

Exploratory Analysis of Sleep–Wake Rhythms and Sensory Processing in School-Aged Children with Autistic Spectrum Disorder: An Actigraphic Study

Yuki Kondo¹, Kenji Tsuchiya^{1,2}, Masako Matsushita¹, Hiroko Takeshige³, Fusae Tozato⁴

¹Department of Rehabilitation, Nagano University of Health and Medicine, Nagano, Nagano, Japan; ²Graduate School of Health Sciences, Nagano University of Health and Medicine, Nagano, Nagano, Japan; ³Department of Children's Mental and Physical Developmental Health Care, Takeshige Hospital, Nagano, Nagano, Japan; ⁴Department of Rehabilitation Science, Sendai Seiyō Gakuin University, Sendai, Miyagi, Japan

Correspondence: Kenji Tsuchiya, Department of Rehabilitation, Nagano University of Health and Medicine, 11-1 Imaihara, Kawanakajima-machi, Nagano, Nagano, Japan, Tel +81-26-214-0419, Fax +81-26-283-6122, Email tsuchiya.kenji@shitoku.ac.jp

Purpose: This study aimed to explore and examine the relationship between sleep–wake rhythms and sensory processing characteristics in school-age children with autistic spectrum disorder (ASD) using objective sleep measurement indices.

Patients and Methods: This cross-sectional exploratory study included 30 children with ASD aged 6–9 years. Sleep–wake rhythms were recorded continuously for at least 14 days using a waist-worn actigraph (MTN-220) and analyzed with SleepSign Act. Sensory processing ability was assessed using the Japanese version of the Sensory Profile (SP-J), with SP-J quadrant and sensory processing scores. Associations between sleep variables and SP-J quadrant and sensory processing scores were examined using Spearman's rank correlation coefficient, applying Bonferroni correction within each pre-specified correlation set.

Results: Of the 30 children initially enrolled, 11 were excluded, yielding data from 19 participants. After Bonferroni correction, no significant associations were found between SP-J quadrant scores and sleep variables ($r = -0.411-0.540$). Regarding associations with sensory processing scores, the oral sensory score showed a positive correlation with the mean wake time ($r = 0.698, p = 0.006$). However, no other significant associations were found between sensory processing scores and sleep variables.

Conclusion: These results suggest that the relationship between oral sensory scores and the average wake time remains strong even during the school-age period when sleep–wake rhythms change. Although exploratory, this study provides foundational insights with clinical significance for understanding and supporting sleep disorders in children with ASD.

Keywords: sleep–wake rhythm, autistic spectrum disorder, school-aged children, sensory processing, actigraphy

Introduction

Autistic spectrum disorder (ASD) is “a neurodevelopmental disorder characterized by persistent deficits in social communication and interpersonal interaction, including restricted and repetitive patterns of behavior, interests, and activities”, as defined in the American Psychiatric Association's 2013 Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM–5).¹ Children with ASD have been reported to be more likely to experience sleep–wake rhythm abnormalities. Sleep problems are observed in 20–25% of typically developing children and more than 50% of children with ASD, which is two to three times higher than that in typically developing children.^{1–4} Additionally, a review comparing objectively measured sleep parameters (primarily using polysomnography and actigraphy) between children with ASD and typically developing children showed that children with ASD had a shorter total sleep time, longer sleep onset latency, and lower sleep efficiency than typically developing children,^{5,6} indicating sleep quality issues. Among these, children reaching school age experience significant changes in their living environment, such as school life, extracurricular activities, cram school attendance, friendships, and digital media use, which may disrupt their sleep schedules and sleep quality. Sleep problems during the school-age years have shown association with emotional, behavioral, and academic difficulties, such as depression,⁷ school refusal,⁸ and academic performance,⁹ potentially

having broad effects on daily life and social adaptation. Therefore, sleep problems in school-aged children with ASD represent a critical clinical challenge that cannot be overlooked. Thus, understanding the underlying factors, identifying elements that can lead to assessment and support, and integrating this knowledge into clinical and educational settings for evaluation and intervention are crucial.

Atypical sensory processing is a core feature of ASD, reported in 69–95% of cases.¹⁰ These atypical sensory processing difficulties are associated with anxiety, attention deficits, problem behaviors, sleep disturbances, and gastrointestinal symptoms, potentially requiring clinical consideration.¹¹ Furthermore, heightened anxiety is associated with increased reactivity to sensory input,^{12,13} potentially exacerbating related symptoms. Atypical sensory processing may contribute to difficulty initiating and maintaining sleep through disrupted arousal regulation and environmental stimuli (such as light, sound, and touch). Additionally, Dunn's sensory processing framework¹⁴ facilitates the identification of sensory processing characteristics associated with specific sleep parameters (eg, nighttime awakenings and sleep duration) by characterizing quadrant patterns (eg, hypersensitivity and under-registration) and differences in sensory processing. Therefore, examining sensory processing characteristics based on the four quadrants and sensory modalities in conjunction with sleep measurements may contribute to elucidating clinically meaningful mechanisms underlying sleep problems in children with ASD.

Previous studies have frequently employed subjective measures such as the children's sleep habit questionnaire (CSHQ) to analyze sleep habits.^{15,16} Furthermore, several studies have examined the relationship between CSHQ and sensory profile (SP) scores. Mazurek reported that anxiety disorders and sensory sensitivity were significantly associated with sleep disorders.¹⁵ Furthermore, in a study of children aged 3–7 years with ASD, Tzischinsky et al reported that CSHQ scores were associated with tactile and oral sensory processing, particularly low tactile thresholds.¹⁶ Thus, the association of specific sensory patterns assessed by subjective measures with sleep problems is gradually becoming clearer.^{17,18} However, parent-reported sleep assessments using subjective scales were reported to underestimate nighttime sleep and overestimate sleep duration.¹⁹ Although sleep questionnaires and sleep logs are practical for long-term monitoring in home settings, they do not agree well with actigraphy, and subjective reports may exhibit systematic biases in estimating sleep timing and duration.²⁰ Compared with actigraphy, an objective measure of sleep, parental records have lower sensitivity in detecting nighttime awakenings.²¹ Parents of older or more independent children may not accurately report their child's nighttime awakenings or other symptoms. Numerous studies using subjective measures have emphasized the need for objective indicators to assess sleep–wake rhythms.^{16–18}

Previous studies investigating the relationship between sleep–wake rhythms and sensory processing characteristics in children with ASD have often focused on preschoolers or covered a broad age range from preschool to school age, with very few studies specifically targeting school-age children. Furthermore, these studies often relied on parental subjective measures for sleep assessment. To the best of our knowledge, only Kosaka et al (2021) investigated the relationship between sleep–wake rhythms and sensory processing characteristics by actigraphy; however, the study was limited to the early childhood period.²² Therefore, whether a relationship exists between sleep–wake rhythms and sensory processing characteristics using objective measures in school-aged children with ASD remains insufficiently elucidated.

This study aimed to exploratory examine the relationship between sleep–wake rhythms and sensory processing characteristics in school-age children with autism spectrum disorder (ASD) using objective sleep measurement indices. This study represents the first report to explore the relationship between sensory processing characteristics and objective sleep indicators in school-aged children with ASD. Clarifying this relationship may provide a foundation for understanding sleep problems in school-age children with ASD and be beneficial for considering assessment and support strategies in clinical and educational settings. Furthermore, the findings may serve as foundational knowledge for future research aiming to elucidate the relationship between sleep disorders and sensory processing characteristics, paving the way for future intervention studies and predictive model development research.

Materials and Methods

Participants

This cross-sectional observational study included children aged 6–9 years who attended the pediatric outpatient clinic at Takeshige Hospital between January and April 2022 and were diagnosed with ASD according to the DSM-5 criteria.

The inclusion criteria were as follows: (1) being a boy or girl aged 6–9 years, (2) having a diagnosis of ASD based on DSM-5 criteria, (3) having visited the pediatric outpatient department at Takeshige Hospital between January and April 2022, (4) being able to wear an activity monitor during the planned recording period, and (5) having a parent or guardian able to complete the questionnaire.

The exclusion criteria were as follows: (1) comorbid neurodevelopmental diagnoses such as attention-deficit/hyperactivity disorder, (2) Intelligence Quotient (IQ) ≤ 75 , (3) current treatment for a sleep disorder, and (4) severe psychosomatic comorbidities that could contribute to sleep disturbance.

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Review Committee of Nagano University of Health and Medicine (Approval No. 2021–2). Written informed consent was obtained from parents/guardians, and assent was obtained from the children when appropriate.

Sample Size Calculation

In a previous study examining the association between sleep–wake rhythms and sensory processing characteristics in children with ASD,²² the reported effect size was $r = 0.59$. In the present study, repeated correlation analyses were performed across the four quadrant scores and six sensory processing score domains, necessitating multiple comparison corrections. The Bonferroni method was applied for multiple comparison corrections. Although the significance levels were 0.012 (0.05/4) and 0.008 (0.05/6) for the quadrant and sensory processing score, respectively, we set the significance level at 0.008.²³ Statistical power was set at the conventional level of 0.80.²⁴ Based on these parameters, the required sample size was calculated using G*Power 3.1,^{25,26} assuming an effect size of 0.59, an alpha level of 0.008, and a power of 0.80. Accordingly, 27 participants were required. In addition, previous actigraphy-based studies involving children with ASD have reported sample sizes of 32^{27,28} and 20.²² Based on these findings, the sample size for the present study was set at 30 participants.

Measures

Basic Information

Gender, age, week of conception, birth weight, and intellectual ability were obtained from medical record information with the permission of the attending physician. Intellectual abilities were transferred from the “FSIQ” of the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) or the “Cognitive Composite Scale” of the Kaufman Assessment Battery for Children-Second Edition (KABC-II). Information on comorbid diagnoses and current medication use was obtained from medical records. The use of other psychotropic medications was recorded.

Sleep–Wake Rhythms

Sleep assessment based on activity levels was performed using SleepSign Act ver. 2.0 (Kissei Comtec, Matsumoto, Nagano, Japan), an analysis software that is compatible with MTN-220 (ACOS Co Ltd., Nagano, Japan). The device is designed for individuals aged 5 years and older. It measures 27 mm in diameter and 9.1 mm in thickness, weighing approximately 9 g. It is primarily worn on the lower back. Using the Felica short-range wireless communication system, the device can record data for up to 100 days with a time resolution of 2 min. Exercise intensity is categorized into 64 levels, and postural information is collected in six orientations (upright, inverted, supine, left and right lateral recumbent, and prone) via a 3-axis accelerometer.

Sleep–wake states derived from waist-worn actigraphy analyzed with SleepSign Act have been validated against polysomnography, with previous studies reporting high epoch-by-epoch agreement (approximately mid–high 80% range).^{29,30} Actigraphy is considered a useful objective method for estimating sleep parameters over multiple nights, although wakefulness during the sleep period may be underestimated compared with polysomnography.³¹

Actigraphy data were downloaded and imported into SleepSign Act (ver. 2.0) and scored in 2-min epochs. Before analysis, recordings were visually inspected to identify missing data and artifacts; days in which non-wear was suspected were excluded, for example, prolonged periods of near-zero activity counts and/or obvious discontinuity in the recording during the intended nocturnal sleep interval. Sleep variables were computed according to the sleep variables defined by the Japanese Sleep Society and summarized for each participant by averaging across all valid nights.³² To ensure reliable

estimation of habitual sleep, multiple nights of recording were required. Prior work indicates that at least five nights of usable data are needed for reliable actigraphic sleep estimates in children and adolescents.³³

The main sleep variables evaluated were as follows:

- a. Sleep period time: the time between sleep onset and the end of sleep.
- b. Total sleep time: the sleep period time minus the total duration of awakenings after sleep onset.
- c. Sleep efficiency: the total sleep time divided by sleep time.
- d. Wake after sleep onset: the sum of waking hours during sleep time.
- e. Number of awakenings.
- f. Average duration of wakefulness: wake after sleep onset divided by the number of wake bouts.

The Japanese Version of the Sensory Profile (SP-J)

This study used SP-J, a caregiver-report questionnaire originally developed by Dunn (1999),³⁴ for which reliability and psychometric properties (including standardization and internal consistency) have been reported in a Japanese community sample.³⁵ The questionnaire was administered by parents or guardians who were familiar with the evaluated individuals. The questionnaire comprises 125 items. Each item is scored on a 5-point scale ranging from 1 to 5, with 1 indicating never (0%), 2 indicating seldom (25%), 3 indicating occasionally (50%), 4 indicating frequently (75%), and 5 indicating always (100%). Scores can be analyzed by quadrant, section, and factor. In this study, we focused on four quadrant scores: “low registration”, “sensation seeking”, “sensation sensitivity”, and “sensation avoiding”, along with the sensory processing score for each of the six senses: “auditory”, “visual”, “vestibular”, “tactile”, “multisensory”, and “oral sensory”. The calculated scores were classified according to the following system: average (mean \pm 1 standard deviation (SD) or lower), high (\pm 1 SD to \pm 2 SD range), and very high (\pm 2 SD or higher).³⁶

Procedure

Recruitment was limited to a single outpatient clinic and a pre-specified period; thus, a feasibility-based recruitment approach with random selection from the eligible pool was used to help minimize selection bias. Eligible participants were identified from medical records at Takeshige Hospital by a pediatric neurologist (co-investigator). Parents and children received written and verbal explanations. After written informed consent from parents and assent from children were obtained, caregivers completed the SP-J questionnaire. Children were then fitted with the activity monitor (MTN-220) on the lower back after a brief demonstration. Caregivers were instructed on the recording period and precautions, such as informing schools and other settings where the device would be worn. Actigraphy was recorded for at least 14 consecutive days.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences version 27.0 (IBM Statistics, SPSS Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$. Continuous variables were presented as mean \pm SD, whereas nominal variables were presented as numbers. Sleep variables obtained using the activity meter were presented as median (minimum–maximum).

Because sleep variables were not normally distributed, nonparametric Spearman’s rank correlations were used. Correlation coefficients (r) were interpreted as effect sizes. For the primary analyses, correlations were computed between sleep variables and (1) SP-J quadrant scores and (2) SP-J sensory processing scores. To control for multiple comparisons, Bonferroni correction was applied within each pre-specified set of correlations for each sleep variable (quadrants: $p_{\text{adj}} = 0.05/4 = 0.012$; sensory processing: $p_{\text{adj}} = 0.05/6 = 0.008$).

Results

Demographic Characteristics of the Participants

Of the 30 children randomly selected, 11 were excluded in this study due to lack of follow-up visits during the study period and refusal to participate by the children or their parents. Among the 19 participants, 13 were boys, and 6 were girls, with an age range of 7–9 (mean 7.6 ± 0.9) years (Table 1). Of the 19 participants, 17 underwent the WISC-IV to

Table 1 Demographic Characteristics of the Children with ASD (n = 19)

| | |
|------------------------------------|----------------|
| Gender | |
| Male | 13 |
| Female | 6 |
| Age | |
| 7 years | 12 |
| 8 years | 3 |
| 9 years | 4 |
| Birth weight (g) | 3084.3 ± 278.4 |
| Number of weeks born (week) | 39.1 ± 1.2 |
| Mother's age (years) | 41.1 ± 3.5 |
| Number of siblings | 1.2 ± 0.7 |
| FSIQ (score)*1 | 102.6 ± 12.4 |
| Fluid-Crystallized Index (score)*2 | 82 |

Notes: Values are shown as mean ± standard deviation. *1: FSIQ was measured in 17 cases at WISC -IV. *2: Fluid-Crystallized Index was measured in two cases at KABC-II. Descriptive classification based on WISC-IV and KABC-II scores, WISC-IV and KABC-II scores below 69: very low, 70–79: low (WISC-IV: borderline), 80–89: below average, 90–109: average, 110–119: above average, 120–129: high, 130 and above: very high.

Abbreviation: FSIQ, Full Scale Intelligence Quotient.

assess intellectual functioning, with a mean Full Scale IQ of 102.6 ± 12.4 , which fell within the “average” to “above average” range according to descriptive classification methods. The remaining two participants were assessed using the KABC-II, with a mean standard score of 82 on the Cognitive Composite Scale, classified as “below average”. Thus, the intellectual functioning of the study population ranged from below average to above average. Regarding medication status, one participant was taking risperidone, whereas the others were not taking any medication. The activity trackers were worn for 13–24 days, with an average wear time of 16.3 days.

Sleep Variables Measured Using the Activity Meter and SleepSign Act

The median values of various sleep variables obtained from the activity tracker, which reflects the sleep–wake rhythm, were as follows: bedtime was 21:32, sleep onset occurred at 21:47, final awakening time was 06:04, and rise time was 06:09. The sleep period time was 506.1 min, total sleep time was 413.5 min, total time in bed was 529.5 min, sleep latency was 12.0 min, and wake after sleep onset was 97.7 min. The average number of awakenings during the night was 13.1, with an average duration of wakefulness of 7.3 min, and the number of posture changes was 20.2 (Table 2).

Table 2 The SleepSign-Act Pattern Among the School-Aged Children with ASD

| | | (n = 19) |
|-------------------------|-----|---------------------|
| Bedtime | | 21:32 (19:32–22:54) |
| Time one falls sleep | | 21:47 (19:48–23:01) |
| Last awakening time | | 6:04 (4:49–7:42) |
| Time to get out of bed | | 6:09 (4:57–7:54) |
| Sleep Period Time (SPT) | Min | 506.1 (440.6–612.9) |
| Total Sleep Time (TST) | Min | 413.5 (300.3–515.1) |

(Continued)

Table 2 (Continued).

| | | (n = 19) |
|--|-------|---------------------|
| Time In Bed (TIB) | Min | 529.5 (475.8–638.6) |
| Sleep Latency (SL) | Min | 12 (7.4–18.6) |
| Bed Out Latency (BOL) | Min | 8.2 (4.0–12.0) |
| Sleep Efficiency (SEI) | % | 77.6 (63.3–90.2) |
| Wake After Sleep Onset (WASO) | Min | 97.7 (38.4–154.0) |
| Number of awakenings in the middle of the day | Count | 13.1 (6.5–17.0) |
| Average awakening duration | Min | 7.3 (5.9–10.9) |
| Number of postural transformations (every 2 min) | Count | 20.2 (12.5–33.4) |
| Number of awakenings over 8 min | Count | 5.8 (1.7–9.1) |

Note: Values are shown as median (minimum–maximum).

Sensory Processing Characteristics (SP-J)

The median (minimum–maximum) quadrant scores were 29 (15–64) for poor registration, 42 (26–100) for sensation seeking, 37 (20–51) for sensory sensitivity, and 66 (33–90) for sensation avoiding. The median (minimum–maximum) sensory processing section scores were 19 (8–30) for auditory, 17 (11–29) for visual, 19 (11–29) for vestibular, 26 (18–46) for touch, 12 (7–22) for multisensory, and 19 (12–38) for oral sensory (Table 3).

Relationship Between SP-J Quadrant and Sensory Processing Scores and Sleep Variables

After Bonferroni correction, no significant correlations were found between the SP-J quadrant scores (low registration, sensation seeking, sensation sensitivity, and sensation avoiding) and sleep variables ($r = -0.411$ – 0.540). After Bonferroni correction, among the SP-J sensory processing scores (auditory, visual, vestibular, tactile, multisensory, and oral sensory),

Table 3 The Sensory Profile Scores of the School-Aged Children with ASD

| | (n = 19) |
|---------------------|-------------|
| Quadrant | |
| Poor Registration | 29 (15–64) |
| Sensation Seeking | 42 (26–100) |
| Sensory Sensitivity | 37 (20–51) |
| Sensation Avoiding | 66 (33–90) |
| Sensory Processing | |
| Auditory | 19 (8–30) |
| Visual | 17 (11–29) |
| Vestibular | 19 (11–29) |
| Touch | 26 (18–46) |
| Multisensory | 12 (7–22) |
| Oral Sensory | 19 (12–38) |

Note: Values are shown as median (minimum–maximum).

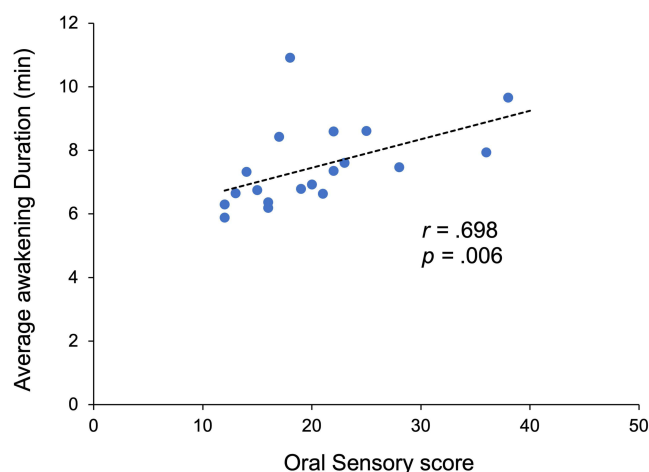


Figure 1 Relationship between oral Sensory score and Average awakening duration.

a significant positive correlation was observed between the oral sensory scores and the mean wake time of the sleep variable ($r = 0.698$, $p = 0.006$, 95% CI = 0.345, 0.878) (Figure 1). No correlations were found between the other items (Table 4).

Table 4 Correlation Coefficient Between Sleep Variables and Section Sensory Processing Scores

| | Auditory | Visual | Vestibular | Touch | Multisensory | Oral Sensory |
|--|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|---------------------------------------|
| Bedtime | 0.369 [-.117,0.712] | -0.001 [-.467,0.465] | 0.139 [-.349,0.568] | 0.427 [-.048,0.745] | 0.433 [-.041,0.748] | 0.198 [-.295,0.607] |
| Time one falls sleep | 0.375 [-.109,0.716] | 0.052 [-.424,0.506] | 0.193 [-.299,0.605] | 0.454 [-.015,0.759] | 0.470 [0.006,0.768] | 0.189 [-.303,0.602] |
| Last awakening time | 0.461 [-.006,0.763] | 0.244 [-.250,0.637] | 0.288 [-.205,0.665] | 0.171 [-.320,0.590] | 0.354 [-.134,0.704] | 0.116 [-.370,0.552] |
| Time to get out of bed | 0.480 [0.018,0.773] | 0.228 [-.266,0.627] | 0.293 [-.200,0.668] | 0.187 [-.305,0.601] | 0.376 [-.109,0.716] | 0.126 [-.361,0.559] |
| Sleep Period Time (SPT) | 0.065 [-.413,0.515] | 0.193 [-.299,0.604] | 0.115 [-.370,0.551] | -0.305 [-.675,0.187] | -0.062 [-.513,0.416] | -0.261 [-.648,0.233] |
| Total Sleep Time (TST) | 0.043 [-.431,0.499] | 0.059 [-.418,0.511] | 0.087 [-.395,0.531] | -0.386 [-.722,0.097] | -0.094 [-.536,0.389] | -0.389 [-.724,0.093] |
| Time In Bed (TIB) | 0.056 [-.420,0.509] | 0.177 [-.314,0.594] | 0.079 [-.401,0.525] | -0.256 [-.645,0.238] | -0.086 [-.530,0.396] | -0.281 [-.660,0.212] |
| Sleep Latency (SL) | 0.141 [-.347,0.569] | 0.057 [-.420,0.509] | 0.014 [-.455,0.476] | -0.200 [-.609,0.293] | 0.252 [-.242,0.642] | -0.247 [-.639,0.247] |
| Bed Out Latency (BOL) | -0.105 [-.544,0.379] | -0.409 [-.734,0.071] | -0.109 [-.547,0.376] | 0.017 [-.452,0.479] | 0.151 [-.338,0.576] | -0.016 [-.478,0.453] |
| Sleep Efficiency (SEI) | 0.079 [-.401,0.525] | 0.022 [-.448,0.483] | 0.148 [-.341,0.574] | -0.337 [-.694,0.153] | -0.021 [-.482,0.449] | -0.416 [-.739,0.061] |
| Wake After Sleep Onset (WASO) | -0.085 [-.530,0.396] | -0.014 [-.477,0.454] | -0.144 [-.571,0.345] | 0.267 [-.227,0.652] | -0.03 [-.489,0.442] | 0.465 [-.001,0.765] |
| Number of awakenings in the middle of the day | -0.100 [-.540,0.384] | -0.145 [-.572,0.343] | -0.088 [-.532,0.393] | 0.145 [-.344,0.572] | -0.091 [-.534,0.391] | 0.244 [-.250,0.637] |
| Average awakening duration | 0.061 [-.417,0.512] | 0.140 [-.348,0.569] | -0.02 [-.481,0.450] | 0.449 [-.021,0.757] | 0.008 [-.459,0.472] | 0.698* [0.345,0.878] |
| Number of postural transformations (every 2 min) | -0.127 [-.559,0.360] | 0.136 [-.352,0.566] | 0.035 [-.438,0.493] | -0.004 [-.469,0.462] | -0.036 [-.494,0.437] | 0.241 [-.253,0.635] |
| Number of awakenings over 8 min | -0.084 [-.529,0.397] | -0.064 [-.514,0.414] | -0.173 [-.591,0.318] | 0.292 [-.201,0.757] | -0.011 [-.475,0.457] | 0.436 [-.038,0.749] |

Notes: Values are Spearman's rank correlation coefficients (r) with 95% confidence intervals in brackets [lower, upper]. Bonferroni correction was applied across the six sensory processing scores for each sleep variable ($p = 0.05/6 = 0.0083$). $p < 0.0083$ was considered significant. Significant correlations were observed between oral sensation and mean arousal time, with $p < 0.008$ (values indicated by * and emphasized in bold).

Discussion

This cross-sectional exploratory study investigated the relationship between sleep–wake rhythms, measured with objective actigraphy measures and sensory processing characteristics in 19 school-aged children with ASD. It also investigated whether an association exists between SP-J quadrant scores, six sensory processing scores, and sleep variables of the sleep–wake rhythm. After Bonferroni correction, no significant associations were found between the SP-J quadrant scores and sleep variables. However, among the six sensory processing scores, the oral sensory score showed a high correlation with the mean wake time. To the best of our knowledge, this study is the first to demonstrate the relationship between sensory processing characteristics and sleep in school-aged children with ASD using objective sleep measures.

In this study, a relatively high positive correlation was found between the oral sensory score of the sensory processing scores and the sleep variable mean wake time ($r = 0.698$), and this correlation remained significant after Bonferroni correction (Table 4 and Figure 1). Based on the observed effect size ($r = 0.698$), sample size ($n = 19$), and post-hoc power calculations using the Bonferroni-adjusted p level, the achieved power was 0.802 (Supplementary table). This indicates that under the conditions of this analysis, the association observed for the oral sensory score would have been detectable. The lack of significant correlations with correlation coefficients ranging from $r = -0.411$ to 0.540 and -0.416 to 0.480 should not be interpreted as indicating no relationship. Given the small sample size and the stricter significance level imposed by multiple corrections, small-to-moderate correlations may have gone undetected (ie, potential type II errors). Although Bonferroni correction reduces the risk of type I errors in multiple testing, it does not eliminate false positives and may increase the probability of false negatives.³⁷ Therefore, correlations between quadrant scores, other sensory processing scores, and sleep variables could not be statistically demonstrated. However, the results of this study indicated an association between the oral sensory score and the mean wakefulness duration.

The finding that oral sensory scores in school-aged children with ASD correlated with average wakefulness duration suggests that oral sensory hypersensitivity may be associated with difficulty returning to sleep after nighttime awakenings. This finding of an association between oral sensory processing and sleep variables was generally consistent with the results of previous studies involving preschool children and a broader age range.^{16,22} The results of this study suggest that the association between sensory processing scores and sleep–wake patterns persists into the school-age period, despite changes in school life, daily rhythms, and increased independence. This finding indicates the potential clinical significance extending beyond early childhood. As a potential mechanism, oral sensory hypersensitivity may enhance awareness of nocturnal oral discomfort or oral stimuli, increasing wakefulness levels during alert periods and potentially leading to sustained wakefulness after a sleep disruption.¹⁵ Furthermore, oral sensory hypersensitivity may indirectly disrupt sleep continuity by making bedtime routines (eg, eating and brushing teeth) challenging, thereby increasing distress and arousal before sleep.³⁸

The use of actigraphy is a strength of this study, as it provides objective estimates of sleep–wake patterns across multiple nights in the home environment. Prior work in children with ASD validated actigraphy against polysomnography; however, wakefulness during the sleep period may still be underestimated compared with PSG, particularly in more fragmented sleep.²⁹ Consistent with prior syntheses of objective sleep in ASD, our sample showed patterns of sleep disruption that are commonly reported in autistic populations (eg, prolonged wake after sleep onset and reduced sleep efficiency).³⁹

This study has several limitations. First, participants were recruited from a single outpatient department over a limited period and enrolled via convenience sampling, potentially introducing selection bias; thus, the results cannot be generalized to a broader community sample. Second, the cross-sectional design does not allow for inferences of causality. Third, the sample size was small and determined by feasibility, which means that the study had statistical power to detect only high correlations, potentially overlooking smaller associations. Fourth, sensory processing was assessed using the caregiver-reported SP-J, which may be influenced by caregiver perceptions or reporting bias. Finally, the absence of typically developing controls and the lack of ASD symptom severity measures (eg, Autism Diagnostic Observation Schedule and Childhood Autism Rating Scale) prevented verification of whether associations differed by severity. These

exploratory findings require replication in larger, multicenter studies. Future research should incorporate large samples, longitudinal designs, multisource sensory assessments, and complementary measures.

Conclusion

This study exploratory investigated the relationship between sensory processing characteristics and objectively measured sleep–wake rhythms in school-aged children with ASD. The results were generally consistent with previous studies involving preschool children and a broader age range. These findings suggest that the association between sensory processing scores and sleep–wake rhythms persists into the school-age period, despite changes in sleep–wake rhythms because of school life and altered daily routines. Although exploratory and small-scale, this study provides foundational insights with clinical relevance for understanding and supporting sleep problems in children with ASD.

Data Sharing Statement

Data are not publicly available due to ethical and privacy considerations. De-identified data are available from the corresponding author upon reasonable request.

Acknowledgments

We extend our heartfelt gratitude to all participants and their guardians who kindly cooperated with this study. We also express our deep appreciation to the entire staff of the Department of Child Mental and Physical Developmental Medicine at Takeshige Hospital for their extensive support and cooperation throughout the entire research process.

Funding

This work was supported by JSPS KAKENHI Grant Number 25K23252.

Disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*. 5th ed, text rev (DSM-5-TR). Japanese ed. Tokyo, Japan: Igaku-Shoin Ltd; 2023.
2. Mindell JA, Owens JA, Carskadon MA. Developmental features of sleep. *Child Adolesc Psychiatr Clin N Am*. 1999;8(4):695–725.
3. Krakowiak P, Goodlin-Jones B, Hertz-Picciotto I, Croen LA, Hansen RL. Sleep problems in children with autism spectrum disorders, developmental delays, and typical development: a population-based study. *J Sleep Res*. 2008;17(2):197–206. doi:10.1111/j.1365-2869.2008.00650.x
4. Souders MC, Mason TB, Valladares O, et al. Sleep behaviors and sleep quality in children with autism spectrum disorders. *Sleep*. 2009;32(12):1566–1578. doi:10.1093/sleep/32.12.1566
5. Elrod MG, Hood BS. Sleep differences among children with autism spectrum disorders and typically developing peers: a meta-analysis. *J Dev Behav Pediatr*. 2015;36(3):166–177. doi:10.1097/DBP.000000000000140
6. Díaz-Román A, Zhang J, Delorme R, Beggiano A, Cortese S. Sleep in youth with autism spectrum disorders: systematic review and meta-analysis of subjective and objective studies. *Evid Based Ment Health*. 2018;21(4):146–154. doi:10.1136/ebmental-2018-300037
7. Alfano CA, Gamble AL. The role of sleep in childhood psychiatric disorders. *Child Youth Care Forum*. 2009;38(6):327–340. doi:10.1007/s10566-009-9081-y
8. Hochadel J, Frölich J, Wiater A, Lehmkuhl G, Fricke-Oerkermann L. Prevalence of sleep problems and relationship between sleep problems and school refusal behavior in school-aged children in children’s and parents’ ratings. *Psychopathology*. 2014;47(2):119–126. doi:10.1159/000345403
9. Stormark KM, Fosse HE, Pallesen S, Hysing M. The association between sleep problems and academic performance in primary school-aged children: findings from a Norwegian longitudinal population-based study. *PLoS One*. 2019;14(11):e0224139. doi:10.1371/journal.pone.0224139
10. Hazen EP, Stornelli JL, O’Rourke JA, Koesterer K, McDougle CJ. Sensory symptoms in autism spectrum disorders. *Harv Rev Psychiatry*. 2014;22(2):112–124. doi:10.1097/01.HRP.0000445143.08773.58
11. Takahashi H, Kamio Y. Sensory features in autism spectrum disorder. *Psychiatry et Neurologia Japonica*. 2018;120(5):369–383.
12. Tsuji H, Miyawaki D, Kawaguchi T, et al. Relationship of hypersensitivity to anxiety and depression in children with high-functioning pervasive developmental disorders. *Psychiatry Clin Neurosci*. 2009;63(2):195–201. doi:10.1111/j.1440-1819.2008.01916.x
13. Lane SJ, Reynolds S, Dumenci L. Sensory overresponsivity and anxiety in typically developing children and children with autism and attention deficit hyperactivity disorder: cause or coexistence? *Am J Occup Ther*. 2012;66(5):595–603. doi:10.5014/ajot.2012.004523
14. Dunn W. The sensations of everyday life: empirical, theoretical, and pragmatic considerations. *Am J Occup Ther*. 2001;55(6):608–620. doi:10.5014/ajot.55.6.608

15. Mazurek MO, Petroski GF. Sleep problems in children with autism spectrum disorder: examining the contributions of sensory over-responsivity and anxiety. *Sleep Med.* 2015;16(2):270–279. doi:10.1016/j.sleep.2014.11.006
16. Tzischinsky O, Meiri G, Manelis L, et al. Sleep disturbances are associated with specific sensory sensitivities in children with autism. *Mol Autism.* 2018;9:22. doi:10.1186/s13229-018-0206-8
17. Manelis-Baram L, Meiri G, Ilan M, et al. Sleep disturbances and sensory sensitivities co-vary in a longitudinal manner in pre-school children with autism spectrum disorders. *J Autism Dev Disord.* 2022;52(2):923–937. doi:10.1007/s10803-021-04973-2
18. Mazurek MO, Dovgan K, Neumeyer AM, Malow BA. Course and predictors of sleep and co-occurring problems in children with autism spectrum disorder. *J Autism Dev Disord.* 2019;49(5):2101–2115. doi:10.1007/s10803-019-03894-5
19. Rönnlund H, Elovainio M, Virtanen I, Matomäki J, Lapinleimu H. Poor parental sleep and the reported sleep quality of their children. *Pediatrics.* 2016;137(4):e20153425. doi:10.1542/peds.2015-3425
20. Lockley SW, Skene DJ, Arendt J. Comparison between subjective and actigraphic measurement of sleep and sleep rhythms. *J Sleep Res.* 1999;8(3):175–183. doi:10.1046/j.1365-2869.1999.00155.x
21. Lam JC, Mahone EM, Mason TB, Scharf SM. Defining the roles of actigraphy and parent logs for assessing sleep variables in preschool children. *Behav Sleep Med.* 2011;9(3):184–193. doi:10.1080/15402002.2011.583906
22. Kosaka T, Kawatani M, Ohta G, et al. Low threshold to Vestibular and Oral Sensory stimuli might affect quality of sleep among children with autism spectrum disorder. *Brain Dev.* 2021;43(1):55–62. doi:10.1016/j.braindev.2020.07.010
23. Bland JM, Altman DG. Multiple significance tests: the Bonferroni method. *BMJ.* 1995;310(6973):170. doi:10.1136/bmj.310.6973.170
24. Cohen J. A power primer. *Psychol Bull.* 1992;112(1):155–159. doi:10.1037//0033-2909.112.1.155
25. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Meth.* 2007;39(2):175–191. doi:10.3758/bf03193146
26. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Meth.* 2009;41(4):1149–1160. doi:10.3758/BRM.41.4.1149
27. Alder ML, Johnson CR, Zauszniewski JA, Malow BA, Burant CJ, Scahill L. Feasibility of actigraphy for evaluating sleep and daytime physical activity in children with autism spectrum disorder. *J Autism Dev Disord.* 2023;53(9):3670–3682. doi:10.1007/s10803-022-05661-5
28. Allik H, Larsson JO, Smedje H. Insomnia in school-age children with Asperger syndrome or high-functioning autism. *BMC Psychiatry.* 2006;6:18. doi:10.1186/1471-244X-6-18
29. Enomoto M, Endo T, Suenaga K, et al. Newly developed waist actigraphy and its sleep/wake scoring algorithm. *Sleep Biol Rhythms.* 2009;7(1):17–22. doi:10.1111/j.1479-8425.2008.00377.x
30. Nakazaki K, Kitamura S, Motomura Y, et al. Validity of an algorithm for determining sleep/wake states using a new actigraph. *J Physiol Anthropol.* 2014;33(1):31. doi:10.1186/1880-6805-33-31
31. Smith MT, McCrae CS, Cheung J, et al. Use of actigraphy for the evaluation of sleep disorders and circadian rhythm sleep-wake disorders: an American Academy of Sleep Medicine clinical practice guideline. *J Clin Sleep Med.* 2018;14(7):1231–1237. doi:10.5664/jcsm.7230
32. The Japanese Society of Sleep Research. *Handbook Sleep Science and Sleep Medicine.* Tokyo, Japan: Asakura Shoten Ltd; 1994.
33. Acebo C, Sadeh A, Seifer R, et al. Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep.* 1999;22(1):95–103. doi:10.1093/sleep/22.1.95
34. Dunn W. *Sensory Profile: User's Manual.* San Antonio, TX: Psychological Corporation; 1999.
35. Ito H, Hirashima T, Hagiwara T. Standardization of the Japanese version of the Sensory Profile: reliability and norms based on a community sample. *Clin Psychiatry.* 2015;55(6):537–548.
36. Tsujii M. *Japanese Version of the Sensory Profile: User's Manual.* Tokyo, Japan: Nihon Bunka Kagakusha; 2005.
37. Perneger TV. What's wrong with Bonferroni adjustments. *BMJ.* 1998;316(7139):1236–1238. doi:10.1136/bmj.316.7139.1236
38. Stein LI, Polido JC, Cermak SA. Oral care and sensory concerns in autism. *Am J Occup Ther.* 2012;66(5):e73–e76. doi:10.5014/ajot.2012.004085
39. Kim H, Kim JH, Kim J, et al. Subjective and objective sleep alterations in medication-naïve children and adolescents with autism spectrum disorder: a systematic review and meta-analysis. *Epidemiol Psychiatr Sci.* 2023;32:e48. doi:10.1017/S2045796023000574

Pediatric Health, Medicine and Therapeutics

Publish your work in this journal

Pediatric Health, Medicine and Therapeutics is an international, peer-reviewed, open access journal publishing original research, reports, editorials, reviews and commentaries. All aspects of health maintenance, preventative measures and disease treatment interventions are addressed within the journal. Practitioners from all disciplines are invited to submit their work as well as healthcare researchers and patient support groups. The manuscript management system is completely online and includes a very quick and fair peer-review system. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <http://www.dovepress.com/pediatric-health-medicine-and-therapeutics-journal>

Dovepress
Taylor & Francis Group