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ORIGINAL ARTICLE

Association of physical activity with muscular strength and fat-free mass in adolescents: the HELENA study

Diego Moliner-Urdiales · Francisco B. Ortega · Germán Vicente-Rodriguez · Juan P. Rey-Lopez · Luis Gracia-Marco · Kurt Widhalm · Michael Sjöström · Luis A. Moreno · Manuel J. Castillo · Jonatan R. Ruiz

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Abstract The objective of this study is to analyse the association of objectively assessed physical activity (PA) with muscular strength and fat-free mass in adolescents, and to determine whether meeting the current PA recommendations is associated with higher levels of muscular strength and fat-free mass. The present cross-sectional study comprised 363 Spanish adolescents (180 females) aged 12.5–17.5 years. PA was assessed by accelerometry and expressed as average PA (counts/min), and min/day of inactive, light, moderate, vigorous and moderate to vigorous PA (MVPA). MVPA was dichotomized into <60 min/day and ≥60. Upper body muscular strength was measured with the handgrip strength test, and lower body muscular strength was measured with the standing broad jump, squat jump, counter movement jump and Abalakov tests. Fat-free mass was measured by DXA. We observed positive associations between vigorous PA and all the lower body muscular strength tests except for the counter movement jump in males. PA was not associated with fat-free mass in both males and females. Male adolescents engaged in at least 60 min/day MVPA performed better in the standing broad jump test. In conclusion, the findings of the present study suggest that only vigorous PA is associated with muscular strength, particularly lower-body muscular strength in male adolescents.

Keywords Physical activity · Muscular strength · Fat-free mass · Accelerometer · Adolescents

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On behalf of the HELENA Study Group

The details of the HELENA Study Group are given in Appendix.

D. Moliner-Urdiales (✉) · G. Vicente-Rodriguez · J. P. Rey-Lopez · L. Gracia-Marco · L. A. Moreno
Growth, Exercise, Nutrition, and Development (GENUD) Research Group, Universidad de Zaragoza,
Corona de Aragón 42, 2nd floor, 50009 Zaragoza, Spain
e-mail: dmoliner@unizar.es

D. Moliner-Urdiales · F. B. Ortega · M. Sjöström · J. R. Ruiz
Unit for Preventive Nutrition,
Department of Biosciences and Nutrition at NOVUM,
Karolinska Institutet, Stockholm, Sweden

F. B. Ortega · M. J. Castillo
Department of Medical Physiology, School of Medicine,
University of Granada, Granada, Spain

G. Vicente-Rodriguez
Facultad de Ciencias de la Salud y del Deporte,
Universidad de Zaragoza, Huesca, Spain

K. Widhalm
Division of Clinical Nutrition and Prevention,
Department of Pediatrics,
Medical University of Vienna, Vienna, Austria

L. A. Moreno
Escuela Universitaria de Ciencias de la Salud,
Universidad de Zaragoza, Zaragoza, Spain

Introduction

There is compelling evidence highlighting the role of muscular strength in the performance of exercise and activities of daily living as well as in improving health and preventing disease in adults (Pollock et al. 2000; Ruiz et al. 2008).

In young people, high levels of muscular strength are associated with a healthier cardiovascular profile and higher levels of bone mineral content (Ortega et al. 2008b). Prospective studies showed that muscular strength

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improvements from childhood to adolescence are inversely associated with central adiposity, yet there is limited evidence on the associations with other cardiovascular disease risk factors such as systolic blood pressure or blood lipids and lipoproteins (Ruiz et al. 2008).

Fat-free mass is the major predictor of muscular strength (Maughan et al. 1983). A loss of muscle mass with aging is thought to contribute to the development of functional limitations and disability in old age, which may partially explain the association between strength and mortality (Melton et al. 2000). Fat-free mass is a strong predictor of bone mineral content (Vicente-Rodriguez et al. 2005, 2008) and has an independent effect on insulin sensitivity and glucose disposal (Dela et al. 1995; Ebeling et al. 1993; Houmard et al. 1991; Poehlman et al. 2000; Tresierras and Balady 2009).

Age-specific resistance training improves muscular strength through increases in fat-free mass, optimization in motor unit recruitment and synchronization and metabolic adaptations of muscle fiber (Folland and Williams 2007). Resistance training is currently recommended by the major health organizations for improving health and fitness (Behm et al. 2008; Bernhardt et al. 2001; Pollock et al. 2000) During adolescence, muscular strength is influenced by gender, body composition (i.e. fat-free mass) and pubertal status. Several studies have reported that daily physical activity (PA) provides an important stimulus over the musculoskeletal system capable of improving muscular strength by increasing fat-free mass (Ara et al. 2004; Baxter-Jones et al. 2008; Vicente-Rodriguez et al. 2004a). We have previously reported that meeting current PA recommendations is associated with a better cardiorespiratory fitness in adolescents (Ortega et al. 2008c) but is unknown whether it is also associated with a higher muscular strength and fat-free mass.

The existence of some contradictory findings, the lack of objective assessment of PA in relation to muscular strength and fat-free mass, and the fact that most of the studies have not controlled the influence of potential confounders like body composition or pubertal status, make necessary additional studies analysing the association of PA with muscular strength and fat-free mass.

Therefore, the purpose of the present study was to determine the association of objectively assessed PA with muscular strength and fat-free mass in a sample of Spanish adolescents participating in the Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study (HELENA-CSS). We also determined whether meeting the current PA recommendations (US Department of Health and Human Services. http://www.health.gov/PAGuidelines/) was associated with higher levels of muscular strength and fat-free mass.

Methods

Subjects

The HELENA-CSS is a multi-centre, cross-sectional study performed in ten European cities that was designed to obtain reliable and comparable data in a sample of European adolescents (Moreno et al. 2008). The present study comprised 363 (180 females and 183 males) adolescents from Zaragoza (Spain) with valid data for at least one muscular strength test, fat-free mass by Dual Energy X-ray Absorptiometry (DXA) and objectively assessed PA. After receiving complete information about the aims and methods of the study, all adolescents and their parents or guardians signed the informed written consent.

All participants were recruited at schools and met the general HELENA-CSS inclusion criteria: age range 12.5–17.5 years, not participating simultaneously in another clinical trial and be free of any acute infection lasting less than 1 week before the inclusion (Moreno et al. 2008). The study was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Edinburgh 2000). For the Spanish sample, the study protocol was approved by the Research Ethics Committee of the Government of Aragón (CEICA, Spain). Complete description of ethical issues and good clinical practice within the HELENA-CSS can be found elsewhere (Beghin et al. 2008).

Physical activity

A uni-axial accelerometer (Actigraph MTI, model GT1M, Manufacturing Technology Inc., Fort Walton Beach, FL, USA) was used to assess PA. Adolescents were instructed to place the monitor underneath the clothing, at the lower back, using an elastic waist band and wear it for seven consecutive days. They were also instructed to wear the accelerometer during all time awake and only to remove it during water-based activities. At least 3 days of recording with a minimum of 8 h registration per day was set as an inclusion criterion. In this study, the time sampling interval (epoch) was set at 15 s. Average PA was defined as the sum of recorded counts per epoch divided by total daily registered time expressed in minutes. Time spent in inactivity and light intensity PA was defined as the sum of time (in minutes) per day in which counts per minute (cpm) were <500 and ≥ 500 to 1,999, respectively. The time engaged at moderate PA [3–6 metabolic equivalents (METs)] was calculated based upon a cut-off of 2,000–3,999 cpm (Andersen et al. 2006). 2,000 cpm is equivalent to brisk walk (i.e. 4.5 km/h). The time engaged at vigorous PA (>6 METs) was calculated based upon a cut-off of 4,000 cpm. Also, the time spent in at least moderate intensity level (>3 METs) was calculated as the sum of time spent in moderate and vigorous PA (MVPA). The cut-offs to define the intensity categories are similar to those used in previous studies (Ekelund et al. 2007). MVPA was dichotomized into <60 and ≥60 min/day according to the recent guidelines launched by the US Department of Health and Human Services and other medical institutions.

Muscular strength

Muscular strength was assessed as previously reported by Ortega et al. (2008a). Upper body muscular strength was measured with a hand dynamometer with adjustable grip (TKK 5101 Grip D; Takey, Tokyo, Japan). Briefly, the adolescent squeezes gradually and continuously for at least 2 s, performing the test with the right and left hands in turn, using the optimal grip span. The maximum score in kilograms for each hand was recorded, and the average of the scores achieved in both handgrip tests was used in the analysis (Ruiz et al. 2006a). Lower body muscular strength was measured with the standing broad jump, the squat jump, the counter movement jump, and the Abalakov tests. For the standing broad jump the adolescent jumps as far as possible from a starting position immediately behind a line, standing with feet approximately shoulder's width apart. For the squat jump test the adolescent performs a vertical jump without rebound movements starting from a half-squat position, keeping both knees bent at 90°, the trunk straight and both hands on hips. Similarly, for the counter movement jump the adolescent in a standing position performs a vertical jump with an earlier fast counter movement. For the Abalakov test the adolescent performs a counter movement jump but freely coordinating the arms and trunk movements to reach the maximum height. The jumps height was recorded in centimetre by an Infrared Platform ERGO JUMP Plus-BOSCO SYSTEM (Byomedic, SCP, Barcelona, Spain).

The scientific rationale for the selection of these tests, as well as the reliability was reported elsewhere (Castro-Pinero et al. 2009; Ruiz et al. 2006b).

Physical examination

The physical examination methods followed in the HELENA-CSS has been described in detail by Nagy et al. (2008). In brief, body height was measured to the nearest 0.1 cm with a stadiometer SECA 225 while adolescents were standing barefoot. Body mass was determined to the nearest 0.05 kg using a balance scale SECA 861 with the subject in their underwear. Body mass index (BMI) was calculated as body mass (kg) divided by height (m) squared. Pubertal status was evaluated by experienced physicians according to the criteria of Tanner and Whitehouse (1976).

Fat-free mass

Total fat-free mass was assessed by DXA using a paediatric version of the software (QDR-Explorer, Hologic Corp., Software version 12.4, Waltham, MA, USA). The DXA was calibrated using a lumbar spine phantom as recommended by the manufacturer, and adolescents were scanned in supine position. Analysis of total fat-free mass was performed using the extended research mode according manufacturer's manual.

Statistical analysis

Data are presented as mean values ± standard deviation unless otherwise stated. Gender differences were assessed by one-way analysis of variance.

Relationships of different indicators of PA (i.e. inactive, light, moderate, vigorous, MVPA, and average PA) with muscular strength tests (i.e. handgrip strength, standing broad jump, squat jump, counter movement jump and Abalakov) were analysed in separate linear regression models that always retained age, pubertal status and fat-free mass as confounders. Relationships between PA and fat-free mass were analysed by linear regression analysis after controlling for age and pubertal status. Since we observed a significant interaction effect for gender in the association of PA with muscular strength and fat-free mass (all $P < 0.05$), all analyses were performed separately for males and females.

Differences in muscular strength (i.e. handgrip strength, standing broad jump, squat jump, counter movement jump and Abalakov tests) by time spent at MVPA (<60 vs. ≥60 min/day) were analysed by one-way analysis of covariance (ANCOVA). MVPA was entered as fixed factor, muscular strength tests were entered as dependent variables and age, pubertal status and fat-free mass were entered as covariates. We performed the same analyses with fat-free mass as dependent variable and age and pubertal status as confounders. Moreover, we repeated all the analyses including height as an additional confounder factor. All the analyses were performed using the Statistical Package for Social Sciences (SPSS, v. 16.0 for WINDOWS; SPSS Inc, Chicago) and the level of significance was set to <0.05.

Results

The characteristics of the study population by gender are shown in Table 1. Males showed higher levels of muscular strength and fat-free mass, and were more physically active than females (all $P < 0.001$). The prevalence of males achieving at least 60 min/day MVPA was also higher than in females (57.9 vs. 23.6%, respectively, $P < 0.001$).

Table 1 Characteristics of the study adolescents by gender

	n	Females	*n*	Males	All
Age (years)	180	14.8 ± 1.2	183	14.7 ± 1.3	14.8 ± 1.2
Tanner stage (%)	180		183		
Stage 1		0.0		0.0	0.0
Stage 2		0.6		4.5	2.6
Stage 3		5.2		10.2	7.7
Stage 4		6.4		20.5	13.5
Stage 5		87.8		64.8	76.2
Height (m)	180	1.6 ± 0.1*	183	1.7 ± 0.1	1.7 ± 0.1
Weight (kg)	180	54.3 ± 9.0*	183	61.0 ± 12.5	57.7 ± 11.4
BMI (kg/m^2)	180	21.1 ± 3.1	183	21.2 ± 3.2	21.2 ± 3.2
Physical activity	180		183		
Inactive (min/day)		633.9 ± 56.3		632.9 ± 67.1	633.4 ± 61.9
Light (min/day)		76.8 ± 17.3		79.6 ± 20.6	78.2 ± 19.0
Moderate (min/day)		35.3 ± 12.7*		41.5 ± 14.7	38.4 ± 14.1
Vigorous (min/day)		13.8 ± 11.0*		24.8 ± 14.3	19.4 ± 13.9
MVPA (min/day)		49.0 ± 20.2*		66.3 ± 24.8	57.7 ± 24.2
Average PA (cpm/day)		367.6 ± 116.9*		476.7 ± 155.6	422.6 ± 148.0
≥60 min/day MVPA (%)	180	23.9	183	57.9	41.1
Handgrip strength (kg)	176	23.1 ± 4.1*	172	32.5 ± 8.2	27.7 ± 8.0
Standing broad jump (cm)	176	136.2 ± 21.7*	173	176.2 ± 31.5	156.0 ± 33.6
Squat jump (cm)	175	18.1 ± 4.4*	170	24.8 ± 6.2	21.4 ± 6.3
Counter movement jump (cm)	176	21.4 ± 4.5*	172	28.3 ± 6.8	24.8 ± 6.7
Abalakov (cm)	176	23.6 ± 5.0*	172	32.3 ± 7.7	27.9 ± 7.8
Fat-free mass by DXA (kg)	180	38.9 ± 4.3*	178	47.6 ± 8.5	43.2 ± 8.0

DXA dual energy X-ray absorptiometry, *MVPA* moderate to vigorous physical activity, *PA* physical activity

* $P \leq 0.001$

In females, there was no association between PA and any strength test after controlling for age, pubertal status and fat-free mass (Table 2). In males, vigorous PA was positively associated with the squat jump and the Abalakov tests as well as with the standing broad jump test (Table 2). In both males and females, PA was not associated with fat-free mass after controlling for age and pubertal status (Table 2). Further controlling for muscular strength tests did not alter the results (data not shown).

Male adolescents engaged in at least 60 min/day MVPA had higher levels in the standing broad jump test (Fig. 1), whereas the other muscular strength tests as well as fat-free mass were similar across MVPA categories (Fig. 1). The results remained the same after removing fat-free mass as a confounder.

All the analyses were repeated including height as a confounder and the results remained the same.

Discussion

The results of the present study suggest an association between vigorous PA and muscular strength in males but not in females. Among the studied PA variables, only vigorous PA was positively associated with lower body muscular strength (i.e. squat jump, Abalakov and standing broad jump tests) in males. This study also indicates that, except for standing broad jump test in males, meeting the current PA recommendation of 60 min/day MVPA does not ensure higher levels of muscular strength. The observed gender differences can be partially explained due to the differences in the relative time spent in vigorous PA by males and females. In fact, vigorous PA represents a 35.8% of the MVPA in males whereas it represents a 25.5% in females. Furthermore, no association was observed between PA variables and fat-free mass or between meeting/not meeting PA recommendations and fat-free mass in the studied adolescents.

The relationship of PA with muscular strength and fat-free mass is poorly understood especially in young people. Cross-sectional studies showed contradictory findings probably due to lack of objective assessment of PA and proper control for potential confounders (e.g. fat-free mass or pubertal status). Sallis et al. (1993) found a weak relationship between a complex PA index and the pull-ups test in 274 boys and 254 girls aged 10 years. Similarly, Katzmarzyk et al. (1998) analysed 356 boys and 284 girls (9–18 years) from the Québec Family Study and found a weak association between PA and static strength of the legs in a

Table 2 Regression analysis of physical activity (PA) with squat jump, counter movement jump, Abalakov, standing broad jump and handgrip strength tests after controlling for age, pubertal status and fat-free mass, and between PA and fat-free mass after controlling for age and pubertal status

Dependent variable	Predictors	Females			Males		
		β	P	R^2 change	β	P	R^2 change
Squat jump (females, $n = 168$, males, $n = 163$)	Inactivity	0.032	0.680	0.001	0.033	0.645	0.001
	Light PA	0.097	0.216	0.009	−0.100	0.216	0.008
	Moderate PA	0.077	0.326	0.006	0.000	0.998	0.000
	Vigorous PA	−0.012	0.883	0.000	0.140	0.047*	0.019
	MVPA	0.043	0.591	0.002	0.080	0.261	0.006
	Average PA	0.026	0.739	0.001	0.073	0.305	0.005
Counter movement jump (females, $n = 169$, males, $n = 165$)	Inactivity	0.097	0.207	0.009	0.059	0.375	0.003
	Light PA	0.128	0.097	0.016	−0.143	0.058	0.016
	Moderate PA	0.122	0.117	0.014	−0.030	0.664	0.001
	Vigorous PA	0.068	0.383	0.004	0.101	0.126	0.010
	MVPA	0.115	0.142	0.013	0.041	0.541	0.002
	Average PA	0.084	0.280	0.007	0.030	0.658	0.001
Abalakov (females, $n = 169$, males, $n = 165$)	Inactivity	0.037	0.639	0.001	0.104	0.115	0.011
	Light PA	0.072	0.358	0.005	−0.067	0.368	0.003
	Moderate PA	0.139	0.079	0.018	−0.027	0.687	0.001
	Vigorous PA	0.062	0.434	0.004	0.154	0.017*	0.024
	MVPA	0.122	0.124	0.014	0.073	0.269	0.005
	Average PA	0.094	0.236	0.008	0.067	0.311	0.004
Standing broad jump (females, $n = 169$, males, n = 166)	Inactivity	−0.058	0.447	0.003	0.090	0.161	0.008
	Light PA	0.043	0.572	0.002	0.089	0.223	0.006
	Moderate PA	0.134	0.084	0.017	0.061	0.352	0.003
	Vigorous PA	0.042	0.587	0.002	0.187	0.003*	0.035
	MVPA	0.108	0.165	0.011	0.143	0.026*	0.020
	Average PA	0.103	0.182	0.010	0.123	0.055	0.015
Handgrip strength (females, $n = 169$, males, $n = 165$)	Inactivity	−0.067	0.316	0.004	−0.096	0.038*	0.009
	Light PA	0.094	0.165	0.009	0.033	0.534	0.001
	Moderate PA	−0.032	0.645	0.001	0.032	0.503	0.001
	Vigorous PA	−0.109	0.110	0.011	0.062	0.180	0.004
	MVPA	0.080	0.243	0.006	0.054	0.249	0.003
	Average PA	−0.072	0.289	0.005	0.075	0.109	0.005
Fat-free mass (females, $n = 173$, males, $n = 176$)	Inactivity	0.023	0.750	0.001	−0.095	0.141	0.009
	Light PA	−0.001	0.984	0.000	0.065	0.376	0.003
	Moderate PA	−0.011	0.881	0.000	0.107	0.106	0.011
	Vigorous PA	0.045	0.540	0.002	0.040	0.538	0.002
	MVPA	0.018	0.808	0.000	0.084	0.194	0.007
	Average PA	0.023	0.752	0.001	0.091	0.157	0.008

MVPA moderate and vigorous PA, R^2 *change* the percentage of the variance of the dependent variable (e.g. squat jump) explained by the predictor (e.g. vigorous PA) after excluding the effect of the covariables (e.g. age, pubertal status and fat-free mass)

maximal voluntary isometric contraction at a knee angle of 90° and a low no significant association between PA and sum of 6 skinfolds. Ara et al. (2004) showed in 114 prepubertal boys (9.4 ± 1.5 years) that participation in at least 3 h per week of extracurricular physical activities and sport competitions was associated with higher squat jump performance and lower fat mass levels compared with non-participants. In contrast, Buchheit et al. (2007) showed no association between PA measured by accelerometry and counter movement jump test in a sample of 67 preadolescents. Foo et al. (2007) observed in 283 Chinese adolescent girls (15.0 ± 0.9) a significant positive association of PA assessed by questionnaire with handgrip strength and fat-free mass. Andersen et al. (2009) studied a representative

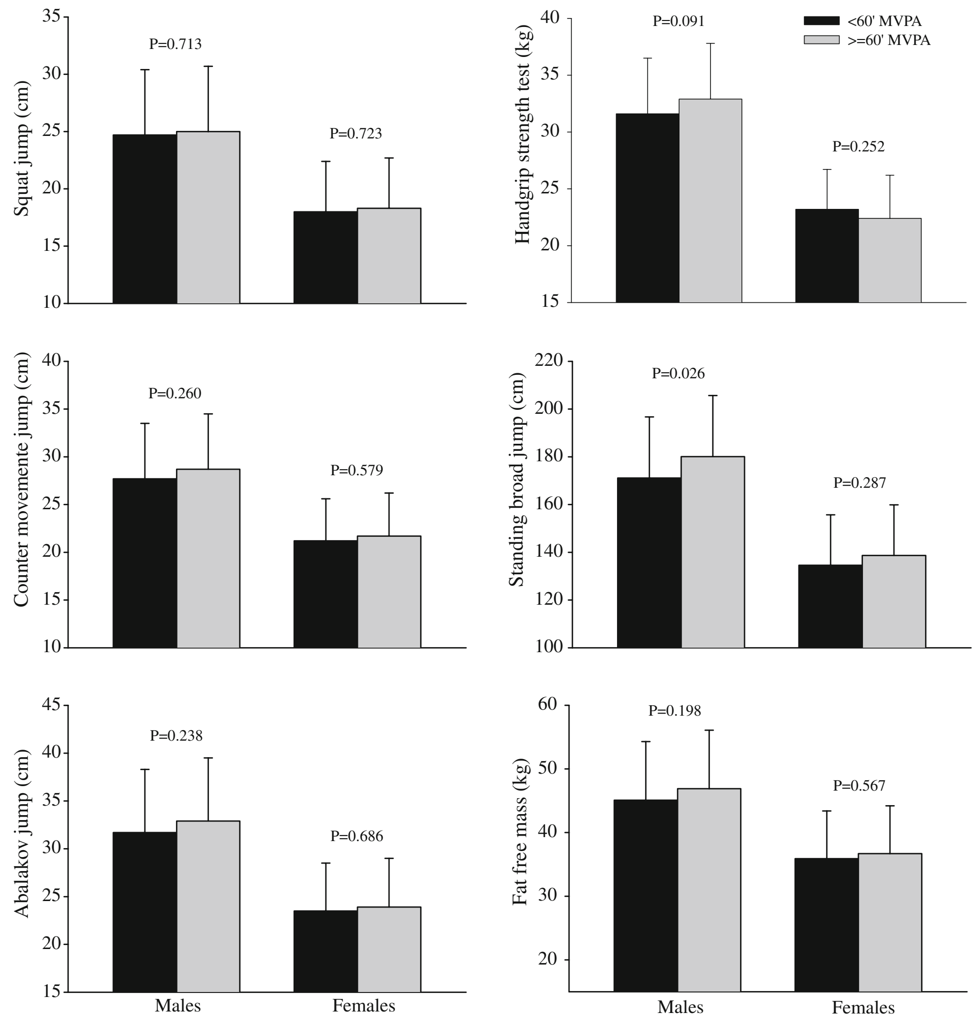

Fig. 1 Muscular strength tests and fat-free mass by time spent at moderate and vigorous physical activity (MVPA). Values are mean and standard deviation

Danish sample of 545 boys and 704 girls (15–19 years) and did not find any association between the kind of transport to school (e.g. passive, walking or cycling) and the performance in the Abalakov jump test.

Longitudinal studies are scarce, showing unequal trends in the evolution of muscular strength and fat-free mass in relation to PA. Andersen (1994) in a 2-year follow-up study with 259 randomly selected adolescents (16.5 years old) showed that changes in PA were not related to changes in arm extensor strength. Vicente-Rodriguez et al. (2004a) analysed fat-free mass and muscular strength (e.g. counter movement jump and knee extension) in 28 children (17 soccer players 8.7 ± 0.4 years and 11 nonphysically active 9.4 ± 0.3 years) over a 3.3 years period and found a higher increase of the fat-free mass in soccer players but no differences were observed in relation to muscular strength. Similarly, Baquet et al. (2006) studied 158 adolescents during 4 years (11–16 years) and showed that increasing or decreasing PA was not associated with changes in the performance of the standing broad jump test. Kanehisa et al. (2006) studied 12 tennis players (10.7–13.2 years) during 2 years, and reported a higher development in torque generation capability during high-velocity knee extensions than non-athletes. Baxter-Jones et al. (2008) followed for 6 years a total of 228 students aged 8–15 years from the Saskatchewan Pediatric Bone Mineral Accrual Study, and observed a significant positive influence of the PA assessed by questionnaire on the development of fat-free mass assessed by DXA. Likewise, Stenevi-Lundgren and Daly (2009) in a 12-month prospective controlled school-based exercise intervention, showed that increasing the amount of moderate intensity PA from 60 to 200 min/week was associated with an increase in lower limb peak muscle strength and fat-free mass in 53 prepubertal females (7–9 years).

Regardless of the evident gender differences, our results do not show any relationship between PA and fat-free mass, and suggest that after controlling for the fat-free mass, vigorous PA is the minimum physical stimulus able to enhance muscular strength. Probably, the level of androgens in males and the differential timing of growth between genders during adolescence may partially explain these gender differences (Beunen and Malina 1988; Bouchard 1990;

Bouchard et al. 1993; Malina et al. 2004). Meeting the PA recommendations was not associated with higher levels of muscular strength or fat-free mass, especially in females, which may indicate that other type of stimulus (e.g. regular sport participation or specific strength training) are needed in order to improve muscular strength and fat-free mass (Vicente-Rodriguez et al. 2004b, 2007).

Due to our study design (cross-sectional), it is not possible to infer a causal relationship of PA with muscular strength or fat-free mass. Although we controlled for several potential confounders, we cannot be certain that other unmeasured confounders such as the type of PA, nutrition or genetic factors do not have influenced our observations. The use of accelerometry to assess PA, the inclusion of different muscular strength tests, and the study of fat-free mass measured by DXA are strengths of this study.

Conclusions

The findings of the present study add new information about the association of PA with muscular strength and fat-free mass, and suggest that high intensity PA is the only variable associated with greater muscular strength despite none of the PA variables studied are related with higher levels of fat-free mass. In addition, our findings suggest that meeting the current PA recommendations does not ensure higher levels of muscular strength or fat-free mass in adolescents. Further interventional studies examining other PA variables like type of PA and/or genetic factors, in addition to PA intensity, muscular strength components and fat-free mass are still needed for a better understanding of these associations in young people.

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The study was performed following the ethical guidelines of the Research Ethics Committee of the Government of Aragón (Spain).

Conflict of interest statement None.

Appendix: HELENA Study Group

Co-ordinator: Luis A. Moreno.

Core Group members: Luis A. Moreno, Fréderic Gottrand, Stefaan De Henauw, Marcela González-Gross, Chantal Gilbert.

Steering Committee: Anthony Kafatos (President), Luis A. Moreno, Christian Libersa, Stefaan De Henauw, Jackie Sánchez, Fréderic Gottrand, Mathilde Kersting, Michael Sjöstrom, Dénes Molnár, Marcela González-Gross, Jean Dallongeville, Chantal Gilbert, Gunnar Hall, Lea Maes, Luca Scalfi.

Project Manager: Pilar Meléndez.

1. Universidad de Zaragoza (Spain): Luis A. Moreno, Jesús Fleta, José A. Casajús, Gerardo Rodríguez, Concepción Tomás, María I. Mesana, Germán Vicente-Rodríguez, Adoración Villarroya, Carlos M. Gil, Ignacio Ara, Juan Revenga, Carmen Lachen, Juan Fernández Alvira, Gloria Bueno, Aurora Lázaro, Olga Bueno, Juan F. León, Jesús Mª Garagorri, Manuel Bueno, Juan Pablo Rey López, Iris Iglesia, Paula Velasco, Silvia Bel.

2. Consejo Superior de Investigaciones Científicas (Spain): Ascensión Marcos, Julia Wärnberg, Esther Nova, Sonia Gómez, Esperanza Ligia Díaz, Javier Romeo, Ana Veses, Mari Angeles Puertollano, Belén Zapatera, Tamara Pozo.

3. Université de Lille 2 (France): Laurent Beghin, Christian Libersa, Frédéric Gottrand, Catalina Iliescu, Juliana Von Berlepsch.

4. Research Institute of Child Nutrition Dortmund, Rheinische Friedrich-Wilhelms-Universität Bonn (Germany): Mathilde Kersting, Wolfgang Sichert-Hellert, Ellen Koeppen.

5. Pécsi Tudományegyetem (University of Pécs) (Hungary): Dénes Molnar, Eva Erhardt, Katalin Csernus, Katalin Török, Szilvia Bokor, Mrs. Angster, Enikö Nagy, Orsolya Kovács, Judit Répasi.

6. University of Crete School of Medicine (Greece): Anthony Kafatos, Caroline Codrington, María Plada, Angeliki Papadaki, Katerina Sarri, Anna Viskadourou, Christos Hatzis, Michael Kiriakakis, George Tsibinos, Constantine Vardavas Manolis Sbokos, Eva Protoyeraki, Maria Fasoulaki.

7. Institut für Ernährungs- und Lebensmittelwissenschaften – Ernährungphysiologie. Rheinische Friedrich Wilhelms Universität (Germany): Peter Stehle, Klaus Pietrzik, Marcela González-Gross, Christina Breidenassel, Andre Spinneker, Jasmin Al-Tahan, Miriam Segoviano, Anke Berchtold, Christine Bierschbach, Erika Blatzheim, Adelheid Schuch, Petra Pickert.

8. University of Granada (Spain): Manuel J. Castillo Garzón, Ángel Gutiérrez Sáinz, Francisco B. Ortega Porcel, Jonatan R Ruiz, Enrique García Artero, Vanesa España Romero, David Jiménez Pavón, Cristóbal Sánchez Muñoz, Victor Soto, Palma Chillón, Jose M. Heredia, Virginia Aparicio, Pedro Baena, Claudia M. Cardia, Ana Carbonell.

9. Istituto Nazionalen di Ricerca per gli Alimenti e la Nutrizione (Italy): Davide Arcella, Giovina Catasta, Laura Censi, Donatella Ciarapica, Marika Ferrari, Cinzia Le

Donne, Catherine Leclerq, Luciana Magrì, Giuseppe Maiani, Rafaela Piccinelli, Angela Polito, Raffaela Spada, Elisabetta Toti.

10. University of Napoli "Federico II" Dept of Food Science (Italy): Luca Scalfi, Paola Vitaglione, Concetta Montagnese.

11. Ghent University (Belgium): Ilse De Bourdeaudhuij, Stefaan De Henauw, Tineke De Vriendt, Lea Maes, Christophe Matthys, Carine Vereecken, Mieke de Maeyer, Charlene Ottevaere.

12. Medical University of Vienna (Austria): Kurt Widhalm, Katharina Phillipp, Sabine Dietrich, Birgit Kubelka, Marion Boriss-Riedl.

13. Harokopio University (Greece): Yannis Manios, Eva Grammatikaki, Zoi Bouloubasi, Tina Louisa Cook, Sofia Eleutheriou, Orsalia Consta, George Moschonis, Ioanna Katsaroli, George Kraniou, Stalo Papoutsou, Despoina Keke, Ioanna Petraki, Elena Bellou, Sofia Tanagra, Kostalenia Kallianoti, Dionysia Argyropoulou, Katerina Kondaki, Stamatoula Tsikrika, Christos Karaiskos.

14. Institut Pasteur de Lille (France): Jean Dallongeville, Aline Meirhaeghe, Szilvia Bokor, Nathalie Fievet, Louisa Goumidi.

15. Karolinska Institutet (Sweden): Michael Sjöstrom, Patrick Bergman, María Hagströmer, Lena Hallström, Mårten Hallberg, Eric Poortvliet, Julia Wärnberg, Nico Rizzo, Linda Beckman, Anita Hurtig Wennlöf, Emma Patterson, Lydia Kwak, Lars Cernerud, Per Tillgren, Stefaan Sörensen.

16. Asociación de Investigación de la Industria Agroalimentaria (Spain): Jackie Sánchez-Molero, Elena Picó, Maite Navarro, Blanca Viadel, José Enrique Carreres, Gema Merino, Rosa Sanjuán, María Lorente, María José Sánchez, Sara Castelló.

17. Campden & Chorleywood Food Research Association (United Kingdom): Chantal Gilbert, Sarah Thomas, Elaine Allchurch, Peter Burguess.

18. SIK - Institutet foer Livsmedel och Bioteknik (Sweden): Gunnar Hall, Annika Astrom, Anna Sverkén, Agneta Broberg.

19. Meurice Recherche & Development asbl (Belgium): Annick Masson, Claire Lehoux, Pascal Brabant, Philippe Pate, Laurence Fontaine.

20. Campden & Chorleywood Food Development Institute (Hungary): Andras Sebok, Tunde Kuti, Adrienn Hegyi.

21. Productos Aditivos SA (Spain): Cristina Maldonado, Ana Llorente.

22. Cárnicas Serrano SL (Spain): Emilio García.

23. Cederroth International AB (Sweden): Holger von Fircks, Marianne Lilja Hallberg, Maria Messerer.

24. Lantmännen Food R&D (Sweden): Mats Larsson, Helena Fredriksson, Viola Adamsson, Ingmar Börjesson.

25. European Food Information Council (Belgium): Laura Fernández, Laura Smillie, Josephine Wills.

26. Universidad Politécnica de Madrid (Spain): Marcela González-Gross, Agustín Meléndez, Pedro J. Benito, Javier Calderón, David Jiménez-Pavón, Jara Valtueña, Paloma Navarro, Alejandro Urzanqui, Ulrike Albers, Raquel Pedrero, Juan José Gómez Lorente.

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