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Sleep and daytime functioning in autistic teenagers: A psychological network approach

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A R T I C L E I N F O

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A B S T R A C T

Background: Although sleep problems in autistic teenagers are associated with impaired daytime functioning, it remains unclear how sleep and daytime functioning are related.
Method: We used a network approach to disentangle patterns between sleep, sleep hygiene, and daytime functioning. Over a three-week period, 31 autistic teenagers answered daily questions about sleep and daytime functioning. Sleep tracker data were collected from 14 of the teenagers. We preregistered the analysis plan for this study at AsPredicted (#34594; https://aspredicted.org/blind.php?x = 3c4t65).
Results: Perceived sleep quality seemed to be the most important sleep variable in relation to daytime functioning (self/parent/teacher reports). We also found that sleep onset latency, total sleep time, and wake time after sleep onset were related to daytime functioning, but mostly indirectly through perceived sleep quality.
Conclusion: These findings are important for developing sleep interventions because perceived sleep quality would be a logical target for increasing the likelihood of actually improving daytime functioning.

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1. Introduction

Sleep problems are common among autistic[1] teenagers: 40% to 80% experience them (Cortesi et al., 2010), compared to 16% to 31% of their peers who do not have an autism spectrum disorder diagnosis (ASD) (Calhoun et al., 2014). Autistic teenagers have a shorter sleep duration and longer nighttime awakenings, and they take longer to fall asleep than teenagers without ASD (Tse et al., 2020). Sleep problems are associated with disturbed daytime functioning in teenagers without ASD (Gregory & Sadeh, 2012). However, as the nature (Tse et al., 2020) and underlying causes (Cortesi et al., 2010) of autistic teenagers' sleep problems seem to differ from those without ASD, the results of studies performed on typical teenagers cannot automatically be applied to autistic teenagers. In addition, though many studies have investigated the relationship between sleep, sleep hygiene, and daytime functioning based on bivariate correlations, correlations cannot disentangle patterns between multiple variables. Thus, we will use a network approach to investigate the relationship between aspects of autistic teenagers' sleep, sleep hygiene, and daytime functioning to learn more about the patterns between them.

Sleep and factors that influence sleep form a complex pattern of direct and indirect relationships between variables (Goelema et al., 2018). Identifying these patterns would provide relevant information about which variables stimulate or inhibit others (Costantini et al., 2015). Besides that network analysis can disentangle patterns between multiple variables which could reveal indirect relationships between variables, it could also identify central or influential variables in the network and uncover clusters of highly interconnected variables which could provide insight into clusters within the data that might not be evident through bivariate correlations. For example, one could find that caffeine intake and electronic device use are associated with a longer sleep onset latency. To shorten that latency, one might prefer an intervention that addresses caffeine intake because this seems easier than addressing electronic device use. However, the pattern of variables might show that electronic device use is directly related to sleep onset latency while caffeine use is indirectly related through electronic device use. Thus, addressing electronic device use could be more effective in improving sleep onset latency than addressing caffeine intake because of the direct relationship.

Here, identifying the network structure between variables could offer new insights into the associations between aspects of sleep, sleep hygiene, and daytime functioning. To validate the complexity of interacting variables (Borsboom & Cramer, 2013) and learn more about interventions that may be effective, we will use network analyses to identify the network structure between aspects of sleep, sleep hygiene, and daytime functioning.

Several aspects should be considered when unraveling the relationship between sleep, sleep hygiene, and daytime functioning. First, sleep can be measured in different ways: it can be self-reported or reported by the caregiver (sleep diaries and questionnaires) or measured objectively (actigraphy and polysomnography). Self- or caregiver reports and objectively measured sleep could reveal different outcomes regarding daytime functioning (Richdale et al., 2014).

Second, there are often discrepancies between different informants' reports of a person's daytime functioning (Youngstrom et al., 2001). For example, different contexts could reveal a different presentation of one's functioning, or informants might have different perspectives on the same functioning. Using these different perspectives could reveal relevant information that contributes to creating a comprehensive picture of a person's daytime functioning (Achenbach, 2006).

To address these issues, we investigated the relationship between sleep, sleep hygiene, and daytime functioning using (i) self-reported and objective measures of sleep, and (ii) multiple informants' perceptions of the teenagers' daytime functioning. We used a limited age range and focused on teenagers specifically because age-related changes in sleep patterns occur from childhood to adolescence (Moore & Meltzer, 2008).

We included four sleep variables: sleep onset latency (the time between trying to sleep and falling asleep), total sleep time (total amount of sleep during the night), wake time after sleep onset (total time of wakefulness after sleep onset), and perceived sleep quality (how well someone slept, their feeling of being rested at waking, and ease of waking). We chose these four sleep variables based on Buysse's (2014) recommendation that they should be included in sleep research because of their association with health outcomes.

For daytime functioning, we focused on three variables: daytime sleepiness, mood, and concentration problems (Buysse et al., 2006). The choice of these variables was based on research that showed that daytime sleepiness is a major consequence of disturbed sleep (Buysse et al., 2006; Dahl & Lewin, 2002). Moreover, mood and concentration are other aspects of daytime functioning that are affected by sleep problems (Buysse et al., 2006; Dahl & Lewin, 2002).

Since good sleep hygiene contributes to the quality of sleep (Driver & Taylor, 2000; LeBourgeois et al., 2005), we also included aspects of sleep hygiene: caffeine intake, gaming (engaged in computer games), (intensive) physical exercise and, electronic device use (e.g., reading websites, searching for information online, using WhatsApp). These aspects may play a role in predisposing or perpetuating sleep problems. Therefore, measuring these aspects can provide valuable insights (Driver & Taylor, 2000; LeBourgeois et al., 2005). Although stress and mental effort are not traditionally mentioned as aspects of sleep hygiene, we included those variables because of their impact on sleep (Åkerstedt et al., 2012; Irish et al., 2015). Moreover, including these aspects is relevant because autistic individuals perceive higher levels of stress than individuals without ASD (Hirvikoski & Blomqvist, 2015).

Our research question is: To what extent is there a relationship between characteristics of sleep (sleep onset latency, total sleep time, wake time after sleep onset [objectively measured and self-reported], perceived sleep quality, and sleep hygiene) and daytime functioning (mood, concentration, daytime sleepiness) in autistic teenagers from the perspective of different groups of informants (teenagers, parents, teachers)?

[1] There is no clear agreement about how to describe autism (Buijsman et al., 2022). In this paper, we use identity-first language instead of person-first language with no intention to disregard the various terms used to describe autism.

2. Methods

2.1. Participants

We recruited teenagers aged 12 to 18 from four special education schools, covering pre-vocational, higher general secondary, and pre-university education levels. The participating schools' teachers supported the study through various activities like parent newsletters, class visits, and introductory meetings with both teenagers and parents. Teenagers met the inclusion criteria if: (a) diagnosed with an autism spectrum disorder according to DSM-IV (American Psychiatric Association, 2000) or DSM-5 (American Psychiatric Association, 2013) criteria by a psychiatrist or psychologist, (b) reported sleep issues by either teenagers or parents, (c) were medication-free or on a stable dose during the study, and (d) did not have an intellectual disability, determined by a school-estimated IQ of 70 or higher (American Psychiatric Association, 2021). Initially, 42 participants were screened. After exclusions (5 not having ASD and 5 declined to participate), 32 autistic teenagers (76%) along with their teachers and 27 parents participated (5 teenagers participated without a parent).

Written consent was obtained from all participants (teenagers, teachers, and parents), and for teenagers aged 12 to 15, permission was obtained from both parents or legal representatives. Due to insufficient participants in the initial phase (January–February 2019; 15 participants), data were collected in two phases, including an additional phase (November–December 2019; 17 participants).

This study received approval from the Ethics Review Board of the Faculty of Social and Behavioral Sciences at the University of Amsterdam (2018-EXT-9650) and the Internal Committee Biomedical Experiments of Philips Research (ICBE-2–26243).

2.2. Procedure

This study used a repeated measures design spanning three weeks. Every morning, teenagers filled out a web-based sleep diary, while questions regarding their daytime functioning were answered at day's end (see Fig. 1). Both teachers and parents provided their perspective on the teenagers' daytime functioning using the same daily questions.

Alongside the daily assessments, teenagers completed the Insomnia Severity Index (ISI) (Bastien et al., 2001) at the study's commencement to gauge the severity of their sleep issues. Parents completed the Social Responsiveness Scale-Second Edition (SRS-2) (Roeyers et al., 2015) at the beginning of the research period to evaluate their teenager's social behavior deficits. Furthermore, a sleep tracker was utilized to monitor sleep in a randomly selected subgroup of teenagers throughout the study period (N = 16 due to limited availability of devices).

2.3. Measures

2.3.1. Self-reported sleep

Self-reported sleep was assessed using the Consensus Sleep Diary (Carney et al., 2012), recognized for its validity and usefulness in measuring self-reported sleep (Maich et al., 2018). Sleep diaries are widely used in research involving autistic teenagers (e.g., Loring et al., 2016; Papadopoulos et al., 2019). To prevent retrospective completion of multiple sleep diary entries, teenagers were instructed to complete the diary for a specific day only until midnight, ideally right after waking up.

The sleep diary inquired about bedtime, sleep onset time, nighttime awakenings, and wake time. Responses were used to compute various sleep parameters such as sleep onset latency (the time taken to fall asleep), wake time after sleep onset (total time awake between sleep onset and wake time), and total sleep time (duration from sleep onset to wake time minus wake time after sleep onset). Additionally, teenagers rated their sleep quality, feeling of rest upon waking, and ease of waking (rated on a scale of 1–10, with 1 being very bad and 10 being very good). The mean of these ratings was calculated to indicate their perceived sleep quality.

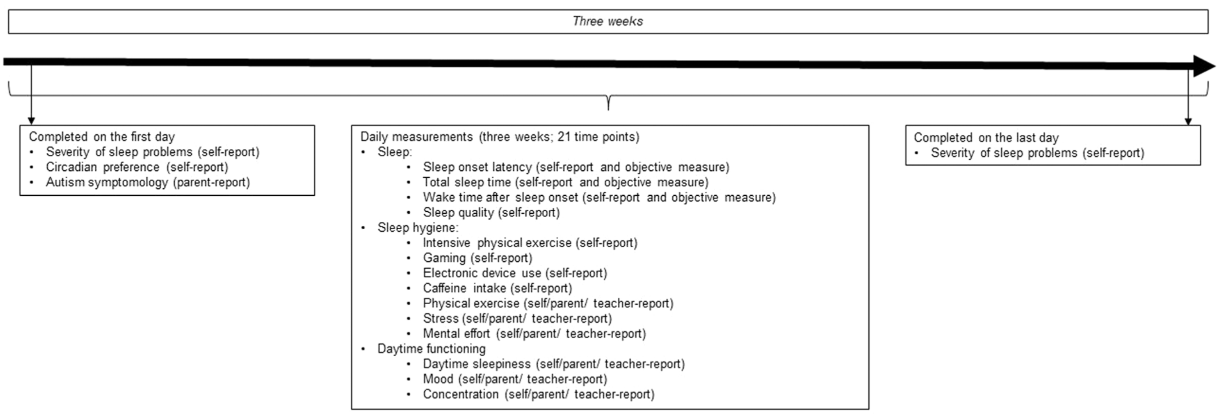

Fig. 1. Overview of study design.

2.4. Sleep hygiene

The teenagers were asked about sleep hygiene at two moment. Firstly, within the sleep diary, they were asked about various activities that might impact their sleep. They reported their activities from the previous night, including intense physical exercise (defined as activities such as soccer, tennis, fitness, or running that induce short-sentence talking and quickened breathing), gaming (explained as computer games, multiplayer or single-player, online or offline), and use of electronic devices (reading websites, online searches, or using WhatsApp). Additionally, they reported their consumption of beverages (cola, coffee, energy drink, tea excluding rooibos or herbal tea, and hot chocolate) to determine caffeine intake. If they engaged in any of these activities or consumed these drinks, they indicated the time of occurrence.

Secondly, each day's end, teenagers rated their levels of physical exercise, stress (defined as tension or pressure), and mental effort (described as the extent of focus required for tasks) on a scale of 1 to 10 (1 =very little to 10 =very much). These questions were developed collaboratively with a sleep expert experienced in questioning autistic teenagers (clinical neurologist SP). The teenagers could respond anytime between 2:00 p.m. and midnight, preferably in the early evening (before 8:00 p.m.) to avoid disrupting bedtime routines.

Moreover, one parent and one teacher of each teenager also provided their perspectives on the teenager's physical exercise, stress, and mental effort for the day. It concerns their own assessment for the period they have seen the teenagers on that particular day. Parents answered within the same timeframe as the teenagers, while teachers, who typically saw their students once a day (possibly in the early morning), were allowed flexibility in responding at any time after their interaction with the teenager.

2.5. Objective sleep

Objective sleep variables were collected using a wrist-worn device combining reflective plethysmography and accelerometry known as a sleep tracker (prototype developed by Philips Research). This device was designed to capture reflective, green-spectrum photoplethysmography data from the skin at a rate of 64 Hz, along with acceleration data from an internal 3D accelerometer at 128 Hz. These data were transformed into inter-beat intervals (the time between consecutive pulses) for sleep analysis.

A validated algorithm (Wulterkens et al., 2021) derived from a study involving adults, teenagers, and children with diverse sleep disorders, utilizing reference polysomnography, was used to compute sleep metrics. Sleep onset latency, total sleep time, and wake time after sleep onset were calculated based on this algorithm. Studies indicated minor biases in these measures; however, as wake time after sleep onset increased, the underestimation of wake time also increased. Similarly, overestimation of sleep onset latency rose with increased sleep latency (Wulterkens et al., 2021).

Teenagers were instructed to wear the sleep tracker when going to bed and remove it upon waking. They initiated and concluded measurements by pressing a button on the device. Additionally, they were asked to press a button when they intended to sleep to mark the onset of sleep latency. Parents were not tasked with monitoring whether their child pressed the sleep intent button to avoid disturbing their child's sleep.

2.6. Daytime functioning

Teenagers were presented the following question: 'How was your day today? Give it a grade.' The teenagers then saw the following aspects of daytime functioning and rated them on a scale from 1 to 10: daytime sleepiness (1 =*not at all sleepy* to 10 =*very sleepy*), concentration, and mood (1 =*very bad* to 10 =*very good*). These assessments were to be completed between 2:00 p.m. and midnight, preferably in the early evening (before 8:00 p.m.).

Additionally, one parent and one teacher per teenager were asked to provide their perspectives on the teenager's daytime functioning based on their interactions on that specific day. It concerns their own assessment for the period they have seen the teenagers on that particular day. Parents were requested to respond within the same timeframe as the teenagers, while teachers, who typically had limited daily interactions with students, could answer at any time after their encounter with the teenager.

2.7. Severity of sleep problems

The study utilized the Insomnia Severity Index (ISI) (Bastien et al., 2001) to gauge the severity of insomnia and its impacts within the preceding two weeks. This index comprises seven items assessing various aspects such as perceived severity of sleep onset problems, sleep maintenance issues, early awakenings, satisfaction with sleep patterns, interference with daily functioning, consequences of disturbed sleep for others, and concerns related to disrupted sleep. Each item was rated on a five-point Likert scale (ranging from 0 = no problem to 4 = very severe problem).

Although initially developed for adults, the ISI has demonstrated reliability (α = .83) and validity (significant correlations with external validators) when applied to adolescent populations (Chung et al., 2011). Moreover, it has been successfully used among autistic teenagers in the Netherlands Autism Register (https://nar.vu.nl/english/what-is-the-nar). The total score obtained by summing all items was utilized in the analyses.

2.8. Severity of autism symptomatology

The study employed the Social Responsiveness Scale-Second Edition (SRS-2), designed for 4- to 18-year-olds, to assess deficits in social behavior. Comprising 65 items, the SRS-2 encompasses two subscales: social communication and interaction, and stereotype behavior and interests (Roeyers et al., 2015). Respondents rated each item using a four-point Likert scale (ranging from 1 =not true to 4 =almost always true).

In a Dutch population, the SRS-2 has demonstrated good reliability (ranging from $\alpha = .93$ to $\alpha = .95$) and validity (with a correlation of.63 between SRS-2 and ADI-R) (Roeyers et al., 2015). One parent of each participating teenager completed the questionnaire, and the sum score of all items was used in subsequent analyses.

2.9. Statistical analyses

In this study, we followed a preregistered analysis plan documented at AsPredicted (#34594; https://aspredicted.org/blind.php?x = 3c4t65), a platform ensuring research plan transparency and minimizing biases. Our primary focus was on examining the relationship between sleep aspects (both objectively measured and self-reported, including sleep hygiene) and daytime functioning among autistic teenagers, as perceived by different informants (teenagers, parents, teachers). To reduce complexity and increase comprehensibility, we chose to focus on the group findings and to exclude the preregistered individual participant analyses.

Using a network approach, we aimed to investigate associations between sleep and daytime functioning. Networks entail nodes (variables) connected by edges (associations between variables). Positive associations were represented by blue edges, while negative associations were represented by red edges, with the edge thickness indicating association strength (Costantini et al., 2015).

To determine the number of sleep variables used in the network analysis, we calculated the correlations between (i) objectively measured (i.e., through the sleep tracker) sleep onset latency and self-reported (i.e., in the sleep diary) sleep onset latency, (ii) objectively measured total sleep time and self-reported total sleep time, and (iii) objectively measured wake time after sleep onset and self-reported wake time after sleep onset. To calculate these correlations we used data from the teenagers who both wore the sleep tracker and completed the sleep diary. If the observations of objectively measured and self-reported sleep onset latency, total sleep time and wake time after sleep onset correlated highly ($\geq$.80) (Field, 2009), the mean of the objective and self-reported observation was used in the subsequent analyses. If the correlation was $<$ .80 for that specific relationship, both the objectively measured and self-reported observations of sleep were used. Our analyses included self-reported data from 31 teenagers and sleep tracker data from 14 teenagers due to missing or unusable data from some participants.

Instead of computing three networks (for teenagers, parents, and teachers separately) in which we were planning to include both self-reported and objectively measured sleep, we computed six networks (for teenagers, parents, and teachers separately combined with self-reported or objectively measured sleep). This deviation from the preregistered analysis plan allowed us to exclude those teenagers that did not wear a sleep tracker from the sleep tracker data analysis. Of the six networks we obtained, we included all 31 teenagers in the first three networks. These were based on their self-reported sleep combined with (i) their self-reported daytime functioning, (ii) the parent-reported daytime functioning, and (iii) the teacher-reported daytime functioning. In networks four to six, we included the 14 teenagers who wore the sleep tracker. Thus, we included the teenagers' objectively measured sleep together with the same variables of daytime functioning reported by the teenager, parent, or teacher. As in this study no hypotheses were tested, this sample size (with observations for 21 consecutive days) is large enough to gather exploratory measures (Costantini et al., 2015).

The nodes in networks represented the variables for that specific network. All networks contained the following nodes: number of minutes for sleep onset latency, total sleep time, wake time after sleep onset (self-reported or objectively measured), the number of minutes before bedtime an activity was performed (intensive physical exercise, gaming, electronic device use, and caffeine intake; if the activity was not performed, the score was set to the highest reported number of minutes for that specific variable), score given for physical exercise, stress, and mental effort, and the scores given for aspects of daytime functioning (daytime sleepiness, concentration or mood; reported by the teenager, parent, or teacher). The network that was based on self-reported sleep contained additionally the perceived sleep quality score (ranging from 1 to 10).

Given higher-than-expected missing values (missing at random; ranging from 18.1% to 52.6%), we deviated from the preregistered analysis plan to solve problems with these missing values. We addressed this by using the R-package Multivariate Imputation by Chained Equations (mice) for robust data imputation (van Buuren & Groothuis-Oudshoorn, 2011; Van Buuren, 2018). This method "fills in" (imputes) missing data through an iterative process using predictive models. During each iteration, the missing values for each specified variable in the dataset are imputed based on the information from other variables in the dataset. With ten and 20 iterations showing comparable results (which showed the stability of the imputations), 20 iterations were selected to ensure robustness. Imputations were conducted separately for self-reported and objectively measured sleep across each informant group (see supplementary material S1 for the imputation code). Thus, six imputations were conducted. Each imputation model used all the variables included in that specific network. Using all variables provides a more accurate imputation by preserving the relationships between variables.

We then used the R-package Mixed Graphical Model (mgm; Haslbeck & Waldorp, 2020) to estimate the networks with the imputed datasets. To reduce the likelihood of including false-positive edges, we used the Least Absolute Shrinkage and Selection Operator (LASSO) including the default threshold of mgm. We used the Extended Bayesian Information criterion (EBIC) to determine the penalty parameter of the LASSO (see supplementary material S2 for the network estimating code). The stability of each network was assessed using the resample function of the mgm package. We ran 80 bootstrap samples for each network; with the argument quantiles, we specified the lower (.05) and upper (.95) quantiles of the sampling distribution. We included the edge in the network if the proportion of inclusion in each resample was at least 90%. This stability check confirms that the relationships we found are robust, so we have confidence in those relationships. The networks were illustrated using the R-package qgraph (Epskamp et al., 2012).

In addition to what was preregistered, we also computed the networks without the data from the first and last day of the research period because most of the missing data was from those days. After visually comparing the results, we concluded that the networks of the teenagers and parents (both with self-reported and objectively measured sleep) were stable. Since we did not want to remove useful data, we included data about all the research days in the networks of the teenagers and parents. However, the teachers' networks were less stable. Since their percentage of missing values was much higher on the first research day than on the other days, we excluded that day from our network analyses.

3. Results

3.1. Participants' characteristics

In total, 24 boys and seven girls with a mean age of 14.87 years (SD=1.88, age range=12–18) participated. The mean ISI score was 17.20 (SD=6.43), which is an indication of clinical insomnia with moderate severity (Bastien et al., 2001). Their mean score on the SRS-2 was 78.74 (SD=27.46). The majority of the participants (78%) scored above the autism cut-off score of 51. Specific data on socioeconomic status, ethnicity and co-occurring conditions were not recorded. Regarding medication use, all participants were medication free of at a stable dose during their participation in the study.

There were no significant difference between the ISI and SRS scores for teenagers that did (ISI: M=17.38, SD=6.24 and SRS: M=85.09, SD=16.41) or did not wear the sleep tracker (ISI: M=16.09, SD=6.01 and SRS: M=72.92, SD=34.43); for the ISI and SRS respectively $t(22) = 0.52$, $p = .61$ and $t(21) = 1.07$, $p = .30$.

3.2. Relationship between self-reported and objectively measured sleep

We found small to moderate correlations between self-reported and objectively measured sleep. Self-reported and objectively measured total sleep time ($r = .46$, $p < .001$) and wake time after sleep onset ($r = .32$, $p < .001$) were moderately correlated. The correlation between self-reported and objectively measured sleep onset latency was small ($r = .28$, $p < .001$). Based on these correlations (all <.80), we included objectively measured and self-reported sleep separately in the following analysis.

3.3. Relationship between sleep and daytime functioning

To estimate the networks, we used the six imputations described in the Methods section. In the presentation of the networks, the node's color reflects the type of question: green nodes relate to aspects of sleep hygiene, blue nodes to aspects of sleep, and orange nodes to aspects of daytime functioning. We describe the associations that are most relevant to our research question: (i) between sleep and daytime functioning, and (ii) between sleep hygiene and sleep. It is important to consider that it is difficult to interpret the absence of relationships with this type of analysis. Therefore, we focus on the presence of relationships rather than their absence.

For more information, an overview of the characteristics of the included variables (including exactly what numbers are included for

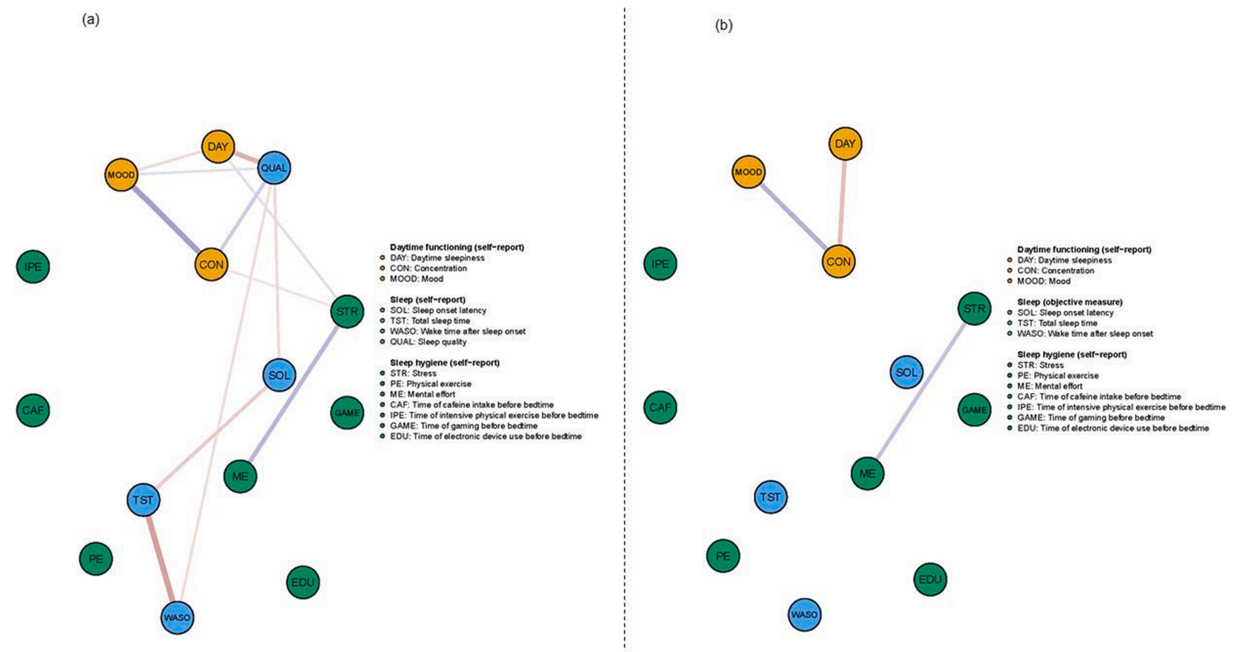

Fig. 2. Graphical Network with Teenagers' Self-Reported (a; N = 31) and Objectively Measured (b; N = 14) Sleep Together with their Self-Reported Daytime Functioning.

each variable) and the correlations for the reports of daytime functioning completed by teenagers, parents, and teachers can be found in supplementary materials S3 and S4, respectively.

3.4. Teenagers

Fig. 2 shows the networks of teenagers' self-reported sleep together with their self-reported daytime functioning (2a) and their objectively measured sleep together with their self-reported daytime functioning (2b). In network 2a, we found that better perceived sleep quality was directly associated with better concentration and mood and less daytime sleepiness. Importantly, it appeared that sleep onset latency and wake time after sleep onset were indirectly related to daytime functioning variables through perceived sleep quality. Network 2b revealed that several aspects of daytime functioning were connected to each other and to two sleep hygiene variables (mental effort and stress).

3.5. Parents

Fig. 3 depicts the results of the networks with parents as informants for daytime functioning. Network 3a shows the results of the teenagers' self-reported sleep together with parent-reported daytime functioning, and network 3b shows the teenagers' objectively measured sleep together with parent-reported daytime functioning.

In network 3a, we found that better perceived sleep quality was directly related to less daytime sleepiness. Moreover, it appeared that sleep onset latency and wake time after sleep onset were indirectly related to daytime sleepiness through perceived sleep quality. In addition, this network showed that a shorter sleep onset latency and a shorter total sleep time were associated with better concentration. Wake time after sleep onset was indirectly related to concentration through total sleep time.

Our analysis of objective sleep variables (3b) showed that several connections remained, such as a relationship between total sleep time and concentration. This network also revealed connections between sleep hygiene and sleep. The longer the time between caffeine intake and bedtime, the longer the total sleep time, and the more stress during the day, the shorter the sleep onset latency.

3.6. Teachers

Fig. 4 shows the networks of teenagers' self-reported sleep together with teacher-reported daytime functioning (4a) and objectively measured sleep together with teacher-reported daytime functioning (4b). As found in other networks, network 4a showed that better perceived sleep quality was related to less daytime sleepiness and a better mood. Simultaneously, we found that a longer sleep onset latency was related to more daytime sleepiness. Total sleep time was indirectly associated with daytime sleepiness through sleep onset latency. This network also showed connections between sleep hygiene and sleep; the more physical exercise, the shorter the total sleep time, and the more mental effort, the shorter the sleep onset latency.

Our analysis of objective sleep variables (4b) showed that the longer the total sleep time, the less daytime sleepiness. We also found

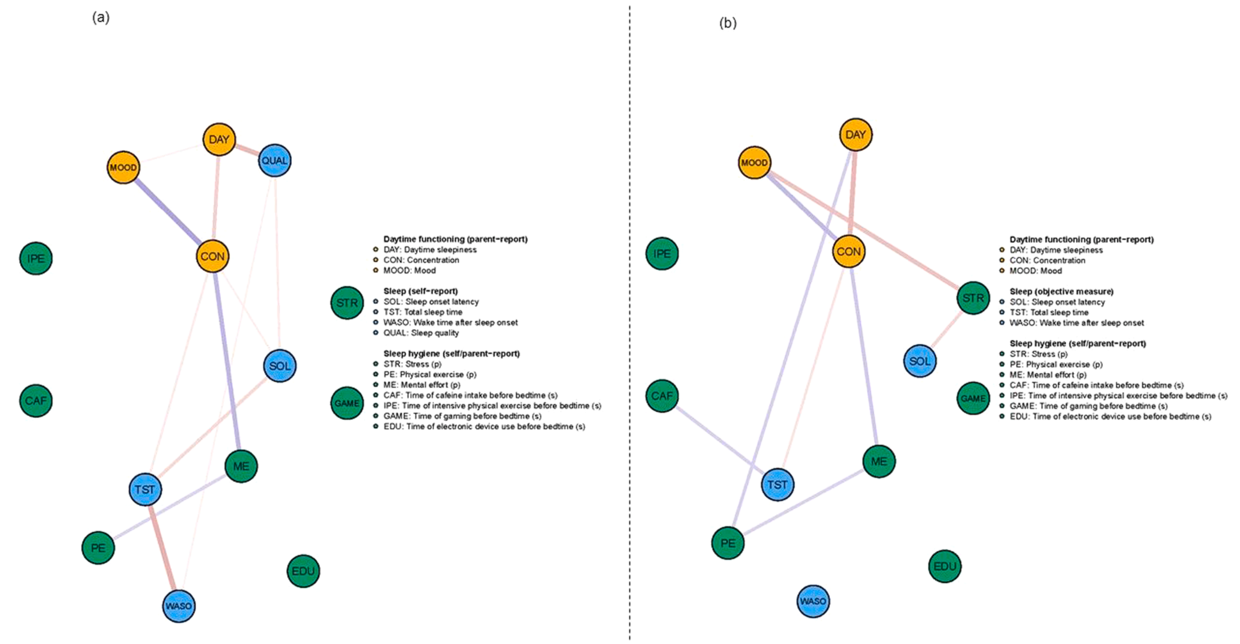

Fig. 3. Graphical Network with Teenagers' Self-Reported (a; N = 31) and Objectively Measured (b; N = 14) Sleep Together with Parent-Reported Daytime Functioning. Note. s = self-reported, p = parent-reported.

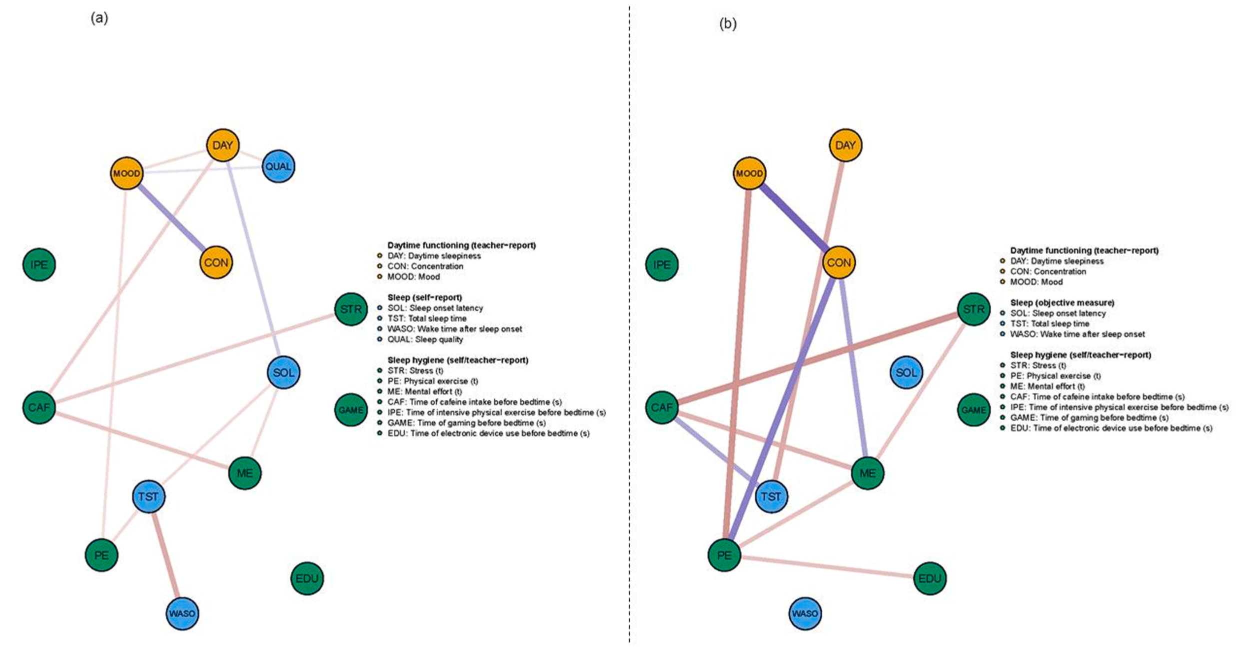

Fig. 4. Graphical Network with Teenagers' Self-Reported (a; N = 31) and Objectively Measured (b; N = 14) Sleep Together with Teacher-Reported Daytime Functioning. Note. s = self-reported, t = teacher-reported.

a connection between sleep hygiene and sleep: the longer the time between caffeine intake and bedtime, the longer the total sleep time. Moreover, this network showed that several sleep hygiene variables are interconnected.

3.7. Additional analysis

All networks revealed that perceived sleep quality is related to one or more aspects of daytime functioning. We combined three items (how well the teenager slept, feeling of being rested at waking, and ease of waking up) in one node to evaluate the variable perceived sleep quality. To determine whether the aspects of perceived sleep quality were related to daytime functioning in different ways, we also created an exploratory network in which we included those three items separately. This network (Fig. 5) showed that of the three aspects of perceived sleep quality, how rested the teenagers feel at awakening was related to daytime functioning.

4. Discussion & Implications

In this study, we used a network approach to investigate the relationship between specific sleep variables and daytime functioning. The results of our analysis of the networks with self-reported sleep revealed that perceived sleep quality was, as expected, related to all aspects of daytime functioning (daytime sleepiness, mood, and concentration) for the teenage informants. Associations between perceived sleep quality and daytime functioning also were found in the parents' and teachers' networks, but to a lesser extent. We also found that sleep onset latency, total sleep time, and wake time after sleep onset were related to daytime functioning, but mostly indirectly through perceived sleep quality. As perceived sleep quality was a variable that combined three items, it is a variable that captures a range of different influences which makes it harder to identify different mechanisms.

The term 'perceived sleep quality' is widely used but not well defined (Krystal & Edinger, 2008). For example, perceived sleep quality has been defined as how rested or restored people feel at awakening based on whether people feel tired at awakening and during the day, based on number of nighttime awakenings, and based on their state of mind before bedtime (Goelema et al., 2018; Harvey et al., 2008). While we agree that circumstances before sleep or during the day are related to sleep, we argue that it is problematic to use elements beyond sleep or waking to define perceived sleep quality. To avoid interference with daytime functioning, we defined perceived sleep quality only using aspects that refer to sleep and waking (how well someone slept, feeling of being rested at waking, and the ease of waking up).

The most prominent finding of this study was the relationship between perceived sleep quality and daytime functioning. To determine whether aspects of perceived sleep quality are related to daytime functioning in different ways, we included an exploratory network with each individual item instead of a sum score for perceived sleep quality. This network showed that the item 'feeling of being rested at waking' was related to daytime functioning. Surprisingly, this network also showed that only the items about how well someone slept and the ease of waking were related to each another. Thus, being rested at waking seems to be different than the other two items. This again raises questions about the definition of perceived sleep quality. Perhaps the item "feeling rested at waking" is not

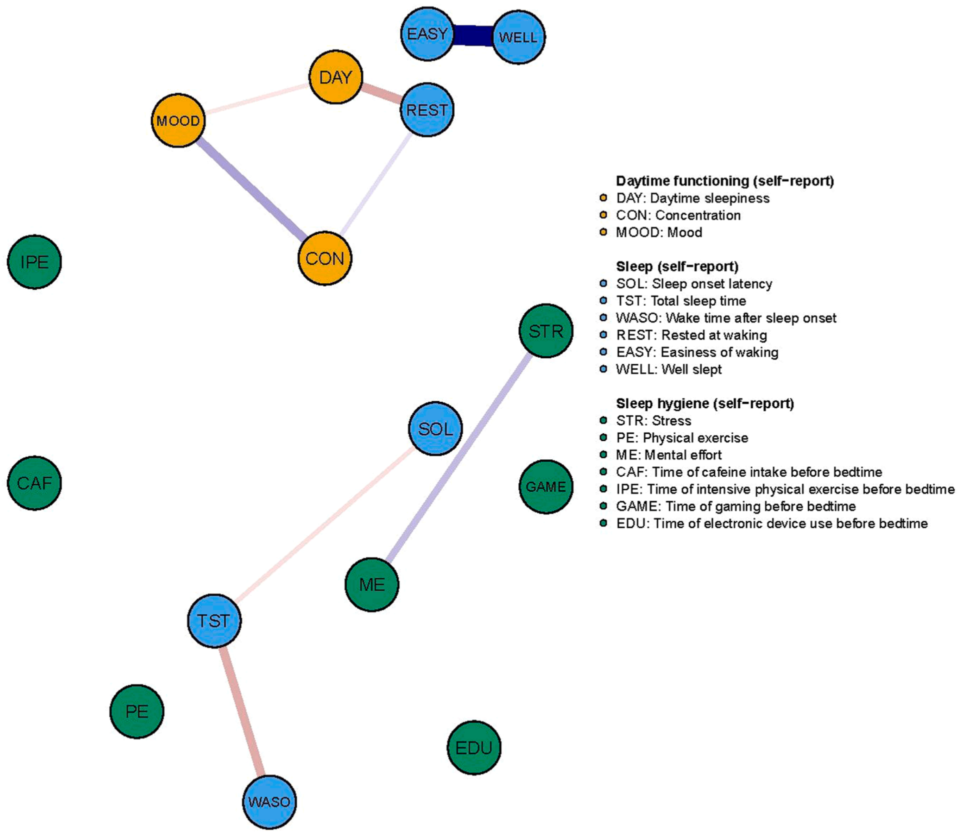

Fig. 5. Graphical Network with Teenagers' Self-Reported (a; N = 31) Sleep (including separate items of sleep quality*) Together with Their Self-Reported Daytime Functioning. *The sleep quality items are (a) how well the teenagers slept (WELL), (b) feeling of being rested at waking (REST), and (c) ease of waking up (EASY).

solely a function of sleep or daytime functioning, so we are not certain whether it should be considered an aspect of perceived sleep quality. Regardless, this finding invites future researchers to further elaborate on what exactly defines perceived sleep quality.

We not only found evidence for the importance of perceived sleep quality in the teenagers' network, but also in the networks of their parents and teachers with the same positive or negative direction (though to a lesser extent). Since discrepancies between reports of different informants are common (Youngstrom et al., 2001), these differences are not surprising. Moreover, these differences could contribute to the comprehensive picture of the relationships between sleep and daytime functioning. However, we did find a puzzling association unique to the parent-network; more physical exercise was associated with a shorter total sleep time. This finding surprised us, as previous research has shown that moderate exercise generally promotes sleep (Irish et al., 2015). However, it is important to recognize that exercise is a multifaceted behavior with various components to consider, such as duration, mode, intensity, and timing. Furthermore, although generally is assumed that more physical exercise is associated with better and longer sleep duration, this relation has not been investigated extensively in people with co-morbidities. A recent study in children with cerebral palsy also revealed a negative correlation between exercise and total sleep time (Gerritsen et al., 2023). Further studies are needed to further clarify this complex and bi-directional relationship, including timing, duration and mode of exercise.

Although parents and teachers had less insight into the teenagers' daytime functioning, they also noticed associations between perceived sleep quality and daytime functioning that emphasize the importance of perceived sleep quality. However, as we found most associations in the teenagers' network, it should be sufficient to only include teenagers as informants when evaluating daytime functioning.

One could also argue that people may rate their perceived sleep quality differently in the morning than later in the day. Such a rating may be a function of several variables or events, and it may mirror how the teenagers felt on a particular day instead of a perceived sleep quality measure. Therefore, we instructed the teenagers to answer the questions as soon as possible after waking. Thus, one should separate daytime aspects from aspects related to sleep and waking when drawing conclusions about perceived sleep quality.

Our study also showed that self-reports and objective measures of sleep were related to daytime functioning in different ways. Information about how someone perceives their sleep is crucial because perceived sleep quality is the most important aspect of sleep for daytime functioning. This finding is in line with previous research by Edinger et al. (2000), which found that people who slept worse according to objective measures but do not experience sleep problems reported better moods and less anxiety than people who experienced sleep problems while sleeping normally according to objective measures. Our finding, combined with the findings of previous research, highlights the importance of focusing on perceived sleep quality in sleep interventions.

4.1. Strengths and limitations

While the relationship between sleep and daytime functioning has been studied extensively in teenagers without ASD (Short et al., 2013) and to a lesser extent in autistic populations (Richdale et al., 2014), this is, to our knowledge, the first attempt to investigate this relationship using a network approach. This approach enabled us to identify the network structure between sleep variables and aspects of daytime functioning, which let us take the first step toward disentangling the complexity of interacting variables. To unravel the complex relationships, we used both daily objective and self-reported measures of sleep, together with measures of daytime functioning, for a period of three weeks. This gave us a better understanding of relationships between specific sleep variables and daytime functioning in autistic teenagers. In addition, using multiple informants gave us insight into the experiences of the relationship between sleep and daytime functioning from multiple perspectives. For example, some relationships were visible in most networks, while others were less pronounced.

It is also worth noting several limitations of this study. First, the study design was vulnerable: for the network analysis it was needed that teenagers completed the sleep diary and questions about daytime functioning on the same day. This means that when teenagers forgot to answer the questions about their sleep, we could not use the answers to the questions about daytime functioning given by the teenagers, their parent, or their teacher.

Second, we instructed informants (teenager, parent, teacher) to answer the questions before a certain time of day. We asked the teenagers to complete the sleep diary as soon as possible after waking and no later than upon arrival at school, and we asked them to answer the questions about daytime functioning, stress, mental effort, and physical exercise no later than 8 p.m. Despite these instructions, we noticed that questions were sometimes answered at later times (to avoid severe problems with recall bias, we limited the time the questions could be completed).

Third, since we had a limited number of sleep trackers available, we could not measure objective sleep in all participants. As a result, the network based on the objective measure of sleep included fewer participants than the network based on self-reported sleep. Certain relationships may not exceed the threshold due to the limited number of participants in this specific network, which would exceed the threshold in a larger group. Therefore, we should not assume an absence of relationships.

Fourth, we used the SRS-2 to identify the presence and severity of difficulties in social behavior on the autism spectrum. However, 22% of the participating teenagers did not score above the autism cut-off score. Still, one of our inclusion criteria for the teenagers was a diagnosis of an autism spectrum disorder by a psychiatrist or psychologist, based on the criteria of the DSM-IV (American Psychiatric Association, 2000) or DSM-5 (American Psychiatric Association, 2013). To determine whether the teenagers met this inclusion criteria, we asked parents if their child had an autism spectrum disorder diagnosis, in which year it was diagnosed, and by which authority this diagnosis was established. All parents answered these questions and declared their child has a formal diagnosis of an autism spectrum disorder that matched our inclusion criteria. Thus, we have no doubts about the diagnosis even though some participants scored below the autism cut-off score on the SRS-2.

Finally, it is essential to acknowledge that the absence of specific data on socioeconomic status, ethnicity, and co-occurring conditions may potentially influence the generalizability of the results. Additionally, it is worth noting that this study did not explore other significant sleep-related factors that could impact sleep, perceived sleep quality, and subsequent daytime functioning. These factors are for example light exposure at bedtime and during the day, engaging in relaxing activities before sleep, and pre-sleep arousal levels. Considering these aspects in future research could provide a more comprehensive understanding of the broader influences on sleep.

4.2. Implications

In this study, we showed how the network approach provided insights into the interplay between specific sleep variables, aspects of sleep hygiene, and daytime functioning. The associations showed that perceived sleep quality was the most important aspect of sleep in relation to daytime functioning because it was directly related to all aspects of daytime functioning. However, sleep onset latency and wake time after sleep onset were related to perceived sleep quality. This means those variables also are indirectly related to daytime functioning.

The knowledge that perceived sleep quality is the most important aspect related to daytime functioning shows the importance of focusing on perceived sleep quality in sleep interventions for having a widespread reach. Moreover, since sleep problems are often overlooked in treatment for autistic teenagers (Reynolds & Malow, 2011), this study highlights the importance of focusing on sleep problems to prevent a negative impact on daytime functioning.

Declaration of Competing Interest

All authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rasd.2024.102332.

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