.841	(0.741–0.954)	.007	
Cardiorespiratory fitness					1.021	(0.710–1.469)	.910	
Socioeconomic status[b] (not eligible)					1			.016
Socioeconomic status (benefit A)					0.867	(0.360–2.090)	.750	
Socioeconomic status (benefit B)					0.369	(0.175–0.778)	.009	

Portugal, academic year 2009/2010.
OR – Odds Ratio.
CI – Confidence Intervals.
[a] Adjusted for socioeconomic status, body mass index and cardiorespiratory fitness.
[b] Reference category.

Better gross MC results may reflect better overall health, as has been suggested in the case of physical fitness (Chomitz et al., 2009) (i.e., better nutrition, more PA and healthier weight status), and good health may contribute positively to AA. As the literature points out, high levels of motor competence/skill are positively associated with PA (Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). Cognitive facilitation by PA is presumably attributable to a direct improvement in cerebral circulation (of glucose, oxygen and energetic substances) and the alteration of neurotransmitter actions in the central nervous system (acetycholine, dopamine, norepinephrine, epinephrine, adrenocorticotropic hormone and vasopressin) (Kashihara, Maruyama, Murota, & Nakahara, 2009). Taras (2005) indicates that PA increases blood flow to the brain and raises the levels of hormones (norepinephrine and endorphins) that reduce stress, improve mood, and induce a calming effect after exercise, possibly leading to an improvement in AA (Taras, 2005). It has also been suggested that increased PA may induce arousal and reduce boredom, leading to increased attention span and better concentration (Shephard, 1996). Additionally, PA may increase feelings of self-efficacy and self-esteem, which can improve class behavior as well as AA. Furthermore, it is assumed that children who participate in PA that promotes cooperation, sharing, and rule-following learn skills that transfer to classroom settings (Taras, 2005).

It is of importance to note that children with poor MC report systematically less participation in organized and free-play activities than their typically developing peers (activity deficit) (Bouffard, Watkinson, Thompson, Causgrove Dunn, & Romanow, 1996; Cairney, Hay, Faught, Mandigo, & Flouris, 2005), and these differences tend to persisted over time (Cairney, Hay, Veldhuizen, Missiuna, & Faught, 2010); therefore, it is possible that these children are not provided with the same opportunity to enhance AA given the benefits of PA on AA.

Our results also showed that boys had higher levels of gross MC and better performance on cardiorespiratory fitness tests than girls. This finding is supported by previous longitudinal research that found that boys had consistently higher results in both MC and physical fitness than girls at each observation (Lopes, Rodrigues, Maia, & Malina, 2009; Pereira et al., 2010). Perhaps the types of sports and PA in which boys are more often involved, i.e., those that require eye-hand (or foot) coordination (evident in a variety of ball games), give them more opportunities to improve their cardiorespiratory fitness and refine their MC.

Only 48.8% of our study participants were classified as having at least normal MC and none showed very good MC. These results are in line with those reported in a study with Portuguese children aged 6–10 years old (Maia & Lopes, 2002). However, our gross MC numbers are considerably lower than those observed by others (Graf et al., 2004; Vandorpe et al., 2011). In a study with German children aged 6–9 years old, Graf et al. (2004) found that only 31.3% of participants showed lower than normal MC. Vandorpe et al. (2011), in a study of Belgian children aged 6–11 years, found that only 21.1% demonstrated lower than normal MC. In the original German (1974) standardization sample with children aged 6–11, only 16% demonstrated lower than normal MC (Kiphard & Schiling, 1974). The low gross MC levels in Portuguese children may possibly be explained partially by the fact that Portuguese children have one of the highest rates of obesity in Europe (Sardinha et al., 2011). Indeed, several studies have described that overweight children have poor results on motor skill tests when compared with their normal-weight counterparts (Graf et al., 2004; Okely, Booth, & Chey, 2004). Additionally, Portuguese children and adolescents have lower levels of PA (Baptista et al., 2012) compared to their European counterparts, a characteristic that correlates with low MC (Okely, Booth, & Patterson, 2001). Furthermore, KTK norms and cut-off values are based on German children tested 36 years ago, while the literature has shown that children's physical fitness (Tomkinson, Leger, Olds, & Cazorla, 2003) and PA (Knuth & Hallal, 2009) are declining; as motor skills are positively associated with both physical fitness (Hands, Larkin, Parker, Straker, & Perry, 2009) and PA (Williams et al., 2008; Wrotniak et al., 2006), perhaps MC levels are decreasing as well. Indeed, Prätorius and Milani (2004) have shown that over the last 30 years, the percentage of German children with low MC has increased substantially, from 16% in the KTK test's original validation to a level of 38% in contemporary children.

Schools are excellent settings in which to provide students with the opportunity for daily PA, to teach the importance of regular PA for health, and to build skills that support active lifestyles. Promoting active lifestyles from a young age is widely recognized as beneficial, and the health benefits of regular PA are extensively acknowledged (Andersen et al., 2006; Strong et al., 2005). The incorporation of PA into daily life and the achievement of recommended PA levels for the maintenance of good health are major public health challenges. Physical education lessons and school recesses are ideal settings in which to develop children's fundamental movement skills and increase PA and fitness (van Beurden et al., 2003), while also contributing to one of the primary missions of schools, i.e., the promotion of academic performance (Dwyer, Sallis, Blizzard, Lazarus, & Dean, 2001).

Given the importance of assessment and evaluation in the education and health fields and the pressures that educational agents are under to achieve academic success for all students, indicators of educational achievement, health, and functional status may allow educators and policy makers to make better informed decisions (Lloyd, Colley, & Tremblay, 2010). Therefore, understanding the relationship between MC and AA is important for ensuring the appropriate assignment of resources as well as the implementation of programs to develop children's health-related behaviors. This study highlights the necessity of providing opportunities for children to engage in PA structured and unstructured that promote a diversity of motor skills, since gross MC seems to play such an important role in AA.

5. Strengths and limitations

This study has some limitations that need to be recognized. The data has been derived from a cross-sectional study so the results do not indicate causality. Our sample is not representative of the Portuguese population and therefore our findings are not generalizable. The use of shuttle-run tests to assess aerobic fitness in children with motor problems is controversial, and has been criticized by Armstrong and Welsman (1997) and Hands and Larkin (2006) for being overly vulnerable to both motivational and environmental effects. Indeed, field-based measures of aerobic capacity rely on the internal motivation of the participants to perform to exhaustion (Rivilis et al., 2011), a circumstance that could be particularly challenging for children with developmental coordination disorders because they generally report less confidence in their physical abilities and may be unlikely to persist in their tasks (Cairney, Hay, Wade, Faught, & Flouris, 2006). Nevertheless, a recent study has shown that the shuttle-run test is moderately to fairly well correlated with lab based cycle ergometer tests for assessing cardiorespiratory fitness in children with and without developmental coordination disorders (Cairney, Hay, Veldhuizen, & Faught, 2010).

Overall, the strengths of our study include the use of direct indicators of AA, namely, scores on standardized national exams; the inclusion of potential confounding factors such as socio-economic status, which is recognized as a major factor in academic performance (Coe et al., 2006); the use of cardiorespiratory fitness, because it was suggested that this could mediate the relationship between PA and AA (Kwak et al., 2009), and the use of body mass index, which has been documented as inversely related with MC (Graf et al., 2004; Okely et al., 2004).

More research is needed to further study the relationship between MC and AA. Longitudinal and interventional studies would provide information on the direction of this association.

6. Conclusions

In this cross-sectional study, children of both genders with lower MC had higher odds of having low AA, after adjusting for potential confounding factors. The early identification of children with poor MC is crucial to implementing activities that develop health-related behaviors.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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