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Assessment of sleep quality in pediatric patients using hearing aids and cochlear implants: cross sectionalstudy

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Abstract

Background Hearing loss in children can negatively impact various developmental domains, but its effect on sleep quality is often overlooked. This study aimed to evaluate and compare the sleep quality of school-aged children with hearing loss using different device modalities—specifically bilateral hearing aids, unilateral cochlear implants, bilateral cochlear implants, and bimodal stimulation—with that of their age- and gender-matched normal-hearing peers.

Results Children with hearing loss exhibited significantly higher total sleep disturbance scores compared to the control group (median total T-score: 64.0 vs. 51.0, $p < 0.001$). Specifically, the study group demonstrated significantly higher disturbances in sleep breathing disorders, disorders of arousal, sleep-wake transition disorders, and sleep hyperhidrosis (all $p < 0.001$). When comparing the study subgroups based on their specific hearing devices (bilateral hearing aids, unilateral cochlear implants, bilateral cochlear implants, and bimodal users), a significant difference was observed uniquely in the domain of disorders of initiating and maintaining sleep ($p = 0.004$); post-hoc analysis confirmed that bilateral cochlear implant users experienced clinical-level difficulties (mean T-score: 74.30 ± 11.10) compared to both bilateral hearing aid (55.80 ± 6.65; adjusted $p = 0.006$) and unilateral cochlear implant users (58.80 ± 5.67; adjusted $p = 0.012$). Additionally, a delayed age of hearing device fitting was positively correlated with increased sleep breathing disorders ($r = 0.324$, $p = 0.030$).

Conclusions The sleep quality of children with hearing loss is significantly more impaired compared to their normal-hearing peers, particularly concerning breathing, arousal, and sleep transitions. These findings support the clinical hypothesis that daytime auditory fatigue and sensory transition contrasts may negatively influence pediatric sleep architecture. Incorporating routine sleep screenings using standardized tools like the SDSC during audiological follow-ups is critical to facilitate timely multidisciplinary referrals to pediatric sleep specialists and ensure optimal holistic development.

Keywords Hearing loss, Hearing aid, Cochlear implant, Sleep quality, Child, Audiologist

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Background

Hearing loss can negatively affect children's language development, leading to delays in cognitive, social, and emotional domains compared to their normal-hearing peers [1]. Failure to detect hearing loss in the early stages leads to lifelong disabilities, poor academic performance, social maladjustment, and emotional distress [2].

Assistive technological devices, primarily hearing aids and cochlear implants, are the standard and most effective interventions to minimize these adverse effects. Following the fitting of these devices and intensive auditory rehabilitation, children can establish more effective communication, which positively influences their psychosocial development [3, 4]. However, adapting to these technological devices and the continuous effort to process artificial auditory stimuli impose a significant daily cognitive and auditory load on pediatric patients.

Sleep is a crucial component of quality of life and is of critical importance for children's physical growth, neurological development, and cognitive recovery [5]. Children with hearing loss often experience higher levels of stress, communication difficulties, and anxiety, which can indirectly disrupt their sleep patterns [6, 7]. Furthermore, the specific impact of using assistive auditory devices on sleep architecture is a growing clinical concern. The intensive nature of habilitation programs, the daily auditory fatigue, and the sudden transition from a sound-enriched environment during the day to absolute silence at night when devices are removed may trigger sleep initiation and maintenance problems, as well as arousal disorders [8, 9].

Despite the profound impact of sleep on neurobehavioral development, the specific influence of auditory rehabilitation devices on the sleep quality of pediatric patients remains underexplored in the current literature [10]. Therefore, the aim of this study was to evaluate the sleep quality of pediatric individuals using hearing aids and cochlear implants, to investigate the potential effects of device type and fitting age on sleep architecture, and to compare their sleep quality with that of their normal-hearing peers.

Additionally, while the primary focus remains on hearing-related clinical parameters, subgroup analyses based on gender and academic achievement were performed. Exploring gender differences is crucial as childhood sleep architecture and susceptibility to sleep-related disturbances can display significant physiological and developmental variations between sexes. Furthermore, since chronic daytime listening effort, cognitive overload, and subsequent sleep disruptions are closely linked to cognitive performance and overall school functioning in pediatric populations, analyzing sleep quality in relation to academic achievement provides a holistic clinical understanding of how auditory fatigue might interact with the daily cognitive demands and academic lives of these children [11, 12].

Methods

Study design

This descriptive and cross-sectional study was conducted to evaluate the sleep quality of pediatric patients using assistive auditory devices. The sample size was determined using G*Power 3.1 software. Based on a two-tailed test with an alpha level of 0.05, a statistical power (1-β) of 0.80, and an anticipated effect size of 0.60, it was calculated that a minimum of 45 participants per group (a total of 90 participants) was required.

The study included a total of 90 children aged between 6 and 16 years. The study group consisted of 45 children diagnosed with hearing loss who had been actively using assistive auditory devices (hearing aids or cochlear implants) for at least six months. The control group consisted of 45 age- and gender-matched normal-hearing peers. Children with additional systemic, psychiatric, or neurodevelopmental pathologies that could independently affect sleep quality, as well as those with incomplete survey forms, were excluded from the study. Data were collected from various pediatric rehabilitation centers and primary schools to ensure a representative sample.

To ensure that secondary diagnoses did not act as confounding variables, children with active, uncontrolled major neurological, systemic, or acute sleep disorders of non-audiological origin were excluded from the study. The additional diagnoses reported in the study group (including stable language delay, mild intellectual disability, stable stuttering, and genetic syndromes) represented stable, secondary clinical co-morbidities commonly managed in pediatric audiological habilitation settings. To verify that these stable conditions did not confound our primary findings, a sensitivity analysis was conducted comparing the overall sleep quality (total SDSC T-scores) of children with isolated sensorineural hearing loss ($n = 36$) against those with these stable secondary co-morbidities ($n = 9$). No statistically significant difference was found between the two subgroups ($U = 153.5$, $p = 0.520$), confirming that the presence of these stable secondary conditions did not significantly skew or confound the sleep disturbance outcomes.

Data collection

Data were collected from the parents of the participants through face-to-face interviews using a Personal Information Form and the Sleep Disturbance Scale for Children (SDSC).

Personal information form A questionnaire developed by the researchers to evaluate the sociodemographic and clinical characteristics of the participants, including age, gender, degree of hearing loss, type of assistive device, age at device fitting, and total duration of device use. Active daily device usage was defined as utilizing the assistive auditory device for more than 8 h per day, which was assessed subjectively based on parental reports during face-to-face interviews and cross-checked with the children's routine clinical audiological follow-up records. Additionally, the child's academic achievement level was assessed subjectively via a 5-point Likert-type scale (Very poor, Poor, Moderate, Good, Very good) incorporated into the Personal Information Form, completed by the parents based on their child's school performance over the last academic year.

Sleep Disturbance Scale for Children (SDSC) Developed by Bruni et al. (1996) to assess sleep disturbances in children aged 6 to 16 years, the SDSC is a 26-item Likert-type scale completed by parents [13]. The items are scored from 1 (never) to 5 (always). The total score ranges from 26 to 130, with higher scores indicating an increased frequency and severity of sleep symptoms. The scale is divided into six subdomains: disorders of initiating and maintaining sleep (DIMS), sleep breathing disorders (SBD), disorders of arousal (DA), sleep-wake transition disorders (SWTD), disorders of excessive somnolence (DES), and sleep hyperhidrosis (SHY). For clinical evaluation, raw SDSC scores were converted into standardized T-scores. According to the scale's guidelines, a T-score < 56 is classified as normal, 56–70 is borderline, and a T-score ≥ 70 indicates clinical-level sleep disturbances requiring medical attention. The validity and reliability of the Turkish version of the scale were established by Agadayi, Çelik, and Ayhan Baser (2020) [14]. The necessary permissions to use the Turkish version of the scale in this study were obtained from the authors via e-mail.

Statistical analysis

Statistical analyses were performed using Jamovi software (The jamovi project) [15, 16]. Descriptive statistics were presented as medians and interquartile ranges (IQR) for continuous variables, and as frequencies (n) and percentages (%) for categorical variables. The conformity of continuous variables to a normal distribution was assessed using the Shapiro-Wilk test. Since the data did not meet the assumptions of normal distribution, non-parametric tests were employed for inferential statistics. The Mann-Whitney U test was used to compare two independent groups, while the Kruskal-Wallis H test was applied for comparisons involving three or more independent groups. The direction and strength of the relationships between continuous clinical variables and sleep scores were evaluated using Spearman's rank correlation analysis. A p-value of < 0.05 was considered statistically significant for all analyses.

Results

Demographic and clinical characteristics

The study included a total of 90 children, comprising a study group of 45 children with hearing loss who used assistive auditory devices and a control group of 45 normal-hearing children. The mean age of the study group was 11.20 ± 3.72 years, and that of the control group was 10.60 ± 2.84 years. When evaluating gender distribution, 51.1% of the study group and 53.3% of the control group were female. The demographic and clinical characteristics of the participants are summarized in Table 1. All children in the study group used their auditory devices actively and regularly for more than 8 h a day, thus controlling for potential effects related to insufficient device usage. For the children utilizing bilateral cochlear implants ($n = 4$, 8.9%), all implantations were performed sequentially, with a mean age of 5.20 ± 1.10 years at the second implantation.

Comparison of sleep quality based on the presence of hearing loss

Since the data did not meet the assumptions of normal distribution, the non-parametric Mann-Whitney U test was applied to investigate the differences in the Sleep Disturbance Scale for Children (SDSC) T-scores between the study and control groups. A statistically significant difference was found between the groups regarding the total sleep quality score ($U = 516.0$, $p < 0.001$). The median total T-score of children with hearing loss (64.0) was significantly higher compared to their normal-hearing peers (51.0).

When examining the subdomains of the scale, the study group demonstrated significantly higher T-scores in Sleep Breathing Disorders (SBD) ($U = 501.0$, $p < 0.001$), Disorders of Arousal (DA) ($U = 443.0$, $p < 0.001$), Sleep-Wake Transition Disorders (SWTD) ($U = 557.0$, $p < 0.001$), and Sleep Hyperhidrosis (SHY) ($U = 575.0$, $p < 0.001$). However, no significant differences were observed in Disorders of Initiating and Maintaining Sleep (DIMS) ($p = 0.322$) and Disorders of Excessive Somnolence (DES) ($p = 0.222$) (Table 2).

Comparison of sleep quality based on hearing device type

The Kruskal-Wallis H test was applied to determine whether the sleep quality T-scores differed according to the type of auditory rehabilitation device used. No statistically significant differences were found between the device groups in terms of total sleep scores, SBD, DA, SWTD, DES, and SHY subdomains ($p > 0.05$).

Table 1 Demographic and clinical characteristics of the study and control groups

Variables	Study Group ($n=45$)	Control Group ($n=45$)	t / χ2	*p*-value
Age (years) (Mean ± SD) [Min–Max]	**11.20 ± 3.72 [6.0–16.0]**	**10.60 ± 2.84 [6.0–16.0]**	**t = 0.83**	**0.407**
Total household members (Mean ± SD) [Min–Max]	**5.02 ± 1.34 [3.0–8.0]**	**5.04 ± 1.51 [3.0–9.0]**	**t = -0.06**	**0.945**
Gender (n, %)				
- Female	**23 (51.1%)**	**24 (53.3%)**	**χ2 = 0.04**	**0.835**
- Male	**22 (48.9%)**	**21 (46.7%)**		
Additional disability /diagnosis (n, %)				
- No	**36 (80.0%)**	**45 (100.0%)**	**χ2 = 10.00**	**0.002**
- Yes*	**9 (20.0%)**	**0 (0.0%)**		
Hearing Device Type (n, %)				
- Bilateral Hearing Aid	**28 (62.2%)**	-	-	-
- Unilateral Cochlear Implant	**12 (26.7%)**	-		
- Bilateral Cochlear Implant	**4 (8.9%)**	-		
- Bimodal (CI + HA)	**1 (2.2%)**	-		
Hearing Loss Degree / dB PTA (n, %)				
- Mild (26–40 dB)	**3 (6.7%)**	-	-	-
- Moderate (41–55 dB)	**8 (17.8%)**	-		
- Moderate-Severe (56–70 dB)	**15 (33.3%)**	-		
- Severe (71–90 dB)	**6 (13.3%)**	-		
- Profound (≥ 91 dB)	**13 (28.9%)**	-		
Clinical Characteristics (Mean ± SD)				
- Age at diagnosis (years)	**3.16 ± 2.34 [0.5–10.0]**	-	-	-
- Age at device fitting (years)	**3.55 ± 2.20 [0.8–11.0]**	-		
- Duration of device use (years)	**6.84 ± 3.38 [0.6–13.0]**	-		

Note. HL: Hearing Loss; NH: Normal Hearing; SD: Standard Deviation; PTA: Pure-Tone Average. All study group participants had bilateral sensorineural hearing loss. *Additional diagnoses in the study group and their respective device utilization include: intellectual disability ($n=3$, bilateral hearing aid), language delay ($n=1$, bilateral CI), schizophrenia ($n=1$, bilateral CI), facial anomaly ($n=1$, bilateral hearing aid), stuttering ($n=1$, bilateral hearing aid), Primrose syndrome ($n=1$, unilateral CI), and ocular problems ($n=1$, bilateral hearing aid). Bold p-values indicate statistical significance ($p<0.05$)

Table 2 Comparison of sleep quality T-scores based on the presence of hearing loss

Variables (T-Score)	Study Group ($n=45$) Median (Mean ± SD)	Control Group ($n=45$) Median (Mean ± SD)	U	*p*-value
DIMS	58.0 (58.4 ± 8.47)	56.0 (55.6 ± 9.05)	891.0	0.322
SBD	60.0 (59.3 ± 10.64)	50.0 (51.4 ± 8.83)	501.0	**< 0.001**
DA	55.0 (63.7 ± 13.07)	45.0 (51.8 ± 10.51)	443.0	**< 0.001**
SWTD	55.0 (56.6 ± 8.29)	48.0 (50.1 ± 9.36)	557.0	**< 0.001**
DES	61.0 (63.2 ± 13.67)	58.0 (59.6 ± 12.70)	862.0	0.222
SHY	54.0 (55.0 ± 7.63)	48.0 (50.0 ± 6.55)	575.0	**< 0.001**
Total Score	**64.0 (63.2 ± 10.59)**	**51.0 (53.9 ± 11.01)**	**516.0**	**< 0.001**

Note. SD: Standard Deviation. DIMS: Disorders of Initiating and Maintaining Sleep; SBD: Sleep Breathing Disorders; DA: Disorders of Arousal; SWTD: Sleep-Wake Transition Disorders; DES: Disorders of Excessive Somnolence; SHY: Sleep Hyperhidrosis. Bold p-values indicate statistical significance ($p<0.05$)

However, a significant difference was detected in the DIMS subdomain based on the device type ($\chi2=13.369$, $p=0.004$). Descriptive statistics revealed that while the mean DIMS T-scores for hearing aid users (55.80 ± 6.65) and unilateral cochlear implant users (58.80 ± 5.67) were within normal limits, the mean score for bilateral cochlear implant users was significantly higher (74.30 ± 11.10). To determine which specific device groups differed significantly, post-hoc pairwise comparisons were conducted using Dunn's test with Bonferroni correction.

These pairwise comparisons confirmed that children utilizing bilateral cochlear implants had significantly higher DIMS T-scores compared to both bilateral hearing aid users (adjusted $p=0.006$) and unilateral cochlear implant users (adjusted $p=0.012$). No statistically significant differences in DIMS scores were observed between bilateral hearing aid users and unilateral cochlear implant users, or between any other device groups (adjusted $p>0.05$). According to the clinical evaluation criteria of the SDSC (T-score ≥ 70), children using bilateral cochlear implants experienced clinical-level problems in falling asleep and maintaining sleep, which accounted for the significant difference between the groups (Table 3).

Correlation between clinical characteristics and sleep quality

Spearman's rank correlation analysis was performed to examine the relationship between the clinical variables (age at diagnosis, age at device fitting, duration of device use) and SDSC scores in the study group. No statistically significant relationships were found between the age of hearing loss diagnosis, duration of device use, and any of

Table 3 Comparison of sleep quality scores according to the type of hearing device

SDSC Subdomains	Bilateral HA ($n=28$)	Unilateral CI ($n=12$)	Bilateral CI ($n=4$)	Bimodal ($n=1$)	χ2	*p*-value
DIMS (Mean ± SD)	55.80 ± 6.65	58.80 ± 5.67	74.30 ± 11.10	62.00	13.369	**0.004**
SBD (Mean ± SD)	58.40 ± 9.10	59.10 ± 10.20	61.20 ± 8.50	55.00	0.317	0.957
DA (Mean ± SD)	62.10 ± 11.40	64.30 ± 12.10	65.00 ± 9.80	58.00	1.833	0.608
SWTD (Mean ± SD)	55.40 ± 7.20	57.10 ± 8.10	59.00 ± 6.40	52.00	5.550	0.136
DES (Mean ± SD)	61.90 ± 12.30	63.80 ± 11.50	66.10 ± 10.90	60.00	2.748	0.432
SHY (Mean ± SD)	54.10 ± 6.80	55.30 ± 7.20	56.40 ± 5.90	51.00	0.920	0.821
TOTAL (Mean ± SD)	62.10 ± 9.80	64.10 ± 10.40	66.80 ± 11.20	59.00	5.830	0.120

Note. HA: Hearing Aid; CI: Cochlear Implant. Bold p-values indicate statistical significance ($p<0.05$)

Table 4 Correlation analysis between clinical characteristics and sleep quality scores

Variables (T-Score)	Age at diagnosis (years)	Age at device fitting (years)	Duration of device use (years)
DIMS	$r=-0.075$, $p=0.625$	$r=-0.079$, $p=0.607$	$r=0.065$, $p=0.671$
SBD	$r=0.230$, $p=0.128$	$\boldsymbol{r=0.324}$, $\boldsymbol{p=0.030}$	$r=-0.023$, $p=0.882$
DA	$r=0.251$, $p=0.096$	$r=0.245$, $p=0.105$	$r=0.063$, $p=0.680$
SWTD	$r=0.083$, $p=0.590$	$r=0.070$, $p=0.648$	$r=0.101$, $p=0.510$
DES	$r=0.238$, $p=0.116$	$r=0.206$, $p=0.174$	$r=0.106$, $p=0.490$
SHY	$r=0.133$, $p=0.382$	$r=0.135$, $p=0.378$	$r=-0.048$, $p=0.752$
Total Score	$r=0.221$, $p=0.144$	$r=0.116$, $p=0.449$	$r=0.145$, $p=0.342$

Note. r represents Spearman's rank correlation coefficient. Bold values indicate statistical significance ($p<0.05$)

the sleep subdomains or total scores ($p>0.05$). However, a positive and statistically significant correlation was identified between the age at device fitting and the SBD subdomain ($r=0.324$, $p=0.030$) (Table 4).

Comparison of sleep quality based on gender

The Mann-Whitney U test indicated no significant difference in the total sleep quality scores between male and female participants across the entire cohort ($N=90$) (U = 859.0, $p=0.222$). However, significant differences were found in the DIMS (U = 759.0, $p=0.041$) and SHY (U = 755.0, $p=0.032$) subdomains. To ensure the validity of sex-based comparisons, baseline characteristics were compared between male ($n=43$) and female ($n=47$) participants across the entire cohort. Statistical analysis confirmed that the male and female subgroups were highly comparable, with no statistically significant differences in terms of mean age ($p>0.05$), the distribution of hearing status (hearing loss versus normal hearing; $p>0.05$), or the specific types of assistive hearing devices utilized ($p>0.05$). This baseline homogeneity effectively rules out potential confounding effects on the reported sex-related sleep outcomes. Male children had significantly higher median T-scores in sleep initiation/maintenance and sleep sweating compared to females, although their overall scores remained below the clinical threshold (Table 5).

Comparison of sleep quality based on academic achievement

The Kruskal-Wallis H test applied to evaluate the relationship between academic achievement levels and sleep quality revealed no statistically significant differences in any of the sleep subdomains or the total score ($p>0.05$). These findings suggest that sleep quality was not a differentiating factor based on academic achievement in this study sample (Table 6).

Discussion

The present study aimed to evaluate the sleep quality of pediatric patients using auditory rehabilitation devices, such as hearing aids and cochlear implants, and to compare it with that of their normal-hearing peers. The results demonstrated that children with hearing loss

Table 5 Comparison of sleep quality T-scores based on gender

Variables (T-Score)	Male Children ($n=43$) Median (Mean ± SD)	Female Children ($n=47$) Median (Mean ± SD)	U	*p*-value
DIMS	60.0 (59.20 ± 10.26)	56.0 (55.10 ± 6.80)	759.0	**0.041**
SBD	55.0 (56.20 ± 10.17)	50.0 (54.70 ± 10.85)	867.0	0.237
DA	55.0 (60.20 ± 13.84)	55.0 (55.40 ± 12.33)	781.0	0.053
SWTD	55.0 (54.30 ± 9.09)	52.0 (52.60 ± 9.65)	892.0	0.334
DES	65.0 (62.00 ± 12.00)	61.0 (60.90 ± 14.38)	946.0	0.599
SHY	54.0 (54.30 ± 7.96)	48.0 (50.90 ± 6.76)	755.0	**0.032**
Total Score	**62.0 (60.40 ± 12.22)**	**57.0 (56.80 ± 11.08)**	**859.0**	**0.222**

Note. SD: Standard Deviation. Bold p-values indicate statistical significance ($p<0.05$)

Table 6 Comparison of sleep quality T-scores based on academic achievement level

Variables (T-Score)	χ2 (Kruskal-Wallis)	df	*p*-value
DIMS	2.580	4	0.630
SBD	8.620	4	0.071
DA	7.810	4	0.099
SWTD	4.820	4	0.306
DES	1.600	4	0.808
SHY	4.370	4	0.359
Total Score	**5.350**	**4**	**0.253**

Note. df: Degrees of Freedom. Statistical significance was accepted as $p < 0.05$

experience significantly poorer sleep quality compared to their normal-hearing counterparts, exhibiting higher disturbance levels particularly in sleep breathing, arousal, sleep-wake transitions, and sleep hyperhidrosis. It is well documented that sleep disturbances in childhood reduce health-related quality of life, impair cognitive performance, and lead to lifelong neurobehavioral morbidities. By utilizing a standardized clinical questionnaire to evaluate sleep disturbances, this study provides valuable insights supporting the hypothesis that the chronic physiological and cognitive demands associated with pediatric hearing loss may potentially persist into the nocturnal period.

The high prevalence of sleep problems in children with hearing loss has traditionally been attributed to psychosocial factors, such as communication difficulties, social isolation, and elevated parenting stress, which indirectly disrupt sleep architecture [6, 7]. However, our novel findings—particularly the elevated scores in arousal and sleep-wake transition disorders—suggest a more complex neurocognitive dynamic associated with auditory device use. Children utilizing hearing aids or cochlear implants must continuously exert a substantial "listening effort" and utilize higher working memory capacities to process artificial auditory input, which imposes a substantial "cognitive load" throughout the day [17, 18].

In fact, recent objective electroencephalography (EEG) studies have proven that deaf children with hearing devices exhibit significantly altered parietal alpha and frontal theta rhythm variations during speech-in-noise tasks, which have been proposed as biological indicators of intense cognitive load and rapid auditory fatigue [19]. The significantly increased arousal and sleep-wake transition disruptions observed uniquely in our study group are may potentially represent clinical manifestations of this daily cognitive overload and accumulated auditory fatigue. While auditory devices provide crucial signal-to-noise ratio gains, the constant cognitive demand to process these signals could potentially influence the child's daily neural energy expenditure, suggesting a possible mechanism that may make smooth sleep transitions biochemically more difficult [18, 20].

Furthermore, a hallmark finding of our study regarding device modality was that children using bilateral cochlear implants experienced clinical-level problems specifically in initiating and maintaining sleep. Children undergoing intensive auditory rehabilitation with bilateral implants are exposed to a highly enriched, hyper-stimulating artificial sound environment during the day. When these devices are removed at bedtime, the sudden transition from intense auditory stimulation to absolute silence has been hypothesized to induce a subjective experience akin to acute sensory deprivation. This drastic environmental contrast could potentially contribute to bedtime anxiety and autonomic hyperarousal, which may theoretically influence stress response pathways—such as the hypothalamic-pituitary-adrenal axis—thereby making sleep initiation more challenging for these children [6, 20]. While these underlying neurophysiological mechanisms require direct objective investigation, our findings draw clinical attention to the potentially significant, yet often overlooked, psychological and sensory burden of the 'device-off' period in bilateral implant users.

Additionally, our study identified a significant positive correlation between a delayed device fitting and increased sleep breathing disorders. Delayed access to auditory rehabilitation prolongs the period of sensory deprivation, communication-related stress, and social isolation. Within the scientific literature, chronic stress and loneliness in early childhood have been associated with prolonged cortisol secretion, which is suggested to negatively affect neurological development and autonomic regulation [20]. Early identification and timely intervention not only promote language development but may also potentially reduce the long-term cognitive strain, thereby potentially supporting the healthy development of the child's sleep architecture.

Limitations of the study

This study has several limitations that should be considered when interpreting the results. First, the research was conducted in a single geographic region with a relatively limited sample size, which may restrict the broad generalizability of the findings. Specifically, while our overall sample size ($N = 90$) was fully powered for the primary study comparisons, the sample sizes within the specific hearing device subgroups (particularly bilateral and bimodal users) were small, which may limit the statistical power and generalizability of the device-specific subgroup findings.

Second, sleep quality was evaluated using the SDSC, a parent-reported questionnaire. Although it is a highly validated clinical tool, it inherently relies on subjective parental observations rather than objective physiological data. Furthermore, the cross-sectional design of the study prevents the establishment of definitive causal relationships. Additionally, the relatively wide age range of the participants (6–16 years) represents a limitation, as sleep architecture and patterns undergo substantial physiological and developmental changes during the transition from childhood to adolescence, introducing potential age-related heterogeneity to the outcomes. Future prospective longitudinal studies incorporating objective measurements, such as polysomnography or nocturnal electroencephalography, are warranted to precisely quantify the neurophysiological impact of daytime auditory fatigue on sleep architecture. Lastly, while major confounders were excluded and stable secondary comorbidities were statistically verified not to confound the findings, specific psychosocial variables like detailed family dynamics and socioeconomic status were not exhaustively controlled.

Conclusions

In conclusion, pediatric patients using hearing aids and cochlear implants experience significantly poorer sleep quality compared to their normal-hearing peers, particularly manifesting as sleep breathing disorders, arousal difficulties, sleep hyperhidrosis, and sleep-wake transition disruptions. These findings support the clinical hypothesis that the intense cognitive load and auditory fatigue experienced during daytime listening effort may potentially persist into the nocturnal period as neurophysiological disruptions. Furthermore, specific clinical parameters critically influence sleep architecture; a delayed age of device fitting is positively associated with increased sleep breathing disorders, and children utilizing bilateral cochlear implants face distinct clinical-level challenges in initiating and maintaining sleep.

Given the profound impact of sleep on neurocognitive and physical development, sleep quality assessments must no longer be overlooked. They should be routinely integrated into the comprehensive audiological management and follow-up programs for children with hearing loss. Specifically, audiologists should utilize standardized screening tools like the SDSC during routine follow-ups to identify at-risk pediatric patients, facilitating timely referrals to pediatric sleep specialists, behavioral sleep medicine clinics, or multidisciplinary pediatric clinics when sleep disturbances are clinically suspected to ensure optimal holistic development and well-being.

Abbreviations

CDC	Centers for Disease Control and Prevention
DA	Disorders of Arousal
DES	Disorders of Excessive Somnolence
df	Degrees of Freedom
DIMS	Disorders of Initiating and Maintaining Sleep
EEG	Electroencephalography
IQR	Interquartile Range
SBD	Sleep Breathing Disorders
SD	Standard Deviation
SDSC	Sleep Disturbance Scale for Children
SHY	Sleep Hyperhidrosis
SWTD	Sleep-Wake Transition Disorders

Author contributions

U.K.D. and Z.D. confirm contribution to the paper as follows: study conception and design: U.K.D., Z.D.; data collection: U.K.D.; analysis and interpretation of results: Z.D.; draft manuscript preparation: U.K.D., Z.D.; critical revision of the manuscript: Z.D. All authors reviewed the results and approved the final version of the manuscript.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval was granted by the Ethics Committee of Istanbul Gelisim University (Approval Date: 17.04.2026, Approval Number: 2026-05-34). Written informed consent was obtained from the parents or legal guardians of all pediatric participants included in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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