Association between objectively measured physical activity and plasma BDNF in adolescents: DADOS Study

Mss. MR Beltran-Valls; Phd. [a, b]

Mss. M Adelantado-Renau; MSc. [a]

Mr. D Moliner-Urdiales; Phd. [a]

[a] LIFE Research Group, University Jaume I, Av. de Vicent Sos Baynat, s/n, PC 12071 Castellon, Spain.

[b] EUSES Health and Sport Sciences School, Rovira i Virgili University, Tarragona, Spain. Postal address: C/ Sebastià Joan Arbó, 2, PC 43870, Amposta, Spain.

Corresponding author: Diego Moliner Urdiales, email address: dmoliner@uji.es; postal address: Faculty of Humanities and Social Sciences, Department of Education, University Jaume I, Av. de Vicent Sos Baynat, PC 12071, Castellon, Spain. Telephone number: 00 34 964 729782; Fax: 00 34 964 729264.

ABSTRACT

BACKGROUND: Brain-derived neurotrophic factor (BDNF) is suggested to play a key role in moderating the benefits of physical activity (PA) on cognition. Previous research found that PA may have an impact on peripheral BDNF expression. The aim of our study was to analyse the association between objectively measured PA with circulating BDNF in a group of active adolescents. METHODS: 234 adolescents (132 boys) aged 13.9±0.3 years old from the DADOS study were included in this cross-sectional analysis. PA was assessed by GENEActiv triaxial accelerometer. Participants wore the accelerometer on their non-dominant wrist for 6 consecutive 24-h days, including weekends. PA was expressed as the average (min/day) of light, moderate and vigorous PA. Fasting plasma BDNF concentrations at rest were measured using an enzyme-linked immunosorbent assay. Partial correlations and linear regression analyses were performed with a significance level established at $p<0.05$. RESULTS: No correlations were found between BDNF and PA variables. Plasma levels of BDNF at rest were not significantly associated with daily PA in either boys or girls ($p>0.05$). CONCLUSION: Based on previous research and our own data, the association between daily PA and baseline levels of BDNF remains inconclusive. Further research is needed to shed light on the relationship between regular PA and BDNF in adolescents.

KEY WORDS: adolescence, health, active behaviour, cognition, neurotrophins.

INTRODUCTION

The importance of maintaining an active lifestyle during youth is well accepted nowadays, not only for its benefits on physical health but also for its influence on cognition (Hillman et al. 2015). Prior research indicates that regular physical activity (PA) induces several physiological adaptations like enhanced brain function and increased vascularization, which may translate into cognitive benefits (Lubans et al. 2016). Evidence from animal and human studies suggests that brain-derived neurotrophic factor (BDNF) could be a key molecule behind those physiological adaptations (Phillips, Baktir, Srivatsan, & Salehi, 2014).

BDNF is a protein member of the nerve growth factors family which in humans is mostly expressed in the central nervous system, but it is also produced peripherally (i.e. skeletal muscle, adipose tissue) (Noble et al. 2011). Although BDNF cannot be measured centrally in humans, central BDNF can cross the blood-brain barrier bi-directionally (Pan et al. 1998); thus, it is suggested that peripheral levels of BDNF may have central effects (Serra-Millàs 2016). BDNF has been found to play an important role in various aspects of brain development like neuronal survival, regeneration and proliferation, as well as synapse formation and plasticity, which may translate into better cognitive functions (Park and Poo 2013). Indeed, higher BDNF levels have been related to improved cognitive processes like memory (Whiteman et al. 2014) as well as improved cortical brain development (Herting et al. 2016).

BDNF concentrations have been found to increase peripherally, both in plasma and serum, after acute and chronic aerobic exercise in healthy adults (Huang, Larsen, Ried-Larsen, Møller, & Andersen, 2014). These findings have supported the idea that exercise could be viewed as a potential strategy for inducing BDNF secretion. Despite some knowledge has been acquired from studies in adult population, the association between circulating BDNF at rest with long-term effects of PA has been poorly investigated in healthy youth (Pareja-Galeano et al. 2013; Lee et al. 2014; Kim 2016; Huang et al. 2017; Jeon and Ha 2017). In addition, results are contradictory in this age-

span since both direct (Jeon & Ha, 2015, 2017; Pareja-Galeano et al., 2013) and inverse relationships have been reported (Lee et al. 2014; Kim 2016; Huang et al. 2017).

Adolescence is a period of significant neurodevelopment (Hueston et al. 2017) characterized by the establishment of many health-related behaviours (Sawyer et al. 2012). Thus, investigating factors related to neurogenesis in this age-span is particularly consequential. Given the suggested benefits of BDNF on cognition, it is of interest to elucidate if daily PA is associated with circulating BDNF levels at rest in adolescents. Thus, the aim of our study was to analyse the association between objectively measured PA with circulating BDNF in a group of physically active adolescents.

MATERIAL AND METHODS

Study design and participants

The present study is part of the DADOS (Deporte, ADOlescencia y Salud) study which has been described previously (Beltran-Valls et al. 2017). Briefly, it is a 3-year longitudinal research project aimed to investigate the influence of PA on health and development in adolescents. All participants were volunteers recruited from secondary schools and sports clubs of Castellon (Spain), and met the general DADOS inclusion criteria: born in 2001, enrolled in the 2nd grade of secondary school, and free of any chronic disease. The results presented in this cross-sectional analysis belong to baseline data obtained between February and May of 2015. A total of 234 adolescents (132 boys) with valid data for BDNF, body mass index (BMI), pubertal status and achieving 60 min/day of Moderate and Vigorous PA (MVPA) as proposed by the World Health Organization (WHO. 2010), were included in the analysis. Adolescents and their parents or guardians were informed of the nature and characteristics of the study, and all provided a written informed consent. The study was performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Fortaleza 2013), and the study protocol was approved by the Research Ethics Committee of the University Jaume I (Spain).

Physical Activity Measurement

PA levels were objectively measured using the GENEActiv accelerometer (Activinsights Ltd, Kimbolton, UK), a waterproof device which contains a triaxial microelectromechanical-accelerometer that records both motion-related and gravitational acceleration and has a linear and equal sensitivity along the three axes. Participants wore the accelerometer on their non-dominant wrist for 6 consecutive 24-h days, including weekend and week days. GENEActiv accelerometer has been found to be a reliable (Coefficient of Variation intra-instrument = 1.4%, Coefficient of Variation inter-instrument = 2.1%) (Esliger et al. 2011) and valid objective measure of PA in young people ($r = 0.925$, $P = 0.001$) (Phillips, Parfitt, & Rowlands, 2013). Devices were programmed with a sampling frequency of 100 Hz, and data were stored in gravity (g) units (1 g = 9.81 m/s^2). The raw acceleration output was converted to 1 second epochs using the GENEActiv Post-Processing PC Software (version 2.2, GENEActiv). By combining all registered days for each participant and according to Phillips et al. (2013), PA was expressed as the average (min/day) of light, moderate, vigorous and moderate plus vigorous PA. Total PA was calculated by adding all PA intensities.

Plasma BDNF concentrations

After an overnight fast, blood samples (~20ml) were drawn from the antecubital vein while subjects remained in seated position in our laboratory (between 8:00-9:00 am). Blood samples in EDTA tubes (Greiner bio-one, Kremsmünster, Austria) were used for plasma collection by centrifugation of blood at 3500 rpm×10 min at 4ºC. Plasma samples were aliquoted and stored at −80 °C until analysis. Plasma BDNF concentration was measured using a commercially available sensitive ELISA kit for BDNF (EIA-4147 BDNF Enzyme-Linked Immunosorbent Assay; DRG Instruments GmbH, Marburg, Germany), according to manufacturer's instructions. The sensitivity of the BDNF concentration assay was 15.6 pg/mL, with intra-assay coefficients of variation of <10%.

Covariates

Due to the influence of age, sex, pubertal status, BMI, sport participation and weekly training sessions on circulating BDNF levels, these factors were included in the analyses as confounders (Lommatzsch et al. 2005; Iughetti et al. 2011).

Pubertal status was self-reported according to the 5 stages described by Tanner and Whitehouse (Tanner and Whitehouse 1976). It is based on external primary and secondary sex characteristics, which are described by the participants using standard pictures according to Tanner instructions.

Body mass index (BMI) was calculated as weight/height square (kg/m^2). Body weight was measured to the nearest 0.1 kg using an electronic scale (SECA 861, Hamburg, Germany). Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (SECA 213, Hamburg, Germany). Measures were assessed in duplicate and average measures were used for the analyses.

The adolescents reported their participation in organized sports and number of training sessions per week by answering the following questions: *For how many years have you participated in organized sports?* and *how many training sessions do you complete during a standard week?* Organized sport was defined as sport activities guided by a coach and having regular competitions. Participants reported the number of years training and it was included in the data analyses as a continuous variable. The options for number of training sessions were: “5 or more per week”, “4 per week”, “3 per week”, “2 per week”, and “once per week”.

Statistical analysis

To achieve normality, values of BMI, PA and BDNF levels were log transformed before analyses. Descriptive sample characteristics were summarized by sex and were presented as mean ± standard deviation (SD). Differences between boys and girls were examined using independent *t*-test. Partial correlation analysis controlling for age, sex, pubertal status, BMI, sport participation and weekly training sessions were performed to examine the associations between PA and BDNF levels.

Linear regression models were implemented to analyse the associations between PA and BDNF, controlling for age, pubertal status, BMI, sport participation and weekly training sessions. Even though we did not observe a significant interaction effect for sex and BDNF, analyses were performed separately for boys and girls due to the reported impact of sex on BDNF circulating levels (Lommatzsch et al. 2005) and the differences in PA levels found between sexes. All the analyses were performed using the IBM SPSS Statistics for Windows version 22.0 (Armonk, NY: IBM Corp). The level of significance was set at $p<0.05$.

RESULTS

Table 1 shows descriptive characteristics of the study sample by sex. Boys were taller and more physically active than girls ($p<0.001$). No differences between sexes were found for age, BMI or BDNF levels.

Table 1 around here

Partial correlations did not reveal any significant association between PA and BDNF levels after controlling for age, sex, pubertal status, BMI, sport participation and weekly training sessions (table 2).

Table 2 around here

Table 3 shows the association between PA variables and BDNF levels for boys and girls. Neither the total daily PA nor the specific PA intensities showed a significant association with resting plasma BDNF levels in boys or girls ($p>0.05$). Linear regression analyses performed on the whole sample (including boys and girls) did not show either any significant association between PA variables and BDNF levels ($p>0.05$, data not shown).

Table 3 around here

DISCUSSION

The main finding of this cross-sectional study showed that, after controlling for potential confounders, objectively measured PA levels were not associated with resting plasma BDNF in a sample of adolescents meeting daily PA recommendations (≥60min/day MVPA). The present study expands the scarce current literature analysing the association between PA and BDNF in healthy and physically active adolescents.

Previous intervention research analysing the effect of aerobic exercise on BDNF levels in adolescents showed contradictory results since several studies identified an increase in BDNF levels (Jeon & Ha, 2015, 2017; Pareja-Galeano et al., 2013), while others reported a decrease (Lee et al. 2014; Kim 2016). Similarly to our study, Huang et al. (2017) analysed the association between BDNF and PA in a sample of 415 adolescents and found a negative association of BDNF levels with MVPA only in boys. The lack of association between BDNF and PA identified in our sample of healthy adolescents could be partially explained by the fact that all the participants in the study were physically active adolescents (≥ 60 min/day MVPA). In addition, the discrepancy between our results and previous research could be related to the fact that they investigated the association between BDNF and PA in serum (Lee et al. 2014; Jeon and Ha 2015, 2017; Kim 2016).

The association between BDNF and different levels of PA has been analysed only by Jeon & Ha (2017) in an intervention study performing 12 weeks of aerobic exercise with a small sample of 40 male adolescents. They found that the group performing high intensity exercise increased significantly the BDNF levels at rest compared to the low intensity exercise and the control groups. Despite the different design of the study, our results revealed no association between BDNF and any PA levels. Again, the specific characteristics of our sample and the methodological differences among both studies could partially explain the lack of agreement between the findings.

All in all, we believe that methodological issues could be behind the controversial results found in the recent scientific literature. Firstly, different results could be related to the matrix (serum versus plasma) in which BDNF is measured in the studies. Since BDNF is stored and released by platelets (Fujimura et al. 2002), it is possible that factors affecting platelets functioning like exercise

(El-Sayed et al. 2005), clotting time or temperature of serum collection (Pareja-Galeano et al. 2015) might influence the concentration of BDNF in serum. Therefore, BDNF levels from plasma and serum in different studies might not be directly comparable (Serra-Millàs 2016). Secondly, analysing BDNF with ELISA kits does not allow to differentiate between the two forms of BDNF: mature BDNF and pro-BDNF which both can be found in circulation and are thought to exert distinct and opposed functions (Serra-Millàs 2016), as well as to respond differently to PA (Brunelli et al. 2012). Therefore, our and other studies showing results obtained from ELISA procedure did not account for differential levels of those two circulating molecules of BDNF in the population investigated. Finally, genetic factors might play a role in the association analysed. A single nucleotide polymorphism within the BDNF gene, known as the val66met, has been identified and related to BDNF secretion and functioning alterations (Egan et al. 2003). Indeed, individuals carrying the polymorphisms have shown decreased activity-dependent secretion of BDNF as compared to the not carriers (Egan et al. 2003). Moreover, it has recently been suggested that BDNF genotype may moderate the relationship between aerobic fitness and cortical structure in adolescents (Herting et al. 2016) and the benefits of exercise on cognition in young adults (Hopkins et al. 2012). Thus, the comparison between results of different studies might be hampered by genetic features if this issue is not considered in the population investigated.

The present study has some strengths including the objective assessment of different levels of daily PA with an accelerometer that can be worn continuously for 24h, as well as the relatively large and homogeneous sample in terms of age. In addition, the statistical analyses were controlled for age, pubertal status, BMI, sport participation and weekly training sessions. However, the cross-sectional design of the study limits our ability to make assumptions about the causal nature of the analysed association.

In conclusion, we found no association between circulating resting levels of plasma BDNF and different levels of objectively assessed daily PA in healthy and physically active adolescents. Given the inconclusive results in the current scientific literature, further research which considers the

methodological issues raised is needed to shed light on the relationship between BDNF and PA during adolescence. Increasing the knowledge of behaviours which influence this neuroplasticity-related protein might help understanding determinants of cognitive performance.

FUNDING: DADOS Study is funded by the Spanish Ministry of Economy and Competitiveness, MINECO (DEP2013-45515-R) and by the University Jaume I of Castellon, UJI (P1 1A2015-05). This work is partly supported by a Sunny Sport research grant from the Schweppes Suntory Spain Company. M.A.R is supported by a Predoctoral Research Grant from UJI (PREDOC/2015/13).

CONFLICT OF INTEREST: The authors declare that they have not conflict of interest.

REFERENCES

Beltran-Valls MR, García Artero E, Capdevila-Seder A, et al (2017) Regular Practice of Competitive Sports Does Not Impair Sleep in Adolescents: DADOS Study. Pediatr Exerc Sci 17:1–8. doi: 10.1123/pes.2017-0129

Brunelli A, Dimauro I, Sgrò P, et al (2012) Acute exercise modulates BDNF and pro-BDNF protein content in immune cells. Med Sci Sports Exerc 44:1871–80. doi: 10.1249/MSS.0b013e31825ab69b

Egan MF, Kojima M, Callicott JH, et al (2003) The BDNF val66met polymorphism affects activity-dependent secretion of BDNF and human memory and hippocampal function. Cell 112:257–69

El-Sayed MS, Ali N, El-Sayed Ali Z (2005) Aggregation and activation of blood platelets in exercise and training. Sports Med 35:11–22

Esliger DW, Rowlands A V, Hurst TL, et al (2011) Validation of the GENEA accelerometer. Med Sci Sports Exerc 43:1085–1093. doi: 10.1249/MSS.0b013e31820513be

Fujimura H, Altar CA, Chen R, et al (2002) Brain-derived neurotrophic factor is stored in human platelets and released by agonist stimulation. Thromb Haemost 87:728–34

Herting MM, Keenan MF, Nagel BJ (2016) Aerobic Fitness Linked to Cortical Brain Development in Adolescent Males: Preliminary Findings Suggest a Possible Role of BDNF Genotype. Front Hum Neurosci 10:327. doi: 10.3389/fnhum.2016.00327

235 Hillman CH, Khan NA, Kao SC (2015) The Relationship of Health Behaviors to Childhood
236 Cognition and Brain Health. Proc Ann Nutr Metab 66:1–4. doi: 10.1159/000381237
237 Hopkins ME, Davis FC, Vantieghem MR, et al (2012) Differential effects of acute and regular
238 physical exercise on cognition and affect. Neuroscience 215:59–68. doi:
239 10.1016/j.neuroscience.2012.04.056
240 Huang T, Gejl AK, Tarp J, et al (2017) Cross-sectional associations of objectively measured
241 physical activity with brain-derived neurotrophic factor in adolescents. Physiol Behav 171:87–
242 91. doi: 10.1016/j.physbeh.2016.12.026
243 Huang T, Larsen KT, Ried-Larsen M, et al (2014) The effects of physical activity and exercise on
244 brain-derived neurotrophic factor in healthy humans: A review. Scand J Med Sci Sports 24:1–
245 10. doi: 10.1111/sms.12069
246 Hueston CM, Cryan JF, Nolan YM (2017) Stress and adolescent hippocampal neurogenesis: diet
247 and exercise as cognitive modulators. Transl Psychiatry 7:e1081. doi: 10.1038/tp.2017.48
248 Iughetti L, Casarosa E, Predieri B, et al (2011) Plasma brain-derived neurotrophic factor
249 concentrations in children and adolescents. Neuropeptides 45:205–11. doi:
250 10.1016/j.npep.2011.02.002
251 Jeon YK, Ha CH (2017) The effect of exercise intensity on brain derived neurotrophic factor and
252 memory in adolescents. Environ Health Prev Med 22:27. doi: 10.1186/s12199-017-0643-6
253 Jeon YK, Ha CH (2015) Expression of brain-derived neurotrophic factor, IGF-1 and cortisol
254 elicited by regular aerobic exercise in adolescents. J Phys Ther Sci 27:737–741. doi:
255 10.1589/jpts.27.737
256 Kim Y Il (2016) The impact of exercise training on basal BDNF in athletic adolescents. J Phys Ther
257 Sci 28:3066–3069. doi: 10.1589/jpts.28.3066
258 Lee TMC, Wong ML, Lau BWM, et al (2014) Aerobic exercise interacts with neurotrophic factors
259 to predict cognitive functioning in adolescents. Psychoneuroendocrinology 39:214–224. doi:
260 10.1016/j.psyneuen.2013.09.019

Lommatzsch M, Zingler D, Schuhbaeck K, et al (2005) The impact of age, weight and gender on BDNF levels in human platelets and plasma. Neurobiol Aging 26:115–123. doi: 10.1016/j.neurobiolaging.2004.03.002

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

Noble EE, Billington CJ, Kotz CM, Wang C (2011) The lighter side of BDNF. AJP Regul Integr Comp Physiol 300:R1053–R1069. doi: 10.1152/ajpregu.00776.2010

Pan W, Banks WA, Fasold MB, et al (1998) Transport of brain-derived neurotrophic factor across the blood-brain barrier. Neuropharmacology 37:1553–61

Pareja-Galeano H, Alis R, Sanchis-Gomar F, et al (2015) Methodological considerations to determine the effect of exercise on brain-derived neurotrophic factor levels. Clin Biochem 48:162–166. doi: 10.1016/j.clinbiochem.2014.11.013

Pareja-Galeano H, Brioche T, Sanchis-Gomar F, et al (2013) Impact of exercise training on neuroplasticity-related growth factors in adolescents. J Musculoskelet Neuronal Interact 13:368–71

Park H, Poo M (2013) Neurotrophin regulation of neural circuit development and function. Nat Rev Neurosci 14:7–23. doi: 10.1038/nrn3379

Phillips C, Baktir MA, Srivatsan M, Salehi A (2014) Neuroprotective effects of physical activity on the brain: a closer look at trophic factor signaling. Front Cell Neurosci 8:170. doi: 10.3389/fncel.2014.00170

Phillips LRS, Parfitt G, Rowlands A V. (2013) Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. J Sci Med Sport 16:124–128. doi: 10.1016/j.jsams.2012.05.013

Sawyer SM, Afifi RA, Bearinger LH, et al (2012) Adolescence: a foundation for future health. Lancet 379:1630–1640. doi: 10.1016/S0140-6736(12)60072-5

287 Serra-Millàs M (2016) Are the changes in the peripheral brain-derived neurotrophic factor levels
288 due to platelet activation? World J Psychiatry 6:84. doi: 10.5498/wjp.v6.i1.84
289 Tanner JM, Whitehouse RH (1976) Clinical longitudinal standards for height, weight, height
290 velocity, weight velocity, and stages of puberty. Arch Dis Child 51:170–179
291 Whiteman AS, Young DE, He X, et al (2014) Interaction between serum BDNF and aerobic fitness
292 predicts recognition memory in healthy young adults. Behav Brain Res 259:302–312. doi:
293 10.1016/j.bbr.2013.11.023
294 WHO. (2010) Global Recommendations on Physical Activity for Health. World Health
295 Organization. Geneva. Switzerland.
296 http://apps.who.int/iris/bitstream/10665/44399/1/9789241599979_eng.pdf
297
298

Table 1. Characteristics of the study sample by sex (n=234).

Variable	**All (n=234)**	**Boys (n=132)**	**Girls (n=102)**	**p**
Demographics				
Age (y) [a]	13.9 ± 0.3	13.9 ± 0.3	13.9 ± 0.3	0.71
Tanner stages [b]				
Stage 2	18 (8)	13 (10)	18 (8)	
Stage 3	82 (35)	43 (33)	82 (35)	
Stage 4	107 (46)	55 (42)	107 (46)	
Stage 5	25 (11)	19 (14)	25 (11)	
Anthropometry [a]				
Height (cm)	163.1 ± 8.0	164.7 ± 8.5	160.9 ± 6.6	**0.00**
Weight (kg)	54.0 ± 8.8	54.3 ± 8.9	53.6 ± 8.8	0.25
BMI (kg/m^2)	20.2 ± 2.6	19.9 ± 2.2	20.6 ± 2.9	0.07
PA (min/day) [a]				
Total PA	275.0 ± 74.2	277.2 ± 73.6	272.0 ± 75.1	0.23
Light PA	179.5 ± 58.0	176.8 ± 59.0	183.1 ± 56.7	0.21
Moderate PA	81.4 ± 24.3	84.2 ± 23.7	77.9 ± 24.8	**0.00**
Vigorous PA	14.0 ± 8.1	16.3 ± 7.5	10.9 ± 7.8	**0.00**
MVPA	95.4 ± 28.3	100.5 ± 27.2	88.9 ± 28.4	**0.00**
BDNF (pg/ml) [a]	251.8 ± 113.5	254.1 ± 111.7	248.9 ± 116.1	0.69

Data are presented as [a] mean ± standard deviation, [b] frequency (%). Differences between sexes were examined by independent *t*-test.

BMI: body mass index; PA: physical activity; MVPA: moderate and vigorous physical activity; BDNF: Brain-derived neurotrophic factor.

299

300

Table 2. Partial correlation between BDNF and PA variables (n=234).

	Total PA	Light PA	Moderate PA	Vigorous PA	MVPA
BDNF	-0.02	-0.01	-0.06	0.05	-0.04
Total PA		**0.95**	**0.75**	**0.28**	**0.73**
Light PA			**0.50**	0.10	**0.47**
Moderate PA				**0.34**	**0.97**
Vigorous PA					**0.55**

Data are presented in the correlation coefficient *R*. Values in bold indicate significant results with $p<0.001$. Analyses controlled for age, sex, pubertal status, BMI, sport participation and frequency of training.

PA: physical activity; MVPA: moderate and vigorous physical activity; BDNF: Brain-derived neurotrophic factor

301

302

303

Table 3. Linear regression analyses between PA and BDNF.

	Boys (n=132)			Girls (n=102)		
	β	**95% CI**	**P**	**B**	**95% CI**	**P**
Total PA	-0.05	-0.54; 0.28	0.53	0.07	-0.30; 0.68	0.44
Light PA	-0.06	-0.53; 0.26	0.49	0.06	-0.32; 0.63	0.52
Moderate PA	-0.04	-0.40; 0.25	0.64	0.15	-0.36; 0.41	0.88
Vigorous PA	0.07	-0.11; 0.23	0.48	0.15	-0.06; 0.25	0.24
MVPA	-0.03	-0.37; 0.27	0.76	0.06	-0.28; 0.49	0.59

Data are presented as standardized β and 95% CI. Analyses were adjusted for age, pubertal status, BMI, sport participation and frequency of training.

PA: physical activity; MVPA: moderate and vigorous physical activity; BDNF: Brain-derived neurotrophic factor; CI: confidence intervals.

304