

Motor competence moderates relationship between moderate to vigorous physical activity and resting EEG in children with ADHD

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ABSTRACT

Background: Children with ADHD display abnormal electroencephalographic (EEG) activity, in particular an elevated theta to beta ratio (TBR) during the resting state.

Aims: To assess whether the motor competence (MC) and moderate-to-vigorous physical activity (MVPA) were associated with TBR, and whether MC moderated the relationship between MVPA and TBR.

Methods: Data from a total of 73 children with ADHD (69 boys and 4 girls, mean age = 9.92 years, SD = 1.56 years) were analyzed. EEG readings were taken as participants rested with their eyes open. MC was assessed using the Movement ABC-2 measure, and MVPA was evaluated using an ActiGraph accelerometer.

Results: MC was negatively associated with TBR, and an interaction between MVPA and MC on TBR was observed. It was found that there was a negative correlation between MVPA and TBR in those with high MC, whereas the relationship was positive in those with low MC.

Conclusions and implications: The current study found that increased MC was associated with less deviant cortical activity in the resting state, as measured by TBR, and that MC moderated the relationship between MVPA and TBR after controlling for age. It highlights the importance of increasing motor competence within physical activity to improve cortical functioning of children with ADHD.

1. Introduction

According to the hypo-arousal model (Lubar, 1991; Satterfield & Cantwell, 1974), children with ADHD often display an elevated theta-to-beta ratio (TBR) during the resting state due to dysfunction in the brain's ascending reticular activation system (ARAS) (Saad, Kohn, Clarke, Lagopoulos, & Hermens, 2018; Snyder & Hall, 2006). This has been interpreted as a state of impaired sensory function, which in turn causes several symptoms such as inattention, impulsivity, and hyperactivity (Barry, Clarke, & Johnstone, 2003; Saad, Kohn, Clarke, Lagopoulos, & Hermens, 2018). Studies have also shown that the higher TBR is related to lower executive functions (EFs) (Zhang, Li, et al., 2017; Zhang, Roodenrys, et al., 2017). In addition, studies found that neurofeedback training (NFT) targeting on lowering TBR at Cz site resulted in reduced symptoms (i.e. impulsivity or hyperactivity) and

enhanced EFs in children with ADHD (Bluschke, Broschwitz, Kohl, Roessner, & Beste, 2016; Janssen et al., 2016; Monastra, Monastra, & George, 2002). Thus, to develop an effective strategy to decrease TBR, it's necessary to explore the specific factors that are related to TBR in children with ADHD.

The impairment in sensory processing in children with ADHD could result in hyperactivity behavior, as manifested by more physical activities, in daily life. For example, Lin, Yang, and Su (2013) found that children with ADHD exhibited higher levels of moderate-to-vigorous physical activity (MVPA) than typical development children. However, it should be noted that previous interventional studies that targeted on increasing levels of MVPA with a variety of activities requiring different motor competence (e.g., moving objects to different locations, various forms of locomotion— skipping, running, hopping, crab walking) was found to alleviate inattentive and hyperactivity symptoms in children

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with ADHD (Smith et al., 2013; Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2012). These results suggest that it's not only the quantity and intensity, but also the nature of physical activities (such whether the activities develop motor competence), that moderate the relationship between MVPA and TBR.

MC refers to the degree of proficiency in performing a wide variety of motor skills including both gross (e.g., jumping) and fine (e.g., manual dexterity or precision) motor skills as well as the underlying mechanisms including coordination, control, and quality of movement (Haga, 2008). These processes depend on the thalamus which is responsible for receiving sensory input and sending information to the cortical cortex to execute movements (Sherman, 2016; Sommer, 2003). According to maturational lag and hyper-arousal model, elevated TBR is partly the result of delayed development of the brain's ascending reticular activation system (ARAS) that results in a disturbance in thalamus-cortical transactions (John, 2002; Saad, Kohn, Clarke, Lagopoulos, & Hermens, 2018), which possibly affects MC in children with ADHD (Sherman, 2016; Sommer, 2003). Several studies found that children with ADHD show worse performances on MC than typical development children (TD) (Kaiser, Schoemaker, Albaret, & Geuze, 2015). In addition, Huang et al. (2018) found that children with ADHD demonstrated poorer performances on MC as well as higher TBR relative to TD. Therefore, a negative association between TBR and MC might be expected in children with ADHD.

Considering the close relationship between MC, ARAS function, and TBR in children with ADHD, it is reasonable to speculate that whether MVPA is positively or negatively associated with TBR in children with ADHD may depend on children's MC. Thus, the present study aimed to concurrently examine the relationship among MC, MVPA, and TBR with an emphasis on exploring the possible moderating role of MC. While previous studies relied on parent-reported assessments of PA level which may be inaccurate (Tong, Xiong, & Tan, 2016), the current study utilized objective measures such as accelerometers to record PA levels. Overall, we hypothesized that MC would individually be negatively associated with TBR, and that MC would moderate the relationship between MVPA and TBR, such that negative association between MVPA and TBR would be seen in children with higher MC whereas positive association in children with lower MC.

2. Methods

2.1. Participants

Data used in the present study was derived from a larger project, which was approved by the Research Ethics Committee of National Taiwan Normal University. A total of 90 children with ADHD, ranging in age from 7 to 12 years, were recruited from elementary schools in Taipei from 2013 to December 2014. All participants met the following inclusion criteria: (1) Previously diagnosed as having ADHD by a medical professional; (2) No history of brain injury or neurological conditions such as exhibited epileptic seizures, serious head injuries, or periods of unconsciousness; (3) free of co-morbid conditions such as conduct/oppositional defiant disorder; (4) free of intellectual disability.

2.2. Procedure

Participants visited the laboratory on two separate testing sessions. The two sessions were separated by at least 7 days. Participants were required to refrain from food and drink consumption, except water, for 1.5 h, and be free of medications and behavioral treatments for at least 24 h, prior to each session. During the first session, the experimental procedure was explained to participants and their legal guardians by experimenters. Then the legal guardians were asked to complete a health history, demographics questionnaire, ADHD-T, Chinese version of Child Behavior Checklist (CBCL) for ages 6–18 (Chen, Huang, & Chao, 2006) originally developed by (Achenbach & Rescorla, 2001),

and an informed consent form based on the protocols approved by the Institutional Review Board of National Taiwan Normal University. MC measures were then taken by means of the Movement ABC-2. Afterwards, the participants' height and weight were measured and they were given an accelerometer (RT3 Triaxial) and instructed to wear it for 7 consecutive days. In the second session, participants returned the accelerometer, and were then instructed to sit on a chair in a sound-attenuated testing room where they were fitted with an electrode cap for the electrophysiological (EEG) recordings. After verifying that the EEG signals were below 10 k Ω , participants were instructed to sit calmly for 1 min with their eyes-closed (EC), or eyes-opened (EO) with a fixed gaze, for four sections (OCOC). Since the EO condition has been found to better reflect a more comparable resting state (Barry, Clarke, Johnstone, & Brown, 2009), only EEG from EO condition were analyzed. Participants were given \$20 compensation after they completed the second session.

2.3. Measurement

2.3.1. Movement-ABC-2 (motor competence assessment battery for children)

Motor competence was measured by the Movement ABC-2 measure, which is composed of eight fine and gross motor subtests categorized into three domains: manual dexterity (placing pegs, threading lace, and drawing trials), ball skills (two-hand catch and throwing a beanbag onto a mat) and static and dynamic balance (one-board balance, walking heel-to-toe forward, and hopping on mats), and has been found to have a composite score reliability coefficient of 0.80 and coefficients ranging from 0.73 to 0.84 for its three sub-component scores: manual dexterity, aiming and catching, and balance. Total scores was converted into age-adjusted standard scores (Henderson, Sugden, & Barnett, 2007).

2.3.2. Moderate-to-vigorous physical activity (MVPA) assessment

Physical activity was measured with a triaxial Actigraph accelerometer model wGT3X+ (ActiGraph GT3x+, Pensacola, FL, USA) (Trost, Pate, Freedson, Sallis, & Taylor, 2000). The Actigraph accelerometer has generated a substantial amount of research attention and is one of the most widely used measures of physical activity in young people (Trost, Loprinzi, Moore, & Pfeiffer, 2011). Participants were instructed to wear the accelerometer on their waist with an elastic, nylon belt for seven complete days during their waking hours except when participating in water activities (e.g., bathing, swimming, showering) (Trost et al., 2000). To participate in the current study, it was necessary to provide a minimum of 3 weekdays and 1 weekend day of data, with at least 7 h of wear time each day (Hinkley et al., 2012). The mean wear time was 534 min/day (SD = 51.32). Data were recorded in epochs of 60 s and output using a 12-bit analog-to-digital converter at a rate of 30 Hz. The volume of PA (mean counts/min), and time spent at different intensity levels were recorded. Intensity levels were defined as follows: sedentary: < 100 counts/min, corresponding to activities such as lying and sitting; moderate: > 2295 and \leq 4011 counts/min, reflecting brisk walking; vigorous: \geq 4012 counts/min (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008), which is comparable with measures used in other field-based studies (Trost et al., 2011). MVPA was assessed in terms of the total amount of moderate and vigorous PA per day.

2.3.3. Electrophysiological recording and analyzing

Electroencephalographic (EEG) activity was recorded at 30 sites using an elastic electrode cap (Quick-Cap; Compumedics Neuroscan, Inc., Charlotte, NC, USA). The electrode sites were mounted according to the modified International 10–20 System (Chatrian, Lettich, & Nelson, 1985). Electro-oculographic (EOG) activity was collected from electrodes placed above and below the left eye and at the outer canthus of each eye. A ground electrode was attached to the middle of the

forehead, and all electrodes were referenced to linked ears (e.g., A1 and A2). All electrode impedances were below 10 k Ω . The electrical signals were digitized with a sampling rate of 500 Hz using a DC-to-100 Hz filter. In addition, a 60-Hz notch filter was applied during the data acquisition. During data processing, the EEG data were filtered using a band-pass filter from 1 Hz to 30 Hz (12dB/oct), and EOG were corrected using an algorithm by developed by an algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986). Continuous EEG data were segmented into 2-s epochs. After baseline-correction based on the entire sweep, epochs with amplitudes outside the range of $\pm 75 \mu\text{V}$ were excluded. The mean epoch was 43.29 ± 12.25 . The cleaned EEG data were Fast Fourier transformed to provide power estimates for the theta (4–7.5 Hz) and beta (13.5–25 Hz) bands. In the present study, theta/beta ratio (TBR) was calculated at the Cz site, which has been found to be the most sensitive area in terms of its ability to distinguish between ADHD and normally developing children (Markovska-Simoska & Pop-Jordanova, 2017; Monastra et al., 1999).

2.4. Statistical analysis

Means and standard deviations were calculated for all data. In an effort to identify significant covariates, Pearson correlations were conducted between demographic variables, age, CBCL-AAA profile, BMI (Body mass index), Socioeconomic status (SES), and MVPA, MC and TBR. CBCL-AAA profile is defined as positive by as T-scores on the sum of the Attention, Aggression, and Anxious/Depressed CBCL scales, which can be clinically useful in distinguishing between children with varying levels of deficits (Biederman et al., 2012). SES based on Hollingshead's two-factor index, which was computed based on the following formula: (occupation score * 7) + (education score * 4). Lower scores corresponded to higher socioeconomic status (Hollingshead, 1957, pp. 351–359). To test the hypothesis that whether MC moderates the relationship between MVPA and TBR, each variable was transformed into a Z-score and a 4-step hierarchical regression analysis was performed with TBR as the dependent variable. In the first step, all demographic variables with a significant relationship with TBR were entered into the equation. The second, third, and fourth steps then added MVPA, MC, and the MC \times MVPA interaction term respectively. To interpret the interaction effect, we conducted simple slopes analysis based on previous work (Hayes & Matthes, 2009).

Independence between variables was defined by a Durbin-Watson statistic between 1.5 and 2.5 and collinearity was considered judged by whether the Variance Inflation Factor was less than 10 (Mason & Perreault Jr, 1991). According to Harris' rule-of-thumb, the final sample size of 73 was sufficient to detect a medium size effect (.13) in a regression analysis (Green, 1991), which is similar to Cohen's criteria with alpha set at .05, and power set to .08 ($n = 74$). All statistical analyses were performed using SPSS® version 23.0 (IBM Corporation, Armonk NY, USA) for Windows®, with the level of significance set at $\alpha = .05$.

3. Results

3.1. Demographic analyses

Of the originally recruited 90 participants, 17 were excluded from analysis due to: (1) having less than 4 valid days of accelerometer data ($n = 7$); (2) missing accelerometer data ($n = 8$); (3) poor EEG data ($n = 2$). The remaining 73 participants consisted of 69 boys and 4 girls; 36 children were being treated with methylphenidate (e.g. Ritalin, Concerta) that is a central nervous stimulant to increase dopamine levels in the brain (Kimko, Cross, & Abernethy, 1999); 30 diagnosed as ADHD-I, 5 as ADHD-H, and 38 as ADHD-C. 61.4% of children with ADHD had an aggregate cut-off score of > 180 but < 210 (1SD), 16.4% of children with ADHD had an aggregate cut-off score of ≥ 210 on the A-A-A scales of the CBCL. The M-ABC-2 total standard score was greater

Table 1
Demographic and physical characteristics of the participants ($n = 73$).

Characteristics.	Mean (\pm SD)	Ranges	Median
Age (years)	9.96 (\pm 1.58)	7–12	10
CBCL-AAA	193.12 (\pm 19.54)	150–238	193
BMI	17.89 (\pm 3.02)	12.57–25.78	17.91
SES	28.72 (\pm 6.02)	18–47	29
MVPA (min/day)	27.57 (\pm 16.89)	2.57–94.3	23.14
MC (standard scores)	10.84 (\pm 2.99)	6–19	11

Note: CBCL-AAA = Anxiety/Depression, Aggression, and Attention (A-A-A) scales. BMI-D = Body mass index.
SES = Socioeconomic status.

than 5 (i.e. the 5th percentile) indicating an absence of significant MC problems. Descriptive characteristics of participants are presented in Table 1.

3.2. Multiple regression results

The preliminary correlation analysis showed that age ($r = -.427$, $p < .001$) and MC ($r = -.231$, $p < .05$) were significantly correlated to TBR, but CBCL-AAA, BMI-D, SES, MVPA were not ($p > .05$) (see Table 2). As a result, only age was entered in the initial step of the hierarchical regression analyses, age ($\beta = -.178$, $p < .001$) and it was found to account for 18.5% of the total variance of TBR ($R^2 = .183$, $F(1, 71) = 15.876$, $p < .001$). In step 2, the addition of MVPA ($\beta = .014$; $p > .05$) explained almost no additional variance after controlling for age ($R^2 = .184$, $F(1, 70) = 0.94$; $p = .760$). In step 3, MC ($\beta = -.093$; $p < .05$) was found to contribute an additional 4.8% of variance after controlling for age and MVPA ($R^2 = .232$, $F(1, 69) = 4.326$; $p < .05$). In step 4, the interaction variable MC \times MVPA was also shown to be significantly associated with TBR ($\beta = -.132$; $p < .05$), ($R^2 = .285$, $F(1, 68) = 5.121$; $p < .05$). Hierarchical regression analyses result was shown in Table 3. In addition, a test of the slope of the regression line between TBR and MVPA found to be greater for ADHD children with lower MC scores. ($t = -1.168$, $p < .05$) (see Fig. 1). To disaggregate the MVPA \times MC interaction, participants were divided into High MC (Mean = 8.38, SD = 1.26) and Low MC (Mean = 12.97, SD = 2.33) groups based on whether their standard scores were above or below the median score and the correlation analysis was then repeated. These results showed that MVPA was negatively related to TBR under high MC conditions ($r = -.291$, $p < .05$), and positively related to TBR under low MC conditions ($r = .582$, $p < .001$).

3.3. Further exploratory calculations

To examine whether medicine use and ADHD-type affected our results, student's t-test, and analysis of variance (ANOVA) analyses, respectively, were carried out. The results showed that there were no significant difference in TBR ($t(71) = .266$; $p = .791$) between participants taking and not taking medication, or among ADHD subtypes ($F(2, 70) = .844$; $p = .434$).

Table 2
Pearson correlation results ($n = 73$).

Variables	Age	CBCL-AAA	BMI	SES	MVPA	MC
TBR	-.427**	.095	-1.87	-.142	-.012	-.231*
AGE		-.306*	-.350**	.055	.105	.052
CBCL-AAA			-.357**	-.141	-.015	-.263*
BMI				-.013	.115	-.043
SES					-.010	-.020
MVPA						.171

* = $p < .05$; ** = $p < .001$.

Table 3
Hierarchical regression analyses results (n=73).

Model		Unstandardized Coefficients		Standardized Coefficients	Collinearity Statistics		R Square Change	F Change	Durbin-Watson
		B	Std. Error	Beta	Tolerance	VIF			
1	Z(AGE)	-.178**	.045	-.427**	1	1	.182	15.876	
2	Z(AGE)	-.179**	.045	-.431**	.989	1.011	.001	.094	
	Z(MVPA)	.014*	.045	.033	.989	1.011			
3	Z(AGE)	-.176**	.044	-.424**	.988	1.012	.048	4.326	
	Z(MVPA)	.031	.045	.075	.954	1.048			
	Z(MABC)	-.093*	.045	-.224*	.962	1.039			
4	Z(AGE)	-.148**	.045	-.357**	.914	1.094	.054	5.121	1.607
	Z(MVPA)	.068	.047	.164	.837	1.195			
	Z(MABC)	-.117*	.045	-.282*	.907	1.103			
	MABC*MVPA	-.132*	.058	-.252*	.786	1.272			

a. Dependent Variable: TBR; * = $p < .05$; ** = $p < .001$.

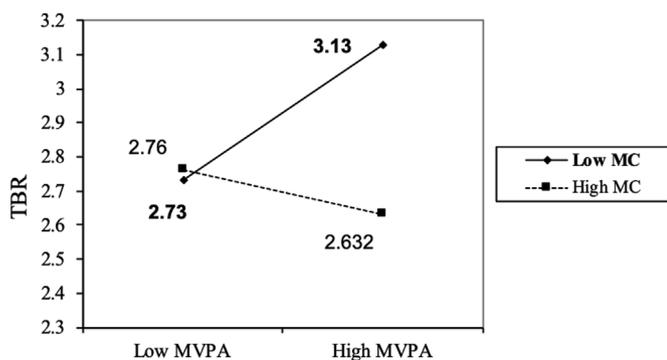


Fig. 1. Simple slope test: MVPA × MC interaction with TBR.

4. Discussion

The aim of this study was to investigate whether MVPA and MC were associated with TBR, and whether MC moderated the relationship between MVPA and TBR in children with ADHD. Results indicated that there was a negative association between MC and TBR, and that MC moderated the relationship between MVPA and TBR while controlling for age. Specifically, MVPA is negatively related to TBR in children with ADHD with high MC, whereas there was a positive relationship in those with low MC.

The findings that, after controlling for age, MC is negatively related to TBR was consistent with expectations. Elevated TBR is partly the result of delayed development of the brain's ascending reticular activation system (ARAS) that results in a disturbance in thalamus-cortical transactions (Castro-Alamancos, 2002; John, 2002; Lubar, 1991). This dysfunction affects motor control that relies on the brain-thalamus relay structure to receive sensory input and send this information on to the cortex (Sherman, 2016; Sommer, 2003) Since children with ADHD often have lower MC and higher TBR than normal children (Huang et al., 2018; Markovska-Simoska & Pop-Jordanova, 2017; Pitcher, Piek, & Hay, 2003), the present findings provides more support for a link between MC and TBR in children with ADHD. Given the close relationship between TBR and EF (Loo et al., 2013; Zhang, Li, et al., 2017; Zhang, Roodenrys, et al., 2017), our findings provide an understanding of the positive association between MC and EF in children with ADHD (Hung et al., 2013; Zierys & Jansen, 2016). Increased theta activity, along with decreased beta activity, in those with ADHD may lead to an inefficient cortical state (e.g., hypo-arousal and inattention) (Barry et al., 2003; Mann, Lubar, Zimmerman, Miller, & Muenchen, 1992), which impairs EF performances. Rectifying this state seems to improve EF. For example, Bluschke et al. (2016) found that children with ADHD produced fewer 'No-go' false alarms after neurofeedback intervention aimed at decreasing TBR. These results not only demonstrate the importance of TBR as an indicator of EF performance, but also imply that

MC may be used as a means of normalizing TBR in children with ADHD.

MVPA itself was not related to TBR but was associated with TBR through the moderation of MC, which partially supported this study's hypothesis. Previous findings on the relationship between MVPA recorded by accelerometers and cognitive function have been inconsistent (Gapin & Etnier, 2010; Pindus et al., 2016) which may reflect a failure to account for the effects of MC.

MVPA was found to be negatively related to TBR in those with high MC, whereas a positive relationship was observed in those with low MC. The former result is consistent with expectations since there is considerable evidence that exercise intervention program involving MVPA within a framework of activities that employed a variety of movement skills is beneficial to cognitive performances, MC, and behavior regulations in children with ADHD (Chang, Hung, Huang, Hatfield, & Hung, 2014; Smith et al., 2013; Verret et al., 2012). Recent studies showed that chronic MC-related exercise training (i.e. gymnastics or Tai Chi Chuan) had a general facilitative effect on executive functions in TD (Hsieh, Lin, Chang, Huang, & Hung, 2017) as well as in older adults (Wu et al., 2018). Liu et al. (2018) revealed that exercise intervention requiring aerobic and MC components (i.e. jump rope) is an effective approach to improve inhibitory control in obesity adolescents. The similar effect was found in a single bout of exergaming physical activity intervention in children with ADHD (Benzing, Chang, & Schmidt, 2018). In addition, Schmidt, Jäger, Egger, Roebbers, and Conzelmann (2015) found that a team ball exercise intervention involving both MC and aerobic fitness resulted in a greater benefit to EF than those involving aerobic exercise alone in TD. Although the present study measured cortical states instead of task performance, the current findings provide preliminary evidence that, for children with ADHD, MC contributes to the relationship between MVPA and cognitive function.

On the other hand, the finding of a positive relationship between MVPA and TBR for those with low MC is worth to be noted. Children with ADHD are characterized by deficits in sensory function and hyperactivity and, according to the hypo-arousal model, this should result in elevated TBR (Lubar, 1991; Satterfield & Cantwell, 1974). Lin et al. (2013) found that children with ADHD exhibited higher MVPA than TD, and an association between poorer sensory modulation and higher MVPA was observed in children with ADHD. Given that the current study found a negative correlation between TBR and MC, one possibility is that MVPA reflected a greater level of hyperactivity in those with lower MC, probably as a result of delayed maturation of the ARAS and cortical-thalamus transactions.

Several factors should be considered in interpreting the current study. First, the cross-sectional design employed precludes causal inferences. Nevertheless, this work lays the foundation for future longitudinal or experimental studies to examine the possibility of ameliorating aspects of ADHD - related cortical dysfunction through motor skill training.

Secondly, although we followed criteria for standard analysis of accelerometer data such as data from a minimum of 3 weekdays and 1 weekend, and at least 7 h of wear time on each day (Hinkley et al., 2012), the total average of accelerometer wear time (534 min/day) was lower than previous study (816 min/day) (Herman et al., 2014), which could partly explain the low levels of MVPA in our data. Therefore, the participants who were with high level of MVPA should be further examined.

Thirdly, there is a possibility that the medication being taken by participants acted as a confounding factor due to differences in their type and dose levels. Nevertheless, participants were required to refrain from medication for at least 24 h prior to the study, which is greater than 6 half-lives for methylphenidate (Kimko et al., 1999). While additional analyses showed no difference in TBR between participants with and without medicine use. Therefore, the confounding effect of medication could have been mitigated in the current study. Finally, TBR may differ by ADHD subtype (Loo et al., 2013). Further analyses showed no difference in TBR among ADHD subtypes; it should be noted that only five participants were diagnosed with ADHD-H in the current study and this may have been too small a sample to detect differences in this specific subtype.

Finally, although the M-ABC measurement can be used in educational settings (Cools, De Martelaer, Samaey, & Andries, 2009; Griffiths, Toovey, Morgan, & Spittle, 2018), and has high internal consistency ($\alpha = .90$), and intraclass correlation coefficient (.97) with the subject population (Wuang, Su, & Su, 2012), it is limited on explicitly assessing all MC components due to fewer measurement items, especially fine motor competence relative to other measurement (e.g. BOT-2) (van Hartingsveldt, de Groot, Aarts, & Nijhuis-Van Der Sanden, 2011).

In conclusion, the current study found that increased MC was associated with less deviant cortical activity in the resting state, as measured by TBR, and that MC moderated the relationship between MVPA and TBR after controlling for age. The current study highlights the importance of increasing MC demand within MVPA activity to improve cortical functioning of children with ADHD, and, as such, has practical implications for physical activity experts and education specialists.

Declaration of competing interest

All authors report no potential conflict of interest. We declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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