Age-related differences in accelerometer-assessed physical activity and sleep parameters among children and adolescents with and without autism spectrum disorder a meta-analysis

JAMA Network Open

Original Investigation | Psychiatry

Age-Related Differences in Accelerometer-Assessed Physical Activity and Sleep Parameters Among Children and Adolescents With and Without Autism Spectrum Disorder

A Meta-Analysis

Xiao Liang, PhD; Justin A. Haegele, PhD; Sean Healy, PhD; Andy Choi-Yeung Tse, PhD; Hui Qiu, PhD; Shi Zhao, PhD; Chunxiao Li, PhD

Abstract

IMPORTANCE Physical inactivity and sleep disorders are health-related concerns of youth with autism spectrum disorder (ASD) that can persist from childhood and exacerbate core symptoms. However, evidence on group differences in accelerometer-assessed physical activity and sleep parameters among youth with and without ASD is inconclusive and age-specific effects remain unclear.

OBJECTIVE To synthesize evidence on group differences in accelerometer-assessed physical activity and sleep parameters and examine the moderating effects of age between children and adolescents with and without ASD.

DATA SOURCES American Psychological Association PsychInfo, CINAHL Ultimate, ERIC, MEDLINE, SPORTDiscus with Full Text, and Web of Science from inception to February 2023.

STUDY SELECTION Two independent reviewers screened articles for observational research comparing accelerometer-assessed physical activity levels and sleep parameters in children and adolescents with and without ASD.

DATA EXTRACTION AND SYNTHESIS After developing a standardized form, relevant data were extracted. Quality was assessed using the McMaster Critical Review Form and rated based on sample, measurement, and analyses. The Preferring Reporting Items for Systematic Reviews and Meta-Analyses guideline was followed.

MAIN OUTCOMES AND MEASURES The primary outcomes were actigraphy-measured MVPA, sleep latency, sleep efficiency, total sleep time, and wake after sleep onset. Data were pooled using a random-effects model. Hedges *g* was used to express the effect size index. Meta-regression on age was also performed to investigate the potential moderating effects.

RESULTS Collectively, 1757 studies were initially identified. Among 104 articles that were assessed, 28 were included, comprising moderate-to-vigorous physical activity (MVPA), 4 sleep parameters, and 73 independent effect sizes. A total of 28 studies were included in analysis, comprising 805 children and adolescents with ASD and 1573 without ASD (age range, 5.1-16.9 years). Compared with peers without ASD, children and adolescents with ASD had a small-to-moderate difference in MVPA (g = −0.450; 95% CI, −0.622 to −0.277), total sleep time (g = −0.332; 95% CI, −0.574 to −0.090), sleep efficiency (g = −0.424; 95% CI, −0.645 to −0.203), and a moderate difference in sleep latency (g = 0.514; 95% CI, 0.351 to 0.677) measured by actigraphy. Children and adolescents with ASD experienced an age-related decline in moderate-to-vigorous physical activity (β = −0.049 [95% CI,

(continued)

Key Points

Question What differences in accelerometer-assessed physical activity and sleep parameters exist in children and adolescents with and without autism spectrum disorder (ASD), and are associations affected by age?

Findings This meta-analysis including 28 studies with 805 participants found that youth with ASD were associated with lower moderate-to-vigorous physical activity (MVPA), total sleep time, and sleep efficiency but higher sleep latency than peers without ASD. An age-related decline was only observed in MVPA.

Meaning These results suggest that public health initiatives are needed to reduce disparities in MVPA and sleep health among children and adolescents with ASD.

+ Supplemental content

Author affiliations and article information are listed at the end of this article.

Abstract (continued)

−0.097 to −0.001]; *P* = .045), indicating that younger children with ASD showed a smaller difference in MVPA compared with their peers without ASD. Moderating effects of age on sleep parameters were not significant.

CONCLUSIONS AND RELEVANCE The findings of this meta-analysis suggested that children and adolescents with ASD had lower MVPA and worse sleep than peers without ASD, and the difference in MVPA varied with age. These findings reinforce the need for public health initiatives aimed at reducing these group disparities.

JAMA Network Open. 2023;6(10):e2336129. doi:10.1001/jamanetworkopen.2023.36129

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by impaired social communication, repetitive behaviors, and restricted interests[1] affecting approximately 1% of children worldwide.[2] Alongside the core symptoms, physical inactivity and sleep disturbances, as critical health behaviors, typically manifest in school-aged children with ASD.[2,3] It has been proposed that sensory sensitivity abnormalities might contribute to physical inactivity and sleep problems among children with ASD.[4,5] Sensory modulation issues among children with ASD may affect their ability to engage in physical activity with intense sensory stimulation.[6] Similarly, children with ASD who experience hypersensitivity in response to sensory stimulation tend to be more likely to feel anxious at bedtime, resulting in difficulty falling asleep.[7]

Systematic reviews and meta-analyses of randomized clinical trials have shown that engaging in physical activity, especially in moderate-to-vigorous physical activity (MVPA), is associated with diverse physical and psychological benefits in children with ASD, such as reduced stereotypic behaviors,[8] improved executive function,[9] motor proficiency,[10] and social functioning.[11] Indeed, due to the evidence underpinning its effectiveness, exercise (ie, planned, structured, and repetitive physical activity) has been identified as an evidence-based strategy for school-aged youth with ASD.[12] However, despite the growing evidence for the wide-ranging benefits of physical activity for youth with ASD, data indicate that this population tends to be less active and is less likely to meet the minimum World Health Organization–recommended MVPA guidelines of 60 minutes per day of MVPA,[13] as compared with their peers without ASD.[14,15]

Sleep disorders occur in 50% to 80% of school-aged children with ASD.[16] Common sleep problems include sleep onset delay, shorter sleep duration, early morning awakenings, and night waking.[17-19] Generally, there is a consensus that children with ASD experience poorer sleep than their peers without ASD.[20,21] However, the reported sleep problems exhibit high heterogeneity,[16] which may be due to age differences of the samples between studies, interindividual differences across ASD groups, and variations in assessment methods (eg, parent-reported questionnaire and sleep diary vs actigraphy and polysomnography [PSG] measures).[16]

Despite physical activity and sleep health being recognized as critical health behaviors for children with ASD, there remains a lack of consensus on the differences in these behaviors among youth with ASD vs youth without ASD. We identified 4 gaps in current research that warrant a meta-analysis of group differences in physical activity and sleep among children and adolescents with and without ASD. First, a 7-country survey indicated that only 7.2% of youth with ASD met the daily recommended physical activity guidelines (MVPA over 60 minutes), while 55.9% met the sleep duration guidelines (9 to 11 hours/night).[22] Reliance on parental reports can be problematic as they are likely to underestimate the child's physical inactivity and disturbed sleep over time[23] and may have difficulty removing bias from their observation, leading to inaccurate records. Second, a 2022 meta-analysis addressing accelerometer-measured physical activity[24] indicated that children and adolescents with ASD have significantly lower physical activity levels than their peers without ASD.

However, their review included 2 studies involving preschool children with ASD[25,26] and 3 studies assessed physical activity only during segments of the school day (eg, inclusive physical education and recess),[27-29] which limits interpretations relevant to habitual physical activity, which is the typical activity pattern of children in daily life. Third, device-based assessments of sleep parameters are inconsistent across studies.[21] In particular, PSG-based studies showed several disturbed sleep parameters in youth with ASD, while actigraphy-based studies reported significantly longer sleep latency in youth with ASD than their peers without ASD, with nonsignificant results documented in other sleep parameters.[21] Perhaps this discrepancy is attributable to the fact that their review included very few studies which reported accelerometer-assessed sleep parameters (6 studies). Finally, previous reviews have suggested that physical activity levels and sleep issues in children with ASD are age-related. Specifically, younger children displayed increased physical activity,[15] bedtime resistance, and anxiety,[30] while older children experienced increased insomnia.[30] However, the moderating role of age has not been examined in a meta-analysis of accelerometer-assessed PA and sleep quality. Moreover, increasingly physical activity and sleep are being considered as part of the 24-hour movement framework and therefore being studied in unison.[31] Reporting on meta-analyses on both behavioral outcomes in 1 report may continue to encourage this more holistic perspective of daily health behaviors. The present study, therefore, aimed to (1) systematically review and perform a meta-analysis of mean differences in physical activity levels and 4 sleep parameters (eg, sleep latency, total sleep time, sleep efficiency, wake after sleep onset [WASO]) among children and adolescents with and without ASD, as measured via accelerometers, and (2) examine the moderating effect of age.

Methods

This study adhered to the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) guidelines. The protocol for this study has been registered in the International Prospective Register of Systematic Reviews (PROSPERO) (CRD42023398508).

Search Strategy

To identify all relevant published articles that reported on the comparison of accelerometer-assessed physical activity levels or sleep parameters between children and adolescents with and without ASD, electronic searches were performed using 6 databases, from inception to February 2023: American Psychological Association PsychInfo (via Ovid), CINAHL Ultimate (via EBSCOhost), ERIC (via EBSCOhost), MEDLINE (via Ovid), SPORTDiscus with Full Text (via EBSCOhost), and Web of Science. The search was limited to articles written in English on human-related topics. A snowballing search was performed to identify additional relevant articles, where the reference lists of the retrieved studies (backward snowballing), and references that cited the eligible studies (forward snowballing) were checked for additional eligible studies.

Eligibility Criteria

Inclusion criteria were studies that (1) compared accelerometer-assessed physical activity levels and/or sleep parameters (eg, MVPA, sleep latency, total sleep time, sleep efficiency, WASO), recorded on at least 3 valid days or nights,[32] between children and adolescents with and without ASD; (2) were observational-based research (cross-sectional, case-control, and cohort); (3) reported the duration of MVPA, sleep latency, total sleep time, and WASO in minutes and sleep latency in percentage; (4) were peer-reviewed, English-language articles with full-text availability; (5) involved participants with ASD aged between 5 and 18 years diagnosed using standardized diagnostic tools (eg, *Diagnostic and Statistical Manual of Mental Disorders* [Third Edition] [*DSM-3*]; *DSM-4*; *DSM-5*; *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* [*ICD-10*]; and Autism Diagnostic Observation Schedule–Second Edition [ADOS-2]) or parental reports; and (6) provided complete research data whereby physical activity and sleep continuity could be

computed. Exclusion criteria were studies that (1) collected data from self-reported measurements; (2) only included participants with ASD and not those without; (3) were written in a language other than English; (4) reported intervention-based research (eg, clinical and field trials); (5) were review studies, case or government reports, conference papers, book chapters, or policy documents; and (6) included preschool children (ages 0 to 4 years old) or adults (ages 18 years and older).

Outcome Variables

MVPA refers to the length of moderate-to-vigorous physical activity levels in the form of duration in minutes per day. Sleep latency refers to the time in minutes from lights out to falling asleep. Total sleep time refers to the total time in minutes spent asleep per night. WASO refers to time awake after sleep onset, namely awake time length in minutes between sleep onset and sleep offset. Sleep efficiency refers to the percentage of total sleep time divided by the time in bed between sleep onset and sleep offset.

Study Selection and Data Extraction

Multi-step screening was conducted by 2 independent reviewers (X.L. and H.Q.).[15] Agreement was reached by consensus-aimed discussion. Interrater reliability was measured using Cohen κ statistic.[33] After developing a standardized data extraction form, the relevant study characteristics were extracted: bibliographic details (author, year, and country or regions in which studies occurred), research design, participant characteristics (sample size, sex, age, medication status, and diagnosis), physical activity measures and levels, sleep measures and duration or percentages, recorded duration, and major findings.

Quality Assessment

The methodological quality of each study was assessed by 2 reviewers (X.L. and H.Q.) using the McMaster Critical Review Form for Quantitative Studies[34] and rated based on 3 key criteria.[35] The sample criterion evaluated whether selection bias was reduced, whether the sample size was suitable for the research design and questions, and whether the participant characteristics were clearly described. The measurement criterion examined whether measurement bias was controlled (eg, reliability and validity of the measurement tool, recall/memory). The analyses criterion examined whether the reported analyses were appropriate for the research questions and outcome measures (eg, reported statistical significance, point estimates and variability, and discussed clinical importance).[35] Each criterion was scored as 1 star (no evidence that the study met the requirement), 2 stars (insufficient evidence or unclear reporting), or 3 stars (the evidence met the criteria).[15,35]

Statistical Analysis

A meta-analysis was performed using Comprehensive Meta-Analysis software version 3 (Biostat Inc). The MVPA, sleep latency, total sleep time, and WASO (in minutes) and sleep efficiency (as a percentage) were used to calculate effect size. Hedges *g* was used to measure the effect size index with small-sample bias correction.[36] A random-effects model using the DerSimonian-Laird method was employed to compute the potentially heterogeneously distributed effect sizes with a 95% CI between the groups. The magnitude of Hedges *g* values was classified as small (under 0.2), moderate (0.5), and large (over 0.8) effect sizes.[37] Statistical heterogeneity was assessed using I^2 with Cochran *Q* statistic *P* value. The I^2 values represented small (25% or lower), medium (50%), or large (75% or higher) heterogeneity.[38] A cut-off point of 50% I^2 was set to evaluate the heterogeneity across studies, with an I^2 value above 50% indicating the existence of heterogeneity. Sensitivity analysis was used to determine whether the elimination of any study influenced the overall effect size.[11] Funnel plots and Egger regression were used to assess possible publication bias. Finally, meta-regression analysis was performed to compare the physical activity levels and sleep parameters of those with and without ASD depending on age (mean age). Statistical significance was considered $P < .05$ for all tests.

Results

Study Identification

In total, 1757 articles were identified upon initial screening (eFigure 1 in Supplement 1). After removing duplicates, 677 articles were screened by title or abstract. A total of 104 abstracts and 25 articles met the inclusion criteria (κ = 0.86 and κ = 0.92, respectively). Three articles, identified via a manual snowball search, also met the inclusion criteria. Finally, 28 studies[39-66] were selected for systematic review and meta-analysis as the data was considered sufficient.

Characteristics of Included Studies

The 28 studies included 805 participants with ASD (679 male [84.3%]) and 1573 without ASD (895 male [56.9%]); ages ranged from 5.1 to 16.9 years (eTable 1 in Supplement 1). Only 9 studies[39,40,42,44,45,54,58,64] (32.1%) reported medication use status, of which, 5 studies[42,44,45,58,64] included medicine-naive children and adolescents with ASD as participants. While 24 studies[39-42,44-53,55-57,59,60,62-66] (85.7%) confirmed ASD diagnosis using standardized diagnostic methods (eg, *DSM-4*, *DSM-5*, *ICD-10*, and ADOS-2), only 7 studies[39,41,49,50,53,54,57] (25.0%) provided a clear classification of ASD severity. The differences in physical activity levels and sleep parameters between children and adolescents with and without ASD are summarized in the **Table**. Twelve studies[43,46,47,49,50,53,55,57,60-62,65] recorded physical activity levels of the duration of the actigraph measurements ranging from 4 to 14 days and measured MVPA duration as an outcome to represent daily physical activity. Furthermore, we identified within-group differences in physical activity levels between weekdays[47,49,50,55,60,65] and weekend days[55,60,65] among participants with ASD and found that children and adolescents with ASD spent more time in MVPA on weekdays (67.56 min/d) than on weekend days (39.01 min/d). Furthermore, 17 studies[39-42, 44, 45, 47, 48, 51, 52, 54, 56, 58, 59, 63, 64, 66] assessed sleep parameters via actigraphy, across 3 to 7 nights of measurement. Lastly, 7 studies[44,45,47,51-53,56] (25.0%) controlled for confounders such as sex and age.

Meta-Analysis of Accelerometer-Assessed Physical Activity Levels

A significant small-to-moderate group difference in MVPA was observed in children and adolescents with ASD compared with those without (κ = 12; g = −0.450 [95% CI, −0.622 to −0.277]), with small heterogeneity (Q = 13.370; I^2 = 17.7%; P < .001) (**Figure 1**). Overall, children and adolescents with ASD undertook less daily MVPA (mean [SD], 58.73 [39.09] min/d) than peers without ASD (77.03 [52.03] min/d). Sensitivity analysis revealed no significant changes in the effect size following the elimination of any individual paper (g = −0.450 [95% CI, −0.622 to −0.277]). The Egger test failed to find evidence for publication bias. Meta-regression analysis demonstrated that age was a significant moderator for the group difference in MVPA between children and adolescents with and without ASD (β = −0.049 [95% CI, −0.097 to −0.001]; P = .045) (eFigure 4 in Supplement 1), indicating that the size of the difference in physical activity levels between children and adolescents with and without ASD increased with age.

Meta-Analysis of Accelerometer-Assessed Sleep Parameters

Of the 17 studies, 2 reported cross-cultural comparison in sleep patterns between countries: UK vs Korea,[41] UK vs Singapore.[63] Thus, we included contrasts between participants with and without ASD in each country and treated them as independent contrasts in the analysis. In total, 61 contrasts across 17 studies were identified: 17 effect sizes[39-42,44,45,47,51,52,54,56,59,63,64,66] reported sleep latency results, 19 effect sizes[39-42, 44, 45, 47, 48, 51, 52, 54, 56, 58, 59, 63, 64, 66] reported total sleep time, 18 effect sizes[39-42, 44, 45, 47, 48, 52, 54, 56, 58, 59, 63, 64, 66] reported sleep efficiency, and 7 effect sizes[42,44,47,54,56,58,64] reported WASO.

A significant moderate-to-large group difference in sleep latency was observed in those with ASD compared with those without (κ = 17; g = 0.514 [95% CI, 0.351–0.677]), with small heterogeneity (Q = 22.539; I^2 = 29%; P < .001) (**Figure 2**). Children and adolescents with ASD

Table. Summary of Included Studies on Moderate-to-Vigorous Physical Activity (MVPA) and Sleep Parameters

Study name, year (country)	Study design	Measurement model	Duration of actigraph data	Accelerometer-assessed MVPA or sleep parameters				
				Parameters	ASD, mean (SD)	TD, mean (SD)	Major findings[a]	Confounders
Allik et al,[39] 2006 (Sweden)	Cross-sectional	Actiwatch	7 d	SL (min); weekdays	32.2 (17.9)	15.7 (10.6)	SL positive	NA
				SL (min); weekend	21.5 (20.0)	11.4 (10.3)	SL positive	
				TST (min); weekday	511 (34.7)	523 (35.0)	NS	
				TST (min); weekend	514 (44.4)	522 (42.5)	NS	
				SE (%); weekdays	87.1 (3.6)	90.3 (4.1)	NS	
				SE (%); weekend	88.6 (4.7)	90.1 (4.1)	NS	
Allik et al,[40] 2008 (Sweden)	Longitudinal	Actiwatch	7 d	SL (min); weekdays	25.3 (22.1)	17.8 (11.3)	NS	NA
				SL (min); weekend	28.1 (25.1)	14.2 (16.3)	NS	
				TST (min); weekend	434 (32.5)	445 (39.5)	SE positive for weekends	
				TST (min); weekend	462 (50.8)	465 (44.3)	NS	
				SE (%); weekdays	81.8 (5.0)	83.5 (4.0)	NS	
				SE (%); weekend	79.5 (5.6)	83.4 (5.2)	NS	
Baker et al,[51] 2013 (Australia)	Cross-sectional	MicroMini Motionlogger	7 d	SL (min)	59.30 (41.27)	33.83 (16.14)	SL positive	NA
				TST (min)	470.95 (57.82)	492.01 (40.11)	NS	
Bandini et al,[60] 2013 (US)	Cross-sectional	Actical	7 d	MVPA (min); weekdays	48.0	59.2	NS	Children without ASD are more likely to be an only child
				MVPA (min); weekend	53.5	52.1	NS	
Bennett et al,[61] 2022 (US)	Cross-sectional	ActiGraph GT3x	4 d	MVPA (min)	29.0 (15.4)	38.0 (18.9)	NS	NA
Bricout et al,[62] 2018 (France)	Cross-sectional	SenseWear Pro-3	7 d	MVPA (min)	27 (29)	42 (24)	NS	NA
Chua et al,[63] 2022 (UK)	Cross-sectional	MotionWatch8	5 nights	SL (min); Singapore cohort	30.15 (17.41)	20.35 (13.50)	SL positive	School session
				SL (min); UK cohort	60.00 (48.55)	21.15 (13.23)	SL positive	
				TST (min); Singapore cohort	420 (71)	392 (34)	NS	
				TST (min); UK cohort	455 (61)	487 (34)	NS	
				SE (%); Singapore cohort	74.23 (10.03)	78.15 (6.87)	NS	
				SE (%); UK cohort	76.49 (9.86)	82.01 (4.83)	SE positive	
Goldman et al,[64] 2009 (US)	Cross-sectional	AW-64 Actiwatch	7 d	SL (min)	53.4 (25.6)	33.7 (33.2)	SL positive	NA
				TST (min)	481.6 (56.8)	475.9 (38.8)	NS	
				SE (%)	80.9 (6.6)	84.7 (4.6)	SE positive	
				WASO (min)	39.5 (12.6)	31.7 (12.4)	NS	
Haegele et al,[65] 2021 (US)	Cross-sectional	ActiGraph GT3x	7 d	MVPA (min); weekend	36.52 (18.28)	37.00 (14.80)	NS	NA
				MVPA (min); weekend	27.20 (22.04)	35.63 (45.63)	NS	
Hering et al,[66] 1999 (Israel)	Cross-sectional	Ambulatory actigraph	3 nights	SL (min)	22.59 (1.02)	23.26 (1.23)	NS	NA
				TST (min)	425.8 (47.7)	431.8 (80.2)	NS	
				SE (%)	88.71 (4.45)	87.19 (5.25)	NS	
Jeon et al,[41] 2023 (UK)	Cross-sectional	MotionWatch8	7 d	SL (min); Korean cohort	25.38 (17.84)	19.3 (11.7)	NS	Age
				SL (min); UK cohort	42.09 (39.51)	25.3 (14.6)	SL positive	
				TST (min); Korean cohort	432.6 (42.0)	439.8 (43.8)	NS	
				TST (min); UK cohort	479.4 (52.2)	495.0 (36.6)	NS	
				SE (%); Korean cohort	78.93 (5.79)	78.0 (5.0)	NS	
				SE (%); UK cohort	78.98 (8.05)	81.3 (3.87)	NS	
Kosaka et al,[42] 2021 (Japan)	Cross-sectional	Actiwatch	7 d	SL (min)	4.5 (4.7)	4.0 (2.7)	NS	NA
				TST (min)	439.0 (37.8)	460.3 (28.4)	NS	
				SE (%)	82.8 (4.8)	86.6 (3.1)	SE positive	
				WASO (min)	70.2 (17.9)	57.1 (16.1)	WASO positive	
Lobenius-Palmér et al,[43] 2018 (Sweden)	Cross-sectional	ActiGraph, GT1M	7 d	MVPA (min)	79 (63)	142 (80)	MVPA positive	NA

(continued)

Table. Summary of Included Studies on Moderate-to-Vigorous Physical Activity (MVPA) and Sleep Parameters (continued)

Study name, year (country)	Study design	Measurement model	Duration of actigraph data	Accelerometer-assessed MVPA or sleep parameters			Major findings[a]	Confounders
				Parameters	ASD, mean (SD)	TD, mean (SD)		
Martinez-Cayuelas et al,[44] 2021 (Spain)	Cross-sectional	Ambulatory circadian monitoring	7 d	SL (min)	26.5 (26.9)	14.4 (13.75)	SL positive	NA
				TST (min)	517.3 (50.6)	543.7 (31.6)	NS	
				SE (%)	88.20 (5.62)	91.85 (3.09)	SE positive	
				WASO (min)	24.5 (9.78)	23.02 (5.18)	NS	
Martinez-Cayuelas et al,[45] 2022 (Spain)	Cross-sectional	Ambulatory circadian monitoring	7 d	SL (min)	21.16 (15.58)	11.60 (7.8)	SL positive	NA
				TST (min)	510.88 (46.90)	546.63 (26.9)	TST positive	
				SE (%)	89.36 (4.48)	92.30 (1.90)	SE positive	
Moludi et al,[46] 2019 (Iran)	Cross-sectional	ActiGraph GT3x	7 d	MVPA (min)	28.68 (18.94)	33.70 (19.97)	NS	NA
Mughal et al,[59] 2020 (UK)	Cross-sectional	Actiwatch 8	7 d	SL (min)	38.18 (34.12)	26.08 (26.49)	NS	Socioeconomic status, sex, age
				TST (min)	444.33 (63.03)	486.55 (4.44)	TST positive	
				SE (%)	72.68 (7.55)	80.02 (6.99)	SE positive	
Nguyen et al,[47] 2021 (France)	Cross-sectional	Sensewear Pro Armband3	5 d	MVPA (min); weekdays	156 (75)	209 (59)	MVPA positive	NA
				SL (min)	13.6 (9.7)	15.9 (6.6)	NS	
				TST (min)	420 (54)	426 (47)	NS	
				SE (%)	74.9 (7.1)	74.4 (7.4)	NS	
				WASO (min)	113.0 (41.0)	126.7 (49.3)	NS	
Pace et al,[48] 2016 (France)	Cross-sectional	Sensewear Pro Armband3	7 nights	TST (min)	413.8 (37.2)	412.0 (46.6)	NS	NA
				SE (%)	70 (7)	69 (8)	NS	
Pan et al,[49] 2015 (Taiwan)	Cross-sectional	ActiGraph GT1M	5 d	MVPA (min); weekdays	69.61 (50.30)	97.07 (47.67)	MVPA positive	NA
Pan et al,[50] 2016 (Taiwan)	Cross-sectional	ActiGraph GT1M	7 d	MVPA (min); weekdays	64.23 (48.78)	90.68 (49.14)	MVPA positive	NA
				MVPA (min); weekend	63.14 (84.00)	55.78 (36.09)	NS	
Phung and Goldberg,[52] 2017 (US)	Cross-sectional	Micro motionlogger	7 d	SL (min)	42.48 (27.40)	22.46 (11.56)	SL positive	Sex
				TST (min)	419.35 (84.61)	378.61 (70.77)	TST positive	
				SE (%)	91.92 (6.63)	88.49 (8.93)	NS	
Sandt and Frey,[53] 2005 (US)	Cross-sectional	ActiGraph MT1	14 d	MVPA (min)	127.5 (72.3)	162.1 (45.6)	MVPA positive	Sex
Souders et al,[54] 2009 (US)	Cross-sectional	MicroMini-Motionlogger	7 nights	SL (min)	34.42 (21.94)	21.71 (8.97)	SL positive	NA
				TST (min)	452.00 (65.07)	469.57 (52.63)	NS	
				SE (%)	83.63 (7.93)	84.21 (6.23)	NS	
				WASO (min)	88.03 (41.8)	87.46 (32.99)	NS	
Stanish et al,[55] 2017 (US)	Cross-sectional	Actical	7 d	MVPA (min); weekdays	31.0	55.2	MVPA positive	Sex, age
				MVPA (min); weekend	12.2	40.9	MVPA positive	
Surtees et al,[56] 2019 (UK)	Cross-sectional	Actiwatch 2	7 d	SL (min)	38 (32)	29 (26)	NS	NA
				TST (min)	485 (39)	492 (45)	NS	
				SE (%)	82.08 (4.17)	83.88 (5.68)	NS	
				WASO (min)	52 (17)	48 (16)	NS	
Thomas et al,[57] 2022 (Australia)	Cross-sectional	ActiGraph GT3x	8 d	MVPA (min)	87.03 (38.28)	82.10 (40.45)	NS	NA
Tse et al,[58] 2020 (Hong Kong)	Cross-sectional	ActiGraph GT3x	7 d	TST (min); weekdays	462 (30)	498 (36)	TST positive (weekdays and weekend)	NA
				TST (min); weekend	492 (36)	558 (30)	SE positive (weekdays and weekend)	
				SE (%); weekdays	81.1 (6.4)	90.7 (8.3)	WASO positive (weekdays and weekend)	
				SE (%); weekend	86.3 (9.1)	94.8 (9.7)	NS	
				WASO (min); weekdays	60.0 (27.2)	40.5 (26.9)	NS	
				WASO (min); weekend	51.6 (36.3)	21.9 (33.5)	NS	

Abbreviations: MVPA, moderate-to-vigorous physical activity; NA, not applicable; NS, not significant; SE, sleep efficiency; SL, sleep latency; TST, total sleep time; WASO, wake after sleep onset.

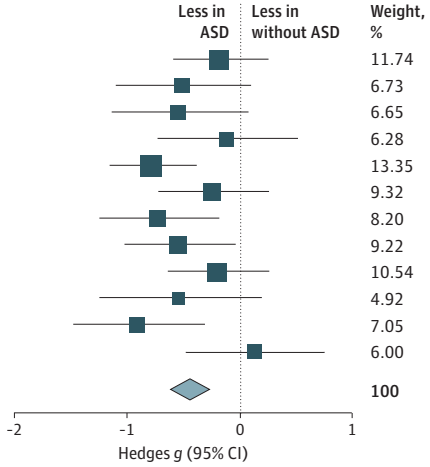
[a] Statistically significant associations are reported as positive or negative associations.

showed longer sleep latency duration (mean [SD], 32.57 [14.57] min) than their peers without ASD (20.06 [7.65] min). Sensitivity analysis revealed no significant changes in the effect size following the elimination of any individual paper. The Egger test did not find evidence for publication bias. Meta-regression analysis indicated that the group difference in sleep latency between children and adolescents with and without ASD was not moderated by age (β = 0.025 [95% CI, −0.036 to 0.885]; P = .42) (eTable 2 in Supplement 1).

There was a statistically significant between-group differences in total sleep time (κ = 19; g = −0.332 [95% CI, −0.574 to −0.090]), with medium-to-large heterogeneity (Q = 66.782; I^2 = 73%; P = .007) (**Figure 3**). Total sleep time was significantly lower in children and adolescents with ASD (mean [SD], 461.00 [34.05] min) than in those without (474.54 [48.76] min). Sensitivity analysis revealed no significant changes in the effect size following the elimination of any individual paper. Egger regression revealed publication bias among the included papers; 5 additional studies were needed to balance the total sleep time plot (eFigure 2 in Supplement 1). Meta-regression analysis demonstrated that age did not moderate the group differences in total sleep time between

Figure 1. Meta-Analysis of Accelerometer-Assessed Moderate-to-Vigorous Physical Activity

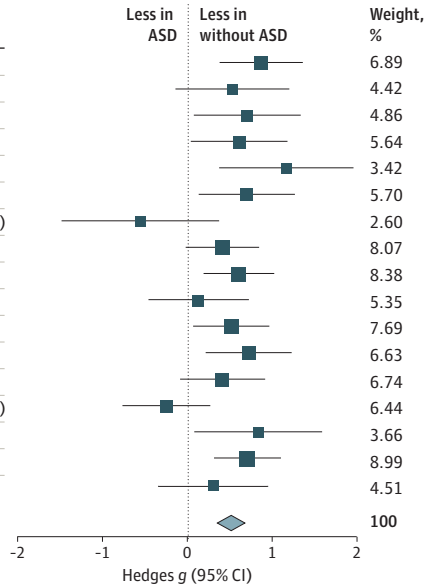
Source (country or region)	Hedges g (95% CI)
Bandini et al,[60] 2013 (US)	-0.191 (-0.627 to 0.244)
Bennett et al,[61] 2022 (US)	-0.523 (-1.138 to 0.092)
Bricout et al,[62] 2018 (France)	-0.552 (-1.172 to 0.067)
Haegele et al,[65] 2021 (US)	-0.129 (-0.769 to 0.511)
Lobenius-Palmér et al,[43] 2018 (Sweden)	-0.791 (-1.191 to -0.392)
Moludi et al,[46] 2019 (Iran)	-0.255 (-0.760 to 0.251)
Nguyen et al,[47] 2021 (France)	-0.736 (-1.282 to -0.189)
Pan et al,[49] 2015 (Taiwan)	-0.553 (-1.062 to -0.044)
Pan et al,[50] 2016 (Taiwan)	-0.211 (-0.679 to 0.257)
Sandt and Frey,[53] 2005 (US)	-0.547 (-1.282 to 0.188)
Stanĭsh et al,[55] 2017 (US)	-0.916 (-1.515 to -0.317)
Thomas et al,[57] 2022 (Australia)	0.122 (-0.535 to 0.779)
Heterogeneity: Q = 13.37 , I^2 = 17.7% Test for overall effect: Z = -5.116, P < .001	**-0.450 (-0.622 to -0.277)**



ASD indicates autism spectrum disorder. Size of the boxes vary by study weighting.

Figure 2. Meta-Analysis of Accelerometer-Assessed Sleep Latency

Source (country or region)	Hedges g (95% CI)
Allik et al,[39] 2006 (Sweden)	0.868 (0.359 to 1.376)
Allik at el,[40] 2008 (Sweden)	0.528 (-0.160 to 1.217)
Baker et al,[51] 2013 (Australia)	0.704 (0.056 to 1.352)
Chua et al,[63] 2022 (UK, Singapore)	0.608 (0.022 to 1.194)
Chua et al,[63] 2022 (UK, UK)	1.164 (0.357 to 1.970)
Goldman et al,[64] 2009 (US)	0.698 (0.116 to 1.280)
Hering et al,[66] 1999 (Israel)	-0.561 (-1.507 to 0.386)
Jeon et al,[41] 2023 (UK)-KOR	0.412 (-0.037 to 0.862)
Jeon et al,[41] 2023 (UK)-UK	0.604 (0.168 to 1.040)
Kosaka et al,[42] 2021 (Japan)	0.128 (-0.480 to 0.736)
Martínez-Cayuelas et al,[44] 2021 (Spain)	0.514 (0.047 to 0.981)
Martínez-Cayuelas et al,[45] 2022 (Spain)	0.720 (0.197 to 1.243)
Mughal et al,[59] 2020 (UK)	0.411 (-0.160 to 0.928)
Nguyen et al,[47] 2021 (France)	-0.253 (-0.787 to 0.282)
Phung and Goldberg,[52] 2017 (US)	0.833 (0.059 to 16.08)
Souders et al,[54] 2009 (USA)	0.705 (0.295 to 1.115)
Surtees et al,[56] 2019 (UK)	0.301 (-0.379 to 0.980)
Heterogeneity: Q = 22.539, I^2 = 29.0% Test for overall effect: Z = -6.172, P < .001	**0.514 (0.351 to 0.677)**

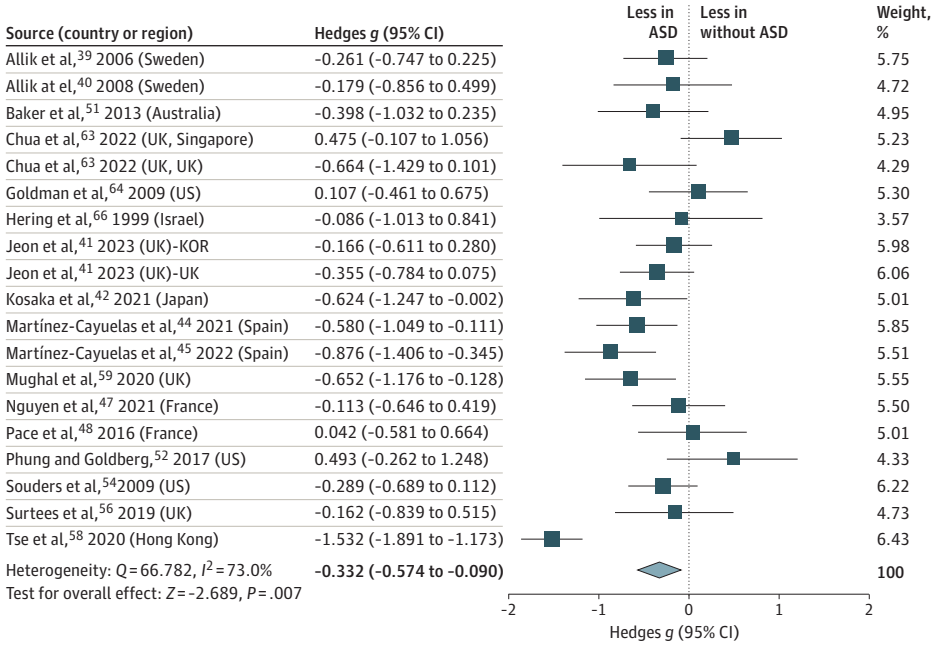


ASD indicates autism spectrum disorder. Size of the boxes vary by study weighting.

children and adolescents with and without ASD (β = 0.037 [95% CI, −0.054 to 0.128]; *P* = .43) (eTable 2 in Supplement 1).

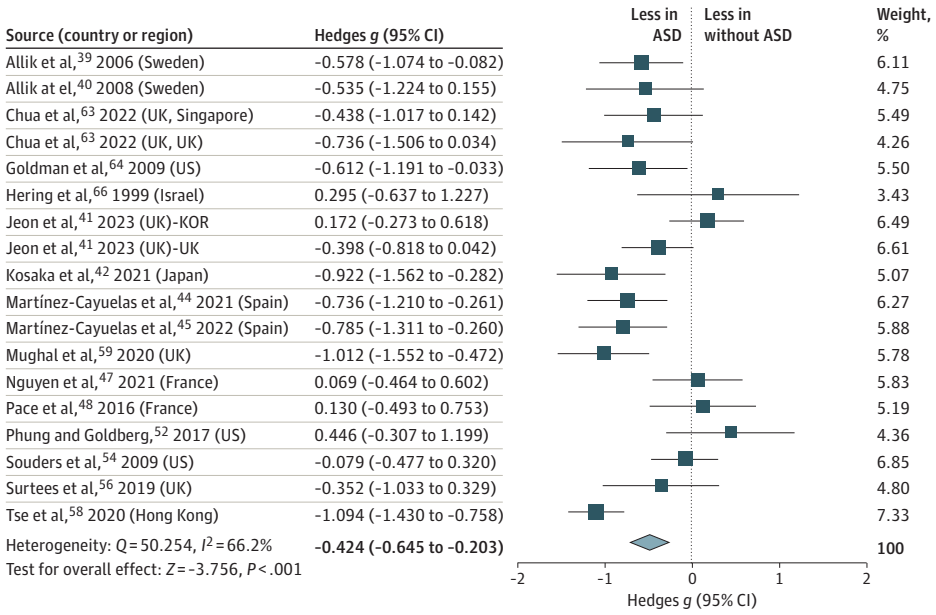
A statistically significant group difference in sleep efficiency was observed (κ = 18; *g* = −0.424 [95% CI, −0.645 to −0.203]) with medium heterogeneity (*Q* = 50.254; I^2 = 66%; *P* < .001) (**Figure 4**). Significantly lower SE was found in youth with ASD (mean [SD] 81.82% [6.02%]) than in peers without ASD (84.52% [6.39%]). Sensitivity analysis revealed no significant changes in the effect size following the removal of any individual paper. The Egger test did not identify publication

Figure 3. Meta-Analysis of Accelerometer-Assessed Total Sleep Time



ASD indicates autism spectrum disorder. Size of the boxes vary by study weighting.

Figure 4. Meta-Analysis of Accelerometer-Assessed Sleep Efficiency



ASD indicates autism spectrum disorder. Size of the boxes vary by study weighting.

bias. Meta-regression analysis demonstrated nonsignificant differences in sleep efficiency between children and adolescents with and without ASD depending on age (β = 0.060 [95% CI, −0.033 to 0.153]; *P* = .209) (eTable 2 in Supplement 1).

Between-group differences in WASO were not statistically significant (κ = 7; *g* = 0.324 [95% CI, −0.002 to 0.650]), with medium heterogeneity (*Q* = 18.466; I^2 = 68%; *P* = .051) (eFigure 3 in Supplement 1). Descriptively, WASO was slightly longer in children with ASD (mean [SD] 62.34 [27.95] min) than in those without (54.55 [36.09] min). As less than 10 studies were included in the analysis (7 studies total), analyses for publication bias and meta-regression were not conducted.

Quality Assessment

Six studies[39,41,42,45,46,51] met all 3 criteria for quality assessment (eTable 1 in Supplement 1). All studies used a convenience sample; male participants dominated sample selection. Only 7 studies[39,41,42,45,46,49,51] provided a detailed classification of ASD severity. Only 1 study[65] reported actigraphy-based simultaneous physical activity and sleep measurements, with most studies focusing on 1 health indicator independently. All studies addressed the research questions, reported statistical significance, and discussed clinical importance.

Discussion

This study explored between-group differences in accelerometer-assessed physical activity levels and sleep parameters between children and adolescents with and without ASD. Youth with ASD had less MVPA, longer sleep latency, shorter total sleep time, and lower sleep efficiency compared with those without ASD. No differences were observed in WASO between groups. Notably, differences in MVPA varied with age, but this was not the case for sleep parameters.

Consistent with previous reviews,[14,15] our findings showed that accelerometer-assessed habitual physical activity was significantly lower in children and adolescents with ASD than in their peers without ASD. Moreover, those with ASD were less likely to meet the World Health Organization–recommended daily MVPA.[13] Consistent with previous reviews,[15,24] our findings confirmed that children and adolescents with ASD (aged 5.5 to 15.9 years) experienced age-related reductions in MVPA. A recent longitudinal study exploring physical activity behavior change timings (aged 9 to 18 years) found that MVPA disparities between children with and without ASD began at 9 years of age and progressively worsened until 13 years.[67] Similarly, a 2020 meta-analysis[68] indicated an annual MVPA decline of 6 minutes per day in 9-year-old male (−7.8%) and female (−10.2%) children without ASD. By adolescence, a more severe decline in MVPA exists for children with ASD. A plausible mechanism for these observed MVPA differences could be that because of early abnormal sensory sensitivity to stimuli, children with ASD demonstrate difficulties in participating in activities with physical demands and social communication as they age.[69] Children and adolescents with ASD are less likely to participate in physical activity with higher social demands (eg, basketball, football, and volleyball), and are therefore less likely to engage in MVPA than their peers without ASD. Indeed, physical inactivity is a global pandemic, contributing to a range of chronic diseases and premature deaths.[70] Thus, multilevel coordinated efforts at the individual, community, and governance levels are needed to increase physical activity across all ages and abilities, including among youth with ASD.[15]

Findings from accelerometer-assessed sleep parameters suggest that, on average, children and adolescents with ASD had longer sleep latency, shorter total sleep time, and lower sleep efficiency than their peers without ASD. These results were inconsistent with the findings of a previous meta-analysis,[21] which reported that children with ASD had increased sleep onset latency as compared with children without ASD, but there were no differences in total sleep time and sleep efficiency between groups as measured by actigraphy. Notably, their review included a limited number of actigraphy-measured studies reporting sleep latency, total sleep time, and sleep efficiency, suggesting that conclusions should be interpreted with caution. Contrastingly, we provide

meta-analytic evidence for the accelerometer-assessed sleep parameters,[21] with actigraphy recordings displaying considerable sleep impairments in children and adolescents with ASD. Additionally, our results are generally consistent with those of PSG-based studies,[21] specifically of studies that showed that, compared with children without ASD, children with ASD experienced multiple significant sleep impairments, including lower total sleep time, longer sleep latency, higher stage 1 sleep duration, and lower sleep efficiency.[21] Usually, PSG is recorded over 1 to 2 nights in a sleep laboratory, whereas actigraphy is recorded for 7 consecutive days in the home environment. Although PSG is widely considered the criterion standard for measuring sleep architecture,[20] the sleep laboratory may lead to worsening sleep for children with ASD, who are particularly sensitive to transfer from a familiar environment. Hence, actigraphy offers more naturalistic sleep measurements in real-world settings. Additionally, discrepancies between sleep parameters measurements were noted, whereby PSG-assessed total sleep time (standardized mean difference, −0.90) and sleep efficiency (−1.20) in a previous study[21] significantly differed with current actigraphy-assessed total sleep time (g = −0.332) and sleep efficiency (g = −0.424); thus, both PSG and actigraphy should be implemented to ensure accurate measurements.

The recently developed 24-hour Movement Behavior Framework recommends at least 60 minutes of MVPA per day, as well as 540 to 660 minutes of sleep hours per night, for school-aged children and adolescents.[71] Unfortunately, studies included in this analysis showed that children and adolescents with ASD tend not to adhere to the recommended guidelines. It has been shown that the specific combinations of movement behaviors (eg, high MVPA and long sleep time) are associated with lower odds ratios for developing physiological health issues, such as overweight and obesity[72] and unfavorable body mass index scores,[22] among children with ASD. Thus, rather than consider MVPA and sleep separately, future research focused on youth with ASD should consider the intercorrelated associations between physical activity and sleep, as well as screen-time, within the 24-hour movement behavior framework.

In the current study, differences between those with and without ASD in sleep parameters did not vary with age, which is inconsistent with findings of another meta-analysis that revealed age-related differences in SL and SE between children with and without ASD (aged 2 to 19 years).[20] However, their review only included 10 studies and combined the results of actigraphy and PSG, causing potential selection and insensitive measurement bias. Moreover, in parent-reported studies of children with ASD aged 6 to 11 years, parasomnia and bedtime resistance appeared to decline with age.[73,74] Such variability may be explained by age and measurement differences between studies. In the future, larger PSG- or actigraphy-recorded studies of children and adolescents with and without ASD will be pivotal to gaining new insights into group differences in sleep parameters from childhood to adolescence.

Limitations

This study had several limitations. First, the number of available studies measuring WASO was limited, which may have caused underestimation or overestimation of WASO effect sizes. Second, male participants dominated the ASD group (84.3%), which restricted our ability to detect sex differences in physical activity and sleep parameters. Third, physical activity and sleep actigraphy recording protocols were inconsistent across studies, which may distort the synthesis of results owing to high heterogeneity. Fourth, only 9 studies (32%) reported medication status, causing difficulties in interpreting their effects on physical activity and sleep quality. Fifth, only 25% of the included studies controlled for confounders such as sex and age. As such, sensitivity analyses could not be conducted on each of these confounders. Lastly, only 1 included study[47] assessed both (physical activity and sleep) behaviors. Thus, we cannot compare the results in 1 assessed behavior and both behaviors to explore the potential confounding factors.

Conclusion

Based on meta-analyses of actigraphy-derived estimates of physical activity and sleep parameters, this review found small-to-moderate differences, in favor of children and adolescents without ASD, in MVPA, total sleep time, and sleep efficiency. A moderate-to-large difference, in favor of children and adolescents without ASD was demonstrated for sleep latency. Importantly, an age-related MVPA decline was observed in our study. These findings reinforce the need for public health initiatives aimed at reducing disparities in physical activity and sleep health among children and adolescents with ASD. Moreover, the findings signal the need for a standard protocol for actigraphy measurement in children and adolescents with ASD.

ARTICLE INFORMATION

Accepted for Publication: August 22, 2023.

Published: October 6, 2023. doi:10.1001/jamanetworkopen.2023.36129

Corresponding Authors: Xiao Liang, PhD, Department of Rehabilitation Sciences, Faculty of Health and Social Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong (shawn.liang@polyu.edu.hk); Chunxiao Li, PhD, Professor, School of Physical Education & Sports Science, South China Normal University, 378 Waihuan West Road, Guangzhou 510006, China (chunxiao.li@m.scnu.edu.cn).

Author Affiliations: Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong (Liang); Department of Human Movement Sciences, Old Dominion University, Norfolk, Virginia (Haegele); Center for Movement, Health, & Disability, Old Dominion University, Norfolk, Virginia (Haegele); Department of Physical Education and Sports Science, University of Limerick, Limerick, Ireland (Healy); Department of Health and Physical Education, The Education University of Hong Kong, Hong Kong (Tse); Department of Educational Administration and Policy, The Chinese University of Hong Kong, Hong Kong (Qiu); JC School of Public Health and Primary Care, The Chinese University of Hong Kong, Hong Kong (Zhao); School of Physical Education & Sports Science, South China Normal University, Guangzhou, China (Li); Adapted Physical Activity Laboratory, South China Normal University, Guangzhou, China (Li).

Author Contributions: Dr Liang had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Liang, Haegele, Li.

Acquisition, analysis, or interpretation of data: Liang, Healy, Tse, Qiu, Zhao, Li.

Drafting of the manuscript: Liang.

Critical review of the manuscript for important intellectual content: All authors.

Statistical analysis: Liang, Tse, Qiu, Zhao.

Obtained funding: Liang.

Administrative, technical, or material support: Qiu.

Conflict of Interest Disclosures: None reported.

Funding/Support: This study was supported by the PolyU Start-up Fund from The Hong Kong Polytechnic University (grant No. P0044251).

Role of the Funder/Sponsor: The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Data Sharing Statement: See Supplement 2.

REFERENCES

1. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*. 5th ed. American Psychiatric Association; 2013.

2. Zeidan J, Fombonne E, Scorah J, et al. Global prevalence of autism: a systematic review update. *Autism Res*. 2022;15(5):778-790. doi:10.1002/aur.2696

3. Matson JL, Goldin RL. Comorbidity and autism: trends, topics and future directions. *Res Autism Spectr Disord*. 2013;7(10):1228-1233. doi:10.1016/j.rasd.2013.07.003

4. Mazurek MO, Petroski GF. Sleep problems in children with autism spectrum disorder: examining the contributions of sensory over-responsivity and anxiety. *Sleep Med*. 2015;16(2):270-279. doi:10.1016/j.sleep.2014.11.006

5. Reynolds S, Bendixen RM, Lawrence T, Lane SJ. A pilot study examining activity participation, sensory responsiveness, and competence in children with high functioning Autism Spectrum Disorder. *J Autism Dev Disord*. 2011;41(11):1496-1506. doi:10.1007/s10803-010-1173-x

6. Srinivasan SM, Pescatello LS, Bhat AN. Current perspectives on physical activity and exercise recommendations for children and adolescents with autism spectrum disorders. *Phys Ther*. 2014;94(6):875-889. doi:10.2522/ptj.20130157

7. Deliens G, Leproult R, Schmitz R, Destrebecqz A, Peigneux P. Sleep disturbances in autism spectrum disorders. *Rev J Autism Dev Disord*. 2015;2:343-356. doi:10.1007/s40489-015-0057-6

8. Tarr CW, Rineer-Hershey A, Larwin K. The effects of physical exercise on stereotypic behaviors in autism: small-n meta-analyses. *Focus Autism Other Dev Disabl*. 2020;35(1):26-35. doi:10.1177/1088357619881220

9. Liang X, Li R, Wong SHS, et al. The effects of exercise interventions on executive functions in children and adolescents with autism spectrum disorder: a systematic review and meta-analysis. *Sports Med*. 2022;52(1):75-88. doi:10.1007/s40279-021-01545-3

10. Ruggeri A, Dancel A, Johnson R, Sargent B. The effect of motor and physical activity intervention on motor outcomes of children with autism spectrum disorder: a systematic review. *Autism*. 2020;24(3):544-568. doi:10.1177/1362361319885215

11. Healy S, Nacario A, Braithwaite RE, Hopper C. The effect of physical activity interventions on youth with autism spectrum disorder: a meta-analysis. *Autism Res*. 2018;11(6):818-833. doi:10.1002/aur.1955

12. National Professional Development Center for Autism Spectrum Disorder. What Are Evidence-Based Practices? 2015. Accessed May 19, 2023. https://autismpdc.fpg.unc.edu/evidence-based-practices

13. World Health Organization. *WHO Guidelines on Physical Activity and Sedentary Behaviour*. World Health Organization; 2020.

14. Jones RA, Downing K, Rinehart NJ, et al. Physical activity, sedentary behavior and their correlates in children with Autism Spectrum Disorder: a systematic review. *PLoS One*. 2017;12(2):e0172482. doi:10.1371/journal.pone.0172482

15. Liang X, Li R, Wong SHS, Sum RKW, Sit CHP. Accelerometer-measured physical activity levels in children and adolescents with autism spectrum disorder: a systematic review. *Prev Med Reports*. 2020;19:101147. doi:10.1016/j.pmedr.2020.101147

16. Deliens G, Peigneux P. Sleep-behaviour relationship in children with autism spectrum disorder: methodological pitfalls and insights from cognition and sensory processing. *Dev Med Child Neurol*. 2019;61(12):1368-1376. doi:10.1111/dmcn.14235

17. Carnett A, McLay L, Hansen S, France K, Blampied N. Sleep problems in children and adolescents with autism: type, severity and impact. *J Dev Phys Disabil*. 2021;33(6):977-991. doi:10.1007/s10882-020-09783-5

18. Carnett A, Hansen S, McLay L, Neely L, Lang R. Quantitative-analysis of behavioral interventions to treat sleep problems in children with autism. *Dev Neurorehabil*. 2020;23(5):271-284. doi:10.1080/17518423.2019.1646340

19. Elkhatib Smidt SD, Gooneratne N, Brodkin ES, Bucan M, Mitchell JA. Sufficient sleep duration in autistic children and the role of physical activity. *Autism*. 2022;26(4):814-826. doi:10.1177/13623613211053671

20. Elrod MG, Hood BS. Sleep differences among children with autism spectrum disorders and typically developing peers: a meta-analysis. *J Dev Behav Pediatr*. 2015;36(3):166-177. doi:10.1097/DBP.0000000000000140

21. Díaz-Román A, Zhang J, Delorme R, Beggiato A, Cortese S. Sleep in youth with autism spectrum disorders: systematic review and meta-analysis of subjective and objective studies. *Evid Based Ment Health*. 2018;21(4):146-154. doi:10.1136/ebmental-2018-300037

22. Li C, Haegele JA, Sun F, et al. Meeting the 24-h movement guidelines and health-related outcomes among youth with autism spectrum disorder: a seven-country observational study. *Child Adolesc Psychiatry Ment Health*. 2022;16(1):50. doi:10.1186/s13034-022-00488-5

23. Benson S, Bender AM, Wickenheiser H, et al. Differences in sleep patterns, sleepiness, and physical activity levels between young adults with autism spectrum disorder and typically developing controls. *Dev Neurorehabil*. 2019;22(3):164-173. doi:10.1080/17518423.2018.1501777

24. Rech JP, Irwin JM, Rosen AB, Baldwin J, Schenkelberg M. Comparison of physical activity between children with and without autism spectrum disorder: a systematic review and meta-analysis. *Adapt Phys Activ Q*. 2022;39(4):456-481. doi:10.1123/apaq.2021-0152

25. Ketcheson L, Hauck JL, Ulrich D. The levels of physical activity and motor skills in young children with and without autism spectrum disorder, aged 2-5 years. *Autism*. 2018;22(4):414-423. doi:10.1177/1362361316683889

26. Tatsumi Y, Mohri I, Shimizu S, Tachibana M, Ohno Y, Taniike M. Daytime physical activity and sleep in pre-schoolers with developmental disorders. *J Paediatr Child Health*. 2015;51(4):396-402. doi:10.1111/jpc.12725

27. Pan CY. Objectively measured physical activity between children with autism spectrum disorders and children without disabilities during inclusive recess settings in Taiwan. *J Autism Dev Disord*. 2008;38(7):1292-1301. doi:10.1007/s10803-007-0518-6

28. Pan CY. School time physical activity of students with and without autism spectrum disorders during PE and recess. *Adapt Phys Activ Q*. 2008;25(4):308-321. doi:10.1123/apaq.25.4.308

29. Pan CY, Tsai CL, Hsieh KW. Physical activity correlates for children with autism spectrum disorders in middle school physical education. *Res Q Exerc Sport*. 2011;82(3):491-498. doi:10.1080/02701367.2011.10599782

30. Burman D, Ramanujam K, Manzar D, et al. Sleep and autism spectrum disorder: a comprehensive review of diagnosis, markers, interventions, and treatments. *Sleep Vigil*. 2023;7:9-22. doi:10.1007/s41782-022-00222-3

31. Tremblay MS, Ross R. How should we move for health? The case for the 24-hour movement paradigm. *CMAJ*. 2020;192(49):E1728-E1729. doi:10.1503/cmaj.202345

32. Quante M, Kaplan ER, Rueschman M, Cailler M, Buxton OM, Redline S. Practical considerations in using accelerometers to assess physical activity, sedentary behavior, and sleep. *Sleep Health*. 2015;1(4):275-284. doi:10.1016/j.sleh.2015.09.002

33. Orwin RG. Evaluating Coding Decisions. In: Cooper H, Hedges LV, eds. *The Handbook of Research Synthesis*. Russell Sage Foundation; 1994:139-162.

34. Law M, Stewart D, Letts L, et al. McMaster University's Guidelines for Critical Review Form—Quantitative and Qualitative Studies. McMaster University. Published online 1998. Accessed May 19, 2023. https://canchild.ca/system/tenon/assets/attachments/000/000/366/original/quantguide.pdf

35. Imms C. Children with cerebral palsy participate: a review of the literature. *Disabil Rehabil*. 2008;30(24):1867-1884. doi:10.1080/09638280701673542

36. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol*. 2013;4:863. doi:10.3389/fpsyg.2013.00863

37. Hedges LV, Olkin I. *Statistical Methods for Meta-Analysis*. Academic Press; 1985.

38. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539-1558. doi:10.1002/sim.1186

39. Allik H, Larsson JO, Smedje H. Sleep patterns of school-age children with Asperger syndrome or high-functioning autism. *J Autism Dev Disord*. 2006;36(5):585-595. doi:10.1007/s10803-006-0099-9

40. Allik H, Larsson JO, Smedje H. Sleep patterns in school-age children with Asperger syndrome or high-functioning autism: a follow-up study. *J Autism Dev Disord*. 2008;38(9):1625-1633. doi:10.1007/s10803-008-0543-0

41. Jeon M, Neoh MJY, Esposito G, Halstead E, Haghighatfard A, Dimitriou D. Cross-country comparison of parental reports and objective measures of sleep patterns of typically developing children and autistic children between the UK and South Korea. *Sleep Med*. 2023;101:162-177. doi:10.1016/j.sleep.2022.10.024

42. Kosaka T, Kawatani M, Ohta G, et al. Low threshold to vestibular and oral sensory stimuli might affect quality of sleep among children with autism spectrum disorder. *Brain Dev*. 2021;43(1):55-62. doi:10.1016/j.braindev.2020.07.010

43. Lobenius-Palmér K, Sjöqvist B, Hurtig-Wennlöf A, Lundqvist LO. Accelerometer-assessed physical activity and sedentary time in youth with disabilities. *Adapt Phys Activ Q*. 2018;35(1):1-19. doi:10.1123/apaq.2015-0065

44. Martínez-Cayuelas E, Rodríguez-Morilla B, Soriano-Guillén L, Merino-Andreu M, Moreno-Vinués B, Gavela-Pérez T. Sleep problems and circadian functioning in children and adolescents with Autism Spectrum Disorder. *Pediatr Neurol*. 2022;126:57-64. doi:10.1016/j.pediatrneurol.2021.09.009

45. Martinez-Cayuelas E, Gavela-Pérez T, Rodrigo-Moreno M, et al. Melatonin rhythm and its relation to sleep and circadian parameters in children and adolescents with Autism Spectrum Disorder. *Front Neurol*. 2022;13(June):813692. doi:10.3389/fneur.2022.813692

46. Moludi J, Ebrahimi B, Maleki V, et al. Comparison of dietary macro and micronutrient intake with physical activity levels among children with and without autism: a case-control study. *Prog Nutr*. 2019;21:49-55. doi:10.23751/pn.v21i2-S.6578

47. Nguyen TD, Guinot M, Bricout VA. Effect of daily physical activity on sleep characteristics in children with autism spectrum disorder. *Sports (Basel)*. 2021;9(7):91. doi:10.3390/sports9070091

48. Pace M, Dumortier L, Favre-Juvin A, Guinot M, Bricout VA. Heart rate variability during sleep in children with autism spectrum disorders. *Physiol Behav*. 2016;167:309-312. doi:10.1016/j.physbeh.2016.09.027

49. Pan CY, Hung CS, Chung IC, Lo SY, Liu YJ, Hsu PJ. Physical activity during the segmented school day in adolescents with and without autism spectrum disorders. *Res Autism Spectr Disord*. 2015;15-16:21-28. doi:10.1016/j.rasd.2015.04.003

50. Pan CY, Tsai CL, Chu CH, Sung MC, Ma WY, Huang CY. Objectively measured physical activity and health-related physical fitness in secondary school-aged male students with autism spectrum disorders. *Phys Ther*. 2016;96(4):511-520. doi:10.2522/ptj.20140353

51. Baker E, Richdale A, Short M, Gradisar M. An investigation of sleep patterns in adolescents with high-functioning autism spectrum disorder compared with typically developing adolescents. *Dev Neurorehabil*. 2013;16(3):155-165. doi:10.3109/17518423.2013.765518

52. Phung JN, Goldberg WA. Poor sleep quality is associated with discordant peer relationships among adolescents with Autism Spectrum Disorder. *Res Autism Spectr Disord*. 2017;34:10-18. doi:10.1016/j.rasd.2016.11.008

53. Sandt DDR, Frey GC. Comparison of physical activity levels between children with and without autistic spectrum disorders. *Adapt Phys Activ Q*. 2005;22(2):146-159. doi:10.1123/apaq.22.2.146

54. Souders MC, Mason TBA, Valladares O, et al. Sleep behaviors and sleep quality in children with autism spectrum disorders. *Sleep*. 2009;32(12):1566-1578. doi:10.1093/sleep/32.12.1566

55. Stanish HI, Curtin C, Must A, Phillips S, Maslin M, Bandini LG. Physical activity levels, frequency, and type among adolescents with and without autism spectrum disorder. *J Autism Dev Disord*. 2017;47(3):785-794. doi:10.1007/s10803-016-3001-4

56. Surtees ADR, Richards C, Clarkson EL, et al. Sleep problems in autism spectrum disorders: a comparison to sleep in typically developing children using actigraphy, diaries and questionnaires. *Res Autism Spectr Disord*. 2019;67:101439. doi:10.1016/j.rasd.2019.101439

57. Thomas S, Barnett LM, Papadopoulos N, Lander N, McGillivray J, Rinehart N. How do physical activity and sedentary behaviour affect motor competence in children with Autism Spectrum Disorder compared to typically developing children: a pilot study. *J Autism Dev Disord*. 2022;52(8):3443-3455. doi:10.1007/s10803-021-05205-3

58. Tse ACY, Yu C, Lee PH. Comparing sleep patterns between children with autism spectrum disorder and children with typical development: a matched case-control study. *Autism*. 2020;24(8):2298-2303. doi:10.1177/1362361320936827

59. Mughal R, Hill CM, Joyce A, Dimitriou D. Sleep and cognition in children with fetal alcohol spectrum disorders (FASD) and children with autism spectrum disorders (ASD). *Brain Sci*. 2020;10(11):1-20. doi:10.3390/brainsci10110863

60. Bandini LG, Gleason J, Curtin C, et al. Comparison of physical activity between children with autism spectrum disorders and typically developing children. *Autism*. 2013;17(1):44-54. doi:10.1177/1362361312437416

61. Bennett HJ, Ringleb SI, Bobzien J, Haegele JA. Are gait biomechanics related to physical activity engagement? an examination of adolescents with Autism Spectrum Disorder. *Med Sci Sports Exerc*. 2022;54(3):447-455. doi:10.1249/MSS.0000000000002810

62. Bricout VA, Pace M, Dumortier L, Baillieul F, Favre-Juvin A, Guinot M. Reduced cardiorespiratory capacity in children with autism spectrum disorders. *J Clin Med*. 2018;7(10):361. doi:10.3390/jcm7100361

63. Chua B, Neoh M, Jeon M, et al. Impact of sleep on attention in primary school-aged autistic children: exploratory cross-cultural comparison between Singapore and UK children. *Res Dev Disabil*. 2022;128(June):104271. doi:10.1016/j.ridd.2022.104271

64. Goldman SE, Surdyka K, Cuevas R, Adkins K, Wang L, Malow BA. Defining the sleep phenotype in children with autism. *Dev Neuropsychol*. 2009;34(5):560-573. doi:10.1080/87565640903133509

65. Haegele JA, Zhu X, Bennett HJ. Accelerometer measured physical activity among youth with autism and age, sex, and body mass index matched peers: a preliminary study. *Disabil Health J*. 2021;14(3):101102. doi:10.1016/j.dhjo.2021.101102

66. Hering E, Epstein R, Elroy S, Iancu DR, Zelnik N. Sleep patterns in autistic children. *J Autism Dev Disord*. 1999;29(2):143-147. doi:10.1023/A:1023092627223

67. Dahlgren J, Healy S, MacDonald M, Geldhof J, Palmiere K, Haegele JA. Physical activity and screen time among youth with autism: a longitudinal analysis from 9 to 18 years. *Autism*. 2021;25(4):1090-1099. doi:10.1177/1362361320981314

68. Farooq A, Martin A, Janssen X, et al. Longitudinal changes in moderate-to-vigorous-intensity physical activity in children and adolescents: a systematic review and meta-analysis. *Obes Rev*. 2020;21(1):e12953. doi:10.1111/obr.12953

69. Thye MD, Bednarz HM, Herringshaw AJ, Sartin EB, Kana RK. The impact of atypical sensory processing on social impairments in autism spectrum disorder. *Dev Cogn Neurosci*. 2018;29:151-167. doi:10.1016/j.dcn.2017.04.010

70. Pratt M, Ramirez Varela A, Salvo D, Kohl Iii HW, Ding D. Attacking the pandemic of physical inactivity: what is holding us back? *Br J Sports Med*. 2020;54(13):760-762. doi:10.1136/bjsports-2019-101392

71. Tremblay MS, Carson V, Chaput JP, et al. Canadian 24-hour movement guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. *Appl Physiol Nutr Metab*. 2016;41(6)(suppl 3):S311-S327. doi:10.1139/apnm-2016-0151

72. Xu WH, Qi J. Meeting 24-hour movement guidelines: their relationships with overweight and obesity among Chinese children with autism spectrum disorder. *Res Autism Spectr Disord*. 2022;99:102066. doi:10.1016/j.rasd.2022.102066

73. Hodge D, Carollo TM, Lewin M, Hoffman CD, Sweeney DP. Sleep patterns in children with and without autism spectrum disorders: developmental comparisons. *Res Dev Disabil*. 2014;35(7):1631-1638. doi:10.1016/j.ridd.2014.03.037

74. Goldman SE, Richdale AL, Clemons T, Malow BA. Parental sleep concerns in autism spectrum disorders: variations from childhood to adolescence. *J Autism Dev Disord*. 2012;42(4):531-538. doi:10.1007/s10803-011-1270-5

SUPPLEMENT 1.

eFigure 1. PRISMA Flow Diagram of the Selection of Studies
eFigure 2. Funnel Plot for Visual Inspection of Publication Bias of Total Sleep Time
eFigure 3. Meta-Analysis of Accelerometer-Assessed WASO
eFigure 4. Meta-Regression of MVPA Between Children and Adolescents With and Without ASD Depending on Age
eTable 1. Summary of Participants' Characteristics and Quality Assessment of Included Studies (ASD vs Without ASD)
eTable 2. Moderator Analysis of Group Difference in MVPA and Sleep Parameters Between Children and Adolescents With and Without ASD

SUPPLEMENT 2.

Data Sharing Statement