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The implication of sleep disturbances on daily executive functioning and learning problems in children with autism without intellectual disability

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ABSTRACT

Background: Individuals with autism spectrum disorder (ASD) often have sleep disturbances, executive functioning difficulties, and learning problems. The aim of this study was twofold. First, to examine the quality of sleep in children with ASD without intellectual disability and typically developing (TD) children. Second, to explore the implication of sleep disturbances in the association between daily executive functioning and learning problems in children with ASD without intellectual disability.

Method: The sample included 47 children with autism without intellectual disability and 32 TD children. Parent-reported questionnaires were used to assess participants' sleep disturbances, daily executive functions, and learning problems. All statistical analyses performed were adjusted for age, IQ, and medication.

Results: As expected, the prevalence of sleep disturbances was significantly higher in the ASD group than in the TD group. Regarding the second aim of the study, the total score of sleep disturbances was significantly associated with learning problems and the metacognition subdomain of executive functioning in children with autism without intellectual disability. In turn, executive functions and learning problems were also significantly associated. Finally, sleep disturbances were found to mediate the relationship between global executive functioning and learning problems in children with ASD without intellectual disability.

Conclusions: The findings suggest that sleep disturbances are common in children with autism, and that they play a mediating role in the association between executive functions and learning problems. Therefore, sleep should be a crucial aspect of interventions to improve the learning and academic performance of school-aged children with ASD without intellectual disability.

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1. Introduction

Sleep disturbances are common among individuals with neurodevelopmental conditions (Halstead et al., 2021), particularly among children with autism spectrum disorder (ASD). Although the prevalence rates vary considerably across studies, a recent systematic review indicated high rates of sleep problems in all cases, ranging from 37% to 93% (Schwichtenberg et al., 2022). These rates are significantly higher than those observed in typically developing (TD) children, which generally range from 25% to 46% (Estes et al., 2023; Köse et al., 2017; Reynolds et al., 2019; Tyagi et al., 2019).

Among children with ASD, some of the most common sleep disturbances include sleep initiation and maintenance disorders. These disorders are characterized by delayed sleep onset or frequent night awakenings (Calhoun et al., 2020; Cann, 2023; Carnett et al., 2021; Köse et al., 2017; Tyagi et al., 2019). Children with autism often experience bedtime resistance, parasomnias such as nightmares, and sleep-disordered breathing (Cann, 2023; Díaz-Román et al., 2018). Sleep-wake transition disorders, such as jerking of legs, changing positions, or teeth grinding, are also commonly observed (Tyagi et al., 2019).

Sleep disturbances have significant negative implications for the quality of life of children with ASD, exerting detrimental effects on various domains of their physical, cognitive, social, and psychological well-being (Carnett et al., 2021; Delahaye et al., 2014). One of the effects of poor sleep is the potential increase in the severity of core ASD traits, which include persistent deficits in communication and social interaction, as well as restrictive and repetitive patterns of behavior, interests, or activities (DSM-5-TR; American Psychiatric Association, 2022) (Schreck et al., 2004; Tudor et al., 2012). Moreover, sleep disturbances can adversely affect the executive functioning of children with autism, which could have certain implications for their learning abilities and academic achievement.

1.1. Sleep disturbances and executive functioning in ASD without intellectual disability

Executive functions refer to essential cognitive processes that facilitate effective human performance by guiding actions and behaviors necessary for daily tasks while regulating and monitoring them (Baggetta & Alexander, 2016). In scientific literature, there are various conceptualizations of executive functioning and various theories about the components or processes encompassed by that term. One of the most widely supported postulates is that there are three core subdomains of executive functioning: inhibition (including self-control and interference control), cognitive flexibility (or shifting), and working memory (Best & Miller, 2010). Another approach is that of Gioia et al. (2002), which distinguishes three dimensions of executive functioning: the metacognitive dimension, which encompasses processes such as working memory, initiative, planning, material organization, and monitoring; the behavioral regulation dimension, which includes inhibition and self-monitoring; and the emotional regulation dimension, which comprises emotional control and shifting.

Children with ASD without intellectual disability often exhibit deficits in executive functioning, which can limit their adaptive functioning and learning abilities (Demetriou et al., 2018; Zhang et al., 2020). In fact, according to the theory of executive dysfunction, these deficits in executive functioning might explain some of the ASD traits, particularly those related to behavioral problems (Pennington & Ozonoff, 1996).

Several studies have examined the relationship between sleep and executive functions, considering that the prefrontal cortex of the frontal lobe serves as the anatomical basis for executive functioning (Funahashi & Andreau, 2013). Moreover, this brain region is particularly susceptible to the impact of sleep disturbances (Krause et al., 2017). However, the association between sleep and executive functions in individuals with autism remains unclear, as previous research has yielded inconsistent results (Karavasilis & Statiri, 2022).

For instance, Han et al. (2022) conducted a comprehensive meta-analysis of 49 studies encompassing individuals with ASD across different age groups, cognitive profiles, and developmental stages. Their analysis aimed to evaluate the robustness of associations between sleep disturbances and various aspects of daytime functioning in individuals with autism, including children, adolescents, and adults. The results showed that sleep problems were significantly associated with more clinical symptomatology and worse daytime functioning.

Furthermore, in a recent study conducted by Holingue et al. (2021), the association between parent-reported sleep disturbances and executive functioning was examined in a sample of children with ASD without intellectual disability. The study considered essential factors such as demographic variables, stimulant medications, and IQ. The results indicated a significant association between sleep disturbances and executive dysfunction in children with autism. However, it was observed that the relationship between sleep problems and the two subdomains of executive functioning, namely shift and emotional control, was partially mediated by anxiety. Furthermore, when considering symptoms of inattention and hyperactivity in children with ASD, the association between sleep disorders and the metacognition subdomain was not significant.

In a longitudinal study by Tesfaye et al. (2021), the association between early childhood sleep disturbances reported by parents and the teachers-reported trajectory of executive functioning in school-aged children with ASD with varying cognitive profiles was investigated. The findings revealed a significant association between sleep disturbances and subsequent difficulties in behavioral regulation and inhibitory control. However, no significant association was found between sleep disturbances and the metacognitive processes of executive functioning.

In contrast, a study by Gisbert-Gustemps et al. (2021) explored the relationship between sleep disturbances and executive functioning in children and adults with ASD without intellectual disability. In the case of children, instruments reported by caregivers were used for measuring both aspects, while in adults, self-reported instruments were employed. Surprisingly, no significant association was observed between sleep disturbances and executive functioning in either group.

1.2. Learning problems in ASD without intellectual disability

Deficits in executive functioning have been shown to have a detrimental impact on children's academic performance (Cortés-Pascual et al., 2019), particularly in tasks involving complex processes such as reading comprehension, written expression, and math exercises, which require skills like planning, problem-solving, memorization, shifting, and self-monitoring (Beisly et al., 2022; Meltzer & Krishnan, 2007; Zelazo & Carlson, 2020). Research conducted on students with autism without intellectual disability has revealed that working memory may be associated with their academic performance, whether it is low or high (Bullen et al., 2022; Chen et al., 2019; Davidson et al., 2018).

While children with ASD do not exhibit a uniform profile of academic achievement, studies have consistently found that their performance in specific areas tends to be lower than their typically developing peers (Keen et al., 2016). Specifically, they often experience difficulties in reading comprehension, written expression, and math problem-solving, leading to lower levels of achievement (Bullen et al., 2022; Mayes et al., 2020; Miller et al., 2017).

1.3. The implication of sleep disturbances in executive functioning and learning problems in ASD

Consistent with previous literature, sleep disturbances play a role in the association between different aspects that affect the well-being of individuals with autism. For instance, Tsai et al. (2021) found that sleep problems mediated the relationship between the 'restricted and repetitive behavior' autistic traits and executive functioning in children. Similarly, in a study conducted with adults, McArthur et al. (2022) concluded that sleep disturbances and anxiety mediate the link between autistic traits and working memory. However, when examining the influence of sleep on the relationship between working memory and symptoms of attention deficit and hyperactivity disorder (ADHD) in children with ASD without intellectual disability, Cremone-Caira et al. (2019) found no significant implication of sleep problems in this association.

Given the established relationship between executive functions, particularly working memory, and the academic achievement of children and adolescents in mathematics and reading (Bullen et al., 2022; Chen et al., 2019; Davidson et al., 2018), as well as their association with sleep quality (Han et al., 2022; Holingue et al., 2021), sleep disturbances may play a role in the connection between executive functioning and learning problems. Sleep disturbances may mediate the relationship between executive functioning and learning problems in children with ASD without intellectual disabilities; however, this area of research has received limited attention thus far. To our knowledge, the only study that has examined this analysis is the one conducted by Calhoun et al. (2020). The authors proposed three different models regarding the potential implications of sleep disturbances in the association between working memory and learning problems in adolescents with ASD without intellectual disability. While their findings did not support the assumption that sleep disturbances are the underlying mechanism explaining the impact of working memory deficits on the severity of learning problems in adolescents with ASD, they did demonstrate a moderating role of sleep disturbances in the relationship between working memory and learning problems. According to Calhoun et al. (2020), sleep disturbances could amplify the impact of working memory deficits on learning problems in adolescents with autism.

Table 1
Demographics and clinical characteristics.

	TD (n = 32) Mean (SD)	ASD (n = 47) Mean (SD)	t/F	χ^2	*p*
Age (years)	8.75(1.22)	9.37 (1.75)	1.56	-	.112
IQ	100.4 (8.22)	98.37 (10.92)	.93	-	.109
Sex (% boys)	65.6%	89.3%		6.64	.010 *
P. Education	3.27 (.95)	3.05 (1.09)	.57	-	.561
Medication (% yes)	0.0%	41.7%			
ADI-R	-	28.3 (5.7)			
DIMS	9,4%	25,5%			
SBD	6,3%	6,4%			
DA	0,0%	4,3%			
SWTD	3,1%	21,3%			
DOES	3,1%	8,5%			
CHY	0,0%	2,1%			
T. Sleep d	21,9%	68,1%			
BRIEF-BRI	50.81 (7.08)	74.23 (7.54)	13.99		< .01 *
BRIEF-ERI	53.34 (6.33)	75.36 (9.65)	11.45		< .01 *
BRIEF-CRI	51.06 (6.38)	74.63 (9.11)	12.77		< .01 *
BRIEF-GEC	52.09 (5.84)	76.47 (7.62)	15.28		< .01 *
Learning problems	52.47 (7.07)	67.43 (8.42)	10.01		< .01 *

Note. P. Education (Parental education), ADI-R (Autism Diagnostic Interview-Revised), DIMS (Disorders of initiating and maintaining sleep), SBD (sleep breathing disorders), DA (disorders of arousal), SWTD (sleep-wake transition disorders), DOES (disorders of excessive somnolence), SHY (sleep hyperhidrosis), T. Sleep d (Total Sleep disturbances), BRI (Behavioural regulation index), ERI (Emotional regulation index), CRI (Cognitive regulation index), GEC (Global Executive Composite index).
* $p < .05$

1.4. About the present study

Previous literature has highlighted the presence of sleep disturbances (Díaz-Román et al., 2018; Schwichtenberg et al., 2022), executive functioning (Demetriou et al., 2018; Zhang et al., 2020), and learning problems (Calhoun et al., 2020; Keen et al., 2016; Mayes et al., 2020) among individuals with ASD without intellectual disability. However, there is a lack of understanding regarding the interaction between these three elements, specifically the role of sleep disturbances in the relationship between daily executive functioning and learning. To address this research gap, this study aims: 1) to examine the prevalence of sleep disturbances in children with ASD without intellectual disability compared to TD children. Most importantly, 2) the study explores the mediating role of sleep disturbances in the relationship between daily executive functions and learning problems in children with ASD without intellectual disability.

2. Methods

2.1. Participants

The study included a total of 79 participants, with 47 children diagnosed with autism ASD and 32 TD children. The age range of the participants was 8 to 12 years. The groups were matched on age and IQ, with all participants having IQ scores equal to or above 80 as measured by the Kaufman Brief Intelligence Test (K-BIT) (Kaufman & Kaufman, 2000). Among the participants, 79% were boys, and 21% were girls. Based on the criteria established by Bruni et al. (1996), a total sleep problem score of 39 or higher in The Sleep Disturbance Scale for Children (Bruni et al., 1996) was considered indicative of significant sleep disturbances. The prevalence of sleep problems was 21.8% in the TD group (n = 7) and 68.1% in the ASD group (n = 32) (see Table 1).

The clinical sample for this study was recruited from specialized psychoeducational care centers in Spain. The diagnosis of autism spectrum disorder was confirmed using standardized assessment tools, including the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2006) and the Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2001). These assessments were administered by psychologists who were research-certified in using these instruments. In addition to the clinical assessments, parents completed a self-report questionnaire to assess ASD symptoms based on the criteria outlined in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5; American Psychiatric Association, 2013).

The TD children were recruited from public schools that agreed to participate in the study. None of these children had a history of psychopathologies or met the criteria for ASD or ADHD diagnosis according to DSM-5 and completed by parents and teachers. The exclusion criteria for all groups included having an IQ below 80 and having motor or sensory deficits, mental disorders, or neurological diseases.

2.2. Measures

2.2.1. Sleep disturbances

The Sleep Disturbance Scale for Children (SDSC; Bruni et al., 1996) is a 26-item parent-reported questionnaire used to assess sleep disturbances in children aged 6–16 years over a six-month period. Each item is rated on a 5-point scale, ranging from "never" to "always", resulting in a continuous variable between 26 and 130. Higher scores indicate more severe sleep disturbance symptoms. The first two items measure total sleep time and latency to sleep onset, while the remaining items assess the frequency of sleep-related behaviors across six subscales: disorders of initiating and maintaining sleep (DIMS), sleep breathing disorders (SBD), disorders of arousal (e.g., sleepwalking, sleep terrors) (DA), sleep-wake transition disorders (SWTD), disorders of excessive somnolence (DOES), and sleep hyperhidrosis (falling asleep sweating and night sweating) (SHY). The total sleep disturbances score is obtained by summing scores across all subscales.

The scale has good internal consistency, with a reliability coefficient of $\alpha = 0.79$ (Bruni et al., 1996) and it has been used to measure sleep difficulties in children with ASD (Precenzano et al., 2017). The test-retest reliability over a 6-month interval was reported as $r = 0.71$, indicating reasonable stability of the scale's measurements (Bruni et al., 1996). In the context of this study, the Spanish version of the scale developed by Pagerols et al. (2023) showed good psychometric properties ($\alpha = .82$).

2.2.2. Daily executive functions

The Behavioral Rating Inventory of Executive Function (BRIEF-2 Family Report; Gioia et al., 2015) is a questionnaire used to assess daily executive functions. It consists of 63 items that are rated on a frequency scale, ranging from "never (1)" to "frequently (3)." The BRIEF-2 Family provides four main indexes and scores on various scales related to executive functions: a) the Behavioral Regulation Index (BRI), which includes inhibition and self-monitoring scales; b) the Emotional Regulation Index (ERI), with the scales of switching and emotional control; c) the Cognitive Regulation Index (CRI), which comprises initiative, working memory, planning, organization, and task monitoring scales; and d) the Global Executive Composite (GEC), representing overall executive functioning. The first three indices, BRI, ERI, and CRI, align with three dimensions of executive functions: inhibitory control, emotional regulation, and meta-cognition, respectively (Hendrickson & McCrimmon, 2019).

For this study, the main indexes of the BRIEF-2 Family were utilized. Raw scores are converted into age-corrected T-scores, with a score greater than 70 on any of the scales indicating clinically significant difficulties. The BRIEF-2 Family has demonstrated high internal consistency for the Index and Composite scores, with Cronbach's alpha ranging from 0.90 to 0.97. It also exhibits good test-retest reliability, with correlation coefficients above 0.80 (Gioia et al., 2015). The BRIEF-2 Family is a suitable tool for screening

executive difficulties in the ASD population (Hendrickson & McCrimmon, 2019).

2.2.3. Learning problems

The Conners-3 Parent Short Form (Conners-3) was employed to assess learning problems. This parent-report questionnaire evaluates behavioral and regulation disorders as well as ADHD in children and adolescents aged 6–18 years (Conners, 2008), although it has been used to measure children's problems in ASD population (May et al., 2014). The questionnaire consists of 45 items grouped into six scales: inattention, learning problems, aggression, family relations, hyperactivity/impulsivity, executive functioning, and peer relations. In the context of this study, the focus was on the nine-item Conners-3 Learning Problems scale. This scale gathers parent-reported observations on the participants' spelling, reading, math, and concept learning difficulties. By utilizing this scale, the study aimed to assess and evaluate learning problems in the participants.

Parents reported their children's problems using a four-point scale ranging from 0 to 3 (never to very often). The scale provides T-scores that range from 40 to 90. A lower total score indicates a less severe impairment. The T-scores are interpreted as follows: scores below 40 are considered low, scores between 40 and 59 are considered average, scores between 60 and 69 are considered elevated, and a score of 70 indicates a very elevated level of impairment. The Conners-3 Parent Short-form version demonstrates good internal consistency ($\alpha = 0.85–0.92$) and test–retest reliability ($r = 0.73–0.97$) (Conners, 2008).

2.2.4. Demographics

The demographic information collected at enrollment included age, sex, and parental education. Parental education was categorized based on the highest level of education achieved by either the mother or father, using the following scale: 0 = No education, 1 = Primary Education, 2 = Lower Secondary Education, 3 = Higher Secondary Education, 4 = University Education. Parents also provided information regarding their children's medication use.

2.3. Procedure

Parents completed the battery of questionnaires in one session with the research team that had been trained in the administration of the questionnaires used. Furthermore, children were evaluated in a quiet room of the Faculty of Psychology by two psychologists. The present study follows the statements of the Ethics Committee of the Universitat de València (UV-INV_ETICA-1905517) and the Declaration of Helsinki. The parents provided their oral and written informed consent.

2.4. Data analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software, version 26.00 (SPSS Inc., Chicago, IL, USA). The distribution of the variables was analyzed, as well as their fit to the normal distribution curve, by applying Kolmogorov-Smirnov tests.

To address Aim 1, multivariate covariance (MANCOVA) analysis was carried out to analyze the differences between ASD and TD groups in sleep disturbances domains, adjusting for IQ, age, and medication as covariates. The differences on the entire test were verified through additional covariate analyses of variance (ANCOVAs). For the additional ANCOVAs, the significance level was set at $p < .007$, after applying the Bonferroni correction, and the value of Partial Eta Squared ($\eta 2p$) was calculated to test the strength of the association.

To address Aim 2, partial correlation analyses were conducted within the ASD group, considering age, IQ, and medication as covariates, to investigate the relationships between sleep disturbances, daily executive functions, and learning problems. Multivariate regressions were used to assess the impact of executive functions and sleep disturbances (independent variables) on learning problems (dependent variable) in the ASD group. A significance level of $p < 0.05$ was considered statistically significant.

Finally, based on the pattern of significant correlations found and regression analyses, a simple mediation model was examined to assess the mediating role of total sleep disturbances in the relationship between daily executive functions and learning problems. The

Table 2
Differences between children with TD and ASD on Sleep disturbances (ANCOVAs).

	TD (n = 32)		ASD (n = 47)			
	M	SD	M	SD	F (1,74)	η2P
DIMS	6.78	2.15	14.60	5.61	54.82 *	.42
SBD	3.50	0.84	4.38	1.73	7.39 *	.09
DA	3.28	0.81	5.45	2.41	22.85 *	.23
SWTD	8.06	2.26	11.98	4.41	14.73 *	.17
DOES	7.03	3.21	9.47	3.72	9.30 *	.11
SHY	3.13	1.60	3.62	1.82	2.70	.03
T. Sleep d	31.78	4.07	49.49	12.81	53.42 *	.42

Note. DIMS (Disorders of initiating and maintaining sleep), SBD (sleep breathing disorders), DA (disorders of arousal), SWTD (sleep-wake transition disorders), DOES (disorders of excessive somnolence), SHY (sleep hyperhidrosis), T. Sleep d (total sleep disturbances). (*) $p < .007$ (Bonferroni correction)

PROCESS program, specifically the PROCESS macro for SPSS (Hayes, 2018; Model 4), was employed for conducting the analyses. A total of 10,000 repetitions were performed to verify the mediator effect of sleep disturbances, with a confidence interval of 95%. The significance of the indirect effect was determined by assessing whether it significantly differed from zero, following the guidelines of MacKinnon et al. (2004) and Preacher and Hayes (2004). The analyses were adjusted for age, IQ, and medication.

3. Results

3.1. Sleep disturbances between children with ASD without intellectual disability and TD children

The results of the MANCOVA revealed a significant main effect of group on the different variables of sleep disturbances, controlling for age, IQ, and medication [Wilk's Lambda (Λ) = .52, F(6,69) = 10.57, p < .001, η2p = .48]. The statistical analysis for the covariates showed the following: age [Wilk's Lambda (Λ) = .96, F(6,69) = .41,p = .866, η2p = .03], IQ [Wilk's Lambda (Λ) = .90, F(6,69) = 1.24, p = .295, η2p = .09] and medication [Wilk's Lambda (Λ) = .91, F(6,69) = 1.02, p = .383, η2p = .08].

The confirmation ANCOVAs yielded the following results (see Table 2); significant differences were found between the groups, for disorders of initiating and maintaining sleep (DIMS), F(1,74)= 54.82 p < .001, η2p = .42; sleep breathing disorders (SBD), F(1,74) = 7.39 p = .008, η2p = .09; disorders of arousal (e.g., sleepwalking, sleep terrors) (DA), F(1,74)= 22.85 p < .001, η2p = .23; sleep-wake transition disorders (SWTD), F(1,74) = 14.73 p < .001, η2p = .17; disorders of excessive somnolence (DOES), F(1,74)= 9.30 p = .003, η2p = .11, and total sleep disturbances, F(1,74) = 53.42 p < .001, η2p = .42. However, no significant differences were found between both groups in the sleep hyperhidrosis (SHY) subscale, F(1,74)= 2.70 p = .104, η2p = .03 (Table 2).

3.2. The mediating role of sleep disturbances in the relationship between daily executive functions and learning problems in children with ASD without intellectual disability

First, a partial correlation analysis was conducted in the ASD group, including age, IQ, and medication as covariates (Table 3). The results revealed significant associations between learning problems and the Cognitive Regulation Index (CRI) (r = .34, p = .018), Global Executive Composite (GEC) (r = .41, p < .01), disorders of arousal (DA) (r = .38, p < .01), and total sleep disturbances (r = .49, p < .01). Additionally, significant correlations were found in the ASD group, between certain domains of daily executive functions and sleep disturbances. Specifically, the Emotional Regulation Index (ERI) showed a significant correlation with disorders of initiating and maintaining sleep (DIMS) (r = .35, p = .017); and the Cognitive Regulation Index (CRI) exhibited a significant correlation with total sleep disturbances (r = .32, p = .031).

The multivariate regressions conducted in the ASD group indicated that in Model 2, the combined predictors accounted for 34% of the variance in learning problems. The results showed that total sleep disturbances (β = .39, t = 2.82, p = .007) and Global Executive Composite (GEC) (β = .51, t = 2.17, p < .035) were significant predictors of increased learning problems in the ASD group, after adjusting for age, IQ, and medication (see Table 4).

The results of the correlation and regression analyses provided evidence supporting the need for a mediation analysis. The simple mediation model (Fig. 1), which examined the mediating role of sleep disturbances in the relationship between the Global Executive Composite and learning problems, demonstrated that the full model accounted for a significant 16.9% of the variance in learning problems (F(4, 42) = 2.14, R = 0.41, R2 = 0.169, p = 0.010). The total effect of executive function on learning problems was significant (β = 0.13, SE = 0.05, t = 2.25, 95% CI [0.0137, 0.249]), and the direct effect became non-significant when the indirect effect was considered (β = 0.077, SE = 0.05, t = 1.39, 95% CI [−0.0344, 0.189]). The indirect effect mediated by sleep disturbances, using

Table 3
Partial correlations between sleep disturbances, executive functions main domains and learning problems in children with ASD without intellectual disabilities. Adjusting for age, IQ, and medication.

	1	2	3	4	5	6	7	8	9	10	11
1. BRIEF-BRI	-										
2. BRIEF-ERI	.56 * *	-									
3. BRIEF-CRI	.61 * *	.20	-								
4. BRIEF-GEC	.82 * *	.68 * *	.82 * *	-							
5. Learning p	.28	.25	.34 *	.41 * *	-						
6. DIMS	.15	.35 *	.155	.09	.20	-					
7. SBD	.08	.09	.13	.09	.26	.27	-				
8. DA	.14	.04	.27	.16	.38 * *	.33 *	.16	-			
9. SWTD	.11	.11	.10	.03	.25	.34 *	.10	.38 * *	-		
10. DOES	.23	.09	.20	.20	.15	.27	.26	.37 *	.12	-	
11. SHY	.11	.04	.24	.16	.35 *	.23	.44 * *	.25	.21	.45 * *	-
12.T. Sleep d	.24	.07	32 *	.29	.49 * *	.57 * *	.42 * *	.61 * *	.46 * *	.67 * *	.45 * *

Note. BRI (Behavioural regulation index), ERI (Emotional regulation index), CRI (Cognitive regulation index), GEC (Global Executive Composite index), Learning p (Learning problem), DIMS (Disorders of initiating and maintaining sleep), SBD (sleep breathing disorders), DA (disorders of arousal), SWTD (sleep-wake transition disorders), DOES (disorders of excessive somnolence), SHY (sleep hyperhidrosis), T. Sleep d (Total Sleep disturbances)
* $p \leq .05$. * * $p \leq .01$

Table 4
Multiple linear regression models for total sleep disturbances and daily executive functions predicting learning problems in children with ASD without intellectual disability.

Models	B	SE	β	*p*	R2
1					.07
Age	.54	.31	.26	.088	
IQ	.02	.05	.07	.631	
Med	.05	.26	.03	.834	
2					.34 *
Age	.45	.27	.21	.112	
IQ	.05	.04	.01	.907	
Med	.12	.23	.07	.599	
T. Sleep d	.11	.04	.39	.007 *	
BRIEF-CRI	.09	.09	.22	.375	
BRIEF-GEC	.12	.05	.51	.035 *	

Note. BRIEF-CRI (Cognitive regulation index), BRIEF-GEC (Global Executive Composite index), T. Sleep d (Total Sleep disturbances), Med (Medication), IQ (intelligence quotient)
* $p \leq .05$. * * $p \leq .01$

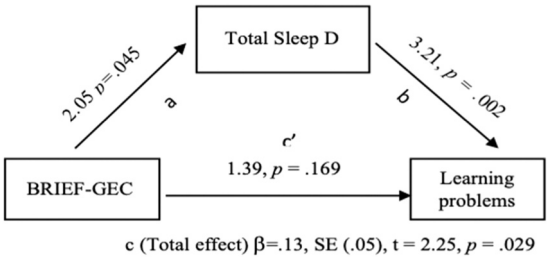

Fig. 1. Simple Mediation Analysis of Sleep disturbances on the relationship between EF and learning problems in the group of children with ASD without intellectual disability (Adjusting for age, IQ and medication).

bootstrapping with 10,000 repetitions and a 95% confidence interval (CI), was found to be statistically significant on the *path* between the Global Executive Composite and learning problems (CI [0.0011, 0.120]). As zero was not within this confidence interval, the findings suggest that the indirect effects were significant ($p < .05$). Analysis of the covariates indicated that age ($\beta = .69$, $p = .673$), IQ ($\beta = .12$, $p = .638$), and medication ($\beta = 2.20$, $p = .10$) did not play a significant role. Therefore, the mediation model was supported.

4. Discussion

The current study aimed to address two main objectives. Firstly, it sought to compare sleep disturbances in children with TD and children with ASD without intellectual disability. Secondly, it aimed to investigate the mediating role of sleep disturbances in the relationship between daily executive functioning and learning problems, specifically in the clinical group.

As hypothesized, the findings of this research suggest that sleep disturbances are significantly more prevalent in children with ASD without intellectual disability than in TD children. Specifically, the prevalence of sleep disturbances was 68.1% and 21.8%, respectively. This is consistent with previous studies that have used different measures, such as the Children's Sleep Habits Questionnaire (CSHQ) (Schwichtenberg et al., 2022), and have consistently reported higher prevalence rates of sleep problems in children with ASD without intellectual disability compared to TD children (Estes et al., 2023; Holingue et al., 2021; Köse et al., 2017; Reynolds et al., 2019). Similarly, our findings align with previous studies that employed the SDSQ to compare sleep disturbances among TD children and preschool and school-aged children with ASD without intellectual disability (Romeo et al., 2021; Tyagi et al., 2019).

Additionally, the present study found statistically significant differences between the two participant groups in nearly all subscales of the SDSC, indicating that the sleep quality of children with autism without intellectual disability is significantly lower compared to their TD peers. However, it is worth noting that there are differences with previous studies that used the same scale. In the studies mentioned above (Romeo et al., 2021; Tyagi et al., 2019), significant differences were found in the sleep hyperhidrosis subscale between TD children and children with ASD without intellectual disability, while no significant differences were observed in the disorders of arousal subscale. Furthermore, Romeo et al. (2021) reported no significant differences between the two participant groups in sleep breathing disorders and sleep-wake transition disorders. These variations in findings regarding the specific types of sleep problems can be attributed to the heterogeneity that characterizes autism spectrum disorder, making it difficult to define a singular sleep profile for individuals with ASD (Deliens et al., 2015).

Despite the inconsistencies in the literature, this study's results and existing evidence support the assertion that sleep disturbances are a complex and varied aspect of autism symptomatology (Mayes & Calhoun, 2009). This is crucial because sleep problems in individuals with ASD directly impact their quality of life and can affect social and adaptive functioning (Han et al., 2022; Whelan et al.,

2022). This study found a significant association between sleep and the BRIEF-2 Cognitive Regulation Index in children with ASD without intellectual disability. This suggests that sleep disturbances may influence metacognition, encompassing executive functions such as initiative, working memory, planning, organization of materials, and task monitoring. While the existing literature has mixed findings, our results align with some studies (Calhoun et al., 2020; Holingue et al., 2021) and contradict others (Gisbert-Gustemps et al., 2022), particularly the study by Tesfaye et al. (2021), where a relationship was found between sleep and subsequent behavioral regulation and inhibitory control, but not with the metacognition subdomain. These discrepancies may be partly explained by differences in study design, as Tesfaye et al. (2021) conducted a longitudinal analysis examining the association between parent-reported sleep measures at one-time point and subsequent teacher-reported measures of executive functioning several years later. The disparities in findings between the study by Gisbert-Gustemps et al. (2022) and the current research regarding the relationship of sleep disturbances and executive functioning in children with ASD may be due to methodological differences. Specifically, the statistical analyses conducted were different, as well as the covariates controlled in the analyses. In their case, these included concomitant ADHD and the severity of ASD, among other variables.

In this sense, the recent systematic review conducted by Karavasilis and Statiri (2022) suggests that the mixed findings in this area could be attributed to several factors, including the control of relevant variables that may influence the relationship between sleep disturbances and executive functioning. The present study maintained the association between sleep and the metacognition subdomain while controlling for age, IQ, and medication variables. Holingue et al. (2021) reported a similar finding after adjusting for these factors. However, when considering the symptoms of inattention and hyperactivity in children with ASD, the association between metacognition and sleep disturbances became non-significant. It is important to note that possible comorbidity with ADHD symptoms was not considered in the current research, highlighting the need for future studies to address this aspect and provide further evidence.

Another noteworthy finding is the significant association between the metacognition subdomain, global executive functioning, and learning problems in children with ASD without intellectual disability who participated in the study. This finding is in line with previous research indicating that executive functioning plays a role in academic achievement among school-aged children (Beisly et al., 2022; Cortés-Pascual et al., 2019; Zelazo & Carlson, 2020). It also aligns with earlier studies that have demonstrated a similar association in children with ASD (Bullen et al., 2022; Chen et al., 2019; Davidson et al., 2018), with our research extending beyond working memory to encompass other executive functions.

Moreover, the total score of sleep disturbances was significantly associated with learning problems. While some previous studies have not found a significant relationship between sleep and academic achievement in children with ASD (Mayes & Calhoun, 2009), it is logical to assume that if sleep problems impact the executive functioning of individuals with autism, it would have implications for their academic outcomes (Mazurek et al., 2019).

The simple mediation model yielded significant results, indicating that sleep disturbances mediate the relationship between global executive functioning and learning problems. Furthermore, when sleep disturbances were included in the model, the direct effect of executive function on learning problems became non-significant, suggesting a full mediation effect. These findings collectively suggest that sleep disturbances play a mediating role in the relationship between executive function and learning problems. Notably, a previous study examining a similar question did not yield the same result. While that study rejected the mediation model between working memory and learning problems, it concluded that sleep disturbances moderate the relationship (Calhoun et al., 2020). The disparity in findings could be attributed to differences in the focus on multiple executive functions in our study, the utilization of different measures for sleep and learning problems, and the variation in participant age between the two studies (adolescents versus children). Nonetheless, both studies suggest the involvement of sleep disturbances in the association between executive functioning and learning in individuals with autism without intellectual disability.

4.1. Implications for intervention

The results suggest that deficits in executive functioning and sleep disturbances may produce learning problems in children with ASD without intellectual disabilities. These findings have implications for both health and education professionals, who should value the neurodiversity of their patients or students and should not attribute learning problems to a mere lack of capability or intelligence. On the contrary, professionals should plan interventions to improve the learning and academic achievement of children with ASD from a multidimensional approach, considering other possible variables that could influence them, such as sleep disturbances.

Therefore, based on the findings of this research, addressing sleep disturbances may be a crucial aspect of interventions aimed at improving executive functions, learning, and academic achievement in school-aged children with ASD without intellectual disability. It is important to note that there is still limited evidence regarding effective interventions to improve sleep quality in individuals with ASD (Shaw et al., 2022). However, some promising interventions have shown positive results in improving sleep quality in children with autism, including pharmacological interventions such as melatonin administration and behavioral interventions such as physical activity or sound sleep interventions. These interventions have been associated with improvements in inhibitory control, internalizing symptoms, emotional behavioral disturbances, and overall quality of life (Deliens et al., 2015; Georén, Jansson-Fröjmark et al., 2022; pp. 0, 1359; Papadopoulos et al., 2022; Tse et al., 2019). Further research and the development of targeted interventions are needed to effectively address sleep disturbances and their impact on the functioning and well-being of individuals with ASD.

4.2. Limitations and further research

The present study is not without limitations, which should be considered when interpreting the findings. First, it is important to

note that all measures used in this study relied on parent-reported questionnaires. While these questionnaires provide valuable insights, they are subject to potential reporter bias. It is known that parent reports may differ from objective measures such as actigraphy or polysomnography when assessing sleep disturbances (Shaw et al., 2022; Surtees et al., 2019). However, it is also important to consider the limitations associated with objective measures, including their cost and potential discomfort for children with autism, particularly those with sensory sensitivities (Moore et al., 2017). Objective measures also typically capture data for a limited number of nights, whereas parent questionnaires gather information over a longer period (Díaz-Román et al., 2018). To address these limitations, future research could benefit from combining subjective and objective measures to obtain a more comprehensive understanding of sleep disturbances in children with ASD without intellectual disability.

Another notable limitation of the current study is the limited scope of variables monitored, with only age, medication, and IQ being considered. Given the known comorbidity of autism with anxiety problems, as well as other conditions like ADHD or intellectual disability, it is important to acknowledge that these factors may influence the prevalence of sleep disorders and their association with other domains such as executive functioning, learning, or behavior (Karavasilis & Statiri, 2022; Matson et al., 2008; Whelan et al., 2022). Therefore, future research could extend the study design to include participants with comorbidity with any of the aforementioned conditions, providing a more comprehensive understanding of the relationships involved.

Lastly, it is important to acknowledge the limitations of this study, including the small sample size, which restricts the generalizability of the findings. Additionally, it is worth noting that the participation of girls with autism in the study is underrepresented, despite the known higher prevalence and different types of sleep disturbances among girls compared to boys with ASD (Estes et al., 2023). Considering the significance of analyzing sleep quality in the autistic population, future research should aim to include a larger and more gender-balanced sample to provide a more comprehensive understanding of sleep disturbances in children with ASD without intellectual disability.

5. Conclusions

The findings of this study make a valuable contribution to the existing evidence concerning the high prevalence of sleep disturbances in children with ASD without intellectual disability. Moreover, the study addresses a notable research gap by examining the role of sleep in the relationship between global executive function and learning problems in this population. The results highlight that sleep disturbances are not isolated issues but substantially impact various aspects of well-being in individuals with autism. Specifically, the study uncovers a direct association between sleep problems and metacognition in school-aged children with ASD without intellectual disability. Additionally, the study identifies sleep and daily executive functioning as important predictors of learning problems in this population. These findings have significant implications, supporting the notion that sleep interventions can effectively improve executive functions and enhance academic achievement in children with autism without intellectual disability.

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Nora Choque-Olsson: Conceptualization, Writing – original draft, Writing – review & editing. **Eva Rosa:** Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Investigation, Supervision. **Simona de Stasio:** Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Carmen Berenguer:** Conceptualization, Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Irene Lacruz-Pérez:** Conceptualization, Investigation, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The author(s) declared no potential conflicts of interest with this article's research, authorship, and/or publication.

Data availability

Data will be made available on request.

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