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Traits outperform diagnoses in modelling sleep, repetitive behaviour and their link across autism, ADHD and intellectual disability in youth

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Abstract

Sleep problems and restricted and repetitive behaviours (RRBs) feature prominently in children and adolescents with neurodevelopmental conditions such as autism, attention-deficit/hyperactivity disorder (ADHD), and intellectual disabilities (ID). We investigated whether both sleep disturbance and RRBs as well as their interaction differs between conditions, and whether symptom dimensions might capture differences better than diagnostic categories. In a preregistered cross-sectional analysis of the Healthy Brain Network community sample enriched for neurodevelopmental conditions (n = 2 394, 5–21 years), linear regression modelled parent-reported sleep disturbance and RRBs by diagnostic category and symptom dimensions (autistic traits, ADHD traits, IQ). All symptom dimensions predicted sleep disturbance ($p < .001$), whereas only ADHD consistently predicted greater sleep disturbance ($d = .35$, 95% CI [.24, .47]) among diagnostic categories relative to typical development. All diagnostic categories and symptom dimensions were associated with RRB severity. Sleep disturbance and RRBs were associated in the entire sample ($\beta = .30$, $p < .001$). Sleep disturbance predicted RRBs at all levels of autistic and ADHD traits, but most strongly with high autistic and low ADHD traits ($\beta = .22$) and least strongly when both were high ($\beta = .13$). Dimensional measures explained more variance than diagnoses for sleep disturbance ($R^2 = .14$ vs .03) and RRBs ($R^2 = .38$ vs .21), and provided better model fits in all comparisons. Overall, autistic and ADHD traits shaped the relationship between sleep disturbance and RRBs, whereas diagnoses did not. Neurodevelopmental symptom assessments might be more informative than diagnoses to manage sleep and RRBs.

Introduction

Sleep problems are common health concerns disproportionately affecting individuals with neurodevelopmental conditions[1–3]. Examples of neurodevelopmental conditions with higher rates of sleep disturbance include autism, Attention-Deficit/Hyperactivity Disorder (ADHD), and intellectual disabilities (ID). Common sleep issues in autism include prolonged sleep latency, frequent awakenings at night, and reduced sleep duration[1], and this is linked to emotional, cognitive, behavioural and social difficulties[4,5]. Children with ADHD often experience sleep issues such as delayed sleep onset, and insomnia[1,6–8], which are linked to impaired executive function, adaptive behaviour, low academic achievement and mental health issues[9]. Evidence for a link between stimulant medication and sleep disturbances in ADHD is mixed, with some studies finding that stimulant medication either improves[10] or worsens[11], or does not affect[12] sleep disturbance. Likewise, people with ID spend fewer hours asleep, and experience poorer sleep quality than typically developing individuals[13]. This subgroup also exhibits challenging behaviour, increased symptom severity, and rates of neurological and psychiatric comorbidity[14].

In the last decades, sleep, cognition and sensorimotor function were found to be intertwined processes[15,16]. There is consensus that sleep dysfunction affects multiple cognitive domains such as memory, learning and cognitive control[17]. Sleep disruption has been associated with higher-order

cognitive dysfunctions such as repetitive thoughts and cognitive inflexibility[18,19]. Sleep is also crucial for sensorimotor processing such as sensorimotor learning[16]. In both healthy individuals and psychiatric populations, sensory sensitivity impacts sleep, and vice versa[20–22]. Accordingly, sleep difficulties feature prominently in neurodevelopmental conditions, which are characterised by altered sensorimotor[23,24] and cognitive function[25]. Atypical development can manifest as restricted and repetitive behaviours (RRBs) which encompass both altered sensorimotor processing (such as sensation-seeking, and over- or underreactivity to sensory input, stereotyped motor movements, and atypical object manipulation) and cognitive patterns (such as compulsive behaviours, strict daily routines, intense distress in response to change, and restricted interests)[26,27]. Such behaviours are a core characteristic of autism and also occur in ADHD and ID, albeit not to the same extent[28,29]. For instance, sensation-seeking behaviour features in autism[30], ADHD[23], and ID[24]. Likewise, reduced cognitive flexibility was observed in ADHD[31], autism[32], and ID[33].

Multiple studies support a link between sleep dysfunction and RRBs in autistic children and young people[34]. Although fewer studies address this interaction in other neurodevelopmental conditions, there is also some evidence for a relationship between sleep dysfunction and RRBs in children with developmental delay[34] and ADHD[35]. For instance, children with developmental delay who exhibit higher-order RRBs also reported more sleep disturbance[34]. In people with ID, sleep disturbance was associated with stereotyped behaviour[36]. Similarly, children and adolescents with ADHD who have sleep problems also experience issues with sensory over- and underresponsivity[35,37].

An open question is whether there are systematic differences in the interaction between sleep difficulties and RRBs between neurodevelopmental conditions. There is evidence that both RRBs and sleep dysfunction manifest differently across the three conditions. For instance, RRBs feature more prominently in autism than ADHD or ID[28,38]. Daytime sleepiness is more prominent in ADHD than autism[39]. Bedtime resistance is more prominent in ID than autism, whereas insomnia is more common in the latter[40]. Only pairwise comparisons between conditions flag differences in sleep dysfunction and RRBs, and a comparison of all three conditions is still lacking. Due to substantial symptom overlap between neurodevelopmental conditions, as well as high rates of co-occurring diagnoses[41], it is challenging to determine differences in the interaction between sleep and RRBs between neurodevelopmental conditions. Previous studies found that rates of both sleep disturbance and RRBs increase when multiple diagnoses are present. For example, in autistic children, co-occurring ID was found to contribute to sensation-seeking (e.g. self-stimulation with loud sounds)[29], as well as ritualistic and repetitive behaviours[42]. Autistic children with ADHD report more sleep disturbance and poorer sleep hygiene[43,44]. In people with ID, RRBs were associated with the ADHD traits hyperactivity and impulsivity[45].

To address this issue, it might be more useful to apply a transdiagnostic approach focusing on neurodevelopmental dimensional measures rather than binary diagnostic categories. An alternative

framework termed the neurodevelopmental spectrum describes individuals using transdiagnostic dimensional measures shared between different conditions rather than distinct conditions[41,46]. This way, it recognises that neurodevelopmental conditions share characteristics and that they can be present to various degrees regardless of whether an individual qualifies for a diagnosis[41]. Autism and ADHD are common co-existing conditions among young people. 37–78% of autistic children also have ADHD[47], and ~ 20–50% of children with ADHD also qualify for an autism diagnosis[48]. Even when there is no dual diagnosis, children with ADHD and autism present with similar difficulties, including impairments in social function and RRBs[28,49,50]. Therefore, we suggest that using both symptom dimensions and diagnostic categories will provide a more comprehensive view of the relationship between sleep disturbance and RRBs in neurodevelopmental conditions.

In a preregistered analysis (AsPredicted #296353), we systematically examined the cross-sectional relationship of sleep disturbance and RRBs with autism, ADHD, and ID, as well as tested whether the relationship between sleep and RRBs is moderated by these neurodevelopmental conditions. First, we hypothesised that individuals in the neurodevelopmental groups would exhibit significantly greater sleep disturbance than controls (H1). Second, we predicted RRBs to feature most prominently in autism, followed by ADHD and ID, and finally TD (H2). Third, we expected a cross-sectional relationship between sleep and RRBs across all participants (H3). Since RRBs are most extensively observed in autism[28], we reasoned that this relationship would be strongest in this group, followed by ADHD, ID and weakest in TD (H4). All hypotheses were tested based on (a) diagnostic categories and (b) dimensional measures of neurodevelopmental traits. Due to the clinical overlap between symptoms of autism and ADHD[51–53] as well as autism and ID[54], we also investigated whether the co-occurrence of autism with either of these conditions might compound the influence of autism alone on sleep disturbance, RRBs, or their interaction. For instance, it is possible that autistic young people with ADHD experience more severe sleep disturbance than would be expected from each condition on its own. Therefore, we tested for synergistic or additive effects of concurrent autism and ADHD, as well as autism and ID whenever neurodevelopmental conditions were compared.

Materials and methods

Participants

We performed a secondary data analysis of the Healthy Brain Network (HBN) project sample, which is a large-scale, open-access study initiative focused on child and adolescent mental health[55]. The HBN project recruited participants aged 5–21 seeking out families concerned about their child/children's mental health and learning, using a community-referred sampling model from different community settings located in New York, USA (e.g., schools, clinics, community events). As a result, this sample includes higher rates of neurodevelopmental conditions than expected in the general population[55]. More than one child per family could be recruited. Data until the latest data release (#11, n = 4 867) were used in the current analysis. In our study, participants were assigned to one or multiple of the following

conditions: ADHD, autism, ID, and TD. Assignment to the autism and ADHD groups relied on clinician consensus diagnoses. Specifically, inclusion in the autism group required an ICD-10 diagnosis of F84. Individuals in the ADHD group required an ICD-10 diagnosis of F90 (F90.0, F90.1, F90.2, F90.8, F90.9). Participants completed a web-based version of the Kiddie Schedule for Affective Disorders and Schizophrenia (K-SADS), which is a semi-structured interview examining current and past evidence of psychiatric conditions in children and adolescents based on the DSM-5[56]. Based on clinical interviews and reviews of study participation materials, the clinical team generated consensus diagnoses which were used in our study.

For the purpose of this study, participants had to meet two criteria to be categorised as having ID: (1) a Full-Scale IQ (FSIQ) score of less than 70; (2) a standard score below 85 on at least one domain (Communication, Daily Living Skills, or Socialization) from the Vineland Adaptive Behavior Scale (VABS), measuring adaptive functioning. We did not classify 34 participants with an IQ < 70 (mean IQ = 63.0, SD = 7.22, range = 40–69) as having ID. One participant did not meet the cutoff in the VABS (Communication = 93, Socialization = 85, Daily Living Skills = 85). For the remaining participants, VABS data was incomplete. Participants without any neurological/psychiatric diagnoses (ICD-10 F- or G-code) were categorised as TD.

In total, 3 333 participants had complete data on age, sex, socioeconomic status, IQ, sleep disturbance and restricted and repetitive behaviours (measures defined below). We excluded 197 because no clinician consensus diagnosis was recorded. A further 742 participants who did not meet criteria for inclusion in either the autism, ADHD, ID group also could not be classified as TD since they were diagnosed with a neurological or psychiatric condition (ICD-10 F or G). This resulted in a sample of 2 394 participants. Based on the ICD-10, autistic people were diagnosed with F84.0 (Childhood Autism Spectrum Disorder). 861 (44.2%) individuals with ADHD were predominantly inattentive (F90.0), 107 (5.5%) were predominantly hyperactive (F90.1), 853 (43.8%) presented with a combined type (F90.2), 125 (6.4%) with other type (F90.8), and 2 (0.1%) with an unspecified type (F90.9). Figure 1A provides an overview of concurrent conditions.

In our ID group, 41 (78.8%) of 52 were diagnosed with intellectual disability (F70 mild, n = 35; F71 moderate, n = 6). One participant received a diagnosis of borderline intellectual functioning (R41.83). Co-occurring diagnoses in this group most commonly included ADHD (n = 36, 69.2%), autism (n = 18, 34.6%), developmental speech and language disorder (n = 12, 23.1%), and specific learning disorder with impairment in reading (n = 12, 23.1%). An overview of diagnoses per diagnostic category is shown in Supplementary Table 1.

Our sample was aged on average 9.99 ± 3.02 years (range 5.06–21.9). Guardians reported demographic information, including race and ethnicity (Table 1). Caregivers reported the sex assigned at birth, recorded as male or female. 69.4% were reported as male and 30.6% female. 54.9% reported the participants' race as White, 13.2% as Black/African American, 9.1% as Hispanic, 2.9% as Asian, and 16.6% as of two or more races (1.6% missing). 23.6% reported the participants' ethnicity as

Hispanic/Latino. 54.5% of guardians reported a graduate degree as their highest education, 30.7% a bachelor's degree, 9.2% some college, and 5.6% high school or less. 72.2% of guardians were married or in a domestic partnership, and 14.0% were separated or divorced (1.6% missing). Socioeconomic status, indexed by the Barratt Simplified Measure of Social Status (BSMSS), averaged 50.23 ± 13.96, and FSIQ averaged 99.29 ± 17.00. Ethical approval for the original data was obtained by the Chesapeake Institutional Review Board. Participants' legal guardians gave written consent for their child to take part in the study, and children provided written assent[55]. We did not require further ethical approval for the re-analysis of anonymised open-source data.

Table 1
Demographic information and descriptive statistics of scale measurements

Characteristic	Total N = 2 394[1]	ADHD N = 1 948[1]	Autism N = 433[1]	ID N = 52[1]	TD N = 344[1]
ADHD presentation (ICD-10)					
Combined	853 (35.6%)	853 (43.8%)	191 (44.1%)	17 (32.7%)	0 (0.0%)
No ADHD diagnosis	446 (18.6%)	0 (0.0%)	90 (20.8%)	16 (30.8%)	344 (100.0%)
Other specified	125 (5.2%)	125 (6.4%)	12 (2.8%)	1 (1.9%)	0 (0.0%)
Predominantly hyperactive-impulsive	107 (4.5%)	107 (5.5%)	10 (2.3%)	0 (0.0%)	0 (0.0%)
Predominantly inattentive	861 (36.0%)	861 (44.2%)	130 (30.0%)	18 (34.6%)	0 (0.0%)
Unspecified	2 (0.1%)	2 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Age (years)	10.0 (3.0) [5.1, 21.9]	9.9 (2.9) [5.1, 21.5]	10.3 (3.3) [5.3, 20.9]	11.1 (3.3) [5.4, 18.5]	10.0 (3.2) [5.1, 21.9]
Sex					
Female	733 (30.6%)	563 (28.9%)	71 (16.4%)	22 (42.3%)	144 (41.9%)
Male	1 661 (69.4%)	1 385 (71.1%)	362 (83.6%)	30 (57.7%)	200 (58.1%)
Child race					
Asian	68 (2.9%)	42 (2.2%)	16 (3.7%)	2 (3.8%)	18 (5.4%)
Black/African American	311 (13.2%)	265 (13.8%)	61 (14.3%)	13 (25.0%)	31 (9.2%)
Hispanic	215 (9.1%)	172 (9.0%)	50 (11.7%)	8 (15.4%)	29 (8.6%)
Two or more races	390 (16.6%)	314 (16.4%)	68 (15.9%)	3 (5.8%)	59 (17.6%)
White/Caucasian	1 293 (54.9%)	1 063 (55.4%)	218 (51.1%)	22 (42.3%)	187 (55.7%)

ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; BSMSS = Barratt Simplified Measure of Social Status; FSIQ = Full-Scale Intelligence Quotient; ID = Intellectual Disability; TD = Typically Developing.

Characteristic	Total N = 2 394[1]	ADHD N = 1 948[1]	Autism N = 433[1]	ID N = 52[1]	TD N = 344[1]
Other/Unknown/Declined	79 (3.4%)	63 (3.3%)	14 (3.3%)	4 (7.7%)	12 (3.6%)
Missing	38	29	6	0	8
Child ethnicity					
Decline to specify	121 (5.1%)	100 (5.2%)	22 (5.1%)	2 (3.8%)	18 (5.3%)
Hispanic or Latino	559 (23.6%)	453 (23.5%)	126 (29.4%)	14 (26.9%)	76 (22.4%)
Not Hispanic or Latino	1 657 (70.1%)	1 347 (70.0%)	274 (64.0%)	33 (63.5%)	243 (71.5%)
Unknown	28 (1.2%)	25 (1.3%)	6 (1.4%)	3 (5.8%)	3 (0.9%)
Missing	29	23	5	0	4
Parental marital status					
Married	1 632 (69.3%)	1 312 (68.2%)	305 (71.8%)	26 (50.0%)	247 (74.6%)
Domestic partnership	68 (2.9%)	49 (2.5%)	15 (3.5%)	3 (5.8%)	14 (4.2%)
Separated	125 (5.3%)	110 (5.7%)	20 (4.7%)	6 (11.5%)	11 (3.3%)
Divorced	204 (8.7%)	176 (9.1%)	40 (9.4%)	3 (5.8%)	23 (6.9%)
Never married	326 (13.8%)	277 (14.4%)	45 (10.6%)	14 (26.9%)	36 (10.9%)
Missing	39	24	8	0	13
Highest parental education					
< High school	38 (1.6%)	28 (1.4%)	3 (0.7%)	5 (9.6%)	5 (1.5%)
High school graduate/GED	97 (4.1%)	82 (4.2%)	19 (4.4%)	4 (7.7%)	13 (3.8%)
Some college/Associate's	221 (9.2%)	175 (9.0%)	54 (12.5%)	10 (19.2%)	27 (7.8%)

ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; BSMSS = Barratt Simplified Measure of Social Status; FSIQ = Full-Scale Intelligence Quotient; ID = Intellectual Disability; TD = Typically Developing.

Characteristic	Total N = 2 394[1]	ADHD N = 1 948[1]	Autism N = 433[1]	ID N = 52[1]	TD N = 344[1]
Bachelor's degree	734 (30.7%)	595 (30.6%)	143 (33.0%)	15 (28.8%)	107 (31.1%)
Graduate degree	1 303 (54.5%)	1 067 (54.8%)	214 (49.4%)	18 (34.6%)	192 (55.8%)
Missing	1	1	0	0	0
BSMSS	50.2 (14.0)	50.2 (13.9)	49.2 (14.1)	43.5 (17.5)	51.4 (13.2)
FSIQ	99.3 (17.0)	99.0 (16.6)	94.9 (19.7)	59.8 (7.5)	103.7 (15.8)
ASSQ	7.6 (8.6)	8.0 (8.7)	17.2 (10.2)	11.3 (9.0)	3.4 (5.1)
Missing	13	6	0	0	7
SWAN	0.7 (0.9)	0.9 (0.8)	0.9 (0.9)	1.1 (0.8)	0.0 (1.0)
Missing	14	3	1	1	11
SDSC	41.5 (10.3)	42.2 (10.5)	43.1 (11.2)	40.3 (10.9)	38.3 (8.5)
RBS-R	27.6 (32.8)	28.9 (33.2)	55.8 (39.5)	45.6 (43.4)	14.3 (21.8)

[1]n (%); Mean (SD) [Min, Max]; Mean (SD)

Total counts each participant once. Diagnostic groups overlap: participants with more than one diagnosis appear in more than one diagnostic column, so these columns do not sum to the total. No inferential group comparisons are reported because the groups are not independent.

Guardians reported race and ethnicity separately; "Hispanic" was offered both as a race and as an ethnicity category.

ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; BSMSS = Barratt Simplified Measure of Social Status; FSIQ = Full-Scale Intelligence Quotient; ID = Intellectual Disability; TD = Typically Developing.

Measures

We measured sleep disturbance using the Sleep Disturbance Scale for Children (SDSC)[57], and RRBs with the Repetitive Behavior Scale-Revised (RBS-R)[26]. Autistic traits were quantified using the Autism Spectrum Screening Questionnaire (ASSQ)[58] and ADHD traits using the Strengths and Weaknesses of

ADHD Symptoms and Normal Behavior Scale (SWAN)[59]. FSIQ (M = 100, SD = 15) was measured using the Wechsler Adult Intelligence Scale-IV (WAIS-IV) for participants older than 17[60], the Wechsler Intelligence Scale for Children-V (WISC-V) for participants typically aged 6–17[61], and the Kaufman Brief Intelligence Test-II (KBIT-2) for participants under 6 years[62]. Socioeconomic status was measured using the parent-reported Barratt Simplified Measure of Social Status (BSMSS)[63], and adaptive functioning using the Vineland Adaptive Behavior Scales (VABS)[64]. The VABS was administered only where the clinical team identified low cognitive ability. Caregivers were asked what sex a child was assigned at birth. Sex was recorded as a binary variable (male/female). All scales were used dimensionally. Supplementary Table 2 details all measures.

Analysis

We performed a series of preregistered analyses (AsPredicted #296353) to understand the interaction of sleep disturbance (SDSC) and RRBs (RBS-R) in autism, ADHD and ID in R version 4.6.1 (2026-06-24) using RStudio (v2026.05.1 + 225). Hypotheses were evaluated using diagnostic categories in the ICD-10 as well as using trait dimensions associated with each condition, using the ASSQ for autistic traits, the SWAN for ADHD traits, and IQ for ID. To test our hypotheses, we used linear regression models with age, sex, and BSMSS as covariates. SDSC, RBS-R, ASSQ, SWAN and IQ were mean-centred before modelling. Our preregistration included linear mixed-effects models with family identification number as a random intercept. However, only one family contributed more than one participant with complete data on all variables included in the model, and therefore, we fitted models with ordinary least squares. Before refitting the model to obtain standardised estimates, we z-scored the outcome variable and all continuous predictors. As a result, we used standardised β coefficients as estimates for continuous predictors, and Cohen's d for diagnostic categories. To control for multiple comparisons, we applied FDR-correction using the Benjamini–Hochberg procedure only to key model terms for each hypothesis family. We did not FDR-correct p-values for the covariates. To run post-hoc analyses for interaction effects for models with continuous moderators, we used simple slopes analyses (interactions package v1.2.0) and tested each moderator at the 16th, 50th and 84th percentiles of its observed distribution. For categorical models, we estimated marginal means and trends (emmeans package v1.11.0). We used Tukey-adjustments for pairwise contrasts between diagnostic categories, whereas simple slopes were reported without adjustment. We excluded participants with incomplete data in SDSC, RBS-R, Age, Sex, BSMSS, IQ for all analyses. For analyses including other scales, we only removed participants with incomplete data specific to the survey from the dataset. We set the TD group as the reference level for all models.

Exploratory analyses

We compared dimensional and diagnostic model fits using Vuong tests, and estimated R^2 differences with 95% percentile bootstrap confidence intervals (2 000 runs). Linear regression models adjusted for

age, sex, BSMSS, and SWAN tested whether stimulant medication predicted greater sleep disturbance or higher RRB severity (FDR-corrected) in a subsample with ADHD and available caregiver-reported current psychiatric medication data (n = 1 783, stimulant: n = 390, non-stimulant n = 28, other psychiatric medication only n = 24, no psychiatric medication n = 1 341). To test whether RRB severity is highest in autism followed by ADHD/ID and then TD, we fitted models encompassing all diagnostic categories and covariates, referenced against the TD group, as well as a model with autistic and ADHD traits as well as reversed FSIQ. Per model, coefficients were tested against zero and compared with each other using general linear hypothesis tests (Holm-corrected).

Results

Sleep disturbances are linked to ADHD diagnosis and broadly associated with autistic and ADHD traits as well as IQ

Categorically, ADHD predicted more sleep disturbance than TD (d = .35, 95% CI [.24, .47], t = 6.08, p < .001), whereas ID (d = − .17, 95% CI [-.45, .10], t = -1.25, p = .281) and autism (d = .22, 95% CI [-.01, .45], t = 1.85, p = .102) did not. Autism predicted more sleep disturbance when modelling its interaction with ID (d = .18, 95% CI [.08, .29], t = 3.38, p = .001) but not ADHD (d = .22, 95% CI [-.01, .45], t = 1.85, p = .102). Interactions between autism and ADHD (d = − .03, 95% CI [-.29, .23], t = − .23, p = .816) or autism and ID (d = .29, 95% CI [-.28, .86], t = .99, p = .397) were not associated with sleep disturbance.

Dimensionally, higher ADHD traits (β = .22, 95% CI [.18, .26], t = 10.82, p < .001), higher autistic traits (β = .24, 95% CI [.19, .28], t = 9.92, p < .001), and higher IQ (β = .10, 95% CI [.06, .14], t = 5.11, p < .001) each independently predicted more sleep disturbance. There was neither an interaction of autistic and ADHD traits (β = .01, 95% CI [-.02, .05], t = .65, p = .547) nor autistic traits and IQ (β = − .02, 95% CI [-.05, .02], t = − .88, p = .432), which replicates findings from categorical models. Results for H1 can be found in Fig. 1.

RRBs are associated with interacting ADHD and autistic traits

Categorically, autism (d = 1.13, 95% CI [.92, 1.34], t = 10.69, p < .001), ADHD (d = .25, 95% CI [.14, .35], t = 4.69, p < .001), and ID (d = .41, 95% CI [.16, .65], t = 3.21, p = .002) each independently predicted higher RRB severity. We did not find evidence supporting a synergistic effect of autism and ADHD on RRBs (d = − .14, 95% CI [-.38, .09], t = -1.22, p = .221), which is consistent with an additive effect.

Dimensionally, higher autistic traits (β = .52, 95% CI [.48, .55], t = 25.36, p < .001), higher ADHD traits (β = .11, 95% CI [.08, .14], t = 6.04, p < .001), and lower IQ (β = − .07, 95% CI [-.10, − .03], t = -3.77, p < .001) all predicted greater RRB severity. Unlike in our categorical model, there was an interaction of autistic and ADHD traits (β = .04, 95% CI [.01, .07], t = 2.47, p = .017). Autistic traits predicted greater RRB severity at all levels of ADHD traits, but this effect strengthened as ADHD traits increased (16th percentile of SWAN: β = .48, 95% CI [.43, .53], t = 18.38, p < .001; 84th percentile: β = .55, 95% CI [.51, .59], t = 28.88, p < .001).

Categorically, autism interacted with ID (d = .54, 95% CI [.02, 1.06], t = 2.04, p = .048). There was a stronger link between autism and RRBs in individuals with ID (d = 1.54, 95% CI [.87, 2.21], t = 5.90, p < .001) than without (d = 1.00, 95% CI [.87, 1.12], t = 20.39, p < .001). Dimensionally, there was a negative interaction between autistic traits and IQ (β = − .06, 95% CI [-.09, − .03], t = -3.79, p < .001). As IQ increased, the relationship between autistic traits and RRBs attenuated (16th percentile of IQ: β = .58, 95% CI [.54, .63], t = 26.53, p < .001; 84th percentile: β = .46, 95% CI [.42, .51], t = 18.80, p < .001). Results are found in Fig. 2.

Neurodevelopmental traits, but not categorical diagnoses, moderate the relationship between sleep disturbance and RRBs

More sleep disturbance was associated with higher RRB severity across the whole sample (β = .30, 95% CI [.27, .34], t = 15.91, p < .001), and vice versa (β = .32, 95% CI [.28, .35], t = 15.91, p < .001; Fig. 3A).

Categorically, sleep disturbance (β = .19, 95% CI [.09, .30], t = 3.59, p < .001) predicted higher RRBs, and vice versa (β = .29, 95% CI [.14, .43], t = 3.89, p < .001). ADHD (d = .18, 95% CI [.07, .28], t = 3.28, p = .002), autism (d = 1.09, 95% CI [.88, 1.29], t = 10.67, p < .001), and ID (d = .44, 95% CI [.20, .68], t = 3.66, p < .001) were positively associated with RRBs. Crucially, no three-way interaction involving diagnostic categories reached significance (all p > .05). Co-occurring autism and ID were associated with higher RRB severity (d = .58, 95% CI [.08, 1.09], t = 2.36, p = .035).

Unlike categorical models, dimensional models revealed a three-way interaction between sleep disturbance, autistic traits, and ADHD traits predicting RRBs (β = − .04, 95% CI [-.06, − .01], t = -2.47, p = .027). In a simple slopes analysis, sleep disturbance predicted RRBs at every combination of traits. We found that the association was steepest when autistic traits were high and ADHD traits low (β = .22, 95% CI [.14, .29], t = 5.58, p < .001) but shallowest when both were high (β = .13, 95% CI [.09, .17], t = 5.84, p < .001). However, the equivalent three-way interaction predicting sleep disturbance from RRBs was not significant (β = − .01, 95% CI [-.04, .01], t = − .89, p = .427). We found that the relationship between RRBs and sleep disturbance was moderated by autistic traits (β = − .05, 95% CI [-.08, − .01], t = -2.38, p = .034). The link between RRBs and sleep disturbance attenuated as autistic traits increased (16th percentile: β = .27, 95% CI [.21, .34], t = 8.19, p < .001; 84th percentile: β = .18, 95% CI [.13, .24], t = 6.75, p < .001). IQ also moderated this association (β = .07, 95% CI [.02, .11], t = 2.90, p = .008). Higher RRB severity predicted more sleep disturbance more strongly as IQ increased (16th percentile: β = .17, 95% CI [.11, .23], t = 5.64, p < .001; 84th percentile: β = .30, 95% CI [.23, .38], t = 8.08, p < .001). Results for H4 are shown in Fig. 3B–D. A comprehensive overview of our results is provided in Table 2.

Table 2
Linear regression models predicting sleep disturbance and RRBs (H1–H4)

Predictor	Estimate	SE	Std. β / d	p
H1.1: cat				
Autism	2.233	1.204	0.216	.102
ADHD	**3.634**	**0.598**	**0.352**	**< .001**
ID	-1.795	1.435	-0.174	.281
Age	0.061	0.069	0.018	.374
Sex (Male)	-0.514	0.457	-0.050	.261
Barratt	**-0.070**	**0.015**	**-0.095**	**< .001**
Autism × ADHD	-0.312	1.343	-0.030	.816
H1.1: cont				
ASSQ	**0.277**	**0.028**	**0.236**	**< .001**
SWAN	**2.586**	**0.239**	**0.223**	**< .001**
IQ	**0.063**	**0.012**	**0.104**	**< .001**
Age	**0.163**	**0.066**	**0.048**	**.014**
Sex (Male)	**-1.396**	**0.433**	**-0.136**	**.001**
Barratt	**-0.072**	**0.015**	**-0.097**	**< .001**
ASSQ × SWAN	0.016	0.025	0.012	.547
H1.2: cat				
Autism	**1.881**	**0.557**	**0.182**	**.001**
ID	-2.828	1.770	-0.274	.160
ADHD	**3.558**	**0.536**	**0.345**	**< .001**
Age	0.065	0.069	0.019	.346

SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; FSIQ = Full-Scale Intelligence Quotient; BSMSS = Barratt Simplified Measure of Social Status; ID = Intellectual Disability; TD = Typically Developing; CI = confidence interval. Estimates are unstandardised. Std. β / d = standardised coefficient: β for continuous predictors; d (standardised mean difference relative to participants without the condition) for diagnostic categories; for interactions between a continuous predictor and a diagnostic category, the difference in standardised slope between groups. P-values for focal terms are FDR-corrected using the Benjamini-Hochberg procedure within each hypothesis family, covariates are not. p < .05 is printed in bold.

Predictor	Estimate	SE	Std. β / d	p
Sex (Male)	-0.508	0.457	-0.049	.267
Barratt	**-0.071**	**0.015**	**-0.096**	**< .001**
Autism × ID	2.986	3.018	0.289	.397
H1.2: cont				
ASSQ	**0.283**	**0.024**	**0.238**	**< .001**
IQ	**0.065**	**0.013**	**0.106**	**< .001**
SWAN	**2.592**	**0.239**	**0.223**	**< .001**
Age	**0.161**	**0.066**	**0.047**	**.015**
Sex (Male)	**-1.410**	**0.432**	**-0.137**	**.001**
Barratt	**-0.072**	**0.015**	**-0.097**	**< .001**
ASSQ × IQ	-0.001	0.001	-0.016	.432
H2.1: cat				
Autism	**37.179**	**3.477**	**1.132**	**< .001**
ADHD	**8.100**	**1.725**	**0.247**	**< .001**
ID	**13.318**	**4.143**	**0.406**	**.002**
Age	**-0.970**	**0.199**	**-0.089**	**< .001**
Sex (Male)	**5.010**	**1.320**	**0.153**	**< .001**
Barratt	**-0.308**	**0.043**	**-0.131**	**< .001**
Autism × ADHD	-4.744	3.877	-0.144	.221
H2.1: cont				
ASSQ	**1.928**	**0.076**	**0.517**	**< .001**
SWAN	**3.927**	**0.650**	**0.110**	**< .001**
IQ	**-0.126**	**0.033**	**-0.065**	**< .001**

SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; FSIQ = Full-Scale Intelligence Quotient; BSMSS = Barratt Simplified Measure of Social Status; ID = Intellectual Disability; TD = Typically Developing; CI = confidence interval. Estimates are unstandardised. Std. β / d = standardised coefficient: β for continuous predictors; d (standardised mean difference relative to participants without the condition) for diagnostic categories; for interactions between a continuous predictor and a diagnostic category, the difference in standardised slope between groups. P-values for focal terms are FDR-corrected using the Benjamini-Hochberg procedure within each hypothesis family, covariates are not. p < .05 is printed in bold.

Predictor	Estimate	SE	Std. β / d	p
Age	**-0.819**	**0.180**	**-0.075**	**< .001**
Sex (Male)	**2.969**	**1.178**	**0.090**	**.012**
Barratt	**-0.194**	**0.040**	**-0.082**	**< .001**
ASSQ × SWAN	**0.169**	**0.068**	**0.039**	**.017**
H2.2: cat				
Autism	**32.781**	**1.608**	**0.998**	**< .001**
ID	7.119	5.108	0.217	.174
ADHD	**7.075**	**1.546**	**0.215**	**< .001**
Age	**-0.944**	**0.199**	**-0.087**	**< .001**
Sex (Male)	**5.063**	**1.320**	**0.154**	**< .001**
Barratt	**-0.313**	**0.043**	**-0.133**	**< .001**
Autism × ID	**17.752**	**8.710**	**0.541**	**.048**
H2.2: cont				
ASSQ	**1.982**	**0.066**	**0.523**	**< .001**
IQ	**-0.098**	**0.034**	**-0.056**	**.006**
SWAN	**3.994**	**0.649**	**0.108**	**< .001**
Age	**-0.846**	**0.180**	**-0.078**	**< .001**
Sex (Male)	**2.837**	**1.173**	**0.086**	**.016**
Barratt	**-0.195**	**0.040**	**-0.083**	**< .001**
ASSQ × IQ	**-0.013**	**0.004**	**-0.059**	**< .001**
H3: 1 RBS				
SDSC	**0.968**	**0.061**	**0.304**	**< .001**
Age	**-0.806**	**0.207**	**-0.074**	**< .001**

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Predictor	Estimate	SE	Std. β / d	p
Sex (Male)	**9.452**	**1.355**	**0.288**	**< .001**
Barratt	**-0.284**	**0.045**	**-0.121**	**< .001**
H3: 2 SDSC				
RBS	**0.099**	**0.006**	**0.315**	**< .001**
Age	**0.131**	**0.066**	**0.038**	**.049**
Sex (Male)	**-0.950**	**0.437**	**-0.092**	**.030**
Barratt	**-0.037**	**0.014**	**-0.050**	**.011**
H4.1: 1 RBS				
SDSC	**0.620**	**0.173**	**0.195**	**< .001**
Autism	**35.728**	**3.348**	**1.086**	**< .001**
ADHD	**5.627**	**1.713**	**0.175**	**.002**
ID	**14.452**	**3.951**	**0.440**	**< .001**
Age	**-1.000**	**0.190**	**-0.092**	**< .001**
Sex (Male)	**5.474**	**1.258**	**0.167**	**< .001**
Barratt	**-0.250**	**0.041**	**-0.106**	**< .001**
SDSC × Autism	-0.151	0.364	-0.048	.711
SDSC × ADHD	0.247	0.186	0.078	.240
Autism × ADHD	-5.623	3.743	-0.165	.185
SDSC × Autism × ADHD	0.395	0.393	0.124	.366
H4.1: 2 SDSC				
RBS	**0.091**	**0.023**	**0.289**	**< .001**
Autism	0.523	1.377	0.034	.727
ADHD	**2.960**	**0.617**	**0.295**	**< .001**

SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; FSIQ = Full-Scale Intelligence Quotient; BSMSS = Barratt Simplified Measure of Social Status; ID = Intellectual Disability; TD = Typically Developing; CI = confidence interval. Estimates are unstandardised. Std. β / d = standardised coefficient: β for continuous predictors; d (standardised mean difference relative to participants without the condition) for diagnostic categories; for interactions between a continuous predictor and a diagnostic category, the difference in standardised slope between groups. P-values for focal terms are FDR-corrected using the Benjamini-Hochberg procedure within each hypothesis family, covariates are not. p < .05 is printed in bold.

Predictor	Estimate	SE	Std. β / d	p
ID	-2.935	1.371	-0.285	.058
Age	**0.162**	**0.066**	**0.048**	**.014**
Sex (Male)	**-1.075**	**0.438**	**-0.104**	**.014**
Barratt	**-0.038**	**0.014**	**-0.052**	**.008**
RBS × Autism	-0.058	0.035	-0.186	.135
RBS × ADHD	0.026	0.025	0.084	.344
Autism × ADHD	-1.839	1.548	-0.167	.295
RBS × Autism × ADHD	0.040	0.038	0.128	.344
H4.1: 3 RBS				
SDSC	**0.510**	**0.062**	**0.159**	**< .001**
ASSQ	**1.787**	**0.078**	**0.484**	**< .001**
SWAN	**3.113**	**0.691**	**0.088**	**< .001**
IQ	**-0.156**	**0.033**	**-0.081**	**< .001**
Age	**-0.893**	**0.178**	**-0.082**	**< .001**
Sex (Male)	**3.545**	**1.164**	**0.108**	**.002**
Barratt	**-0.166**	**0.040**	**-0.071**	**< .001**
SDSC × ASSQ	0.009	0.007	0.016	.287
SDSC × SWAN	-0.045	0.067	-0.016	.538
ASSQ × SWAN	**0.237**	**0.075**	**0.053**	**.004**
SDSC × ASSQ × SWAN	**-0.015**	**0.006**	**-0.035**	**.027**
H4.1: 4 SDSC				
RBS	**0.075**	**0.009**	**0.231**	**< .001**
ASSQ	**0.175**	**0.034**	**0.155**	**< .001**

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Predictor	Estimate	SE	Std. β / d	p
SWAN	**2.353**	**0.257**	**0.206**	**< .001**
IQ	**0.070**	**0.012**	**0.116**	**< .001**
Age	**0.225**	**0.065**	**0.066**	**< .001**
Sex (Male)	**-1.631**	**0.427**	**-0.159**	**< .001**
Barratt	**-0.060**	**0.015**	**-0.082**	**< .001**
RBS × ASSQ	**-0.002**	**0.001**	**-0.049**	**.034**
RBS × SWAN	-0.007	0.010	-0.020	.537
ASSQ × SWAN	0.076	0.036	0.055	.062
RBS × ASSQ × SWAN	0.000	0.001	-0.012	.427
H4.2: 1 RBS				
SDSC	**0.843**	**0.064**	**0.265**	**< .001**
Autism	**30.717**	**1.552**	**0.939**	**< .001**
ID	8.847	4.981	0.264	.118
ADHD	**4.089**	**1.486**	**0.125**	**.012**
Age	**-1.003**	**0.190**	**-0.092**	**< .001**
Sex (Male)	**5.517**	**1.257**	**0.168**	**< .001**
Barratt	**-0.246**	**0.041**	**-0.105**	**< .001**
SDSC × Autism	0.236	0.138	0.074	.133
SDSC × ID	-0.318	0.476	-0.100	.538
Autism × ID	**19.936**	**8.464**	**0.583**	**.035**
SDSC × Autism × ID	-1.477	0.760	-0.464	.085
H4.2: 2 SDSC				
RBS	**0.115**	**0.008**	**0.367**	**< .001**

SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; FSIQ = Full-Scale Intelligence Quotient; BSMSS = Barratt Simplified Measure of Social Status; ID = Intellectual Disability; TD = Typically Developing; CI = confidence interval. Estimates are unstandardised. Std. β / d = standardised coefficient: β for continuous predictors; d (standardised mean difference relative to participants without the condition) for diagnostic categories; for interactions between a continuous predictor and a diagnostic category, the difference in standardised slope between groups. P-values for focal terms are FDR-corrected using the Benjamini-Hochberg procedure within each hypothesis family, covariates are not. p < .05 is printed in bold.

Predictor	Estimate	SE	Std. β / d	p
Autism	-1.158	0.645	-0.119	.116
ID	-3.533	1.693	-0.355	.062
ADHD	**2.737**	**0.513**	**0.265**	**< .001**
Age	**0.167**	**0.066**	**0.049**	**.011**
Sex (Male)	**-1.104**	**0.437**	**-0.107**	**.012**
Barratt	**-0.038**	**0.014**	**-0.051**	**.008**
RBS × Autism	-0.025	0.015	-0.078	.135
RBS × ID	-0.042	0.050	-0.133	.459
Autism × ID	**9.600**	**4.317**	**0.900**	**.048**
RBS × Autism × ID	-0.108	0.078	-0.345	.221
H4.2: 3 RBS				
SDSC	**0.461**	**0.057**	**0.144**	**< .001**
ASSQ	**1.849**	**0.071**	**0.488**	**< .001**
IQ	**-0.127**	**0.035**	**-0.070**	**< .001**
SWAN	**2.800**	**0.657**	**0.075**	**< .001**
Age	**-0.925**	**0.178**	**-0.085**	**< .001**
Sex (Male)	**3.541**	**1.160**	**0.108**	**.002**
Barratt	**-0.162**	**0.040**	**-0.069**	**< .001**
SDSC × ASSQ	0.001	0.006	0.002	.907
SDSC × IQ	0.005	0.003	0.026	.212
ASSQ × IQ	**-0.015**	**0.004**	**-0.065**	**< .001**
SDSC × ASSQ × IQ	0.000	0.000	0.000	.978
H4.2: 4 SDSC				

SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; FSIQ = Full-Scale Intelligence Quotient; BSMSS = Barratt Simplified Measure of Social Status; ID = Intellectual Disability; TD = Typically Developing; CI = confidence interval. Estimates are unstandardised. Std. β / d = standardised coefficient: β for continuous predictors; d (standardised mean difference relative to participants without the condition) for diagnostic categories; for interactions between a continuous predictor and a diagnostic category, the difference in standardised slope between groups. P-values for focal terms are FDR-corrected using the Benjamini-Hochberg procedure within each hypothesis family, covariates are not. p < .05 is printed in bold.

Predictor	Estimate	SE	Std. β / d	p
RBS	**0.077**	**0.008**	**0.240**	**< .001**
ASSQ	**0.199**	**0.031**	**0.163**	**< .001**
IQ	**0.074**	**0.013**	**0.124**	**< .001**
SWAN	**2.250**	**0.238**	**0.193**	**< .001**
Age	**0.217**	**0.065**	**0.064**	**< .001**
Sex (Male)	**-1.686**	**0.426**	**-0.164**	**< .001**
Barratt	**-0.059**	**0.015**	**-0.080**	**< .001**
RBS × ASSQ	**-0.002**	**0.001**	**-0.058**	**.001**
RBS × IQ	**0.001**	**0.000**	**0.066**	**.008**
ASSQ × IQ	-0.003	0.002	-0.042	.145
RBS × ASSQ × IQ	0.000	0.000	-0.016	.334

SDSC = Sleep Disturbance Scale for Children; RBS-R = Repetitive Behavior Scale-Revised; ASSQ = Autism Spectrum Screening Questionnaire; SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale; FSIQ = Full-Scale Intelligence Quotient; BSMSS = Barratt Simplified Measure of Social Status; ID = Intellectual Disability; TD = Typically Developing; CI = confidence interval. Estimates are unstandardised. Std. β / d = standardised coefficient: β for continuous predictors; d (standardised mean difference relative to participants without the condition) for diagnostic categories; for interactions between a continuous predictor and a diagnostic category, the difference in standardised slope between groups. P-values for focal terms are FDR-corrected using the Benjamini-Hochberg procedure within each hypothesis family, covariates are not. p < .05 is printed in bold.

Exploratory analyses

RRBs were more severe in autism than in ADHD (Δ = 26.2 RBS-R points, $p < .001$) and ID (Δ = 20.2, $p < .001$), whereas ADHD and ID did not differ ($p = .165$). In all three diagnostic categories, RRBs were more severe compared to TD (all $p \leq .003$). Higher autistic and ADHD traits as well as lower IQ were associated with more severe RRBs (all $p < .001$). This association was stronger for autistic than ADHD traits (Δβ = .43, $p < .001$) and lower IQ (Δβ = .47, $p < .001$). We found that dimensional models explained more variance than categorical models for sleep disturbance ($R^2 = .14$ vs .03; $\Delta R^2 = .11$, 95% CI [.09, .13]) and RRBs ($R^2 = .38$ vs .21; $\Delta R^2 = .17$, 95% CI [.13, .21]), including out of sample (cross-validated $R^2 = .14$ vs .03 and .37 vs .20, respectively). Model fits for dimensional models exceeded diagnostic models in all 8 comparisons (Vuong z = 4.00–8.23, $p < .001$, FDR-corrected). In contrast, diagnostic categories added little variance beyond traits ($\Delta R^2 \leq .02$, Supplementary Table 3). In the ADHD group, current stimulant use was associated with more sleep disturbance (d = .17, $p = .028$) but not RRB severity (d = .05, $p = .784$) compared with no psychiatric medication, and did not moderate the sleep–RRB association ($p = .900$; Supplementary Table 4).

Discussion

Here we systematically investigated differences in sleep disturbance, RRBs, and their interaction, between ADHD, autism, ID and TD. Using both diagnostic categories and symptom dimensions, we found that differences in sleep disturbance, RRBs, and their interaction manifested mostly in symptom dimensions rather than diagnostic categories. Our results confirm previous studies[1] which demonstrated higher rates of sleep disturbance in individuals with diagnosed ADHD relative to TD. Replicating earlier findings[11], we identified a link between stimulant use and greater sleep disturbance. However, autism was only associated with more sleep disturbance in one model, and ID was not linked to sleep disturbance at all. In our sample, mean SDSC scores for ADHD (M = 42.2, SD = 10.5), autism (M = 43.1, SD = 11.2), and ID (M = 40.3, SD = 10.9) but not TD (M = 38.3, SD = 8.5) exceeded the SDSC cutoff score for sleep dysfunction[57]. Considering that 40.1% of TD individuals exceed this cutoff, elevated rates of sleep disturbance in this group might explain this result (Supplementary Table 5). Differences in the definition of ID in our study relative to previous work might also account for this non-replication. We defined ID via FSIQ and Vineland scores thresholds, whereas previous studies differ in their inclusion criteria, e.g., by recruiting individuals with specific conditions such as Prader-Willi Syndrome or Down Syndrome in addition to IQ[65]. We also did not find evidence for our hypothesis that children with a dual diagnosis ADHD and autism or ID experience more sleep disturbance than either condition alone, which is at odds with the literature for ADHD and autism[43,66,67]. In contrast, ADHD and autistic symptom dimensions as well as IQ were positively linked to sleep disturbance. This contradicts previous findings linking more sleep problems to lower cognitive ability[68,69]. Since we use a community-referred sample where young people were referred for psychiatric and developmental issues, our sample is enriched for neurodevelopmental diagnoses. Individuals with high IQ are likely to exhibit at least some functional impairment to be referred for an evaluation regardless of whether they were eventually given a diagnosis. Higher IQ is also correlated with a higher preference for late sleep and wake times[70], which is itself linked to more sleep disturbances[71]. Both autism and ADHD are accompanied by disruptions in circadian rhythm[72,73]. In addition, autistic children and adolescents are thought to experience high arousal before bedtime, potentially driven by anxiety, stress or sensory factors in their sleep environment[74]. Similarly, restlessness in children with ADHD might lead to bedtime resistance and difficulties falling asleep[75,76].

Our results replicated earlier findings that RRBs feature not only in autism[77,78], but also in ADHD[28], and ID[79,80]. There was no synergistic effect of co-occurring autism and ADHD diagnoses, but high ADHD traits exacerbated the effect of autistic traits on RRBs. A combination of autistic and ADHD traits might lead to an increased need for self-soothing or sensory regulation. Co-occurring autistic and ADHD traits might also make it more difficult to suppress or mask RRBs, e.g., due to perceived judgment from observers. Concurrent high autistic traits and ADHD-linked low inhibitory control might result in freer RRB expression[81]. Both for diagnostic categories and symptoms, lower cognitive ability further reinforced the relationship between autism or autistic traits and RRB severity. This aligns with previous studies showing an association between low non-verbal IQ and RRBs in autistic children[82]. We speculate that individuals

with lower IQ might perceive their environment as more unpredictable, and as a result employ RRBs to increase predictability[83]. Alternatively, individuals with higher IQ might be more able to suppress RRBs in situations where they might be seen as socially undesirable by others. In line with previous work[34], high RRBs and sleep disturbance were linked across the entire sample. We also found that RRBs were less strongly associated with sleep disturbance with increasing autistic traits. Possibly, individuals with more autistic traits might employ RRBs to self-regulate[84], and therefore reduce sleep difficulties. It is also possible that the relationship between RRBs and sleep disturbances might be explained by a third factor, e.g., stress or anxiety disorders[85]. Interestingly, ADHD traits alone did not moderate the relationship between RRBs and sleep disturbance. However, in the opposite direction, sleep disturbance was less strongly associated with RRBs in individuals with high levels of both autistic and ADHD traits. Although ADHD traits were associated with more RRBs overall, ADHD and sleep disturbance might both contribute to deficits in top-down control, and thereby prevent individuals from employing sensory self-regulation strategies when autistic traits are prominent[86].

An interesting aspect of our study is that we were largely only able to uncover differences in sleep disturbance, RRBs and their interaction based on symptom dimensions rather than diagnostic groups. Our results speak in favour of a transdiagnostic approach to assessing the relationship between RRBs and sleep. Overlaps in symptom presentation, multiple diagnoses, symptom profiles falling short of the diagnostic threshold and inconsistent diagnostic boundaries challenge research contrasting neurodevelopmental conditions[41]. As previously noted[41], many individuals without a diagnosed neurodevelopmental condition display symptoms of neurodevelopmental conditions without meeting diagnostic criteria. For example, 60% of the general population were found to experience at least one ADHD symptom[87], and 5–25% show sub-clinical autistic traits[88,89]. Trait compositions might vary between individuals with the same diagnosis, and within the same individual depending on context and developmental stage[90,91]. For instance, someone with ADHD might display higher or lower ADHD symptoms, or a different subset of symptoms, as a child than as an adult[90,92]. Categorical models do not distinguish between individuals with ADHD and with elevated autistic traits but no autism diagnosis, and ADHD alone. Modelling the relationship between sleep and RRBs with diagnostic categories results in a loss of variance and less statistical power relative to dimensional symptom models. Therefore, we suggest framing the interaction of sleep issues and RRBs as a characteristic of the neurodevelopmental spectrum rather than individual conditions[4,41].

Several limitations of our study should be acknowledged. First, the HBN dataset is cross-sectional and precludes any causal inferences about RRBs and sleep disturbance. Longitudinal studies are necessary to untangle the trajectories of both variables comparing neurodevelopmental conditions. Second, our study only used caregiver-reports and future research should integrate physiological measures, such as actigraphy or polysomnography for sleep and psychophysiological measures for sensory reactivity. Third, we defined ID using IQ and VABS scores rather than a diagnosis of intellectual developmental disorder or presence of impairment before the age of 18, which can limit the generalisability of our study to other work. However, 41 of 52 ID participants received a diagnosis of a mild (F70) or moderate (F71)

intellectual disability. Fourth, the sample size description in our preregistration differs from the paper due to coding errors which assigned participants to diagnostic categories using primary diagnoses and included participants with neurological and psychiatric conditions in TD. Another limitation pertains to imbalanced diagnostic category sizes. In our dataset, most participants were assigned to the ADHD category, which might explain why we were only able to replicate a link between sleep and ADHD but not the other diagnostic categories in the literature[14,36,74]. This is reflective of the greater ADHD prevalence in the population[93] and therefore supports the ecological validity of our findings. We also note that both the ASSQ and SWAN were designed for participants aged 6–17 but administered to all participants in our sample. Finally, our sample was predominantly White, male and guardians were typically highly educated, potentially limiting the generalisability of our findings. Sex was recorded by caregivers and treated as a binary covariate, which precludes analyses of intersex variations.

In sum, symptom dimensions were better suited to uncover differences between sleep, RRBs, and their interaction than diagnostic categories. Our results support transdiagnostic approaches in psychiatry and encourage clinicians to assess sleep dysfunction and RRBs based on neurodevelopmental symptoms rather than diagnostic categories. We envision that our work might provide a foundation for developing personalised interventions to address sleep dysfunction in individuals with neurodevelopmental conditions, accounting for RRBs.

Declarations

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Conflict of interest

The authors declare no conflict of interest.

Author contributions

MN: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. GM: Supervision, Writing – review & editing. MM: Supervision, Writing – review & editing. AA: Supervision, Writing – review & editing. VN: Supervision, Project administration, Writing – review & editing.

Data and code availability

Data are available through the HBN project (https://fcon_1000.projects.nitrc.org/indi/cmi_healthy_brain_network/). Code is available at https://osf.io/9h7cn/.

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Figures

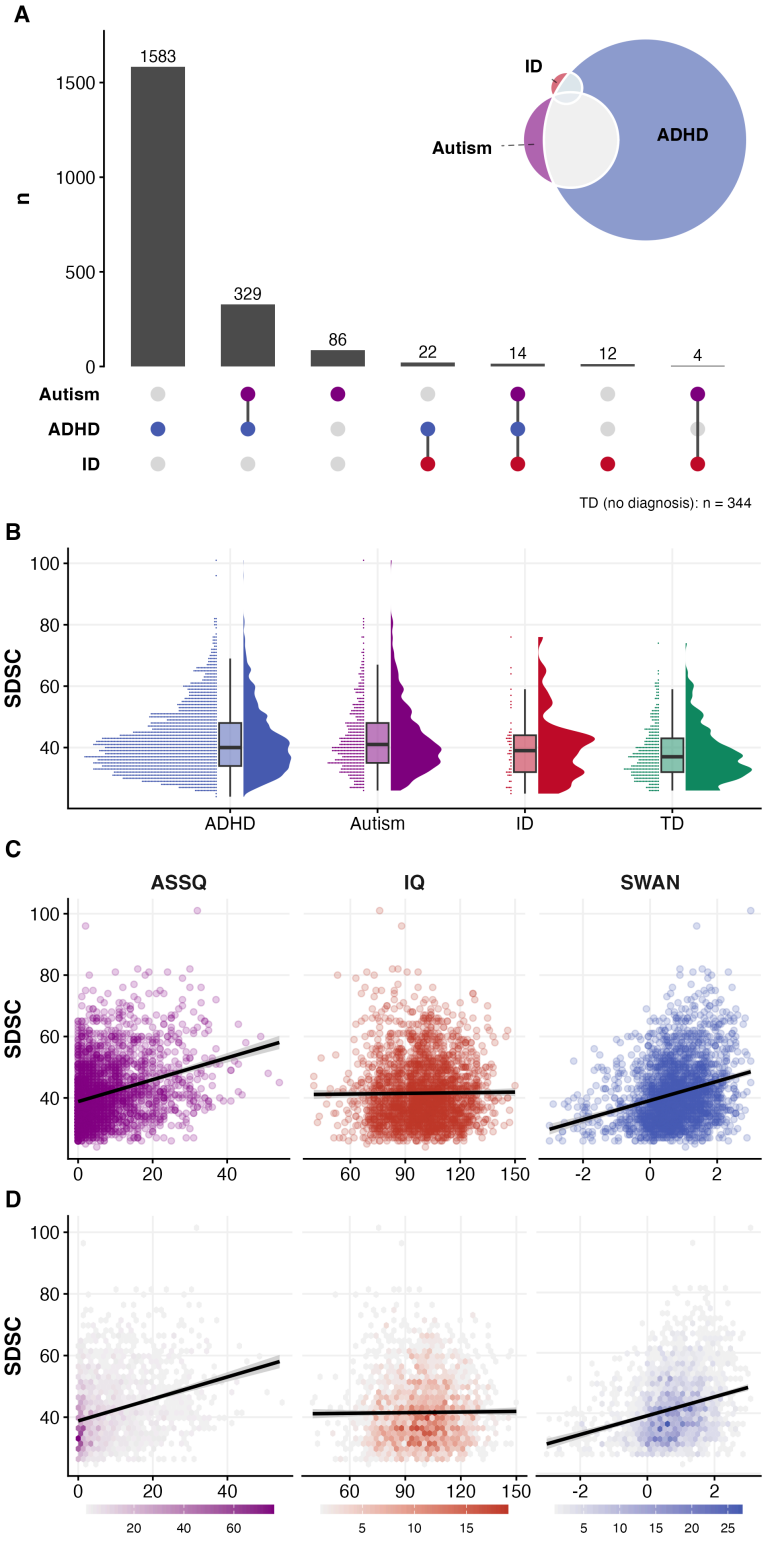


Figure 1

Sleep disturbance across diagnostic groups and symptom dimensions. (A) Co-occurrence of autism, ADHD and ID. (B) Distribution of SDSC scores across diagnostic groups. Raincloud plots display probability density, boxplots (median and interquartile range), and a scatterplot showing individual ratings. (C) Relationship between SDSC score and symptom dimensions for autism (ASSQ), ID (IQ), and ADHD (SWAN) represented with a linear regression line, and shaded regions representing 95% confidence intervals. (D) Bivariate density distributions (hexagonal binning) mapping ASSQ, IQ, and SWAN scores to SDSC, overlaid with linear regression lines. Colour intensity indicates the observation count within each bin.

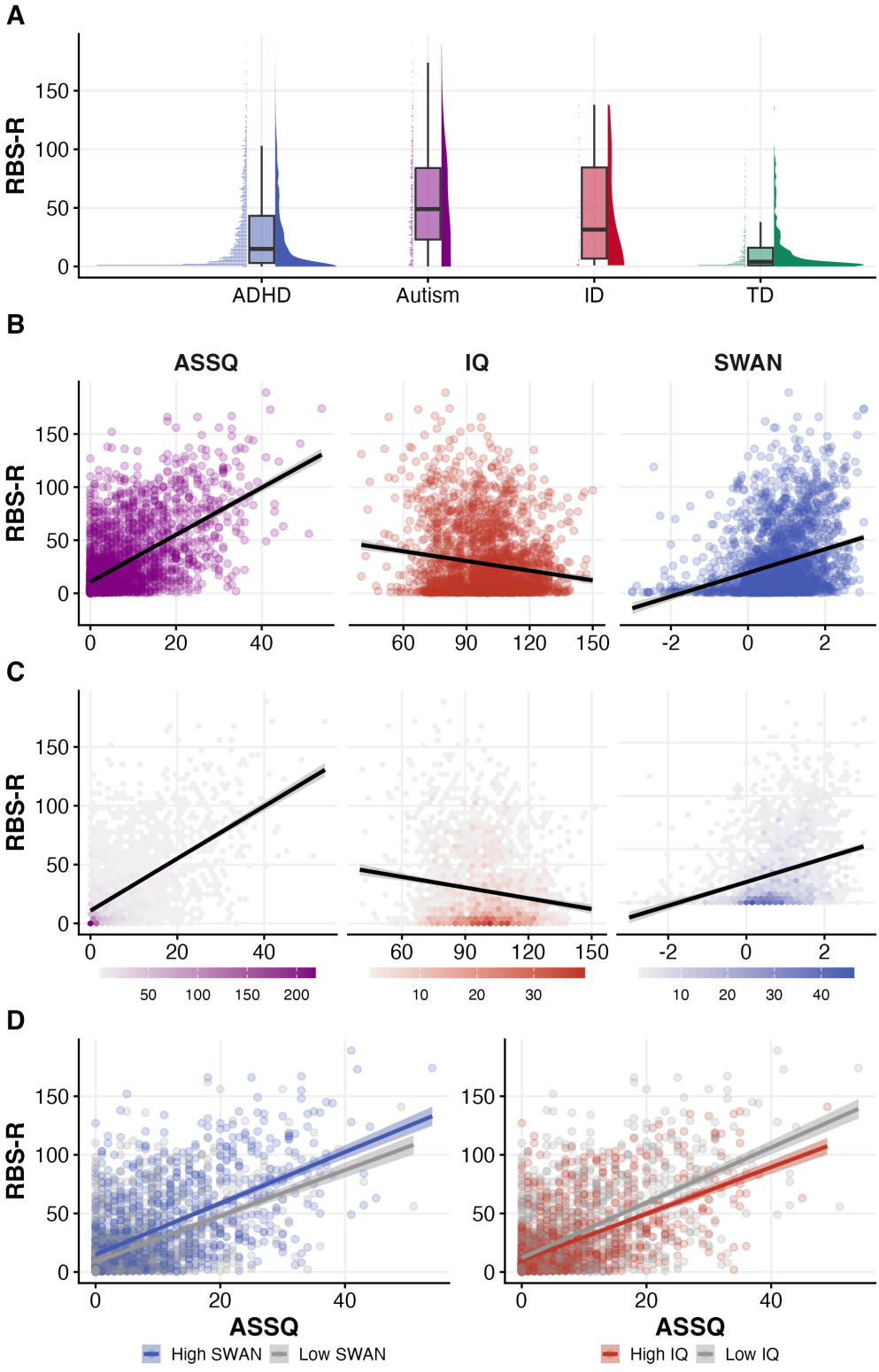


Figure 2

Relationship between RRBs and symptom dimensions.(A) Distribution of RBS-R scores across diagnostic groups, each visualised using a probability distribution slab, a boxplot with median and interquartile range, and a scatterplot. (B) Linear associations between dimensional trait measures (ASSQ, IQ, SWAN) and RBS-R, including 95% confidence intervals shown as shaded regions. (C) Hexagonal bin plots illustrating the density of observations for each trait against RBS-R, overlaid with

linear regression lines. (D) The relationship between ASSQ and RBS-R, stratified by SWAN (left) and IQ (right) using a median split. Regression lines are shown in blue/grey for high/low SWAN (left) and in red/grey for high/low IQ to illustrate moderating effects.

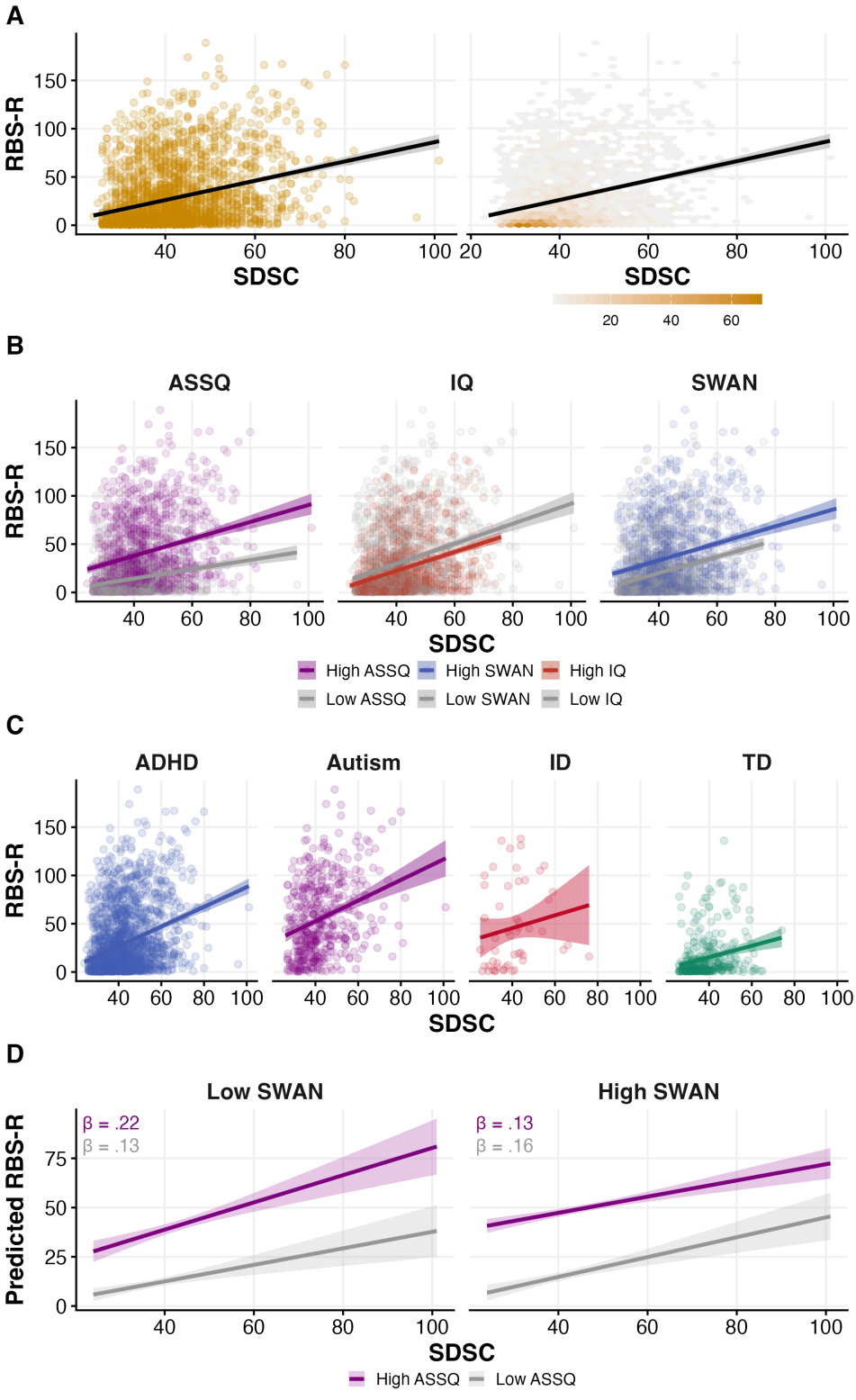


Figure 3

Associations between sleep disturbance and RRBs across symptom dimensions and diagnostic groups. (A) Relationship between SDSC and RBS-R across the entire sample, represented as a standard scatterplot adjacent to a hexagonal density plot with a regression line and shaded 95% confidence intervals. (B) Relationship between SDSC and RBS-R, faceted by dimensional symptom measure (ASSQ, IQ, SWAN). Each facet shows high and low trait levels split along the median, using regression lines (with shaded 95% confidence intervals). (C) Relationship between SDSC and RBS-R shown using scatterplots and regression lines (with shaded 95% confidence intervals) for each diagnostic group. (D) Simple slopes represent SDSC predicting RBS-R from the three-way interaction between SDSC, ASSQ and SWAN. Lines highlight predicted RBS-R for low (16th percentile) and high (84th percentile) ASSQ, faceted by low (16th percentile) and high SWAN (84th percentile), adjusted for age, sex, BSMSS and IQ, with shaded 95% confidence intervals. Labels give standardised simple slopes (β).

Supplementary Files

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