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Research paper

The role of physical activity in the association between ADHD and emotional dysregulation

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ABSTRACT

Background: Emotional dysregulation (ED) represents a burden for individuals with ADHD. Physical activity (PA) is associated with improvements in emotion regulation, but knowledge is limited regarding its role in ED in the context of ADHD. This study aimed to increase understanding of the association between ADHD and ED and to explore the role of PA. Identifying modifiable risk factors could aid the design of future interventions.
Methods: Children from the Swedish Twin Registry were included. ADHD symptoms and PA intensity and frequency were measured using parent-reported questionnaires at age 9/age 12. ED was assessed through questionnaires at age 15. The association between ADHD and ED was assessed through linear GEE regression models. Interaction terms and stratified analyses by level of PA were used to explore the role of PA. Analyses were done separately for boys and girls.
Results: 12,094 children (52 % girls) were included. A positive association between ADHD symptoms and ED remained significant after adjusting for mental comorbidities and unmeasured family-shared confounders ($\beta = 0.07$, 95% CI 0.02–0.12 in boys; $\beta = 0.09$, 95% CI 0.02–0.16 in girls). The association was driven by inattention in boys but combined symptoms in girls. The association remained in all strata of PA. A significant interaction between PA frequency and ADHD symptoms was observed among boys ($p = 0.02$).
Limitations: Results were based on parent-reported PA; findings might differ with sensor-based measurements.
Conclusion: Higher ADHD symptoms in childhood were associated with greater ED in adolescence in all PA levels. Low PA frequency intensified the association among boys.

1. Background

Attention Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental disorders, prevalent in around 4–6 % of children and adolescents worldwide (Cortese et al., 2023). ADHD is characterized by its core symptoms of inattention, hyperactivity, and impulsivity, which reduce the individual's functionality in several life domains (Posner et al., 2020). Although ADHD is treatable, it is still associated with several adverse outcomes, such as higher mortality, higher risk of injuries, mental comorbidities, sleeping disorders, reduced quality of life, and negative labor market outcomes (Bijlenga et al., 2013; Helgesson et al., 2021; Katzman et al., 2017; Nigg, 2013). Besides the core symptoms, individuals with ADHD usually present other difficulties in higher cognitive domains, including difficulties in emotion regulation (Graziano and Garcia, 2016).

Several concepts and labels have been used to refer to difficulties in emotion regulation; one of the most common terms is emotional dysregulation (ED). ED is considered a transdiagnostic trait, which encompasses emotional hyperreactivity, emotional lability, and poor control of attention to emotional stimuli (Shaw et al., 2014). Although ED is not unique to ADHD (England-Mason, 2020; Shaw et al., 2014), ADHD diagnosis has the strongest association with ED compared to other mental disorders (Astenvald et al., 2022). Among individuals with ADHD, ED is associated with higher functional impairments, lower quality of life, and poorer treatment response (Bunford et al., 2015; Faraone et al., 2019; Schreiner et al., 2022). In addition, stimulants and

Abbreviations: A-TAC, Autism–Tics, AD/HD and other Comorbidities inventory; ED, emotional dysregulation; CATSS, The Child and Adolescent Twin Study in Sweden; PA, physical activity; SDQ, Strengths and Difficulties Questionnaire.

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non-pharmacological interventions have small to moderate effects on ED in children and adolescents with ADHD (Faraone et al., 2019; Guo et al., 2022; Lenzi et al., 2018). Since ED represents a burden in ADHD and its treatment remains challenging, it is essential to increase the understanding of this association and find factors that influence the presentation of ED in individuals with ADHD.

The association between ADHD and ED might be dependent on age and type of ADHD symptoms. The relationship between ADHD and ED has been typically studied in children (van Stralen, 2016), with results showing a pronounced association. However, it has been suggested that this relationship could change in adolescents (Bunford et al., 2015), as previous studies have reported an increase in emotion regulation strategies (Sanchis-Sanchis et al., 2020) and a reduction of ED (Biederman et al., 2012) with increased age. Thus, it is relevant to explore if childhood ADHD symptoms are continuously associated with ED in adolescence. In addition, it is unclear whether specific ADHD traits drive the association between ADHD and ED. In a meta-analysis, they could not explore if the ADHD subtype was moderating the association since most previous studies had not analyzed this, mainly due to limited sample sizes (Graziano and Garcia, 2016). More recent studies report mixed findings. In adults, inattention and impulsivity were associated with ED (Hirsch et al., 2018), and combined ADHD had a stronger association with ED compared to the other subtypes (Hirsch et al., 2019). In contrast, among children and adolescents, only hyperactivity predicted ED (Groves et al., 2020), and there was no difference between ADHD subtypes (Bunford et al., 2018). Further research is needed to clarify if specific ADHD symptoms drive the association in this age group.

The development of children with ADHD symptoms may be affected by environmental factors and lifestyle. Physical activity (PA) could be a factor influencing the association between ADHD and ED, but knowledge is limited in this regard. In adult populations without mental disorders, PA measured by accelerometry has been associated with improvements in emotion regulation (Vasilopoulos and Ellefson, 2021). Likewise, aerobic exercise of moderate intensity (Bernstein and McNally, 2017) and aerobic exercise with mindfulness (Norouzi et al., 2023) had a positive effect on emotion regulation. However, no effect has also been observed (Edwards et al., 2018). Different mechanisms have been proposed to explain the effect of PA on emotion regulation, such as improvement of self-efficacy, cognitive control (Bernstein and McNally, 2017), and prefrontal cortex activation (Vasilopoulos and Ellefson, 2021) Hence, exploring if PA influences ED in the context of ADHD is warranted.

The relationship between PA and ADHD is complex, and associations in both directions have been reported. Individuals with ADHD have shown lower PA and participation in sports (Khalife et al., 2014; Kim et al., 2011). However, accelerometry data showed that children with ADHD had higher PA levels than children without ADHD (Villalba-Heredia et al., 2022). Furthermore, some intervention studies report an acute effect of PA reducing ADHD symptoms (Cerrillo-Urbina et al., 2015; Neudecker et al., 2019; Rommel et al., 2015; Xie et al., 2021). Nonetheless, no effect has also been reported, and the long-term effect of PA in ADHD symptoms is unclear (Cerrillo-Urbina et al., 2015; Neudecker et al., 2019). In addition, it is not clear whether PA frequency and intensity influence these associations (Neudecker et al., 2019). This variation in results has been attributed to the large heterogeneity of methodological designs, small sample sizes, and type of PA (Den Heijer et al., 2017).

This study aimed to increase understanding of the association between childhood ADHD symptoms and ED during adolescence. In addition, we aimed to explore the role of PA intensity and frequency in this association. The questions we aimed to answer are: 1) What is the association between childhood ADHD symptoms and ED during adolescence? 2) Does this association vary when analyzing ADHD core symptoms (inattention and hyperactivity) separately? and 3) Does the association vary across levels of PA intensity and frequency? We hypothesized that there is a positive association between ADHD symptoms and ED; higher ADHD symptoms are associated with greater ED. In addition, we hypothesize that this association is stronger in girls than boys, as female sex has been associated with higher ED and emotional symptoms (Astenvald et al., 2022; De Ronda et al., 2023; Robison et al., 2008). We further hypothesized that inattention symptoms are driving the association between ADHD and ED since attention is involved in emotion generation (Gross and Jazaieri, 2014) and use of emotion regulation strategies (Pe et al., 2013) Regarding PA level, we hypothesized that the association weakens as the PA intensity and frequency increase. Increasing the understanding of the association between ADHD and ED, as well as identifying modifiable environmental factors that could influence this association, is essential. This could aid in developing future therapeutic and preventive public health interventions.

2. Methods

In this population-based study, data from the Child and Adolescent Twin Study in Sweden (CATSS) cohort was used. The CATSS is an ongoing nationwide twin study that started in 2004 and includes all twins born in Sweden from July 1992 and onwards. Parents are invited to participate in the study when the twins turn nine years old; however, during the first three years of the study, 12-year-old twins were also recruited. Data is collected at baseline (age 9 or 12) and three follow-up waves (ages 15, 18, and 24). A detailed description of the CATSS has been previously published (Anckarsäter et al., 2011; Zagai et al., 2019). For this study, data was retrieved in August 2022, including children who had completed the assessment at baseline and the first follow-up wave. Participants were excluded if they had missing data on psychiatric symptoms at baseline or on emotional symptoms at follow-up.

2.1. Emotional dysregulation

ED was measured at age 15, through self-reports of the Strengths and Difficulties Questionnaire (SDQ). The SDQ is a validated questionnaire used for assessing the psychological adjustment of children aged four to 17 years (Goodman, 1997, 2001), and was developed as a shorter alternative to the Child Behavioral Checklist (CBCL). The SDQ has satisfactory reliability and validity with values of the area under the receiver operating characteristics (ROC) curves of 0.78 to 0.93 (Goodman, 1997, 2001), with similar values in the Swedish population (Malmberg et al., 2003). This questionnaire comprises 25 items, divided into five scales: emotional symptoms, conduct problems, hyperactivity, peer problems, and prosocial behavior. Each item can be answered on a 3-point Likert scale: “not true”, “somewhat true”, and “certainly true”, and for each subscale, the score can range from 0 to 10. The SDQ is a copyright document; more information can be found on the SDQ website (https://www.sdqinfo.org/).

A “dysregulation profile” was used as a proxy for ED. The dysregulation profile was developed based on the CBCL; however, it can also be derived from the SDQ, and this has been validated in previous studies (Levantini et al., 2024; Deutz et al., 2018; Kunze et al., 2018). This is assessed using three scales of the SDQ: emotional symptoms, conduct problems, and hyperactivity. Conduct problems are included in the dysregulation profile since aggression and behavior problems may reflect dysregulation (Graziano and Garcia, 2016; Levantini et al., 2024). Since this study is focused on ADHD, the hyperactivity scale was excluded to avoid double measurement of the same symptoms, as done in a previous study (Astenvald et al., 2022). In this study, the ED score could range from 0 to 20 and was analyzed as a continuous variable.

2.2. ADHD

ADHD symptoms were assessed at baseline (age 9 or 12) through parental reports of the Autism—Tics, AD/HD, and other comorbidities inventory (A-TAC). The A-TAC is a validated screening instrument for neurodevelopmental disorders and associated conditions, developed by the University of Gothenburg in Sweden (Hansson et al., 2005; Larson et al., 2010). The A-TAC is a telephone interview of 96 "gate" items divided into different modules. It has a good interrater and test-retest reliability (Larson et al., 2014), and has been validated in the Swedish population with values of the area under the ROC curves ranging from 0.77 to 0.91 (Larson et al., 2013). All items can be answered with "No" scored as 0, "Yes to some extent" scored as 0.5, and "Yes" scored as 1. The presence of ADHD symptoms is assessed through two modules: concentration/attention (9 items) and impulsiveness/hyperactivity (10 items). A detailed description of the A-TAC can be found on the University of Gothenburg website.

According to population-based studies, two cut-off points can be used to identify individuals with high ADHD symptoms: a low cut-off point (≥6 points) with high sensitivity (0.95) and a high cut-off point (≥12.5 points) with high specificity (0.95) (Larson et al., 2010, 2013; Mårland et al., 2017). For the descriptive statistics and exploratory analyses, the low cut-off point was used to categorize individuals with low or high ADHD symptoms. However, in the primary analysis, ADHD symptoms were treated as a continuous variable, with a score ranging from 0 to 19. When inattention and hyperactivity symptoms were assessed separately, both were treated as continuous variables, with inattention scores ranging from 0 to 9 and hyperactivity scores ranging from 0 to 10.

2.3. Physical activity

The level of PA during childhood was derived from parental reports at baseline. PA intensity and frequency were approximated using two questions: 1) How often does your child exercise/work out in his/her spare time? and 2) How much does your child exercise? My child exercise… [give examples]. The answer options and the categorization of PA level based on these answers are depicted in Table 1a (see Appendix). The PA questions in the CATSS cohort have not been validated. PA intensity and frequency were categorized into low, moderate, and high. This categorization has been used in a previous study (Wiklund et al., 2024).

2.4. Covariates

Sex, age at baseline, and mental comorbidities were included as covariates. Sex was chosen as a covariate because ADHD is more commonly diagnosed in boys than in girls (Ramtekkar et al., 2010), and it has been suggested that this is due to differences in the diagnostic process and clinical presentations (Babinski, 2024; Mowlem et al., 2019). Furthermore, PA habits (Brazo-Sayavera et al., 2021) and ED (Astenvald et al., 2022) differ between boys and girls. Sex was defined as the "sex assigned at birth", which is based on biological attributes and considered a binary variable (boys/girls).

Based on previous literature, age at baseline and mental comorbidities were chosen as confounders (Corbisiero et al., 2017; Graziano and Garcia, 2016). Additionally, adjustment for mental comorbidities at baseline was done as a way to control for ED at baseline. Age at baseline was treated as a binary variable (age 9/age 12). Mental comorbidities were analyzed as a binary variable (yes/no) and defined as having any neurologic or psychiatric diagnosis other than ADHD. Mental comorbidities were assessed through two questions at baseline: 1) has your child been diagnosed with psychiatric or neurological problems by a doctor, psychologist, or similar person? and 2) What diagnoses did your child get diagnosed with? The diagnoses included in this definition were: eating disorders, autism, cerebral palsy, developmental coordination disorder, depression, dyslexia, chronic motor/vocal tics, obsessive-compulsive disorder, and anxiety.

2.5. Statistical analysis

Baseline characteristics of the study population were summarized by sex and level of ADHD symptoms. Frequencies and proportions were calculated for age at baseline, mental comorbidities, and levels of PA. Additionally, mean and standard deviations of ED at age 15 were calculated separately for boys and girls. Differences between groups were assessed using Chi-square tests for categorical variables and the Wilcoxon sign-rank test for continuous variables. Regression models were performed to determine the association between covariates and ED.

To assess the association between ADHD symptoms and ED, linear regression models in the generalized estimating equations (GEE) framework were used with a robust sandwich estimator to account for the clustered nature of twin data. GEE models were preferred as they make no distributional assumptions about the data. Two models were fitted, Model 1 adjusting for clustering and Model 2 further adjusting for age and mental comorbidities. Regression coefficients, p-values, and 95 % confidence intervals (CI) were calculated. Analyses were repeated, treating inattention and hyperactivity as separate exposures.

To explore the role of PA in the association between ADHD and ED, stratified analyses by the three levels of PA intensity and PA frequency were performed. Regression coefficients, p-values, and 95 % CI were calculated based on Model 2. In addition, an interaction term was added to the regression models for the interaction between ADHD and PA. Interactions were considered significant if the interaction term had a p-value < 0.05. When a significant statistical interaction was observed, further exploratory analyses were performed following the recommendations on interaction analyses (Knol and VanderWeele, 2012).

Since ADHD is highly heritable (Palladino et al., 2019), studying the interplay of ADHD and PA on ED while controlling for familial confounding factors is warranted. Thus, besides the analysis across individuals, within-twin pairs analysis was performed by repeating all steps using conditional linear GEE regression models. This analysis accounted for all the unmeasured family-shared confounders, including genes and shared environment. Since all analyses were done separately for boys and girls, only monozygotic twins and same-sex dizygotic twins were included in the within twin pairs analyses. The package "drgee" in R was used for all analyses.

2.6. Ethical considerations

Ethical approval for this study was obtained from the Regional Ethics Review Board in Stockholm, reference number 2016/2135-31. Data has been pseudonymized to avoid identification of the individuals. Additionally, data was stored in a secure environment with access restricted to the people involved in this research project. Individuals did not receive any direct benefit nor were exposed to a particular risk by being included in this study.

3. Results

3.1. Study population characteristics

A total of 12,094 individuals met the inclusion criteria, of which 52.2 % were girls. Regarding their zygosity, 31.3 % were monozygotic twins, 35.1 % were same-sex dizygotic twins, and 33.4 % were different-sex dizygotic twins. Around 0.2 % of the population had missing data on this. Table 1 summarizes the baseline characteristics of the study population by sex and level of ADHD symptoms. At baseline, approximately 8.7 % of the individuals had high ADHD symptoms; the prevalence differed between boys and girls (10.6 % and 6.0 %, respectively, $p < 0.001$). Mental comorbidities were present in 1.5 % of the population, being more common among boys and children with high ADHD symptoms ($p < 0.001$). The pattern of PA differed between boys and girls ($p < 0.001$). In addition, individuals with high ADHD symptoms were more likely to be in the low PA intensity and low PA frequency categories ($p < 0.001$). The associations between covariates and the outcome of ED are shown in Table 2a (see Appendix). Age at baseline, PA intensity, and PA

Table 1
Characteristics of the study population by sex and level of ADHD symptoms.

	Boys					Girls				
	Low ADHD		High ADHD**		P-value	Low ADHD		High ADHD**		P-value
	N	%	N	%		N	%	N	%	
Total	4928	100.0	584	100.0		6183	100.0	399	100.0	
Age at baseline										
9 years	4401	89.3	486	83.2	<0.001*	5455	88.2	353	88.5	0.94
12 years	527	10.7	98	16.8		728	11.8	46	11.5	
Comorbidities										
Mental comorbidities***	53	1.1	56	9.6	<0.001*	55	0.9	24	6.1	<0.001*
Physical activity intensity										
Low	418	11.2	80	18.1	<0.001*	855	18.7	85	29.2	<0.001*
Moderate	1344	36.1	133	33.1		2381	52.0	133	45.7	
High	1965	52.7	215	48.8		1342	29.3	73	25.1	
Physical activity frequency										
Low	290	7.7	60	13.3	<0.001*	445	9.6	43	14.5	0.01*
Moderate	2612	69.4	291	64.2		3446	74.1	203	68.6	
High	864	22.9	102	22.5		761	16.3	50	16.9	

* Statistically significant.
** High ADHD symptoms based on the low cut-off point (>6 points) of the Autism–Tics, AD/HD and other Comorbidities inventory (A-TAC).
*** Mental comorbidities included psychiatric and neurological disorders (other than ADHD).

frequency were statistically significantly associated with ED. Mental comorbidities were not significantly associated with ED. In addition, girls had higher ED scores compared to boys (5.51 and 3.81, respectively, $p < 0.001$).

3.2. ADHD and ED

Estimates of the linear GEE regression models on the association between ADHD symptoms and ED are shown in Table 2. In Model 1, a statistically significant positive association was found between childhood ADHD symptoms and ED at age 15; this association was stronger in girls than in boys. Since estimates remained almost unchanged when adjusting for age at baseline, only adjustment for mental comorbidities was kept for Model 2. The associations remained similar in Model 2. When considering inattention and hyperactivity as separate exposures, both were significantly associated with ED. In boys, both traits were similarly associated with ED, whereas in girls, hyperactivity was more strongly associated with ED than inattention.

3.3. The role of PA

In the stratified analysis by the level of PA intensity and PA frequency, the association between ADHD symptoms and ED remained significant in all strata. Still, some differences were observed between groups (Table 3). Children with moderate PA intensity had the strongest association, but no significant interaction was found between PA intensity and ADHD symptoms. Regarding PA frequency, boys and girls with low PA frequency had the strongest associations between ADHD symptoms and ED. Among boys, there was a significant interaction between ADHD symptoms and PA frequency (interaction term of 0.10; $p = 0.02$).

In a post-hoc analysis to further explore this interaction, a significant association between PA frequency and ED was found, and it was stronger among those with high ADHD symptoms; however, the association became non-significant when conditioning on the twin pairs (Tables 3a and 4a, see Appendix). When looking at ADHD symptoms and PA frequency as a joint exposure, boys and girls with high ADHD symptoms and low PA frequency had a stronger association with ED compared to those only exposed to high ADHD symptoms or low PA frequency (Table 5a, see Appendix).

3.4. Within twin pair analyses

In the conditional analysis, the association between ADHD symptoms and ED remained significant but weakened and became similar for both sexes (Table 4). When looking at inattention and hyperactivity separately, in boys, only the association between inattention and ED remained and got stronger. Whereas, among girls, the associations became non-significant for both inattention and hyperactivity. In the stratified analyses by level of PA (Table 5), the associations between ADHD and ED became non-significant in most strata. Among boys with low PA frequency, the association between ADHD and ED and the

Table 2
Regression coefficients, 95 % confidence intervals (95 % CI) and p-values of the association between ADHD symptoms and emotional dysregulation, for boys and girls separately.

Emotional dysregulation	Model 1			Model 2		
	β	95 % CI	p-Value	β	95 % CI	p-Value
Boys ($n = 5512$)						
ADHD symptoms	0.10	0.08, 0.12	<0.01*	0.11	0.08, 0.13	<0.01*
Inattention	0.16	0.12, 0.20	<0.01*	0.11	0.06, 0.16	<0.01*
Hyperactivity	0.17	0.12, 0.21	<0.01*	0.10	0.04, 0.15	<0.01*
Girls ($n = 6582$)						
ADHD symptoms	0.18	0.15, 0.22	<0.01*	0.17	0.14, 0.21	<0.01*
Inattention	0.27	0.20, 0.33	<0.01*	0.12	0.04, 0.19	<0.01*
Hyperactivity	0.31	0.25, 0.38	<0.01*	0.23	0.15, 0.30	<0.01*

Model 1: Adjusted for clustered data.
Model 2: Model 1 + adjusted for mental comorbidities.
* Statistically significant.

Table 3
Regression coefficients, 95 % confidence intervals (95 % CI) and *p*-values of the association between ADHD symptoms and emotional dysregulation according to level of physical activity (PA) at baseline, for boys and girls separately.

	ADHD symptoms and emotional dysregulation									
	Boys					Girls				
	N	β	95 % CI	p-Value	Interaction analysis	N	β	95 % CI	p-Value	Interaction analysis
PA intensity					PA intensity × ADHD					PA intensity × ADHD
Low	496	0.12	0.05, 0.19	<0.01*	β = 0.003; p = 0.92	938	0.11	0.02, 0.19	<0.01*	β = −0.04, p = 0.40
Moderate	1485	0.14	0.10, 0.19	<0.01*		2512	0.20	0.14, 0.26	<0.01*	
High	2178	0.09	0.05, 0.13	<0.01*		1414	0.16	0.09, 0.23	<0.01*	
PA frequency					PA frequency × ADHD					PA frequency × ADHD
Low	347	0.20	0.12, 0.28	<0.01*	β = 0.10; p = 0.02*	488	0.21	0.10, 0.32	<0.01*	β = 0.09; p = 0.20
Moderate	2897	0.10	0.06, 0.13	<0.01*		3646	0.16	0.11, 0.21	<0.01*	
High	966	0.11	0.07, 0.16	<0.01*		809	0.11	0.01, 0.21	0.03*	

Model adjusted for clustered data and mental comorbidities.
* Statistically significant.

Table 4
Regression coefficients, 95 % confidence intervals (95 % CI) and *p*-values of the association between ADHD symptoms and emotional dysregulation within twin pairs, for boys and girls separately.

	Emotional dysregulation		
	β	95 % CI	p-value
Boys (n = 3180)			
ADHD symptoms	0.07	0.02, 0.12	<0.01*
Inattention	0.15	0.07, 0.24	<0.01*
Hyperactivity	−0.01	−0.10, 0.08	0.84
Girls (n = 4110)			
ADHD symptoms	0.09	0.02, 0.16	<0.01*
Inattention	0.10	−0.01, 0.22	0.07
Hyperactivity	0.08	−0.03, 0.20	0.17

Model adjusted for cluster data and mental comorbidities.
* Statistically significant.

interaction between ADHD and PA frequency remained significant (interaction term of 0.22; $p = 0.01$).

4. Discussion

This study aimed to increase understanding of the association between ADHD symptoms and ED, as well as to explore the role of PA in this association. In the main analysis, we found that ADHD symptoms during childhood were independently associated with ED during adolescence in boys and girls, even after adjusting for mental comorbidities. Both inattention and hyperactivity/impulsivity were independently associated with ED. Regarding the role of PA in the association between ADHD and ED, we observed that the association remained significant in all strata of PA intensity and PA frequency. However, the association was stronger among boys with low PA frequency. When we controlled for familial confounding factors, the association between ADHD and ED weakened, and only inattention remained significantly associated with ED in boys. Across PA strata, the association remained significant only among boys with low PA frequency.

In this study, we found a positive association between childhood ADHD symptoms and ED in adolescence for both sexes. In a meta-analysis, this association was similar in strength for boys and girls (Graziano and Garcia, 2016). In our analysis across individuals, girls showed a stronger association between ADHD and ED compared to boys. However, the association weakened and became similar for both sexes when adjusting for familial confounding factors. This indicates that the difference between sexes was due to shared genetic and environmental factors. We also found that girls reported higher levels of ED compared to boys, which has been observed in other studies (Astenvald et al., 2022; Bunford et al., 2018). In these previous studies, mental comorbidities were associated with higher ED. However, in our data, mental comorbidities were not significantly associated with ED. This could be due to differences in the study populations in the two studies. For instance, Astenvald et al. included twins of all ages, in whom at least one of the twins had a diagnosed mental disorder (Astenvald et al., 2022). In contrast, we included a population at a young age, when some of the mental disorders have not arisen yet or have not yet been diagnosed, thus identifying just a few individuals with mental comorbidities.

As hypothesized, inattention symptoms were driving the association between ADHD and ED, but this was only observed in boys. Among boys, inattention had a stronger association with ED which remained even after adjusting for familial confounding. Among girls, hyperactivity had a stronger association with ED than inattention; however, both associations became non-significant when adjusting for familial confounding. This could indicate that rather than one dimension, the combination of inattention and hyperactivity symptoms drive the association for girls.

Table 5
Regression coefficients, 95 % confidence intervals (95 % CI) and *p*-values of the association between ADHD symptoms and emotional dysregulation within twin pairs according to level of physical activity (PA) at baseline, for boys and girls separately.

	ADHD symptoms and emotional dysregulation									
	Boys					Girls				
	N	β	95 % CI	p-Value	Interaction analysis	N	β	95 % CI	p-Value	Interaction analysis
PA intensity					PA intensity × ADHD					PA intensity × ADHD
Low	210	0.08	−0.06, 0.23	0.27	β = 0.04; p = 0.50	462	0.16	−0.01, 0.32	0.05	β = 0.03; p = 0.66
Moderate	674	0.11	−0.01, 0.23	0.07		1352	0.11	−0.01, 0.24	0.07	
High	1142	0.11	0.03, 0.19	<0.01*		740	0.10	−0.04, 0.25	0.17	
PA frequency					PA frequency × ADHD					PA frequency × ADHD
Low	130	0.25	0.01, 0.49	0.04*	β = 0.22; p = 0.01*	256	0.23	−0.08, 0.55	0.15	β = 0.09; p = 0.20
Moderate	1548	0.11	0.04, 0.18	<0.01*		2174	0.02	−0.06, 0.10	0.58	
High	534	0.02	−0.09, 0.15	0.63		462	0.15	−0.01, 0.30	0.05	

Model adjusted for clustered data and mental comorbidities.
* Statistically significant.

This goes in line with previous literature stating that attention is involved in emotion generation and regulation processes (Gross and Jazaieri, 2014; Pe et al., 2013). However, other mechanisms have been proposed to explain how ADHD symptoms could affect ED.

Some authors suggest that ED could be considered a core symptom of ADHD (Barkley, 2015; Faraone et al., 2019) since the same brain regions and neurological pathways are involved in ADHD and ED. Other authors conclude that although ED is commonly present in ADHD, it cannot be seen as a core symptom since it is present in other disorders (Soler-Gutiérrez et al., 2023). ADHD could also be related to ED through mediators, such as sleeping disorders and deficits in executive functions. Sleeping disorders are common in ADHD and have been associated with greater ED (Becker et al., 2020; Palmer and Alfano, 2017; Sanabra et al., 2022). In the same way, executive functions have been associated with emotion regulation (Schmeichel et al., 2008), and these are commonly impaired in ADHD. Additionally, an overlap has been found between neural networks involved in executive functions and emotion regulation (Soler-Gutiérrez et al., 2023). Although we found an association between ADHD and ED, we could not explore these mediation pathways.

The amount of PA could also contribute to differences in the level of ED among individuals with ADHD. When stratifying by level of PA frequency, we found that ADHD symptoms were associated with ED to different extents in different contexts of PA frequency. Some biological and psychological mechanisms could explain how PA frequency influences this association. Psychologically, PA could influence ED through distraction, which is one of the emotion regulation strategies (Webb et al., 2012). Biologically, the monoamine hypothesis states that PA helps the regulation of noradrenergic, serotoninergic, and dopaminergic systems (Lin and Kuo, 2013), which are disrupted in ADHD and ED. Furthermore, PA boosts the prefrontal cortex activation, which is involved in emotion regulation processes (Vasilopoulos and Ellefson, 2021). Since this brain area develops throughout childhood and adolescence, it is plausible that a higher PA frequency at an early age would reduce ED later in life.

An interaction effect was observed between ADHD symptoms and PA frequency in the outcome of ED; ED was higher when high ADHD symptoms and low PA frequency were present together. Since ADHD symptoms and PA frequency were measured at the same time point, we could not assess directionality, and the way they affected each other was unclear. It could be that higher PA frequency ameliorates ADHD symptoms and this further reduces ED. Indeed, some studies have found that PA reduces inattention and hyperactivity symptoms (Neudecker et al., 2019; Zang, 2019). On the other hand, ADHD symptoms could affect the amount of PA. In our population, children with high ADHD symptoms were more likely to be in the low PA intensity and low PA frequency categories, which goes in line with epidemiological studies reporting an association between ADHD symptoms and lower levels of PA (Khalife et al., 2014). In addition, specific traits of ADHD have been associated with the level of PA, with inattention predicting lower PA (Selinus et al., 2021). Further longitudinal research is needed to explore the direction of these associations.

Opposite to our hypothesis, PA frequency was only significant in boys but not in girls. This sex-specific effect of PA has been observed in a previous study, in which PA improved depressive symptoms in boys but not in girls (Isaksson et al., 2020). Several factors could contribute to this difference. Firstly, PA could have a greater impact on boys due to differences in the neural circuits that regulate emotions. As mentioned, PA promotes the activation of the prefrontal cortex, and neuroimaging studies indicate that males need to active the prefrontal cortex less to achieve a similar level of emotion regulation compared to females (McRae et al., 2008; Stevens and Hamann, 2012). Secondly, the psychological effect that PA has through distraction could be stronger in boys since girls are more prone to use other non-adaptive emotion regulation strategies such as rumination (Johnson and Whisman, 2013). Thirdly, it could be that PA only impacts the association between ADHD and ED in boys because it mainly improves inattention symptoms. However, there are mixed findings regarding the impact of PA on inattention and hyperactivity (Dastamooz et al., 2023; Neudecker et al., 2019). Finally, this differential effect could be related to the type of PA, but this has not been well explored.

The results of this study highlight the importance of sex, type of ADHD symptoms, and PA frequency when screening and treating ED in ADHD. Since these factors could influence the level of ED, they could be used as predictors and as factors to guide the treatment. Girls, boys with inattentive ADHD, and individuals with low PA frequency could be targeted by preventive interventions and followed closely for early identification and treatment of ED. Although further research is needed to support our findings, promoting higher PA frequency among children with ADHD symptoms could be an alternative public health strategy to ameliorate ED. It is important to point out that, in this study, only 22 % of boys and 16 % of girls met the current WHO recommendations on PA frequency for children and adolescents, which suggest at least 60 min of moderate to vigorous PA per day (World Health Organization, 2020). Promoting WHO recommendations on PA, especially among children with ADHD symptoms, could be a less stigmatizing intervention with low burden for the healthcare system.

This study has several strengths. First, the large sample size and the use of fixed effect models in twin data granted more accurate estimates and a deeper exploration of the association between ADHD and ED. Second, looking at ADHD symptoms on a continuous scale rather than having an ADHD diagnosis is a strength for a few reasons. Firstly, ADHD diagnosis is complex; getting a formal diagnosis is influenced by information and resources; it requires individuals seeking medical attention but also the availability of resources in the healthcare system. By looking at ADHD symptoms, we avoided these potential biases. Secondly, ADHD is believed to be at the end of the spectrum. Assessing symptoms instead of diagnosis allowed us to observe the whole spectrum, including those individuals with subthreshold levels of ADHD symptoms. Another strength was that the separate analyses allowed us to investigate differences between sexes, which could help to design future sex-specific interventions to test for any causal effects.

The results of this study should be interpreted considering its limitations. First, we lacked a measurement of ED at baseline. In an aim to control for this, we adjusted for mental comorbidities at baseline. However, we could not discard that the level of ED in adolescence was influenced by ED in childhood, thus limiting the exploration of causality. Second, ADHD symptoms were only assessed at baseline, but the level of ADHD symptoms could have changed after. Children could have developed ADHD symptoms or initiated ADHD treatment, changing the level of symptoms. This could have diluted our estimates. Ideally, PA intensity and frequency are measured through sensor-based approaches, which give more accurate estimates and increase data granularity. Since we used questionnaires, we had limited granularity and accuracy, especially since it involved the parents' ability to distinguish and report differences between the twins. All these factors could have diluted our estimates on the role of PA; thus, the impact of PA in the association could have been stronger. Fourth, when excluding individuals with incomplete data on psychiatric symptoms or ED, we lost around 20 % of those who had high ADHD symptoms, and this could have caused a loss of power. Fifth, there could be residual confounding by unmeasured factors, such as sleeping difficulties or ADHD medication, and future studies are needed to assess this. In addition, although differences between sexes were analyzed, gender was not assessed; thus, we do not know if this impacts ED. Finally, although our sample was representative of children born in Sweden, associations might differ among immigrants who might be exposed to different risk factors or have a different social context.

5. Conclusion

ADHD symptoms during childhood were associated with ED in adolescence. This association was mainly driven by inattention symptoms in boys and combined symptoms in girls. PA frequency was more relevant than PA intensity, especially among boys. The combination of low PA frequency and ADHD symptoms seemed to be more detrimental than their separate exposure. Future longitudinal studies with multiple time points are warranted to test for individual changes. Further research is needed to explore mediation pathways, genetic and environmental contributions, and different dimensions of PA.

CRediT authorship contribution statement

Narda Ontiveros: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Camilla A. Wiklund:** Writing – review & editing, Supervision, Resources, Methodology. **Anna Ohlis:** Writing – review & editing, Supervision, Conceptualization. **Örjan Ekblom:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Role of the funding source

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Anckarsäter, H., Lundström, S., Kollberg, L., Kerekes, N., Palm, C., Carlström, E., Långström, N., Magnusson, P.K.E., Halldner, L., Bölte, S., Gillberg, C., Gumpert, C., Råstam, M., Lichtenstein, P., 2011. The Child and Adolescent Twin Study in Sweden (CATSS). Twin Res. Hum. Genet. 14, 495–508. https://doi.org/10.1375/twin.14.6.495.

Astenvald, R., Frick, M.A., Neufeld, J., Bölte, S., Isaksson, J., 2022. Emotion dysregulation in ADHD and other neurodevelopmental conditions: a co-twin control study. Child Adolesc. Psychiatry Ment. Health 16, 92. https://doi.org/10.1186/s13034-022-00528-0.

Babinski, D.E., 2024. Sex differences in ADHD: review and priorities for future research. Curr. Psychiatry Rep. 26, 151–156. https://doi.org/10.1007/s11920-024-01492-6.

Barkley, R.A., 2015. Emotional dysregulation is a core component of ADHD. In: Attention-Deficit Hyperactivity Disorder: A Handbook for Diagnosis and Treatment, 4th ed. The Guilford Press, New York, NY, US, pp. 81–115.

Becker, S.P., Tamm, L., Epstein, J.N., Beebe, D.W., 2020. Impact of sleep restriction on affective functioning in adolescents with attention-deficit/hyperactivity disorder. J. Child Psychol. Psychiatry 61, 1160–1168. https://doi.org/10.1111/jcpp.13235.

Bernstein, E.E., McNally, R.J., 2017. Acute aerobic exercise helps overcome emotion regulation deficits. Cognit. Emot. 31, 834–843. https://doi.org/10.1080/02699931.2016.1168284.

Biederman, J., Spencer, T.J., Petty, C., Hyder, L.L., O'Connor, K.B., Surman, C.B., Faraone, S.V., 2012. Longitudinal course of deficient emotional self-regulation CBCL profile in youth with ADHD: prospective controlled study. Neuropsychiatr. Dis. Treat. 8, 267–276. https://doi.org/10.2147/NDT.S29670.

Bijlenga, D., van der Heijden, K.B., Breuk, M., van Someren, E.J.W., Lie, M.E.H., Boonstra, A.M., Swaab, H.J.T., Kooij, J.J.S., 2013. Associations between sleep characteristics, seasonal depressive symptoms, lifestyle, and ADHD symptoms in adults. J. Atten. Disord. 17, 261–275. https://doi.org/10.1177/1087054711428965.

Brazo-Sayavera, J., Aubert, S., Barnes, J.D., González, S.A., Tremblay, M.S., 2021. Gender differences in physical activity and sedentary behavior: results from over 200,000 Latin-American children and adolescents. PLoS One 16, e0255353. https://doi.org/10.1371/journal.pone.0255353.

Bunford, N., Evans, S.W., Wymbs, F., 2015. ADHD and emotion dysregulation among children and adolescents. Clin. Child. Fam. Psychol. Rev. 18, 185–217. https://doi.org/10.1007/s10567-015-0187-5.

Bunford, N., Evans, S.W., Langberg, J.M., 2018. Emotion dysregulation is associated with social impairment among young adolescents with ADHD. J. Atten. Disord. 22, 66–82. https://doi.org/10.1177/1087054714527793.

Cerrillo-Urbina, A.J., García-Hermoso, A., Sánchez-López, M., Pardo-Guijarro, M.J., Santos Gómez, J.L., Martínez-Vizcaíno, V., 2015. The effects of physical exercise in children with attention deficit hyperactivity disorder: a systematic review and meta-analysis of randomized control trials. Child Care Health Dev. 41, 779–788. https://doi.org/10.1111/cch.12255.

Corbisiero, S., Mörstedt, B., Bitto, H., Stieglitz, R.-D., 2017. Emotional dysregulation in adults with attention-deficit/hyperactivity disorder—validity, predictability, severity, and comorbidity. J. Clin. Psychol. 73, 99–112. https://doi.org/10.1002/jclp.22317.

Cortese, S., Song, M., Farhat, L.C., Yon, D.K., Lee, S.W., Kim, M.S., Park, S., Oh, J.W., Lee, S., Cheon, K.-A., Smith, L., Gosling, C.J., Polanczyk, G.V., Larsson, H., Rohde, L. A., Faraone, S.V., Koyanagi, A., Dragioti, E., Radua, J., Carvalho, A.F., Il Shin, J., Solmi, M., 2023. Incidence, prevalence, and global burden of ADHD from 1990 to 2019 across 204 countries: data, with critical re-analysis, from the Global Burden of Disease study. Mol. Psychiatry 1–8. https://doi.org/10.1038/s41380-023-02228-3.

Dastamooz, S., Sadeghi-Bahmani, D., Farahani, M.H.D., Wong, S.H.S., Yam, J.C.S., Tham, C.C.Y., Sit, C.H.P., 2023. The efficacy of physical exercise interventions on mental health, cognitive function, and ADHD symptoms in children and adolescents with ADHD: an umbrella review. EClinicalMedicine 62, 102137. https://doi.org/10.1016/j.eclinm.2023.102137.

De Ronda, A.C., Rice, L., Zhao, Y., Rosch, K.S., Mostofsky, S.H., Seymour, K.E., 2023. ADHD-related sex differences in emotional symptoms across development. Eur. Child Adolesc. Psychiatry. https://doi.org/10.1007/s00787-023-02251-3.

Den Heijer, A.E., Groen, Y., Tucha, L., Fuermaier, A.B.M., Koerts, J., Lange, K.W., Thome, J., Tucha, O., 2017. Sweat it out? The effects of physical exercise on cognition and behavior in children and adults with ADHD: a systematic literature review. J. Neural Transm. (Vienna) 124, 3–26. https://doi.org/10.1007/s00702-016-1593-7.

Deutz, M.H.F., Shi, Q., Vossen, H.G.M., Huijding, J., Prinzie, P., Deković, M., van Baar, A. L., Woltering, S., 2018. Evaluation of the strengths and difficulties questionnaire-dysregulation profile (SDQ-DP). Psychol. Assess. 30, 1174–1185. https://doi.org/10.1037/pas0000564.

Edwards, M.K., Rhodes, R.E., Mann, J.R., Loprinzi, P.D., 2018. Effects of acute aerobic exercise or meditation on emotional regulation. Physiol. Behav. 186, 16–24. https://doi.org/10.1016/j.physbeh.2017.12.037.

England-Mason, G., 2020. Emotion regulation as a transdiagnostic feature in children with neurodevelopmental disorders. Curr. Dev. Disord. Rep. 7, 130–138. https://doi.org/10.1007/s40474-020-00200-2.

Faraone, S.V., Rostain, A.L., Blader, J., Busch, B., Childress, A.C., Connor, D.F., Newcorn, J.H., 2019. Practitioner review: emotional dysregulation in attention-deficit/hyperactivity disorder — implications for clinical recognition and intervention. J. Child Psychol. Psychiatry 60, 133–150. https://doi.org/10.1111/jcpp.12899.

Goodman, R., 1997. The Strengths and Difficulties Questionnaire: a research note. J. Child Psychol. Psychiatry 38, 581–586. https://doi.org/10.1111/j.1469-7610.1997.tb01545.x.

Goodman, R., 2001. Psychometric properties of the strengths and difficulties questionnaire. J. Am. Acad. Child Adolesc. Psychiatry 40, 1337–1345. https://doi.org/10.1097/00004583-200111000-00015.

Graziano, P.A., Garcia, A., 2016. Attention-deficit hyperactivity disorder and children's emotion dysregulation: a meta-analysis. Clin. Psychol. Rev. 46, 106–123. https://doi.org/10.1016/j.cpr.2016.04.011.

Gross, J.J., Jazaieri, H., 2014. Emotion, emotion regulation, and psychopathology: an affective science perspective. Clin. Psychol. Sci. 2, 387–401. https://doi.org/10.1177/2167702614536164.

Groves, N.B., Kofler, M.J., Wells, E.L., Day, T.N., Chan, E.S.M., 2020. An examination of relations among working memory, ADHD symptoms, and emotion regulation. J. Abnorm. Child Psychol. 48, 525–537. https://doi.org/10.1007/s10802-019-00612-8.

Guo, C., Assumpcao, L., Hu, Z., 2022. Efficacy of non-pharmacological treatments on emotional symptoms of children and adults with attention-deficit/hyperactivity disorder: a meta-analysis. J. Atten. Disord. 26, 508–524. https://doi.org/10.1177/10870547211001953.

Hansson, S.L., Svanström Röjvall, A., Rastam, M., Gillberg, Carina, Gillberg, Christopher, Anckarsäter, H., 2005. Psychiatric telephone interview with parents for screening of childhood autism — tics, attention-deficit hyperactivity disorder and other comorbidities (A-TAC): preliminary reliability and validity. Br. J. Psychiatry 187, 262–267. https://doi.org/10.1192/bjp.187.3.262.

Helgesson, M., Björkenstam, E., Rahman, S., Gustafsson, K., Taipale, H., Tanskanen, A., Ekselius, L., Mittendorfer-Rutz, E., 2021. Labour market marginalisation in young

adults diagnosed with attention-deficit hyperactivity disorder (ADHD): a population-based longitudinal cohort study in Sweden. Psychol. Med. 1–9. https://doi.org/10.1017/S0033291721002701.
Hirsch, O., Chavanon, M., Riechmann, E., Christiansen, H., 2018. Emotional dysregulation is a primary symptom in adult Attention-Deficit/Hyperactivity Disorder (ADHD). J. Affect. Disord. 232, 41–47. https://doi.org/10.1016/j.jad.2018.02.007.
Hirsch, O., Chavanon, M.L., Christiansen, H., 2019. Emotional dysregulation subgroups in patients with adult Attention-Deficit/Hyperactivity Disorder (ADHD): a cluster analytic approach. Sci. Rep. 9, 5639. https://doi.org/10.1038/s41598-019-42018-y.
Isaksson, J., Selinus, E.N., Åslund, C., Nilsson, K.W., 2020. Physical activity in early adolescence predicts depressive symptoms 3 years later: a community-based study. J. Affect. Disord. 277, 825–830. https://doi.org/10.1016/j.jad.2020.09.008.
Johnson, D.P., Whisman, M.A., 2013. Gender differences in rumination: a meta-analysis. Pers. Individ. Differ. 55, 367–374. https://doi.org/10.1016/j.paid.2013.03.019.
Katzman, M.A., Bilkey, T.S., Chokka, P.R., Fallu, A., Klassen, L.J., 2017. Adult ADHD and comorbid disorders: clinical implications of a dimensional approach. BMC Psychiatry 17, 302. https://doi.org/10.1186/s12888-017-1463-3.
Khalife, N., Kantomaa, M., Glover, V., Tammelin, T., Laitinen, J., Ebeling, H., Hurtig, T., Jarvelin, M.-R., Rodriguez, A., 2014. Childhood attention-deficit/hyperactivity disorder symptoms are risk factors for obesity and physical inactivity in adolescence. J. Am. Acad. Child Adolesc. Psychiatry 53, 425–436. https://doi.org/10.1016/j.jaac.2014.01.009.
Kim, J., Mutyala, B., Agiovlasitis, S., Fernhall, B., 2011. Health behaviors and obesity among US children with attention deficit hyperactivity disorder by gender and medication use. Prev. Med. 52, 218–222. https://doi.org/10.1016/j.ypmed.2011.01.003.
Knol, M.J., VanderWeele, T.J., 2012. Recommendations for presenting analyses of effect modification and interaction. Int. J. Epidemiol. 41, 514–520. https://doi.org/10.1093/ije/dyr218.
Kunze, B., Wang, B., Isensee, C., Schlack, R., Ravens-Sieberer, U., Klasen, F., Rothenberger, A., Becker, A., BELLA-Study Group, 2018. Gender associated developmental trajectories of SDQ-dysregulation profile and its predictors in children. Psychol. Med. 48, 404–415. https://doi.org/10.1017/S0033291717001714.
Larson, T., Anckarsäter, H., Gillberg, Carina, Ståhlberg, O., Carlström, E., Kadesjö, B., Råstam, M., Lichtenstein, P., Gillberg, Christopher, 2010. The Autism — Tics, AD/HD and other Comorbidities inventory (A-TAC): further validation of a telephone interview for epidemiological research. BMC Psychiatry 10, 1. https://doi.org/10.1186/1471-244X-10-1.
Larson, T., Lundström, S., Nilsson, T., Selinus, E.N., Råstam, M., Lichtenstein, P., Gumpert, C.H., Anckarsäter, H., Kerekes, N., 2013. Predictive properties of the A-TAC inventory when screening for childhood-onset neurodevelopmental problems in a population-based sample. BMC Psychiatry 13, 233. https://doi.org/10.1186/1471-244X-13-233.
Larson, T., Selinus, E.N., Gumpert, C.H., Nilsson, T., Kerekes, N., Lichtenstein, P., Anckarsäter, H., Lundström, S., 2014. Reliability of Autism—Tics, AD/HD, and other Comorbidities (A-TAC) inventory in a test-retest design. Psychol. Rep. 114, 93–103. https://doi.org/10.2466/03.15.PR0.114k10w1.
Lenzi, F., Cortese, S., Harris, J., Masi, G., 2018. Pharmacotherapy of emotional dysregulation in adults with ADHD: a systematic review and meta-analysis. Neurosci. Biobehav. Rev. 84, 359–367. https://doi.org/10.1016/j.neubiorev.2017.08.010.
Levantini, V., Camodeca, M., Gelati, C., 2024. The strengths and difficulties questionnaire dysregulation profile teacher-report: psychometric properties and associations with aspects of school experience. Child Psychiatry Hum. Dev. 55, 831–840. https://doi.org/10.1007/s10578-022-01441-5.
Lin, T.-W., Kuo, Y.-M., 2013. Exercise benefits brain function: the monoamine connection. Brain Sci. 3, 39–53. https://doi.org/10.3390/brainsci3010039.
Malmberg, M., Rydell, A., Smedje, H., 2003. Validity of the Swedish version of the Strengths and Difficulties Questionnaire (SDQ-Swe). Nord. J. Psychiatry 57, 357–363. https://doi.org/10.1080/08039480310002697.
Mårland, C., Lichtenstein, P., Degl'Innocenti, A., Larson, T., Råstam, M., Anckarsäter, H., Gillberg, C., Nilsson, T., Lundström, S., 2017. The Autism–Tics, ADHD and other Comorbidities inventory (A-TAC): previous and predictive validity. BMC Psychiatry 17, 403. https://doi.org/10.1186/s12888-017-1563-0.
McRae, K., Ochsner, K.N., Mauss, I.B., Gabrieli, J.J.D., Gross, J.J., 2008. Gender differences in emotion regulation: an fMRI study of cognitive reappraisal. Group Process. Intergroup Relat. 11, 143–162. https://doi.org/10.1177/1368430207088035.
Mowlem, F.D., Rosenqvist, M.A., Martin, J., Lichtenstein, P., Asherson, P., Larsson, H., 2019. Sex differences in predicting ADHD clinical diagnosis and pharmacological treatment. Eur. Child Adolesc. Psychiatry 28, 481–489. https://doi.org/10.1007/s00787-018-1211-3.
Neudecker, C., Mewes, N., Reimers, A.K., Woll, A., 2019. Exercise interventions in children and adolescents with ADHD: a systematic review. J. Atten. Disord. 23, 307–324. https://doi.org/10.1177/1087054715584053.
Nigg, J.T., 2013. Attention-deficit/hyperactivity disorder and adverse health outcomes. Clin. Psychol. Rev. 33, 215–228. https://doi.org/10.1016/j.cpr.2012.11.005.
Norouzi, E., Rezaie, L., Bender, A.M., Khazaie, H., 2023. Mindfulness plus physical activity reduces emotion dysregulation and insomnia severity among people with major depression. Behav. Sleep Med. 0, 1–13. https://doi.org/10.1080/15402002.2023.2176853.
Palladino, V.S., McNeill, R., Reif, A., Kittel-Schneider, S., 2019. Genetic risk factors and gene-environment interactions in adult and childhood attention-deficit/hyperactivity disorder. Psychiatr. Genet. 29, 63–78. https://doi.org/10.1097/YPG.0000000000000220.
Palmer, C.A., Alfano, C.A., 2017. Sleep and emotion regulation: an organizing, integrative review. Sleep Med. Rev. 31, 6–16. https://doi.org/10.1016/j.smrv.2015.12.006.
Pe, M.L., Raes, F., Kuppens, P., 2013. The cognitive building blocks of emotion regulation: ability to update working memory moderates the efficacy of rumination and reappraisal on emotion. PLoS One 8, e69071. https://doi.org/10.1371/journal.pone.0069071.
Posner, J., Polanczyk, G.V., Sonuga-Barke, E., 2020. Attention-deficit hyperactivity disorder. Lancet 395, 450–462. https://doi.org/10.1016/S0140-6736(19)33004-1.
Ramtekkar, U.P., Reiersen, A.M., Todorov, A.A., Todd, R.D., 2010. Sex and age differences in Attention-Deficit/Hyperactivity Disorder symptoms and diagnoses: implications for DSM-V and ICD-11. J. Am. Acad. Child Adolesc. Psychiatry 49 (217–28), e1–e3.
Robison, R.J., Reimherr, F.W., Marchant, B.K., Faraone, S.V., Adler, L.A., West, S.A., 2008. Gender differences in 2 clinical trials of adults with attention-deficit/hyperactivity disorder: a retrospective data analysis. J. Clin. Psychiatry 69, 213–221. https://doi.org/10.4088/jcp.v69n0207.
Rommel, A.-S., Lichtenstein, P., Rydell, M., Kuja-Halkola, R., Asherson, P., Kuntsi, J., Larsson, H., 2015. Is physical activity causally associated with symptoms of attention-deficit/hyperactivity disorder? J. Am. Acad. Child Adolesc. Psychiatry 54, 565–570. https://doi.org/10.1016/j.jaac.2015.04.011.
Sanabra, M., Gómez-Hinojosa, T., Grau, N., Alda, J.A., 2022. Deficient emotional self-regulation and sleep problems in ADHD with and without pharmacological treatment. J. Atten. Disord. 26, 426–433. https://doi.org/10.1177/1087054720986242.
Sanchis-Sanchis, A., Grau, M.D., Moliner, A.-R., Morales-Murillo, C.P., 2020. Effects of age and gender in emotion regulation of children and adolescents. Front. Psychol. 11. https://doi.org/10.3389/fpsyg.2020.00946.
Schmeichel, B.J., Volokhov, R.N., Demaree, H.A., 2008. Working memory capacity and the self-regulation of emotional expression and experience. J. Pers. Soc. Psychol. 95, 1526–1540. https://doi.org/10.1037/a0013345.
Schreiner, N., Scherer, B., Al Battashi, H., Harwell, C., Topalsky, V., Burant, C., Daly, B., Douglas, S., Woods, S., 2022. Examining the association between emotional dysregulation and treatment burden. West. J. Nurs. Res. 44, 992–1005. https://doi.org/10.1177/01939459211027655.
Selinus, E.N., Durbeej, N., Zhan, Y., Lichtenstein, P., Lundström, S., Ekblom, M., 2021. Inattention and hyperactivity symptoms in childhood predict physical activity in adolescence. BMC Psychiatry 21, 629. https://doi.org/10.1186/s12888-021-03603-6.
Shaw, P., Stringaris, A., Nigg, J., Leibenluft, E., 2014. Emotion dysregulation in attention deficit hyperactivity disorder. Am. J. Psychiatry 171, 276–293. https://doi.org/10.1176/appi.ajp.2013.13070966.
Soler-Gutiérrez, A.-M., Pérez-González, J.-C., Mayas, J., 2023. Evidence of emotion dysregulation as a core symptom of adult ADHD: a systematic review. PLoS One 18, e0280131. https://doi.org/10.1371/journal.pone.0280131.
Stevens, J.S., Hamann, S., 2012. Sex differences in brain activation to emotional stimuli: a meta-analysis of neuroimaging studies. Neuropsychologia 50, 1578–1593. https://doi.org/10.1016/j.neuropsychologia.2012.03.011.
van Stralen, J., 2016. Emotional dysregulation in children with attention-deficit/hyperactivity disorder. Atten. Defic. Hyperact. Disord. 8, 175–187. https://doi.org/10.1007/s12402-016-0199-0.
Vasilopoulos, F., Ellefson, M.R., 2021. Investigation of the associations between physical activity, self-regulation and educational outcomes in childhood. PLoS One 16, e0250984. https://doi.org/10.1371/journal.pone.0250984.
Villalba-Heredia, L., Rodríguez, C., Santana, Z., Nuñez, J.C., Méndez-Giménez, A., 2022. A cross-sectional study to measure physical activity with accelerometry in ADHD children according to presentations. Children (Basel) 10, 50. https://doi.org/10.3390/children10010050.
Webb, T.L., Miles, E., Sheeran, P., 2012. Dealing with feeling: a meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. Psychol. Bull. 138, 775–808. https://doi.org/10.1037/a0027600.
Wiklund, C.A., Ekblom, M.M., Wang, R., Ekblom, Ö., 2024. Associations between physical activity and symptoms of mental health disorders in adolescence: evidence from the longitudinal Swedish twin register. J. Adolesc. Health 0. https://doi.org/10.1016/j.jadohealth.2024.10.017.
World Health Organization, 2020. WHO Guidelines on Physical Activity and Sedentary Behaviour.
Xie, Y., Gao, X., Song, Y., Zhu, X., Chen, M., Yang, L., Ren, Y., 2021. Effectiveness of physical activity intervention on ADHD symptoms: a systematic review and meta-analysis. Front. Psychol. 12, 706625. https://doi.org/10.3389/fpsyt.2021.706625.
Zagai, U., Lichtenstein, P., Pedersen, N.L., Magnusson, P.K.E., 2019. The Swedish twin registry: content and management as a research infrastructure. Twin Res. Hum. Genet. 22, 672–680. https://doi.org/10.1017/thg.2019.99.
Zang, Y., 2019. Impact of physical exercise on children with attention deficit hyperactivity disorders. Medicine (Baltimore) 98, e17980. https://doi.org/10.1097/MD.0000000000017980.