



Can an active lifestyle reduce the risk of obesity in adulthood among adolescents with Attention-Deficit/Hyperactivity Disorder symptoms? An ambispective cohort study

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ARTICLE INFO

Keywords:

Hyperactivity/impulsivity
Inattentive
Abdominal obesity
Physical activity

ABSTRACT

Various studies have associated Attention-Deficit/Hyperactivity Disorder (ADHD) with obesity, but the role of physical activity in this connection is uncertain. This study examined whether adopting an active lifestyle can mitigate the link between adolescent ADHD and the risk of adult obesity. Longitudinal data from the Add Health Study (Waves I, III, and V) were used. Participants self-reported ADHD symptoms (hyperactivity/impulsivity, inattention, combined) during Wave III and self-assessed their recent moderate-to-vigorous physical activity. An "active lifestyle" required meeting activity criteria in both adolescence (Wave I) and adulthood (Wave III-V). Of 2609 participants, 1.42 % exhibited combined ADHD symptoms. A non-linear relationship was observed between inattentive/hyperactive scores and body mass index (BMI) and waist circumference (WC). Individuals with ≥ 6 hyperactivity/impulsivity symptoms had higher BMI (1.29 kg/m²) and WC (1.27 cm) at adulthood. Logistic regressions indicate that, compared to individuals without ADHD maintaining an active lifestyle, both inactive participants with and without ADHD show an elevated risk of obesity (odds ratio [OR]=1.56 to 2.63) and abdominal obesity in adulthood (OR = 1.51 to 2.50). Mediation analysis models further confirm these findings, suggesting that physical activity may explain this association. Though exact mechanisms warrant further exploration, adopting an active lifestyle offers promise for reducing obesity risk among individuals with ADHD symptoms.

1. Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is an impairing neurodevelopmental condition characterized by persistent inattention, impulsivity, and hyperactivity that can severely interfere with social, school, or work functioning (Faraone et al., 2015). The global prevalence is approximately 5.6 % in adolescents (Salari et al., 2023), and 3.1 % among adults (Ayano et al., 2023).

The adolescent phase, marked by both physiological and psychological transformations, constitutes a pivotal stage of growth and change, and the presence of ADHD during this period can cast a long shadow over an adolescent's health journey throughout their life (Wilens and Spencer, 2010). Beyond its immediate cognitive and behavioral manifestations, its implications for later health outcomes, particularly in relation to obesity have been described (Cortese et al.,

2016; Li et al., 2020). Potential reasons for these associations are that the impulsivity and inattention that characterize ADHD might lead to dysregulated eating patterns with consequent weight gain (Cortese et al., 2016; Cortese and Vincenzi, 2012; Galéra et al., 2021; Karhunen et al., 2021).

The World Health Organization and the Physical Activity Guidelines for Americans promote regular physical activity for all individuals, including those with ADHD, given its well-established health advantages (Bull et al., 2020; Piercy et al., 2018). The benefits of physical activity in terms of overall health and disease prevention make it a promising approach, exerting a positive influence on body composition through regular participation (Bull et al., 2020; Piercy et al., 2018). Exercise may also benefit cognition and psychosocial well-being in adolescents with ADHD (Cerrillo-Urbina et al., 2015; Mehren et al., 2020; Réol, 2022).

Nevertheless, symptoms of ADHD can hinder consistent engagement

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<https://doi.org/10.1016/j.psychres.2024.115770>

Received 15 October 2023; Received in revised form 31 January 2024; Accepted 1 February 2024

Available online 2 February 2024

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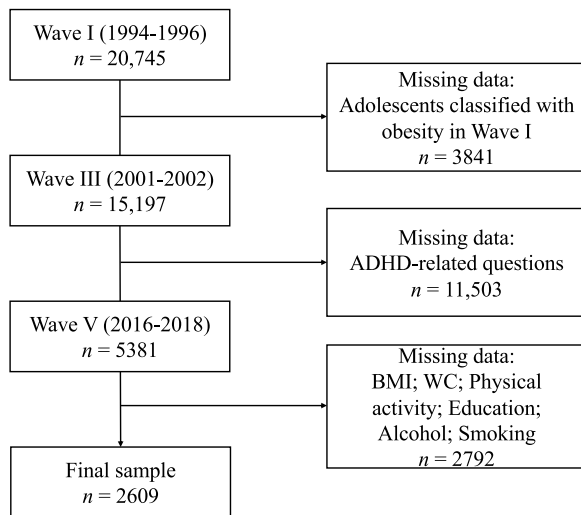


Fig. 1. Flowchart of the participants.

in physical activity (Tandon et al., 2019), leading to sedentary behavior and an increased risk of obesity (Kerr and Booth, 2022; Pinto et al., 2023). The potential impact of maintaining regular physical activity throughout one's life on modifying the relationship between ADHD and obesity in adulthood remains an unexplored area of investigation. In this regard and to date, only one study has provided evidence regarding the mediating effect of physical activity on this association in a longitudinal study from childhood to adolescence (Khalife et al., 2014). Therefore, our main aim was to investigate how a lifelong commitment to regular physical activity may mitigate the risks of ADHD and obesity in adulthood. We hypothesized that physical activity serves as a mediator in the established association between ADHD and obesity. We anticipate that engaging in regular physical activity may play a mediating role, influencing the observed relationship between ADHD and obesity parameters.

2. Methods

2.1. Participants

The reporting of this study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines regarding cohort studies (Von Elm et al., 2007). We utilized data derived from the longitudinal Add Health study, a comprehensive endeavor conducted within the US. The study encompassed a vast scope, which surveyed more than 90,000 students across 80 high schools and 52 middle schools during the years 1994 and 1995. The study methodology involved the administration of both in-school questionnaires and an in-home interview in 1994 (Wave I), comprising 20,745 participants. Subsequently, the trajectories of these individuals were traced during 2001–2002 (Wave III) and again between 2016 and 2018 (Wave V), when participants were aged 33 and 39 years, respectively. Data related to obesity was gathered from a subset of 5381 participants at Wave V.

To ensure the robustness of the analysis, rigorous steps were undertaken. Missing data pertaining to ADHD-related inquiries and covariates were meticulously managed. Adolescents who presented with obesity at Wave I, as defined by a body mass index (BMI) z-score equal to or exceeding three standard deviations as per the International Obesity Task Force growth references chart (Cole and Lobstein, 2012), were excluded from the analysis ($n = 3841$). This led to the formation of a final sample comprising 2609 individuals, upon which subsequent investigations were conducted (Fig. 1).

An independent samples *t*-test and chi-square analyses were performed to assess differences between adolescents included in the final

sample and those excluded from the analysis. No significant differences were observed in demographic variables (age at Wave I, $p = 0.883$; race/ethnicity, $p = 0.455$; sex, $p = 0.325$) between the included and excluded groups. Hence, it can be inferred that missing data did not substantially impact the results within the analytical sample.

The Add Health study received approval from the University of North Carolina Institutional Review Board (IRB). Authorization for secondary analysis was granted by the University Hospital of Navarra Ethics Committee (PI_2020/143).

2.2. Childhood ADHD symptom and subtypes

ADHD symptom subtypes were determined through the utilization of self-reported data obtained during Wave III of the study. At this juncture, participants were asked to retrospectively outline the presence of symptoms experienced between the ages of 5 and 12. A comprehensive set of 17 items derived from the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV) ADHD symptom inventory were employed, encompassing 9 questions that captured inattention symptoms and 8 questions that addressed hyperactivity/impulsivity symptoms (Murphy and Barkley, 1996). Adolescents indicated the frequency of each symptom using response options ranging from "never" or "rarely", "sometimes", "often", and "very often." Participants were designated as exhibiting a symptom if their response fell under "often" or "very often" (Fuemmeler et al., 2010). Following the lead of Fuemmeler et al. (2010) we categorized adolescents into the following four ADHD symptom subtypes: (i) non-ADHD: < 6 inattention symptoms and < 6 hyperactivity/impulsivity symptoms; (ii) inattention: ≥ 6 inattention symptoms and < 6 hyperactivity/impulsivity symptoms; (iii) hyperactivity/impulsivity: < 6 inattention symptoms and ≥ 6 hyperactivity/impulsivity symptoms; and (iv) ADHD combined: ≥ 6 inattention symptoms and ≥ 6 hyperactivity/impulsivity symptoms. The selection of the 6-symptom threshold was made to align with the criteria outlined in DSM-IV for ADHD, which mandates the presence of 6 or more symptoms from either the inattention or hyperactivity/impulsivity symptom domains.

The use of retrospective reporting is common in clinical settings when addressing adults with ADHD, and prior research has validated the reliability and accuracy of these self-reported records (Murphy and Schachar, 2000; Ward et al., 1993). Also, Fuemmeler et al. (2010) have provided additional evidence for the dependability and validity of this approach by demonstrating strong internal consistency among the items ($\alpha = 0.86$). Furthermore, these adolescents showed an increased propensity to indicate the usage of ADHD medications during Wave III (Kollins et al., 2005).

2.3. Obesity

The Add Health study team collected height and weight measurements using digital scales during Wave V, whereas self-reported measurements were used during Wave I. Obesity during Wave V was defined as a BMI of $\geq 30 \text{ kg/m}^2$ (World Health Organization, 1995). Waist circumference (WC) was measured with a precision of 0.5 cm at the iliac crest. Abdominal obesity was classified as $\geq 102 \text{ cm}$ in men and $\geq 88 \text{ cm}$ in women (Third Report of the National Cholesterol Education Program (NCEP), 2002).

2.4. Physical activity

At Wave I, adolescents provided self-reports of their moderate-to-vigorous physical activity (MVPA) engagement during the previous week using a set of three questions. They were asked to indicate the frequency of participation in activities such as rollerblading, roller-skating, skateboarding, bicycling, active sports (e.g., basketball, soccer, swimming), and exercise routines (like jogging, walking, karate, dancing) over the past week. Response options ranged from no

participation to engaging in these activities ≥ 5 times, and corresponding scores were assigned as follows: 0 times, 1.5 times, 3.5 times, and 6 times. Given the absence of a specific measure to gauge adherence to activity guidelines, the criterion of " ≥ 5 MVPA sessions/week" was employed as a substitute, consistent with previous research methodologies (Aubert et al., 2022; Gordon-Larsen et al., 2004).

During Wave III and V of the study, the frequency of MVPA undertaken in the preceding 7 days was assessed using a series of questions. Participants were asked to indicate how frequently they engaged in specific activities within this timeframe. The activities queried included bicycling, skateboarding, dancing, hiking, hunting, yard work, roller blading, roller skating, downhill skiing, snowboarding, racquet sports, aerobics, gymnastics, weightlifting, strength training, individual sports such as running and swimming, as well as team sports like football, soccer, basketball, and others. Additionally, leisure activities like golfing, fishing, bowling, and playing softball or baseball were also included. Participants were categorized as active if they reported partaking in five or more instances of these activities; otherwise, their physical activity level was considered low, indicating inactivity.

Lastly, individuals were categorized as having an "active lifestyle" if they fulfilled the physical activity guidelines during their adolescent years (Wave I) and their adulthood phases (Wave III and V).

2.5. Definitions of covariates

Sociodemographic data including age, sex, race (White, Black, Native American, Asian), region (coded as West, Midwest, South, and Northeast), and educational attainment (based on the highest education level achieved at Wave V, classified as less than a high school education, high school graduate or vocational school, some college, and college graduate or graduate education), were gathered via questionnaires.

Alcohol consumption was assessed via: "Within the last 30 days, on how many days did you have alcohol (beer, wine, liquor)?" Participants who reported "never used" were classified as "never drinkers," those who reported "used, but not in the last 30 days" were labeled as "former drinkers," and those who reported any alcohol consumption within the last 30 days were categorized as "current drinkers".

For smoking, individuals who reported "never used" or "used but not in the past 30 days" were categorized as "not current users," while those who reported any smoking activity within the last 30 days were classified as "current users".

Screen time was measured by a previously described scale Karhunen et al. (2021) using the following questions: "How many hours a week do you watch television?", "How many hours a week do you watch videos?", and "How many hours a week do you play video or computer games?". The number of hours given in the three responses was summed to create a measure of recreational screen time per week. At Wave V, meeting screen time guidelines was considered when adults reported ≤ 3 h per day (Ross et al., 2020).

For sleep time, adults in Wave V reported their sleep duration (in hours) in response to the following question: "How many hours of sleep do you usually get per day and/or night?" Meeting sleep duration guidelines was considered when adults reported from 7 to 9 h per day of sleep (Ross et al., 2020).

2.6. Statistical analysis

Descriptive data are presented as counts/percentages (categorical), means/SDs (normal continuous), and medians/interquartile ranges (non-normal continuous). After examining model assumptions, BMI and WC were log-transformed (base 10) for normalization. The differences between physical activity groups were evaluated using independent Student's *t*-tests or *U* Mann-Whitney tests and χ^2 tests, as appropriate.

To investigate the relationship between inattentive (score) or hyperactive/impulsive (score) (as independent variables) and BMI or WC (as dependent variables) without making any parametric assumptions

Table 1

Descriptive characteristics of the analyzed study sample at Wave V by physical activity categories.

	Inactive lifestyle (n = 2358)	Active lifestyle (n = 203)	p
Sex (women), n (%)	1511 (64.1)	84 (41.4)	<0.001
Age at exam, years	37.08 (1.51)	36.89 (1.50)	0.082
Race category			
White, n (%)	1723 (73.6)	159 (79.1)	0.313
Black, n (%)	441 (18.8)	30 (14.9)	
Native American, n (%)	33 (1.4)	1 (0.5)	
Asian, n (%)	143 (6.1)	11 (5.5)	
Education level			
High school or less, n (%)	351 (15.3)	21 (10.6)	0.096
Vocational or some college, n (%)	892 (39.0)	74 (37.2)	
College degree or higher, n (%)	1045 (45.7)	104 (52.3)	
Alcohol consumption			
Former drinker, n (%)	1012 (42.9)	104 (51.2)	0.013
Smoking status			
Current user, n (%)	516 (22.0)	38 (18.8)	0.328
Screen time (≥ 3 h/day), n (%)	1958 (83.2)	178 (88.1)	0.075
Sleep duration (7–9 h/day), n (%)	1407 (59.6)	132 (65.0)	0.136
Body composition			
BMI, kg/m ²	28.40 (24.40 to 33.50)	27.30 (24.50 to 30.80)	0.001
Obesity*, n (%)	966 (40.9)	59 (29.1)	0.001
WC, cm	93.50 (83.00 to 105.00)	91.00 (81.75 to 99.62)	0.007
Abdominal obesity, n (%)	1124 (47.7)	64 (31.7)	<0.001
ADHD			
Inattentive (0–9)	0.98 (1.70)	0.99 (1.57)	0.924
Inattention, n (%)	80 (3.4)	6 (3.0)	0.989
Hyperactivity/impulsivity (0–8)	1.49 (1.74)	1.88 (1.94)	0.002
Hyperactive/Impulsive, n (%)	97 (4.1)	14 (6.9)	0.071
ADHD-combined, n (%)	34 (1.4)	3 (1.5)	0.991

* Body mass index ≥ 30 kg/m² (WHO, 1995)

Continuous variables showed as mean and standard deviation or median and interquartile range. ADHD, Attention-Deficit/Hyperactivity Disorder; BMI, body mass index; WC, waist circumference.

about the nature of the association, we employed generalized additive models (GAMs). Restricted maximum likelihood for smoothness selection was applied (Wood, 2011), with a shrinkage approach employed as a function of thin plate regression spline smoothers (Marra and Wood, 2011).

We additionally assessed differences in obesity parameters (BMI and WC as dependent variables) between adolescents classified with symptoms of inattention and hyperactivity/impulsivity (i.e., ≥ 6 symptoms) and those without ADHD symptoms (used as the reference group) (as independent variables). These analyses were adjusted for BMI at Wave I, biological sex, race, age at follow-up, highest education achieved, alcohol consumption at follow-up, and smoking habit at follow-up.

Logistic regressions were employed to calculate odds ratios (OR) for obesity and abdominal obesity (as dependent variables) based on participants' ADHD status in each domain (as independent variables). Participants were categorized into four groups: (i) active participants without ADHD (used as the reference group); (ii) inactive participants with ADHD; (iii) inactive participants with ADHD; and (iv) inactive participants with ADHD. The OR were determined while adjusting for various variables, including those mentioned earlier, and accounting for screen time and sleep duration at Wave V. This approach allowed for a comprehensive examination of the relationship between ADHD, physical activity, and obesity, considering different participant profiles.

To assess the influence of physical activity levels on the relationships between ADHD symptoms (independent variables) and obesity

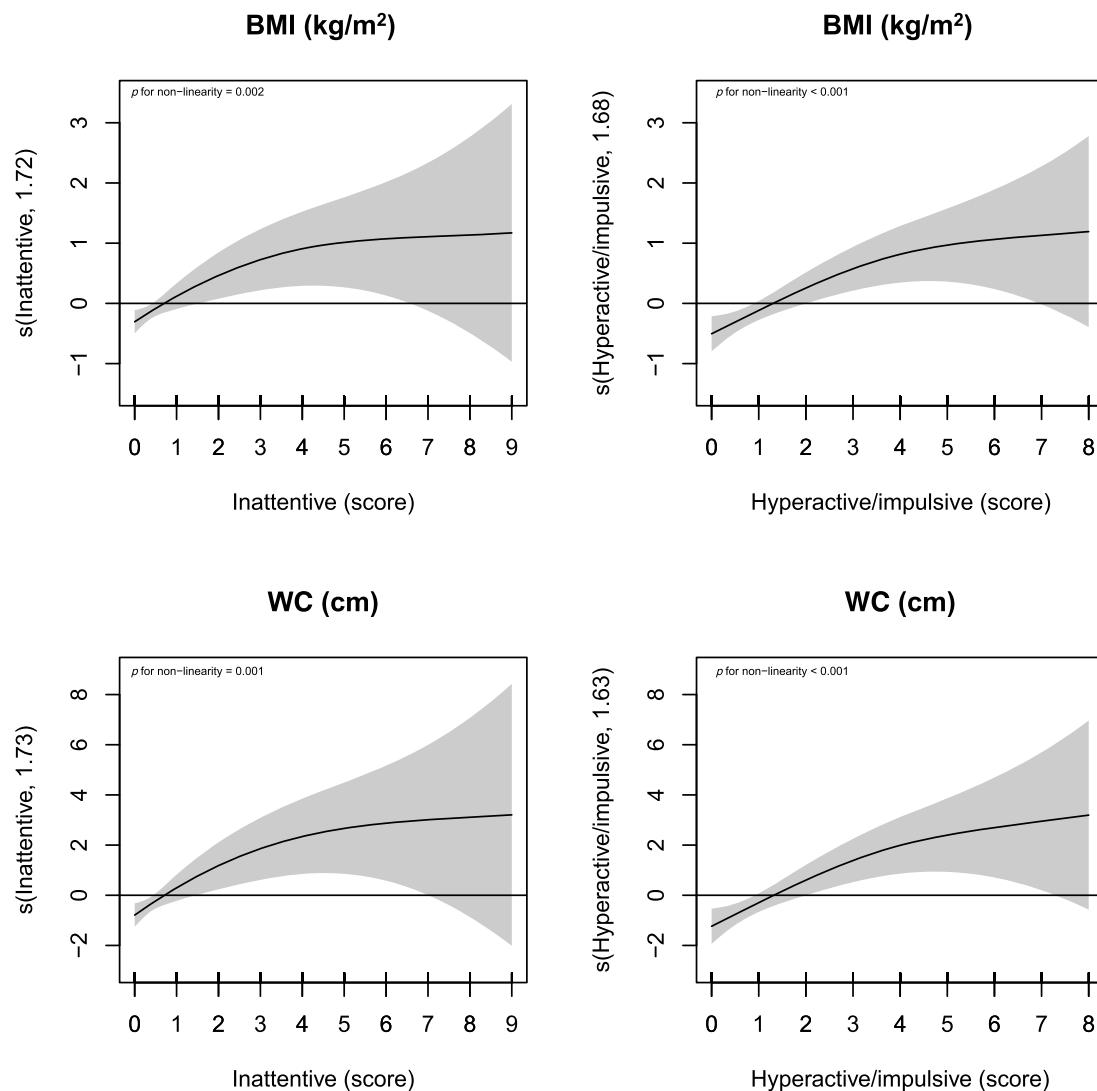


Fig. 2. Smoothed functions from generalized additive models depicting the relationship of body mass index and waist circumference with the inattentive and hyperactive/impulsive score. BMI, body mass index; WC, waist circumference.

parameters (BMI and WC as dependent variables), we employed adjusted linear regression mediation models. A continuous physical activity variable was computed by summing weekly sessions across three time points (Wave I, III, and V), assuming higher session numbers indicate increased physical activity. Following Baron and Kenny's procedure, we used 5000 bootstrapped samples with the PROCESS package. All analyses were conducted in R (Version 4.3.2) and RStudio (Version 2023.09.1+494). Statistical significance was set at two-sided $p < 0.05$.

3. Results

Table 1 presents the descriptive statistics for the variables under consideration. A holistic overview reveals that individuals who adhere to an active lifestyle manifest notably lower values in terms of BMI, WC, and obesity prevalence at Wave V. Furthermore, this active lifestyle cohort exhibits a heightened prevalence of hyperactivity/impulsivity symptoms. Intriguingly, within this same group, a paradoxical trend emerges: a higher proportion of participants currently report alcohol consumption.

Fig. 2 shows smoothed functions from GAMs of BMI and WC as a function of the inattentive or hyperactive/impulsive score. After examining the figure, a nonlinear relationship was found between both the inattentive and hyperactive/impulsive scores and BMI and WC (p for

non-linearity < 0.05 for all).

When we analyze individuals categorized with ADHD symptoms within each distinct domain—specifically those presenting 6 or more symptoms—they showed higher BMI and WC compared to those classified without hyperactivity/impulsivity symptoms. The mean differences stand at 1.29 kg/m^2 (95 % CI 0.31 to 2.59) for BMI and 1.27 cm (95 % CI 0.88 to 4.43) for WC. However, intriguingly, these distinctions are not reflected within the combined ADHD domain (ADHD-combined) and individuals exhibiting inattention symptoms. On the contrary, individuals characterized by an active lifestyle displayed a contrasting pattern. They exhibited lower BMI values, with a mean difference of -1.28 kg/m^2 (95 % CI -1.96 to -0.61) and showcased reduced WC measurements, marked by a mean difference of -3.48 cm (95 % CI -5.44 to -1.51) compared to inactive peers (**Table 2**).

Table 3 illustrates the comprehensive amalgamation of ADHD domains and lifelong physical activity on the risk of developing obesity in adulthood. The findings suggest that, in comparison to individuals without ADHD who led a physically active lifestyle, inactive participants with and without ADHD display an elevated risk of obesity (OR = 1.56 to 2.63) and abdominal obesity in adulthood (OR = 1.51 to 2.50).

Finally, **Fig. 3** illustrates the analysis of the mediating effect of physical activity on the association between ADHD symptoms and obesity parameters. In all instances, mediation models revealed a

Table 2

Differences in obesity parameters at Wave V between each Attention-Deficit/Hyperactivity Disorder symptoms domains (adolescents without Attention-Deficit/Hyperactivity Disorder serving as the reference group) and active participants (inactive adolescents as reference group).

	BMI (kg/m ²)		WC (cm)	
	Mean difference (95 % CI)	<i>p</i>	Mean difference (95 % CI)	<i>p</i>
ADHD domains				
Hyperactivity/ impulsivity	1.29 (0.31 to 2.59)	0.025	1.27 (0.88 to 4.43)	0.036
Inattention	0.75 (-0.71 to 2.20)	0.269	2.07 (-0.95 to 5.09)	0.079
ADHD-combined	0.31 (-1.43 to 2.0.4)	0.988	0.15 (-4.10 to 4.39)	0.669
Active lifestyle*	-1.28 (-1.96 to -0.61)	0.004	-3.48 (-5.44 to -1.51)	0.002

Analysis adjusted for body mass index at Wave I, sex, race, age, highest education achieved, alcohol consumption, and smoking habit at follow-up. ADHD, Attention-Deficit/Hyperactivity Disorder; BMI, body mass index; CI, confidence interval; WC, waist circumference.

* These analyses were also adjusted for screen time and sleep duration at follow-up. Bold indicates a *p* value < 0.05.

Note: to aid interpretation, data were back-transformed from the log scale for presentation in the results.

negative correlation between ADHD symptoms and physical activity in the initial regression equation (path a). In the second equation (path b), physical activity also exhibited a negative correlation with both BMI and WC. The third equation (path c) demonstrated a positive relationship between ADHD symptoms and both BMI and WC. However, the associations between ADHD symptoms and both BMI and WC were diminished when physical activity was included in the model (path c), indicating that physical activity mediates this relationship. The percentage of the total effect mediated by physical activity in the connection between ADHD symptoms and both BMI and WC ranged from 20.4 % to 25.2 %.

4. Discussion

This is the first large-scale study exploring whether an active lifestyle could mitigate the adverse association between ADHD and obesity in adulthood. While both ADHD symptoms and physical inactivity were associated with higher obesity risk, an active lifestyle appeared to reduce these risks, particularly in specific ADHD subgroups. The study provides valuable insights into the interplay of these factors and their potential implications for obesity management and prevention.

Our findings support previous work linking ADHD and obesity (Cortese et al., 2016; Li et al., 2020), extending this association from late childhood to early adulthood (Kase et al., 2021). In this latest study, the authors demonstrate that the association between hyperactive and impulsive symptoms and BMI in this developmental period is highly stable (Kase et al., 2021), which aligns with our findings, where we demonstrate that hyperactivity and impulsivity symptoms in adolescence are associated with higher BMI and WC in adulthood. Although the causal pathway responsible for the connections between obesity and ADHD remained largely unclarified, it likely involves multiple interconnected mechanisms. First, shared neurobiological disruptions in dopamine signaling and reward processing may predispose to both conditions (Patte et al., 2016). Additionally, impulsivity, a hallmark of ADHD, could contribute to impulsive eating behaviors and unhealthy dietary choices, promoting overeating (Egbert et al., 2017). Executive function deficits and difficulty making healthy lifestyle choices (Geuijen et al., 2019), along with genetic (Cortese, 2019; Hané and Cortese, 2018) and inflammatory factors (Anand et al., 2017), likely contribute to the complex interplay between ADHD and obesity.

This study also revealed that among active individuals, the ADHD-

Table 3

Joint influence of Attention-Deficit/Hyperactivity Disorder domains and physical activity during life on the risk of developing obesity or abdominal obesity at adulthood.

Exposure variables		Obesity (BMI ≥ 30 kg/m ²)		Abdominal obesity (WC ≥ 102 cm in men and ≥ 88 cm in women)	
		OR (95 % CI)	<i>p</i>	OR (95 % CI)	<i>p</i>
ADHD domain	Active lifestyle*				
Hyperactivity/ impulsivity	No	1.00 (Reference)		1.00 (Reference)	
No	No	1.56 (1.07 to 2.26)	0.020	1.51 (1.04 to 2.18)	0.030
Yes	No	1.73 (1.01 to 3.12)	0.049	2.06 (1.15 to 3.67)	0.015
Yes	Yes	1.13 (0.32 to 3.99)	0.849	1.34 (0.39 to 4.52)	0.633
Inattention	No	1.00 (Reference)		1.00 (Reference)	
No	No	1.61 (1.11 to 2.32)	0.012	1.54 (1.07 to 2.21)	0.021
Yes	No	2.49 (1.27 to 4.88)	0.008	2.50 (1.32 to 4.72)	0.005
Yes	Yes	3.21 (0.61 to 28.71)	0.142	2.71 (0.64 to 21.48)	0.143
ADHD-combined	No	1.00 (Reference)		1.00 (Reference)	
No	No	1.59 (1.10 to 2.29)	0.012	1.52 (1.06 to 2.18)	0.023
Yes	No	2.63 (1.03 to 6.70)	0.043	2.30 (1.04 to 5.62)	0.048
Yes	Yes	2.70 (0.95 to 15.72)	0.116	3.39 (0.92 to 22.01)	0.063

Analysis adjusted for body mass index at Wave I, sex, race, age, highest education achieved, alcohol consumption, smoking habit, screen time, and sleep duration at follow-up. Bold indicates a *p* value < 0.05.

ADHD, Attention-Deficit/Hyperactivity Disorder; CI, confidence interval; BMI, body mass index; OR, odds ratio; WC, waist circumference.

* ≥ 5 moderate-to-vigorous physical activity sessions/week at Wave I, III and V.

obesity link diminishes or even disappears, whereas it remains unaffected in inactive individuals. Our findings align with growing evidence on the positive influence of regular physical activity on health (Bull et al., 2020; Piercy et al., 2018). Confirming our results, a longitudinal study from childhood to adolescence found that physical inactivity mediates the ADHD-obesity association (Khalife et al., 2014).

Although understudied, physical activity may protect against obesity in ADHD through several mechanisms. For example, exercise can mitigate impulsivity by improving executive function and cognitive control in both children (Cerrillo-Urbina et al., 2015; Zhu et al., 2023) and adults (Mehren et al., 2019), thereby reducing the likelihood of overeating and unhealthy choices (Eichen et al., 2021). Moreover, the release of dopamine and norepinephrine resulting from physical activity (Anish, 2005), not only contributes to mood regulation and attentional processes frequently compromised in ADHD (Wigal et al., 2013), but also holds the potential to curtail emotional eating tendencies (Casey et al., 1997). Shared biological systems like dopamine, brain-derived neurotrophic factor, linked to ADHD (Gray et al., 2006), obesity (Kent et al., 2005), and sedentary behavior (Zoladz and Pilc, 2010), provide additional backing to the idea of an interconnected relationship among these conditions.

The metabolic benefits of physical activity, including improved insulin sensitivity and reduced inflammation, also address the underlying

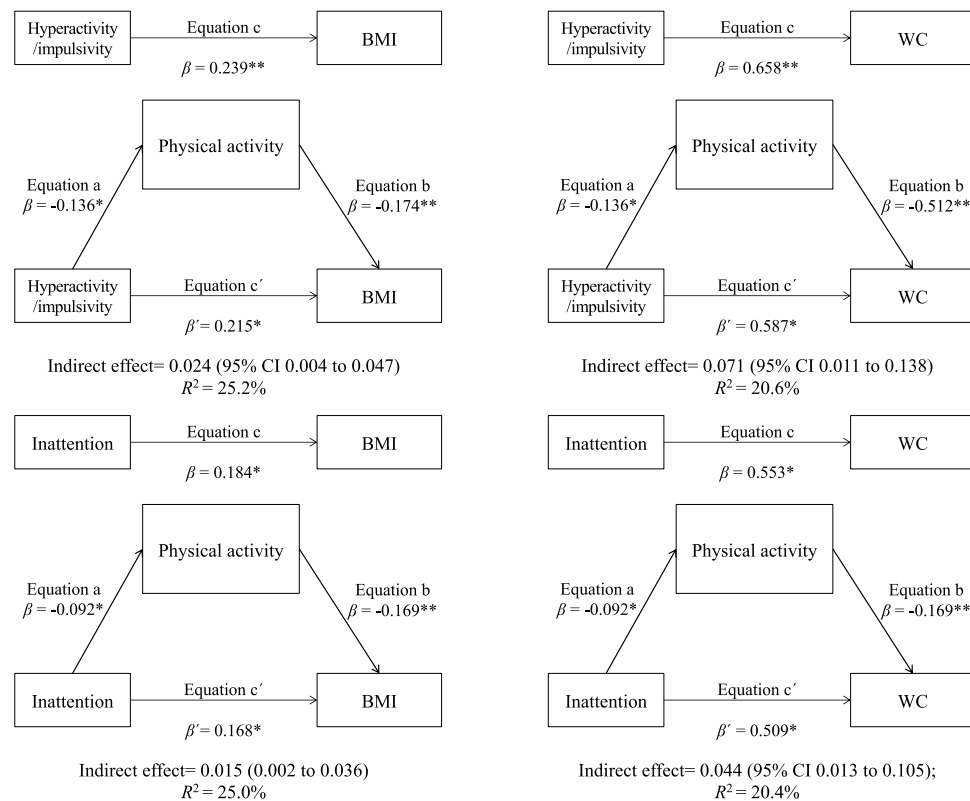


Fig. 3. Physical activity mediation model of the relationship between ADHD symptoms and obesity parameters. BMI, body mass index; WC, waist circumference. Adjusted for body mass index at Wave I, sex, race, age, highest education achieved, alcohol consumption, smoking habit, screen time, and sleep duration at follow-up. * $p < 0.050$; ** $p < 0.001$.

physiological mechanisms that link both ADHD and obesity (Chow et al., 2022; Febbraio, 2017). Furthermore, by boosting the metabolic rate, expending excess calories, and improving overall body composition, regular physical activity plays a role in maintaining a healthy weight and preventing the accumulation of excessive body fat (Hill, 2006). Physical activity also refines appetite regulation and metabolism, further supporting weight management (Beaulieu et al., 2016).

4.1. Strengths and limitations

This study has several notable strengths. First, its longitudinal design allows us to elucidate the directional nature of the relationship between ADHD symptoms and obesity. Second, our investigation incorporated two clinically validated obesity indices: BMI and WC, thereby affording a more comprehensive assessment of adiposity. Lastly, through the examination of core ADHD symptoms, we successfully established that both inattention and hyperactivity play contributory roles in these associations.

Nevertheless, a meticulous evaluation of this study must acknowledge specific limitations. First, the study sample was exclusively drawn from the USA, potentially curtailing the generalizability of the findings to other demographic cohorts or countries. Second, while the ICD-10 and DSM-IV criteria share largely similar symptoms lists, they recommend distinct approaches for establishing a diagnosis. In this study, we adopted the DSM-IV criteria for diagnosis ADHD, thereby introducing the possibility that variations in diagnostic criteria could impact the precision and comparability of the ADHD diagnoses across diverse studies or clinical environments. In our investigation, the prevalence of ADHD was found to be 1.42 %, indicating a lower prevalence than observed in other studies among the US adolescent population (Li et al., 2023; Visser et al., 2014). It is crucial to note, however, that the data is from 1997, and recent studies (Li et al., 2023; Visser et al., 2014),

indicate a noticeable increase in ADHD prevalence among adolescents in the US in recent years. These factors highlight the need for careful interpretation when comparing our findings with more current research. Third, longitudinal studies inherently face the challenge of attrition over time, as some participants were lost to follow-up, which may affect the representativeness of the study cohort. Fourth, the utilization of self-report measures to gauge physical activity levels and ADHD symptoms may introduce recall bias or inaccuracies in reporting. The inclusion of objective measures, such as activity trackers or assessments by clinicians, could significantly enhance the accuracy of data collection. Fifth, it is crucial to acknowledge that the observational design of the study precludes the establishment of a definitive causal relationship. Finally, the potential impact of unexplored variables cannot be ruled out, given that alteration in medication regimens, concurrent psychiatric conditions, and socio-environmental factors might exert influence upon our observations.

5. Conclusion

Recognizing the imperative nature of encouraging and maintaining consistent levels of physical activity becomes central in formulating holistic strategies aimed at mitigating the potential susceptibility to obesity among individuals with ADHD. Subsequent investigations should be undertaken to delve deeper into the intricacies of this interrelationship, thereby paving the way for the creation of customized interventions designed to preempt and address the co-occurrence of ADHD and obesity.

CRedit authorship contribution statement

Antonio García-Hermoso: Writing – review & editing, Supervision, Writing – original draft, Formal analysis, Data curation,

Conceptualization. **Yasmin Ezzatvar**: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Mikel Izquierdo**: Conceptualization, Supervision, Writing – review & editing. **José Francisco López-Gil**: Writing – review & editing, Conceptualization, Data curation, Formal analysis.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article to disclose.

Acknowledgments

AG-H is a Miguel Servet Fellow (*Instituto de Salud Carlos III-FSE – CP18/0150*). This research received no external funding and uses data from Add Health, a program project directed by Kathleen Mullan Harris and designed by J. Richard Udry, Peter S. Bearman, and Kathleen Mullan Harris at the University of North Carolina at Chapel Hill. Open access funding provided by *Universidad Pública de Navarra*.

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