



Original Article

Attention deficit hyperactivity disorder symptom severity and sleep problems in adult participants of the Netherlands sleep registry



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ABSTRACT

Background: We examined whether current overall attention deficit hyperactivity disorder (ADHD), inattention, or hyperactivity symptom severities are associated with the current presence and persistent history of sleep problems.

Methods: $N = 942$ participants of the Netherlands Sleep Registry filled out online several validated questionnaires. Regression analyses were performed to assess the association between (1) current overall ADHD symptom severity and the current presence of sleep problems, (2) current ADHD symptom-severity groups and the persistent history of sleep problems, and (3) current inattention or hyperactivity symptom severities and the current presence of sleep problems.

Results: (1) Current overall ADHD symptom severity was associated with the odds of suffering from probable obstructive sleep apnea syndrome (OSAS), restless legs syndrome (RLS), periodic limb movement disorder (PLMD), insomnia disorder (ID) with predominant difficulties initiating sleep (DIS) and maintaining sleep (DMS), but not with the odds of suffering from narcolepsy or ID with predominant early-morning awakening (EMA). Current overall ADHD symptom severity was also associated with an extreme evening chronotype but not with short sleep. (2) The group with the most severe current ADHD symptoms was more likely to have a history of persistent OSAS, RLS, and ID. (3) The severity of symptoms of hyperactivity, but not of inattention, was specifically associated with probable RLS, PLMD, ID with DIS or DMS, and short sleep. Inattention symptom severity was only related to the probability of being an extreme evening chronotype.

Conclusion: ADHD severity, especially the severity of hyperactivity, is associated with the current presence and persistent history of sleep problems.

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1. Introduction

Sleep disturbances have a considerable impact on quality of life [1] and constitute a risk factor for serious health issues in the long term, such as obesity, diabetes, cardiovascular disease, and cancer

[2–4]. Sleep disturbances are frequently comorbid with mental disorders, including attention deficit hyperactivity disorder (ADHD) [5]. ADHD is characterized by symptoms of hyperactivity, impulsivity, and/or inattention [6] and also affects quality of life [7]. Although the direction of the relationship between ADHD and sleep disturbances remains unknown, the association seems reciprocal: disturbed sleep can aggravate or mimic features of ADHD, and vice versa, ADHD can contribute to sleep problems [8]. For instance, hyperactivity may result in difficulty falling asleep, which is the most frequently occurring sleep disturbance as reported by parents

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of children with ADHD [9]. Research among adults on the association between ADHD symptoms and sleep problems is scarce. Studies reported frequent sleep-onset difficulties also in adults with ADHD [10]. Another report suggests that the prevalence of sleep problems may even be higher in adults (60–80%) than in children and adolescents with ADHD (25–50%) [8].

One aspect of the association between ADHD symptoms and sleep problems that needs further investigation, is the persistence of the sleep problems. Most previous longitudinal studies [11] revealed that sleep problems, such as short sleep duration due to later bedtimes and frequent awakenings, were stable over time among children with ADHD. Two studies in adolescents indicate that sleep problems are more persistent in the presence of ADHD [12,13]. No studies addressed how current ADHD symptom severity in adulthood is related to the persistent history of sleep problems. Analogous to the core symptoms of hyperactivity and inattention that persist into adulthood and old age [14,15], we hypothesize that sleep disturbances are chronic across the lifespan in ADHD patients. Since specifically chronic sleep problems are associated with serious health consequences [2–4], it is important to study whether ADHD symptom severities in adulthood are associated with a persistent history of sleep problems.

Among the many ADHD-sleep studies in children, relatively few studies addressed whether sleep problems might differentially be associated with the severities of either inattention or hyperactivity symptoms. Moreover, this has been rarely studied in adults. Some sleep problems, such as periodic limb movement disorder (PLMD), seem particularly associated with hyperactivity [16,17]. Conflicting differential associations with inattention versus hyperactivity symptom severity have been reported for other sleep problems, including restless legs syndrome (RLS) [17–20], sleep-disordered breathing [21–24], insomnia [25–29], extreme evening chronotype [30–33], and short sleep duration [26,31,34–36]. Altogether, the relationship between inattention and hyperactivity symptom severities and sleep disturbances needs to be further explored. If any prominent patterns across symptom severities are found, this is an important indication of the type of sleep problems that are co-occurring, causing, or the result of the severity of specific ADHD symptoms. This could guide assessment and treatment of sleep problems among those with more severe specific ADHD symptoms.

Using data from adult participants of the Netherlands Sleep Registry, we examined whether current overall ADHD, inattention, or hyperactivity symptom severities are associated with the history and current presence of sleep problems.

2. Material and methods

2.1. Participants

Participants of the Netherlands Sleep Registry (NSR, www.sleepregistry.nl) filled out surveys online. The NSR aims to research insomnia using multiple surveys in a large cohort compromising the full range from very disturbed to very sound sleepers. Participants of the Dutch general population were recruited by advertising in media, by mentioning the NSR in all radio, TV and newspaper interviews and on Facebook and Twitter, and by distributing flyers at healthcare institutions and conventions. In all communications, we stressed the importance of participation by both good sleepers and people suffering from insomnia. Population-representative recruitment was not pursued in the application of the Sleep Registry in the Netherlands. Continued commitment was supported by providing feedback on individual scores, by newsletters, and by reminder e-mails (described in the supplement of the article by Benjamins et al. [37]).

Volunteers of the NSR participate anonymously without revealing their full name and address and are not exposed to interventions or behavioral constraints. The NSR therefore does not fall under the Dutch Medical Research Involving Human Subjects Act, and signed informed consent is not mandatory, as confirmed by the Medical Ethical Committee of the Academic Medical Center of the University of Amsterdam as well as the Central Committee on Research Involving Human Subjects (CCMO), The Hague, The Netherlands. In the present study, we analyzed data from 942 adult participants who completed the questionnaires on ADHD symptoms and sleep disturbances, of whom 598 participants also completed a questionnaire about the chronicity of sleep problems.

2.2. Measurements

The following online questionnaires and structured interviews were used to obtain estimates of ADHD symptom severity, the probability of sleep disorders and two sleep characteristics (extreme evening type and short sleep duration).

2.2.1. Current ADHD symptom severity

The Adult ADHD Self-Report Scale (ASRS) Screener version 1.1 [38] was used to assess current ADHD symptom severity. This screener consists of six items: four on inattention and two on hyperactivity. A previous study by Hesse investigated whether the ASRS Screener measures inattentiveness and hyperactivity independently. Factor analysis showed that the screener is a two-dimensional measure instead of a single unitary measure. Items 1–4 relate to inattention symptoms and loaded on one factor (inattentiveness) and items 5 and 6 loaded on a second factor (hyperactivity). The ASRS screener has been shown to outperform the full version of the ASRS (with 18 items measuring the frequency of all 18 DSM-IV ADHD symptoms) in terms of psychometric properties and classification accuracy [38]. The severity of each symptom over the past 6 months was rated on a five-point Likert scale ranging from 0 (never) to 4 (very often). The scores on both the inattention and hyperactivity items were converted into binary values according to the official scoring system. Overall ADHD symptoms are defined as the sum of the inattention and hyperactivity items. The ASRS screener has been shown to have moderate sensitivity (68.7%), excellent specificity (99.5%), and excellent total classification accuracy (97.9%). Overall ADHD symptom severity was evaluated both continuously and with participants classified into three symptom severity groups: a no symptom group (ASRS symptom score = 0), a medium symptom group (ASRS symptom score = 1–3), and a severe symptom group (ASRS symptom score = ≥ 4). The severe symptom group was considered to have an indication for a diagnosis of ADHD [38]. We chose to use three categories instead of two (indication for a diagnosis of ADHD (yes/no)), because this method provides a more dimensional view, i.e. it is possible to investigate whether an increased number of ADHD symptoms is associated with an increased prevalence of several sleep problems. This allows for a test for a trend, which is more sensitive than when we would have used a dichotomized variable. This may have implications for clinical practice. Current inattention or hyperactivity symptom severities were evaluated continuously.

2.2.2. Sleep disorders

2.2.2.1. Obstructive sleep apnea syndrome. Whereas the diagnosis of Obstructive Sleep Apnea Syndrome (OSAS) requires polysomnographic assessment [39], individuals with a high risk for OSAS can be identified with a sensitivity of 86% and specificity of 77% using the 10-item Berlin questionnaire [40]. The questionnaire comprises three sections with questions relating to snoring (five

items), daytime somnolence (four items), and the presence of hypertension or obesity (one item). For each section, there is a different scoring method. Participants were classified as a high risk for OSAS if two or more sections were scored positively.

2.2.2.2. RLS. The presence of RLS was assessed by evaluating the diagnostic RLS criteria as proposed by the International RLS study group: (1) urge to move the limbs with or without paresthesia either now (past month) or in the past; (2) symptoms begin or worsen during periods of rest; (3) symptoms are partially or totally relieved by movement at least as long as the activity continues; (4) symptoms are worse in the evening or night [41]. RLS is diagnosed if all criteria are met and symptoms cannot solely be accounted for as primary to another medical or a behavioral condition.

2.2.2.3. PLMD. Whereas the diagnosis of PLMD requires polysomnographic assessment [39], the Duke Structured Interview for Diagnosing Sleep Disorders (DSISD) [42] can be used to screen for symptoms suggestive of the diagnosis. The following questions were asked: (1) Have you been told you jerk your legs or twitch repeatedly during sleep either now (past month) or in the past? (2) Have you ever noticed that you jerk your legs or twitch repeatedly during sleep either now (past month) or in the past? (3) Have you experienced unexplained awakenings at a time when you were told you had these leg movements?, and (4) Have you experienced poor, unrefreshing sleep at a time when you were told you had these leg movements?. Individuals were considered to have PLMD symptoms if they had a positive response to either question 1 or 2 in combination with a positive response to either question 3 or 4. Inter-rater agreement of these questions of the DSISD was moderate (spearman correlation coefficient 0.57) [42].

2.2.2.4. Narcolepsy. Whereas the diagnosis of narcolepsy requires polysomnographic assessment and a multiple sleep latency test [39], the five-item Swiss Narcolepsy Scale (SNS) [43] can be used to screen for symptoms suggestive of the diagnosis. The five items were rated on a five-point Likert scale ranging from 1 (never) to 5 (almost always). A score based on these five items was calculated by using an equation ($6 \times \text{item 1} + 9 \times \text{item 2} - 5 \times \text{item 3} - 11 \times \text{item 4} - 13 \times \text{item 5} + 20$) with a result smaller than zero being suggestive of narcolepsy. The SNS has a high sensitivity (96%) and specificity (98%) for narcolepsy [43].

2.2.2.5. Insomnia. Probable ID was assessed using the validated seven-item Insomnia Severity Index (ISI) [44]. The items have a Likert-type format with responses ranging from 0 (not at all) to 4 (very severe/very much). A sum score of 15 or higher suggests clinical insomnia [44]. Using this cut-off point for the sum score, the sensitivity and specificity for insomnia in a community sample were 47.7% and 98.3%, respectively [45].

To further assess the presence of specific insomnia complaints, we used two items of the validated Pittsburgh Sleep Quality Index (PSQI) [46] to assess insomnia with predominant difficulties initiating sleep (DIS) and maintaining sleep (DMS). Participants were asked how often they had trouble sleeping in the past month because they could not get to sleep within 30 min (i.e.DIS) or because they woke up in the middle of the night or early morning (i.e.DMS). Answer options were: not, less than once a week, once or twice a week, and three or more times a week. Specific insomnia complaints were considered present if the answer was three or more times a week. In addition, one item of the circadian rhythm sleep disorders module of the DSISD [42] was used to specifically assess insomnia with predominant early morning awakening (EMA). Participants were asked if they wake up much earlier than others (yes/no). This item was only available in those

participants who endorsed having now or in the past a sleep schedule that was unusual or undesirable to them and different from the sleep-wake patterns of most other people they know ($N = 234$).

2.2.3. Sleep characteristics

2.2.3.1. Eveningness. Chronotype was assessed by using one item of the validated Munich Chronotype Questionnaire (MCTQ) [47], asking participants to classify their chronotype on a seven-point scale (1 = extreme morning chronotype to 7 = extreme evening chronotype). Responses were dichotomized into those who reported to be an extreme evening chronotype (rating of 7) versus those who provided a lower rating.

2.2.3.2. Short sleep duration. Short sleep was defined as a self-reported sleep duration ≤ 6 h on nights before free days. It was calculated from bedtime, sleep-onset latency time, and wake time (i.e. wake time minus bedtime minus sleep-onset latency time) as measured by the MCTQ [47].

2.2.4. Persistence of sleep disturbances

Persistence of sleep problems from childhood on were queried using a lifetime sleep history questionnaire that was developed specifically for the NSR [37]. The questionnaire includes statements about the presence of 32 sleep problems in different age ranges, amongst others. In a matrix format, participants indicated whether they remember experiencing these 32 sleep problems, up to their present age range, in the age ranges of 0–5, 6–12, 13–20, 21–30, 31–40, 41–50, 51–60, 60 + years. Of the 32 sleep problems, we selected the following five sleep problems: breathing pauses or snoring (as an indicator of OSAS), RLS, DIS, DMS, and EMA, since we also focused on the current presence of these problems. Since few participants reported these sleep problems at age 0–5 years, the age categories 0–5 and 6–12 years were combined in our analyses.

2.2.5. Covariates

Sociodemographic characteristics included gender, age, employment status, and household status (having a cohabitant partner and/or having cohabitant children). Use of nicotine (smoking cigarettes/tobacco, cigars, pipe and/or other tobacco in the last month), alcohol (the number of glasses of alcohol on a typical drinking day), and caffeine (frequency of consuming high-caffeine products: coffee or caffeinated energy drinks), as well as current use of medication (using medication in the last month prescribed by a doctor or specialist), were assessed. Alcohol and caffeine use were dichotomized as ≤ 2 or > 2 alcoholic beverages per day and < 4 or ≥ 4 cups of coffee or caffeinated energy drinks per day [48,49]. In addition, information about height, weight and neck circumference was assessed using a questionnaire specifically developed for the NSR: participants were asked what their height, weight and neck circumference were. To accurately measure the neck circumference, participants were instructed to place a tape measure snugly around their neck, just below the Adam's apple, and an instruction picture of this was shown. The presence of mood disorders, stress/anxiety problems, mental or behavioral problems caused by substance use, and psychotic disorders were also assessed by DSISD items: participants were asked whether a doctor or specialist had diagnosed them with psychological health problems in the last month.

2.3. Statistical analyses

Demographic and clinical characteristics were described for the full study sample ($N = 942$) as means and standard deviations, or

frequencies and percentages. First, we investigated whether increased current overall ADHD symptom severity was associated with higher probabilities of sleep problems. We compared prevalence rates of sleep disturbances in those with no, medium, and severe ADHD symptoms using the chi-square test for trend. For each sleep disturbance, a binary logistic regression analysis then evaluated whether the odds for each sleep disturbance increased with ADHD symptom severity, included as continuous independent variable. Potential confounders were determined by assessing Spearman's correlation or Phi coefficient between the variable and ADHD symptoms, and between the variable and the sleep problem of interest. Variables with a sufficiently significant association ($\alpha \leq 0.20$) [50] were added one by one to the models. Those variables that changed the odds ratio by $\geq 10\%$ were retained in the models. Second, we investigated whether current ADHD symptom-severity group was associated with a history of persistent sleep problems. In order to do so, we created a persistence variable for each sleep problem calculated as the number of age categories in which the participant indicated to experience the specific sleep problem divided by the total number of age categories based on the age of the participant. Since the persistence variables of all sleep problems were not normally distributed, we performed ordinal logistic regression analyses with ADHD symptom severity group as independent variable and data-driven persistence tertiles of the specific sleep problems as dependent variable, adjusting for age. We tested whether the assumption of proportional odds was met. If this was not the case, multinomial logistic regression analyses were performed with the same variables; this resulted in similar outcomes. Therefore, only results of ordinal logistic regression are presented. Finally, we examined whether current inattention or hyperactivity symptom severities were more particularly related to the probability of sleep disturbances. We performed binary logistic regression analyses with inattention and hyperactivity symptoms severities as the independent variables and the different sleep problems as dependent variables. A specific relationship between current inattention symptom severity and a sleep problem was considered to be present if the odds ratio of inattention symptom severity was outside the 95% confidence interval of hyperactivity symptom severity for that sleep problem, and vice versa. Covariates were selected in the same way as described for aim 1. Statistical analyses were performed using SPSS software (version 23.0, SPSS inc., Chicago, Illinois, USA). A p -value ≤ 0.05 was considered statistically significant.

3. Results

3.1. Sample characteristics

Table 1 presents sociodemographics, ADHD symptomatology, somatic health factors, current medication use, current psychiatric comorbidity, and sleep disturbances of the whole study sample ($N = 942$). The mean age was 48.5 ± 14.2 years and 72.8% were female. The prevalence rates of sleep problems were as follows: OSAS: 30.8%; RLS: 23.9%; PLMD: 6.2%; narcolepsy: 7.3%; ID: 22.4%; DIS: 16.6%; DMS: 39.0%; EMA: 12.7%; an extreme evening chronotype: 6.1%; sleep ≤ 6 h: 13.3%. In the NSR, with apparent oversampling of people suffering from sleep problems as compared to population-based studies, the prevalence of severe ADHD symptoms, i.e. an indication for a diagnosis of ADHD, was 20.0%. The high prevalence rates of sleep problems and severe ADHD symptoms generate a sample that is extremely suitable for our research aim.

Table 1
Sample characteristics ($N = 942$).

Sociodemographics	
Female, N (%)	686 (72.8)
Age in years, mean (SD)	48.5 (14.2)
Employed, N (%)	596 (63.3)
Household status	
Has a partner, N (%)	562 (59.7)
Has children, N (%)	157 (16.7)
ADHD symptom severity groups	
No ADHD symptoms, N (%)	189 (20.1)
Medium ADHD symptoms, N (%)	565 (60.0)
Severe ADHD symptoms, N (%)	188 (20.0)
Somatic health factors	
Currently smokes ($N = 890$), N (%)	117 (12.4)
Alcohol beverages > 2 per day ($N = 891$), N (%)	193 (20.5)
Caffeine use ≥ 4 times/day ($N = 890$), N (%)	190 (20.2)
BMI, mean (SD)	24.7 (4.3)
Neck circumference ($N = 878$), mean (SD)	36.1 (4.3)
Current use of medication ($N = 891$)	
Psychostimulants, N (%)	12 (1.3)
Anti-depressants, N (%)	87 (9.2)
Benzodiazepines, N (%)	81 (8.6)
Other sleep medication, N (%)	74 (7.9)
Anti-Parkinson medication, N (%)	8 (0.8)
Anti-epileptic medication, N (%)	15 (1.6)
Antipsychotics, N (%)	11 (1.2)
Current psychiatric comorbidity ($N = 895$)	
Mood disorders, N (%)	75 (8.0)
Stress/anxiety problems, N (%)	76 (8.1)
Mental or behavioral problems caused by substance use, N (%)	7 (0.7)
Psychotic disorder, N (%)	3 (0.3)
Sleep disorders	
OSAS, N (%)	290 (30.8)
RLS, N (%)	225 (23.9)
PLMD, N (%)	58 (6.2)
Narcolepsy, N (%)	69 (7.3)
Insomnia Disorder ($N = 747$), N (%)	211 (22.4)
DIS ($N = 748$), N (%)	156 (16.6)
DMS ($N = 748$), N (%)	367 (39.0)
EMA, N (%)	120 (12.7)
Sleep characteristics	
Extreme evening chronotype ($N = 663$), N (%)	57 (6.1)
Sleep ≤ 6 h ($N = 877$), N (%)	125 (13.3)

ADHD, attention deficit hyperactivity disorder; BMI, body mass index; DIS, difficulties initiating sleep; DMS, difficulties maintaining sleep; EMA, early morning awakening; OSAS, obstructive sleep apnea disorder; PLMD, periodic limb movement disorder; RLS, restless legs syndrome; SD, standard deviation.

3.2. Association between current overall ADHD symptom severity and the current presence of sleep problems

Fig. 1 presents prevalences of sleep disturbances in individuals with no, medium, and severe ADHD symptoms. Chi-squared tests for trend showed a positive association between ADHD symptom-severity category and the prevalence of probable OSAS ($p < 0.001$), RLS ($p = 0.005$), PLMD ($p = 0.001$), ID ($p < 0.001$), ID with predominant DIS ($p = 0.013$) and DMS ($p = 0.006$). The ADHD symptom-severity category showed no association with the prevalence of probable narcolepsy ($p = 0.171$) or ID with predominant EMA ($p = 0.347$). A positive association was also found between ADHD symptom-severity category and the prevalence of an extreme evening chronotype ($p = 0.009$) but not with short sleep ($p = 0.913$).

The left part of Table 2 shows the results of binary logistic regression analyses evaluating how the probabilities of sleep disturbances changed with the overall severity of ADHD symptoms. Although some covariates were associated with ADHD symptom severity and the sleep problem of interest ($\alpha \leq 0.20$), those

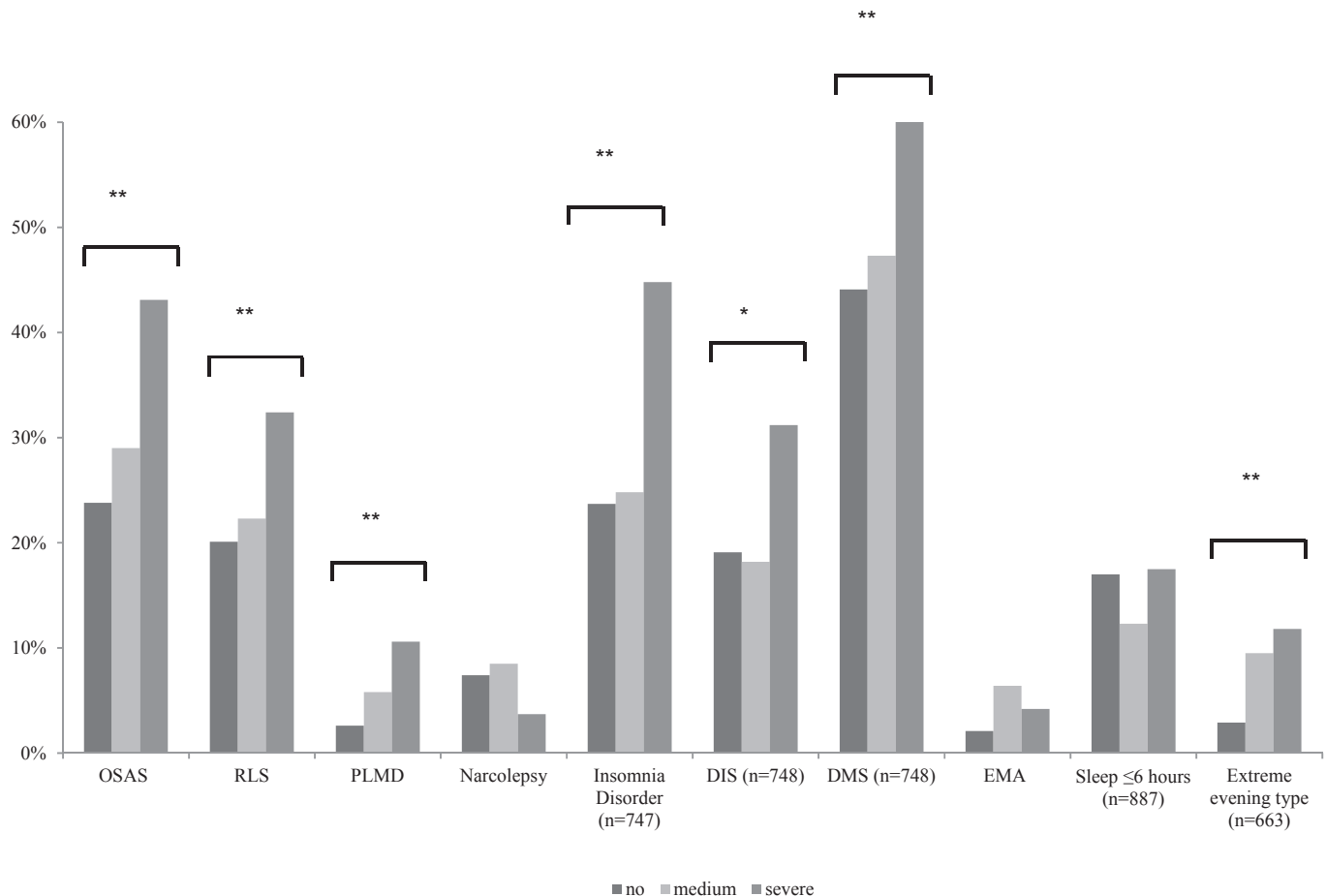


Fig. 1. Percentage of subjects with sleep disturbances in individuals with no, medium, and severe ADHD symptoms ($N = 942$). DIS, difficulties initiating sleep; DMS, difficulties maintaining sleep; EMA, early morning awakening; OSAS, obstructive sleep apnea syndrome; PLMD, periodic limb movement disorder; RLS, restless legs syndrome. Significance levels: * $p \leq 0.05$, ** $p \leq 0.01$.

Table 2
Multiple logistic regression analyses of continuous attention deficit hyperactivity disorder symptom severities as independent variables (columns) and the probability of sleep disturbances as dependent variables (rows) in separate models.

Dependent variables	Independent variable		Independent variables			
	ADHD symptoms overall		Inattention symptoms		Hyperactivity symptoms	
	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>
Sleep disorders						
OSAS ($N = 942$)	1.22 (1.12–1.33)	<0.001	1.17 (1.05–1.30)	0.004	1.39 (1.13–1.70)	0.001
RLS ($N = 942$)	1.14 (1.04–1.25)	0.007	1.07 (0.95–1.20)	0.285	1.38 (1.11–1.70)	0.003
PLMD ($N = 942$)	1.32 (1.12–1.55)	0.001	1.16 (0.95–1.43)	0.149	1.81 (1.28–2.56)	0.001
Narcolepsy ($N = 942$)	0.93 (0.79–1.09)	0.342	0.93 (0.76–1.13)	0.446	0.92 (0.63–1.35)	0.668
Insomnia disorder ($N = 747$)	1.25 (1.12–1.38)	<0.001	1.13 (0.99–1.28)	0.063	1.67 (1.33–2.09)	<0.001
DIS ($N = 748$)	1.18 (1.06–1.32)	0.004	1.12 (0.98–1.29)	0.101	1.37 (1.07–1.76)	0.013
DMS ($N = 748$)	1.13 (1.03–1.24)	0.013	1.05 (0.93–1.17)	0.441	1.41 (1.13–1.75)	0.002
EMA ($N = 942$)	0.98 (0.84–1.15)	0.842	1.00 (0.82–1.21)	0.979	0.95 (0.67–1.36)	0.775
Sleep characteristics						
Extreme evening type ($N = 663$)	1.27 (1.07–1.50)	0.005	1.42 (1.15–1.75)	0.001	0.93 (0.62–1.40)	0.728
Sleep ≤ 6 h ($N = 877$)	1.01 (0.90–1.14)	0.867	0.91 (0.78–1.05)	0.191	1.38 (1.06–1.80)	0.018

ADHD, attention deficit hyperactivity disorder; CI, confidence interval; DIS, difficulties initiating sleep; DMS, difficulties maintaining sleep; EMA, early morning awakening; OR, odds ratio; OSAS, obstructive sleep apnea syndrome; PLMD, periodic limb movement disorder; RLS, restless legs syndrome. Bold *p*-values are significant with $\alpha \leq 0.05$.

variables did not change the odds ratio by $\geq 10\%$ when added one by one to the models, and were therefore not retained. The results of the logistic regression analyses yielded the same significant associations between overall ADHD symptom severity and sleep problems as the analyses presented in Fig. 1.

3.3. Association between current ADHD symptom-severity group and a history of persistent sleep problems

Table 3 describes the results of ordinal logistic regression analyses with data-driven persistence tertiles of the sleep disturbances

Table 3

Ordinal logistic regression analyses of ADHD symptom severity groups as independent variables and the data-driven persistence tertiles of sleep disturbances as dependent variables in separate models, controlling for age ($N = 598$).

	Medium ADHD symptoms ^a ($N = 354$)		Severe ADHD symptoms ^b ($N = 119$)	
	OR (95% CI)	<i>p</i>	OR (95% CI)	<i>p</i>
Snoring or breathing pauses (as indicator of OSAS) (Tertile 1: $N = 317$; Tertile 2: $N = 79$; Tertile 3: $N = 202$)	1.39 (0.92–2.09)	0.119	1.50 (1.01–2.23)	0.044
RLS (Tertile 1: $N = 309$; Tertile 2: $N = 88$; Tertile 3: $N = 201$)	1.37 (0.92–2.06)	0.123	2.14 (1.38–2.97)	<0.001
DIS (Tertile 1: $N = 206$; Tertile 2: $N = 188$; Tertile 3: $N = 203$)	1.19 (0.81–1.74)	0.373	1.54 (1.05–2.25)	0.027
DMS (Tertile 1: $N = 180$; Tertile 2: $N = 223$; Tertile 3: $N = 193$)	1.01 (0.70–1.48)	0.930	2.42 (1.65–3.56)	<0.001
EMA (Tertile 1: $N = 191$; Tertile 2: $N = 222$; Tertile 3: $N = 185$)	1.00 (0.68–1.45)	0.984	1.55 (1.07–2.26)	0.022

DIS, difficulties initiating sleep; DMS, difficulties maintaining sleep; EMA, early morning awakening; OSAS, obstructive sleep apnea syndrome; RLS, restless legs syndrome. Bold *p*-values are significant with $\alpha \leq 0.05$.

^a No ADHD symptoms ($N = 125$) as reference category.

^b No and medium ADHD symptoms together as reference categories.

as the outcome. As compared to currently no ADHD symptoms, currently medium ADHD symptoms were not associated with the history of persistence of any of the sleep disturbances. Compared to currently no and medium ADHD symptoms, currently severe ADHD symptoms were associated with a history of persistent OSAS (OR = 1.50, $p = 0.044$), RLS (OR = 2.14, $p < 0.001$), ID with predominant DIS (OR = 1.54, $p = 0.027$), DMS (OR = 2.42, $p < 0.001$), and EMA (OR = 1.55, $p = 0.022$), even after correction for age.

3.4. Association between current inattention or hyperactivity symptom severities and the current presence of sleep problems

The right part of Table 2 shows the results of binary logistic regression analyses associating inattention and hyperactivity symptom severities with the probability of different sleep problems. Although some covariates were associated with ADHD symptoms and the sleep problem of interest ($\alpha \leq 0.20$), those variables did not change the odds ratio by $\geq 10\%$ when added one by one to the models, and were therefore not retained. Only the severity of hyperactivity symptoms was related to probable RLS (OR = 1.38, $p = 0.003$), PLMD (OR = 1.81, $p = 0.001$), ID (OR = 1.67, $p < 0.001$), ID with predominant DIS (OR = 1.37, $p = 0.013$), DMS (OR = 1.41, $p = 0.002$), and to the sleep characteristic short sleep (OR = 1.38, $p = 0.018$; all odds ratios of hyperactivity symptom severities were outside the 95% confidence interval of inattention symptom severities for these sleep problems). Inattention symptom severity was only related to the probability of being an extreme evening chronotype (OR = 1.42, $p = 0.001$).

4. Discussion

We examined whether current overall ADHD, inattention, or hyperactivity symptom severities were associated with the current presence and persistent history of sleep problems in adult participants of the NSR. We found that ADHD severity, especially the severity of hyperactivity, was associated with both the current presence and persistent history of sleep problems.

Our first finding was that the severity of current overall ADHD symptoms was associated with the prevalence of probable OSAS, RLS, PLMD, ID with predominant DIS, and DMS. The severity of current overall ADHD symptoms showed no association with the prevalence of probable narcolepsy or ID with predominant EMA. Furthermore, current overall ADHD symptom severity was also associated with an extreme evening chronotype but not with short sleep. The observed prevalence rates of the sleep disturbances

varied from 10.6% (for PLMD) to 60.3% (ID with predominant DMS) among those with an indication for an ADHD diagnosis (i.e. severe ADHD symptoms). Although comparison of these prevalences with prevalences from other research is difficult due to variability in the studied samples and methodology, our prevalences of an extreme evening chronotype [30] and ID [51] were quite consistent with those from previous studies. Our prevalences of probable OSAS [52,53], RLS [19,54], ID with predominant DIS [10,30,33,55] and DMS [33,56] were within the range of other studies. Regarding PLMD [56], narcolepsy [57], ID with predominant EMA [33], and sleep ≤ 6 h [58], we observed lower prevalence rates as compared to other studies.

The positive associations between current overall ADHD symptom severity and most sleep problems were confirmed in regression analyses, corroborating many other studies (reviewed in Yoon et al. [8]). Nevertheless, there are studies conflicting with our results, that have shown an association between ADHD symptoms and narcolepsy [59,60], ID with predominant EMA [61], or short sleep (e.g. Ref. [62]), as well as studies among children or adults that have observed no relationships between ADHD symptoms and one or more of the sleep problems that we found (e.g. Refs. [57,63]). Discordance between our results and those of others may be due to differences in sample size, heterogeneity in the study populations (e.g. children vs adults; clinical vs non-clinical), or in the assessment of sleep problems (e.g. on work days vs on free days; objectively measured vs self-reported).

Our second finding was that the group with the most severe current ADHD symptoms was more likely to have a history of persistent OSAS, RLS, and ID with predominant DIS, DMS, and EMA. Our findings coincide with earlier reports among children and adolescents [11], although they stand in contrast with one study [64] with a follow-up period of 12 months, indicating that sleep problems in children with ADHD were commonly transient. This discrepant finding with the latter study could be due to differences in the study population (i.e. children vs adults in this study) or in the assessment intervals of sleep disturbances (i.e. 6-monthly intervals vs multi-annual intervals in this study). We extended these previous studies by measuring the persistent history of sleep problems in adults. Remarkably, we observed an association between current severe ADHD symptoms and a history of persistent ID with predominant EMA. This contradicts our finding in the analysis associating current overall ADHD symptom severity with the current presence of ID with predominant EMA, in which we did not observe an association between them. The discrepant findings may be due to a different formulation of the

questions used in the two analyses; in the question used in the analysis associating current overall ADHD symptom severity with the current presence of ID with predominant EMA, participants were asked if they woke up much earlier than others do, while in the question used in the analysis associating current overall ADHD symptom severity with the persistent history of ID with predominant EMA, participants were asked if they woke up earlier than preferred in the morning. Nevertheless, the question used in the analysis assessing the current presence of ID predominant EMA was filled out only by a selected group (i.e. only by those who endorsed having a sleep schedule that was undesirable to them and different from that of most other people they know). Hence, further studies are required to examine the current presence and persistent history of ID with predominant EMA among adults with ADHD symptoms. If ADHD is not only associated with ID with predominant DIS and DMS, but also with predominant EMA, then ADHD could be viewed as an insomnia-related disorder rather than as a disorder related to a delayed sleep phase [10], which is characterized by DIS only [6].

Our third finding was that the severity of symptoms of hyperactivity, but not of inattention, was specifically associated with probable RLS, PLMD, ID with DIS or DMS, and short sleep. Inattention symptom severity was only related to the probability of being an extreme evening chronotype. These findings are in line with previous research showing associations between only inattention or hyperactivity symptom severities and the specific sleep problems (e.g. Refs. [10,17,19,21,29,32]). However, it contradicts other studies (e.g. Refs. [18,34]). Reasons for inconsistencies with previous results are similar to those mentioned above.

There are several possible explanations for the interrelatedness of ADHD symptoms and sleep problems. First, sleep problems can resemble or aggravate features of ADHD: RLS and PLMD may resemble or aggravate hyperactivity [9]. Also, OSAS can worsen ADHD symptom severity due to sleep disruption, which may cause alterations in the prefrontal cortex, which in turn may lead to difficulty in maintaining attention and controlling hyperactivity during daytime [5]. Vice versa, ADHD symptoms, such as the inattention symptom 'forgetting time', may predispose to late bedtimes, and therefore result in being, or considered to be, an evening chronotype [13]. Furthermore, hyperactivity at night, as shown by actigraphy in ADHD patients, may lead to DMS and short sleep [65]. Second, ADHD is associated with obesity [66], which in turn is related to OSAS [67]. Third, disruptions in dopamine and melatonin may explain relationships between ADHD symptoms and some sleep problems: dopamine deficiency is involved in the pathogenesis of RLS, PLMD, and ADHD, suggesting common biological mechanisms [68]. This is supported by the efficacy of dopaminergic agents in the (combined) treatment of RLS, PLMD, and ADHD [5]. A delayed pattern of melatonin secretion has been shown in children and adults with ADHD with DIS [10,69,70]. Finally, there may be a genetic basis for the association between ADHD and sleep problems [9]. For example, polymorphisms in clock genes have been related to both ADHD and evening chronotype [71].

In conclusion, the results seem to suggest that ADHD symptom severities are associated with the history and current presence of several sleep problems, giving indications of the type of sleep problems that are co-occurring, causing, or the result of the ADHD symptoms. This implies that adults that screen positively for ADHD using the ASRS may profit from evaluation and treatment of sleep problems in order to enhance quality of life [1] and prevent downstream disorders, like obesity, diabetes, cardiovascular disease, and cancer [2–4]. Also, treatment of the related sleep problem may reduce the severity of ADHD symptoms [9]. The treatment should consist of behavior modification, pharmacological

interventions, and/or specific treatment methods depending on the sleep problem type (reviewed in Ref. [72]), such as continuous positive airway pressure (CPAP) in case of OSAS [73].

The findings of this study should be interpreted in the light of some limitations. First, ADHD symptom severity was based on self-report instead of clinical ratings. The observed prevalence of severe ADHD symptoms, i.e. an indication for a diagnosis of ADHD (20.0%), is much higher in comparison with a previously reported adult prevalence estimate of 5.0% in the Netherlands [74]. This is explained by studying ADHD symptoms among sleep registry participants rather than in the general population, which has led to selection bias; poor sleepers participated more often than good sleepers as shown by the greater prevalence of sleep problems in the whole study sample as compared to the general Dutch population [75]. These poor sleepers may well constitute a high-risk group for ADHD symptoms. Therefore, this sample was extremely suitable for our research aim. Furthermore, the time of onset and ADHD symptoms in childhood were not assessed, which are DSM-5 criteria that should be assessed for a clinical ADHD diagnosis. Second, we only used self-report measures of sleep problems and did not include objective measures, such as actigraphy, dim light melatonin onset measurements, or polysomnography. Third, and in line with the previous limitation, we only used single items from the PSIQ and MCTQ in order to assess specific insomnia complaints and eveningness, respectively. Moreover, breathing pauses or snoring are only very rough indicators of OSAS. Fourth, the number of statistical comparisons carries with it some risk of a high experiment-wise error rate. This could cause type I (false positive) and type II (false negative) errors. Fifth, we used retrospective rather than prospective data to examine the association between overall ADHD symptom severity and the history of persistence of sleep problems time. This may result in an underestimation or overestimation of the persistence of sleep problems. Also, ADHD symptom severity was only measured once. Further prospective studies with repeated measurement of both ADHD symptom severity and sleep problems are warranted to examine the direction of causality between these factors.

In summary, the results seem to suggest that ADHD severity, especially the severity of hyperactivity, is associated with the current presence and persistent history of sleep problems. This stresses the importance of evaluating and treating these sleep problems among those with ADHD from childhood on, in order to prevent the development of serious health consequences in the long term [2–4]. Prospective longitudinal studies are needed to examine whether treatment of sleep problems ameliorates the long-term health consequences of chronic sleep problems among ADHD patients.

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Conflicts of interest

AJB has been a speaker for Lundbeck and Eli Lilly. For the remaining authors, no conflicts of interest were declared.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: <https://doi.org/10.1016/j.sleep.2017.09.027>.

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