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RESEARCH ARTICLE

Sleep–Wake Cycle and Circadian Misalignment in People With Autism Across the Lifespan With an Emphasis on Living Conditions

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ABSTRACT

Sleep problems among individuals with autism spectrum disorder (ASD) are a persistent issue that spans from early childhood to adulthood. The present study aimed to objectively investigate sleep continuity and alignment using ambulatory circadian monitoring (ACM) in a group of autistic individuals, with and without intellectual disabilities. We studied 214 participants. Sleep continuity and alignment were assessed using a minimum of 3 days of ACM. Participants were divided into four groups: (1) age < 10 years ($n = 40$, 87.5% males, M = 6.78 ± 1.40 years), (2) age 10–17 years ($n = 53$, 90.6% males, M = 12.62 ± 2.04 years), (3) age 18–27 years ($n = 59$, 74.6% males, M = 23.50 ± 2.60 years), and (4) age 28–65 years ($n = 62$, 74.2% males, M = 39.04 ± 9.49 years). All groups had significantly impaired sleep outcomes, except for TST. Adults had longer SOL and WASO duration, than children and adolescents. However, those differences were attenuated if participants 'percentages of sleep parameters within normal range' were compared. When evaluating circadian misalignment, sleep M5 is delayed in children and adolescents (2:56 am and 3:00 am, respectively), and strongly advanced in the older adults (group 4). Sleep problems that manifest in autism during childhood can endure throughout adulthood. Furthermore, there is a necessity to investigate how living conditions, such as enforced schedules in residential facilities, can influence the timing of the sleep midpoint.

1 | Introduction

Autism spectrum disorder (autism) is a neurodevelopmental condition involving persistent deficits in social communication and interaction, repetitive patterns of behavior, and restricted interests or activities (American Psychiatric Association 2013). The prevalence of autism has been recently updated and affects as many as 1 in 36 newborns (Maenner 2023) with an

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Summary

- Sleep problems are common in autistic individuals and can persist from childhood into adulthood. This study found that while total sleep duration may appear normal, sleep quality is often poor, with difficulties falling and staying asleep.
- Sleep timing also varies by age, with younger individuals experiencing delayed sleep and older adults in residential care having earlier sleep patterns.
- These findings highlight the importance of looking beyond sleep duration and considering factors like sleep disruptions and living conditions when addressing sleep issues in autism.

estimation of 1.97% to 2.42% adult prevalence (Alder et al. 2023), taking account of those who are undiagnosed (Dietz et al. 2020). People with autism[1] have frequent co-occurring conditions including sleep problems, such as insomnia-related symptoms or sleep phase misalignments, which are lifelong challenges (Carmassi et al. 2019; Jovevska et al. 2020). These demand a more comprehensive investigation from the scientific community, using combined evidence-based medical (Cortese et al. 2020), psychosocial, and environmental frameworks (Schreck and Richdale 2020).

An appropriate sleep–wake cycle across the lifespan involves both sufficient sleep (i.e., duration) and proper sleep alignment (i.e., circadian phase of the sleep–wake cycle) both of which have been reported as problematic in autism (Baker and Richdale 2017; Elrod and Hood 2015; Martínez-Cayuelas et al. 2022). Adequate sleep duration ranges from 10 to 12 h in children, around 9–10 h in adolescence, to at least 7 h of sleep during adulthood (Ohayon et al. 2004), with reduced or excessive sleep associated with physical and mental health conditions (Wang et al. 2024). Sleep alignment refers to its synchronization with environmental factors such as the 24-h light/dark cycle (LeGates et al. 2014). The sleep phase drifts to later sleep onset and wake during adolescence associated with pubertal changes; this is reverted in adulthood (Crowley et al. 2007; Roenneberg et al. 2004). A significant portion of children in the general population, ranging from 25% to 40%, experiences challenges with insomnia-related issues, such as settling and bedtime routines, and night awakenings (Ohayon et al. 2017); these struggles can persist or recur in adulthood, with 33%–45% of adults reporting poor sleep (Baker and Richdale 2017). Sleep problems reported by people with autism align with those reported by the general population, as they commonly experience difficulty in falling asleep, poor sleep efficiency, and struggles with sleep maintenance (Díaz-Román et al. 2018; McGovney et al. 2020; Morgan et al. 2020; Schreck and Richdale 2020). These insomnia symptoms in individuals with autism are well-documented from early childhood (Elrod et al. 2016), persist into adolescence (Baker et al. 2013; Goldman et al. 2017; Martinez-Cayuelas et al. 2022; Øyane and Bjorvatn 2005), and are also reported as a common complaint in adulthood (Hohn et al. 2019; Jovevska et al. 2020; Leader et al. 2021), irrespective of cognitive functioning (Baker and Richdale 2017; Ballester et al. 2019).

Among insomnia symptoms, children with autism present with greater bedtime resistance, parasomnia, and night awakenings (Goldman et al. 2012). Adolescents with autism have shorter sleep duration and more daytime sleepiness (Deliens et al. 2015; Díaz-Román et al. 2018; Goldman et al. 2011), while a meta-analytic systematic review of sleep in adults with autism described difficulties in sleep continuity (e.g., longer sleep onset latency, frequent awakenings) and lower self-perceived sleep quality, sleep efficiency, and more napping compared to non-autistic adults (Morgan et al. 2020). However, sleep phase misalignments in autism have received limited attention. Children and adolescents with autism may experience a sleep phase delay (Hodge et al. 2014; Souders et al. 2009; Wasdell et al. 2008; Wiggs and Stores 2004), which is consistent with puberty hormonal shifts that occur in adolescence (Carskadon 2011). Contradictory findings have emerged in adults, as those with unimpaired cognitive ability generally exhibit a delayed phase (Baker et al. 2017a), whereas individuals with autism and intellectual disability living in residential facilities demonstrated a notable phase advancement in comparison to the general population (Ballester et al. 2019). The latter may be due to fixed daily living schedules in residential facilities. However, especially in adults, several other factors contribute to sleep alignment including employment, sleep routine regularity, lifestyle (e.g., living conditions), and light intensity and timing within the 24-h cycle (Deserno et al. 2019; Lawson et al. 2020; Martinez-Cayuelas et al. 2022). Despite their capacity and desire to work, adults with autism have high levels of unemployment or underemployment (Frank et al. 2018). For example, only 37% of adults with autism reported being employed for more than a year in the 4 years following finishing school (Fong et al. 2021). Most adults with autism, regardless of their cognitive ability, struggle with independent living (Ghanouni et al. 2021), and therefore the ability to self-select their sleep schedules according to their preferences (Duncan et al. 2021). Thus, there is a need to better understand sleep and sleep–wake circadian differences in people with autism from childhood through to adulthood.

Sleep variables are usually evaluated using questionnaires, sleep logs, or actigraphy (Moore et al. 2017). To date, there is no work that objectively investigates insomnia-related issues and sleep circadian alignment in autistic people through childhood, adolescence, and adulthood. In this work, we used ambulatory circadian monitoring (ACM) which measures not only sleep but also motion, peripheral temperature, and TAP (see Method), which are useful variables to ascertain sleep phase alignment (Ortiz-Tudela et al. 2010, 2016). Using ACM, which gives insomnia symptom estimations close to polysomnography (Ortiz-Tudela et al. 2014) can not only examine the sleep–wake rhythm but also other rhythms that can affect sleep. Together with acknowledging risk factors and living conditions, ACM allows examination of the potential multifaceted causes of sleep problems in autism, as raised in biopsychosocial models of sleep (Charlton et al. 2023; Gustemps et al. 2021; Henderson et al. 2023; Richdale et al. 2023; Richdale and Schreck 2009; Schreck and Richdale 2020).

Therefore, the purpose of this work was to explore, cross-sectionally, sleep dimensions (e.g., duration, regularity) using ACM in children and adolescents with autism living with their

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parents or legal guardians, and adults with autism living in supported residential accommodation. This study is important, as to the best of our knowledge it is the first that focuses on these crucial aspects of sleep using reliable and objective metrics in individuals with autism across ages.

2 | Methods

2.1 | Ethics

The present study is a sub-analysis of two prospective observational studies UGP14-011 and PIC018_18FJD examining sleep in children, adolescents, and adults with autism. The studies were conducted at Health Alicante Department-General Hospital (Alicante, Spain) and Fundación Jiménez Díaz Hospital (Madrid, Spain) from February 2015 to March 2022, excluding summer (June to August) as weather could affect the accuracy of the temperature sensor. Both studies had Hospital Ethics Review Board approval at both sites and were performed in accordance with the principles of the Helsinki Declaration. All participants and/or their legal guardians received information about the design and purpose of the study. Given that this study included children, adolescents, and adults with intellectual disability, we developed an information sheet that contained the study process in simplified language with images and photos which were handed, when possible, to participants. Depending on the level of cognitive functioning, participants' or legal guardians' informed consent was obtained, and when possible, according to cognitive function, participants assented.

2.2 | Participant Recruitment and Inclusion Criteria

Two hundred and fourteen individuals with an autism spectrum disorder (ASD) diagnosis were included in the study. Participants were included during clinical visits. The adult participants were residents across three institutions for adults with autism, whereas children and adolescents lived at home. For inclusion, participants were aged from 4 to 65 years; gave agreement to an initial clinic visit; and had a previous autism spectrum disorder diagnosis substantiated using the Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) criteria (American Psychiatric Association 2013). Individuals taking medications for sleep, including melatonin, and those with any medical condition that was incompatible with the study conditions were excluded from participation. Diagnosis based on DSM-5 criteria was confirmed by a clinician who was an experienced psychiatrist from our research team, skilled in diagnosing ASD. All children completed an ADOS assessment. Intellectual disability (ID), defined by an IQ < 70, was confirmed from professionals' medical records from the Spanish social services. All participants continued their regular medications, if any, during the study. Existing sleep problems were not required to participate in the study. Participants could withdraw from the study at any time. No participant was receiving a psychological therapy for their sleep.

2.3 | Measurements

2.3.1 | Ambulatory Circadian Monitoring

The ambulatory circadian monitoring (ACM) device measured sleep parameters and sleep alignment, combining information from three sensors. The first measures peripheral temperature (Thermochron iButton DS1921H, ±1 °C accuracy, sampling every 10 min) (Carrier and Monk 1997; Sarabia et al. 2008). The second is an actimeter that estimates physical activity using body triaxial changes of angles between the Y/Z/X-axes (90° verticality to 0° maximum horizontality) HOBO Pendant G Acceleration Data Logger UA-004-64, programmed to record data every minute (Bonmati-Carrion et al. 2015; Carvalho Bos et al. 2003; Mormont et al. 2000). The third sensor is a luxometer capturing the intensity of light received (HOBO Data Logger UA-002 64, measured in 30-s intervals (Martinez-Nicolas et al. 2011)).

Van Someren and Witting non-parametric indexes and sleep parameters were calculated from the ACM loadings. The information stored in the ACM device was transferred via USB to a personal computer using the software provided by the manufacturer, through circadianware software implemented in the Kronowizard platform (https://kronowizard.um.es/). It calculates a single integrated variable, TAP, integrating peripheral temperature (inverted), motor activity and body position. TAP maximum values should occur at the same time of the day indicating a high level of activation (values near 1) or complete rest and sleep (around 0). Sleep was reversely inferred from TAP and converted into a binary code, with 1 corresponding to a resting period and 0 to an active period (Ortiz-Tudela et al. 2014).

2.3.2 | Ambulatory Circadian Monitoring: Sleep Parameters Determination

Sleep continuity parameters were calculated as (a) total sleep time (TST), defined as sleep minutes between sleep onset and sleep offset; (b) time in bed (TIB), total minutes in bed from bedtime until rising time; (c) sleep onset latency (SoL) minutes from bedtime until sleep onset; (d) number of awakenings after sleep onset; (e) awake period duration after sleep onset (WASO), the awake period length in minutes during the TST interval; and (f) sleep efficiency (SE), calculated as the ratio of TST/TIB multiplied by 100. The results of sleep parameters from all participants were classified as normal or abnormal values according to age and ranges previously described for the general population (Natale et al. 2009; Ohayon et al. 2017).

2.3.3 | Ambulatory Circadian Monitoring: Circadian Sleep–Wake Rhythm Disorders Determination

Non-parametric circadian rhythm analysis is a method for extracting circadian characteristics from the rest-activity cycle (Ortiz-Tudela et al. 2014; Van Someren and Van Der Riemersma-Lek 2007; Weitzman et al. 1981; Witting et al. 1990). Of major interest is the relative amplitude (RA), as it shows how activity is distributed throughout the day compared with night: the higher the RA, the better the consolidation of daytime activity and

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nighttime sleep. The RA is calculated from the ratio of the most active 10-h period (M10) to the least active 5-h period (L5) across the averaged 24-h profile. A second characteristic is the inter-daily stability (IS), which quantifies invariability day by day; that is, how well the sleep–wake cycle is synchronized to supposedly stable environmental cues. Third, intra-day variability (IV) gives an indication of the fragmentation of the rhythm. Timing and value (V) information comes from determining the onset of the 5 h with least activity (L5 onset) and onset of the 10 h with most activity (M10 onset); sleep and peripheral temperature rhythms are reverse, measuring M5 and L10. Finally, the circadian function index (CFI), which assesses circadian rhythmicity status, was calculated as (IS + (2 − IV) + RA)/3. CFI has proved to be very sensitive to changes in circadian robustness (Ortiz-Tudela et al. 2010).

2.4 | Procedure

Demographic information (age, biological sex) was obtained from EHRs. Since we wanted to study the evolution of the sleep–wake cycle across the lifespan, groups were established according to age and living conditions. As Tanner stage was unknown, children were classified as those < 10 years; and adolescents were 10–17 years. Adults were split into two age groups according to our previous research results (Ballester et al. 2019), as the present study aimed to explore when the previously reported phase advancement in the sleep–wake cycle appears in adults with autism living in supported accommodation.

Sleep parameters and alignment were obtained using ACM (Kronowise). All participants were asked to follow their usual routines and wore the ACM device on the wrist of their non-dominant arm for 7 days. The device was removed during showering or any other activity where it could get wet; data were collated to remove erroneous measurements produced by its temporary removal. All participants completed a 7-day sleep–wake diary (mornings and evenings). A parent or caregiver was responsible for completing each participant's sleep diary. Sleep diaries were used as a backup for the device recordings if needed.

2.5 | Statistical Analyses

The Shapiro–Wilks normality test was used as the basis for the selection of parametric or non-parametric statistical tests. Continuous variables are presented as mean ± standard deviation (SD), mean ± standard error (SEM) or median and interquartile range (IQR, P25, P75). Categorical variables are expressed as percentages. A Kruskal–Wallis test was used to assess group differences. Frequencies were compared using the Chi-Squared test, with Yate's continuity correction as appropriate, and X^2 was reported. Despite the unequal sex distribution observed between the autism age groups, differences in sleep parameters were analyzed by sex to ensure a lack of bias. All statistical analyses were carried out with IBM SPSS Statistics 29.0.0 and R 4.3.3 software; p-values < 0.05 were considered to indicate significance for all analyses.

3 | Results

A total of 214 participants, aged 4 to 58 years, were included in the study. The sample was predominantly male (80.8%); however, no significant differences among sleep parameter values were found when compared by sex intra-group or inter-groups (all p-values > 0.05). Thus, given the small number of females in each group, we did not use sex as a covariant. All participants were recruited after researchers met with their parents at institutions for those diagnosed with autism (56.5%) or during clinical visits to one of the participating hospitals (43.5%). Participants were placed into one of four age groups: (1) < 10 years ($n = 40$), (2) 10–17 years ($n = 53$), (3) 18–27 years ($n = 59$), and (4) 28–65 years ($n = 62$) (Table 1). According to their EHRs, children and adolescents did not have any co-occurring conditions apart from ID (17%) and were medication naïve. According to EHRs, all adults had ID, and 33% had a diagnosis of epilepsy. Adult participants had a median (IQR) of 4 (3–6) medications (50% antipsychotics, 47% with > 1 antipsychotic simultaneously; 22% anticonvulsants, 16% anxiolytics, and 12% antidepressants).

3.1 | Ambulatory Circadian Monitoring: Sleep Parameters

Comparison of ACM sleep parameter data across the four age groups is presented in Table 2. From all sleep parameters in both adult groups, only the number of awakenings reduced with ongoing anxiolytic medication ($p < 0.05$); other medicines that produce sedation as a side effect did not affect sleep parameters in this study. However, as can be seen in Table 2, the average number of awakenings is high in all groups regardless of medication status. Significant differences among the four age groups were found for TIB, SoL, number of awakenings, WASO, and SE. Sleep duration was not significantly different across the groups. However, that may be due to the greater opportunity for sleep that the two adult groups in residential care have, based on their TIB. Sleep onset latency and WASO were significantly impaired in the adults, and consequently SE. When calculating the percentage of participants exhibiting sleep variable parameters aligned with age recommendations for each parameter within each group, it becomes clear that symptoms of insomnia persist consistently throughout the lifespan. Intra-group ranges were set for TST according to participants' age in the youngest age group (Group 1).

TABLE 1 | Participant Demographics for each age group: 1 (between 0–9 years old), 2 (10–17 years old), 3 (18–27 years old) and 4 (28–65 years old).

Age groups	0–9 years old ($n = 40$)	10–17 years old ($n = 53$)	18–27 years old ($n = 59$)	28–65 years old ($n = 62$)
Sex (n, % male)	35 (87.5%)	48 (90.6%)	44 (74.6%)	46 (74.2%)
Age (mean ± SD)	6.90 ± 1.40	12.77 ± 2.04	23.64 ± 2.60	40.11 ± 9.49

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TABLE 2 | Sleep parameters comparison obtained from ambulatory circadian monitoring (ACM) recordings between the four participant groups 1 (between 0–9 years old), 2 (10–17 years old), 3 (18–27 years old) and 4 (28–65 years old).

Sleep parameters	0–9 years old ($n = 40$)	10–17 years old ($n = 53$)	18–27 years old ($n = 59$)	28–65 years old ($n = 62$)	p
Total sleep time (TST, minutes)	520 ± 49	510 ± 52	526 ± 138	525 ± 108	0.427
% (n) Normal range	42.5 (17)	75.5 (40)	35.8 (19)	36.0 (50)	**< 0.001**
Time in bed (TIB, minutes)	576 ± 72	567 ± 50	683 ± 119	685 ± 91	**< 0.001**
% Normal range, n/N	2.5 (1)	0	0	0	0.566
Sleep onset latency (SOL, minutes)	29 ± 20	32 ± 19	52 ± 34	43 ± 23	**< 0.001**
% (n) Normal range	25 (10)	54.7 (29)	26.41 (14)	32.0 (16)	**< 0.001**
Number of awakenings (n)	3.7 ± 0.9	3.8 ± 1.3	3.3 ± 1.9	3.2 ± 1.9	**0.002**
% (n) Normal range	0	1.9 (1)	17.0 (9)	12.0 (6)	**< 0.001**
Wakes after sleep onset (WASO, minutes)	28 ± 18	24 ± 12	81 ± 56	93 ± 76	**< 0.001**
% (n) Normal range	2.5 (1)	5.7 (3)	9.4 (5)	6.0 (3)	0.363
Sleep efficiency (SE %)	89 ± 5	86 ± 6	76 ± 13	76 ± 13	**< 0.001**
% (n) Normal range	12.5 (5)	66.0 (35)	26.4 (14)	28 (14)	**< 0.001**

Note: Sleep parameters derived from ACM recordings in participants expressed as mean ± SD. Kruskal–Wallis (sleep parameter values) or Chi-Squared (percentages of normality) tests $p < 0.05$ are highlighted in bold. The p-value is the overall comparison between the four groups.

3.2 | Ambulatory Circadian Monitoring: Circadian Sleep–Wake Rhythm Disorders

Analysis of the circadian rhythms (wrist temperature, motor activity, TAP, sleep, and light intensity) showed significant differences between groups (Table 3). The two younger groups with autism (children and adolescents) displayed significantly higher IS values for all rhythms except for light intensity, where no differences were found. In the adult age groups, motor activity was more fragmented according to IV values. The adult groups also presented a wider RA of light intensity and narrower sleep amplitude. The lack of amplitude in the sleep rhythm at night may be compensated by a significantly greater value of sleep VL10 that indicates either napping or daytime somnolence.

The children and adolescents exhibited a phase delay according to phase markers for wrist temperature, motor activity, sleep, light intensity, and TAP. A phase advancement in the adults with ID living in residential facilities, especially in the oldest age group (Figure 1) was also found. When examining how living conditions may cause a shift towards an advanced phase, despite all groups receiving the same light intensity (light intensity VM10), there were timing differences. On average, the oldest group was exposed to either light or darkness 40 min earlier than other age groups (Figure 2).

4 | Discussion

To the best of our knowledge, the present study gathers the largest sample of participants with autism whose sleep has been assessed using an objective measure such as ACM. This study represents a cross-sectional, natural life trajectory for people with an ASD diagnosis, including those under 18 years and living at home, young adults transitioning into adulthood who were living in residential facilities for adults with autism, and older adults who had been in residential care for at least 5 years. Regardless of age, all groups had significantly impaired sleep outcomes. When evaluating circadian misalignment, children and adolescents showed a sleep phase delay. However, adults had a progressive phase advancement of the sleep midpoint, indicating a phase advance and suggesting that their living conditions are responsible for this sleep phase shift in adulthood, as these are largely determined by their residential institution. Children and adolescents were medication-free with no other reported co-occurring conditions except ID, which was present for 17% of children. Conversely, the adults with autism all had co-occurring ID and took multiple ongoing medications, which is dissimilar to studies of adults with autism and no co-occurring ID (Baker and Richdale 2015; Cvejic et al. 2018; Esler et al. 2019). Nevertheless, medication side effects only impacted the average number of nights awakenings; there were no significant associations with other sleep or circadian parameters.

Regarding sleep durability variables, there were no significant age group differences for TST, which was unexpected. While many individuals slept significantly fewer hours than recommended for their age, particularly in the youngest age group where the group average TST was lower than expected for age, the adult group averages were longer than might be expected (Hirshkowitz et al. 2015). The lack of differentiation in total sleep with age is a key finding, as developmentally, total sleep decreases across childhood and into adulthood, decreasing

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TABLE 3 | Comparison among all non-parametric circadian rhythms along 24-h period between the four participant groups 1 (between 0–9 years old), 2 (10–17 years old), 3 (18–27 years old) and 4 (28–65 years old).

Groups	0–9 years old ($n = 40$)	10–17 years old ($n = 53$)	18–27 years old ($n = 59$)	28–65 years old ($n = 62$)	p
Wrist temperature					
IS	0.49 ± 0.19	0.50 ± 0.18	0.39 ± 0.24	0.47 ± 0.22	0.101
IV	0.01 ± 0.04	0.02 ± 0.05	0.13 ± 0.08	0.14 ± 0.08	< **0.001**
RA	0.41 ± 0.14	0.44 ± 0.19	0.30 ± 0.17	0.33 ± 0.18	< **0.001**
M5	2:42 ± 3:22	3:01 ± 2:47	2:08 ± 2:10	1:54 ± 3:41	0.**024**
VM5	33.65 ± 0.89	33.55 ± 0.77	34.32 ± 1.24	34.78 ± 1.22	< **0.001**
L10	16:06 ± 2:44	16:45 ± 4:39	14:01:49 ± 2:27	14:18 ± 1:53	< **0.001**
VL10	31.53 ± 0.89	31.30 ± 1.14	32.43 ± 1.17	32.75 ± 1.19	< **0.001**
CFI	0.61 ± 0.11	0.63 ± 0.12	0.53 ± 0.16	0.52 ± 0.13	< **0.001**
Motor activity					
IS	0.36 ± 0.14	0.30 ± 0.11	0.31 ± 0.15	0.38 ± 0.20	0.**009**
IV	0.45 ± 0.18	0.45 ± 0.24	0.98 ± 0.16	1.01 ± 0.20	< **0.001**
RA	0.71 ± 0.18	0.54 ± 0.19	0.79 ± 0.15	0.74 ± 0.19	< **0.001**
M10	15:11 ± 1:15	14:58 ± 1:57	15:00 ± 2:10	15:06 ± 2:28	0.883
VM10	31.71 ± 8.53	23.91 ± 9.35	29.67 ± 13.30	24.16 ± 9.40	< **0.001**
L5	3:07 ± 1:23	3:27 ± 1:27	2:31 ± 1:56	2:19 ± 2:15	0.**005**
VL5	2.31 ± 1.29	2.18 ± 0.61	4.20 ± 4.53	4.06 ± 4.27	0.102
CFI	0.67 ± 0.05	0.63 ± 0.06	0.54 ± 0.09	0.54 ± 0.12	< **0.001**
TAP					
IS	0.74 ± 0.10	0.64 ± 0.15	0.49 ± 0.22	0.60 ± 0.21	< **0.001**
IV	0.16 ± 0.09	0.18 ± 0.07	0.36 ± 0.24	0.38 ± 0.23	< **0.001**
RA	0.70 ± 0.12	0.63 ± 0.13	0.53 ± 0.19	0.55 ± 0.18	< **0.001**
M10	14:33 ± 1:20	15:28 ± 3:24	14:59 ± 1:24	14:35 ± 1:48	0.268
VM10	0.53 ± 0.07	0.49 ± 0.08	0.57 ± 0.11	0.57 ± 0.12	< **0.001**
L5	2:49 ± 1:40	3:26 ± 1:41	2:34 ± 1:38	1:42 ± 1:39	< **0.001**
VL5	0.10 ± 0.04	0.11 ± 0.03	0.19 ± 0.12	0.17 ± 0.09	< **0.001**
CFI	0.54 ± 0.06	0.51 ± 0.09	0.61 ± 0.13	0.65 ± 0.12	< **0.001**
Sleep					
IS	0.80 ± 0.08	0.73 ± 0.15	0.57 ± 0.23	0.64 ± 0.24	< **0.001**
IV	0.13 ± 0.09	0.12 ± 0.07	0.33 ± 0.14	0.36 ± 0.17	< **0.001**
RA	0.94 ± 0.06	0.90 ± 0.13	0.78 ± 0.26	0.82 ± 0.23	0.**004**
M5	2:58 ± 1:25	3:02 ± 1:20	2:27 ± 1:50	1:58 ± 1:39	< **0.001**
VM5	0.93 ± 0.07	0.91 ± 0.09	0.83 ± 0.19	0.82 ± 0.21	0.**012**
L10	14:42 ± 1:34	14:59 ± 1:32	14:18 ± 2:50	13:38 ± 1:16	0.**005**
VL10	0.01 ± 0.02	0.03 ± 0.12	0.12 ± 0.18	0.12 ± 0.21	< **0.001**
CFI	0.91 ± 0.04	0.89 ± 0.08	0.73 ± 0.14	0.75 ± 0.17	< **0.001**
Light intensity					

(Continues)

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TABLE 3 | (Continued)

Groups	0–9 years old ($n=40$)	10–17 years old ($n=53$)	18–27 years old ($n=59$)	28–65 years old ($n=62$)	p
IS	0.62 ± 0.12	0.57 ± 0.15	0.60 ± 0.19	0.59 ± 0.34	0.214
IV	0.08 ± 0.05	0.07 ± 0.04	0.17 ± 0.10	0.18 ± 0.13	**< 0.001**
RA	0.57 ± 0.16	0.53 ± 0.21	0.99 ± 0.01	0.95 ± 0.19	**< 0.001**
M10	14:25 ± 00:45	14:33 ± 1:14	14:05 ± 00:50	13:33 ± 00:57	**< 0.001**
VM10	1.61 ± 0.42	1.56 ± 0.61	1.61 ± 0.64	1.34 ± 0.62	0.057
L5	2:21 ± 1:18	2:49 ± 1:16	1:39 ± 1:35	1:48 ± 3:18	**< 0.001**
VL5	0.01 ± 0.04	0.003 ± 0.004	0.003 ± 0.01	0.03 ± 0.09	**< 0.001**
CFI	0.85 ± 0.05	0.83 ± 0.07	0.84 ± 0.07	0.79 ± 0.17	**0.037**

Note: Phase markers: maximum (M5 and M10) and minimum (L5 and L10) values indicate consecutive 10- and 5- h period. Non-parametric circadian function indices derived from ACM recordings in participants expressed as mean ± SD. Kruskal–Wallis tests were performed, when $p < 0.05$ are highlighted in bold. The p-value is the overall comparison between the four groups.
Abbreviations: CFI, circadian function index; IS, inter-daily stability; IV, intra-daily variability; RA, relative amplitude.

again in old age (Buysse et al. 1992; Hirshkowitz et al. 2015; Yoon et al. 2003). A recent meta-analysis found that autistic adults, most of whom did not have ID, slept less than comparison samples (Morgan et al. 2020) and reviews report that autistic children also sleep less than typically developing children (e.g., (Hodge et al. 2014)). Adolescents and adults with autism and no ID are reported to sleep about seven hours on average (Baker and Richdale 2015; Jovevska et al. 2020), which is less than the current sample, with adults in middle age having the least sleep of about 6 h (Jovevska et al. 2020). While the adults in the current study had ID, they spent a longer time in bed and therefore had more opportunities to achieve more sleep at night, which most likely accounts for their tendency to increased TST. Other factors that may contribute to differences in adults' TST across studies are employment status, environmental factors associated with residential care including timing of meals, recreation, bedtime, and rising time (Cohen et al. 2018; Lawson et al. 2020).

Adults with autism had longer SoL and WASO than the younger age groups. However, the percentage of individuals with values within the normal range was extremely low across all age groups, which is consistent with previous research in children with autism (Elrod and Hood 2015) and adults (Morgan et al. 2020). Increased SoL and WASO may be associated with the higher rates of anxiety reported for individuals with autism from childhood to adolescence (Haugland et al. 2021), with abnormal values of insomnia-related issues that oscillate from 28% to 77% in childhood (Vasa and Mazurek 2015) and persist into adulthood (Lever and Geurts 2016; Tani et al. 2012). Researchers have speculated that high rates of anxiety may indicate increased cognitive and/or somatic hyperarousal which impacts sleep (Baker et al. 2019a; Mazurek et al. 2019; Mazurek and Petroski 2015). Indeed, Baker found that higher subjective somatic arousal was associated with increased SoL and poorer sleep efficiency among participants with autism; those unmedicated participants had greater reductions in evening cortisol levels, suggesting a hyperarousal hypothesis of insomnia in adults with autism (Baker et al. 2019b).

According to the phase markers, the 24-h temperature rhythm was advanced in both adult groups, and in general, higher values of peripheral temperature were found in the adult groups during both day and night. This higher peripheral temperature can be explained by impaired noradrenergic signaling that interferes with the body's capacity to cool (Wallengren 1997), and it can be altered by selected medications that some adults in our study took (Fazekas et al. 2021). Also, another factor that influences heat loss is the light intensity experienced, as this has the potential to promote an earliermelatonin onset followed by peripheral heat loss prior to bedtime (Benedetti et al. 2022; Baker et al. 2017b). This peripheral temperature advancement could be a *by-proxy* measure of an aberrant function in the melatonin pathway, as reported previously in this population (Tordjman et al. 2018).

The motor activity phase markers represent, in general, a high level of sedentariness across the sample that increases with age. Adolescents had a level of activity that was consistent with a previous report (Liang et al. 2020). The adolescents' rates of movement were like those in the oldest age group. This could indicate that adolescents are more involved in educational/therapeutical activities or screen time than in sport or active leisure activities during breaks and after school hours, compared to typically developing peers (Berard et al. 2022).

Sleep worsened with age in our population, with decreased stability and increased fragmentation, a narrower relative amplitude of the rhythm, and a progressively more advanced sleep midpoint. Circadian sleep–wake disorders have been described in and related to unemployment in adults with autism without cognitive impairment (Baker et al. 2017a, 2019a). The circadian rhythms and sleep–wake disorders in our sample of adults are more like those reported in aged populations with mild cognitive impairment (Gao et al. 2022) or the severely ill (J Madrid-Navarro et al. 2015). In our young adult group, this phenomenon may be explained by factors such as alterations in the melatonin pathway (Díaz-Román et al. 2018) or environmental factors such as reduced light exposure (Siraji et al. 2023). While all age groups were regularly exposed to light and receiving the same amount of light intensity during the day, adults were receiving light 40 min earlier in the day than children and adolescents. A shift towards morning outdoors time with natural light exposure can result in a phase advancement (Siraji et al. 2023).

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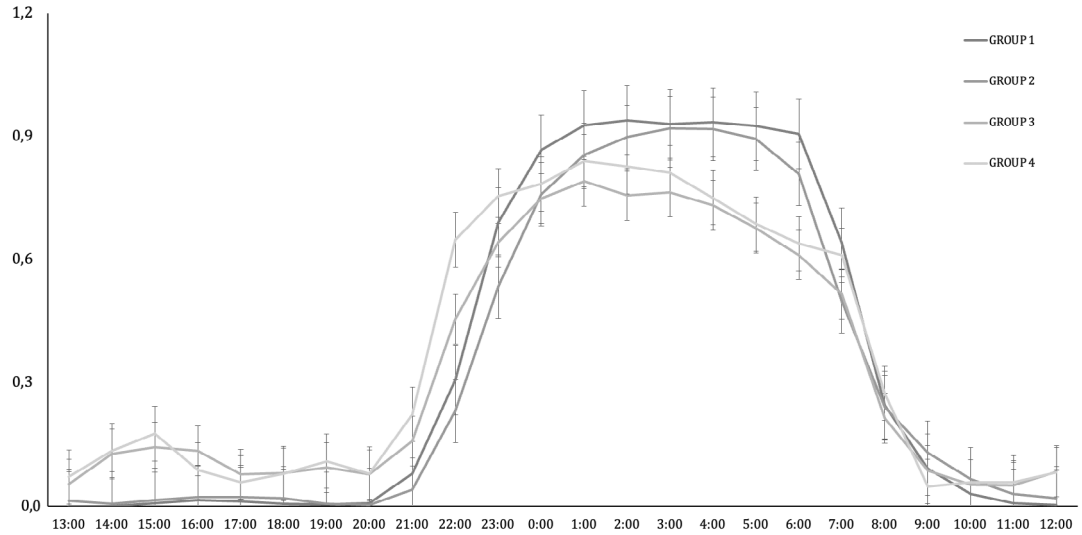

FIGURE 1 | Averaged 24 h wave of the sleep–wake rhythm at the four groups 1 (between 0–9 years old), 2 (10–17 years old), 3 (18–27 years old), and 4 (28–65 years old).

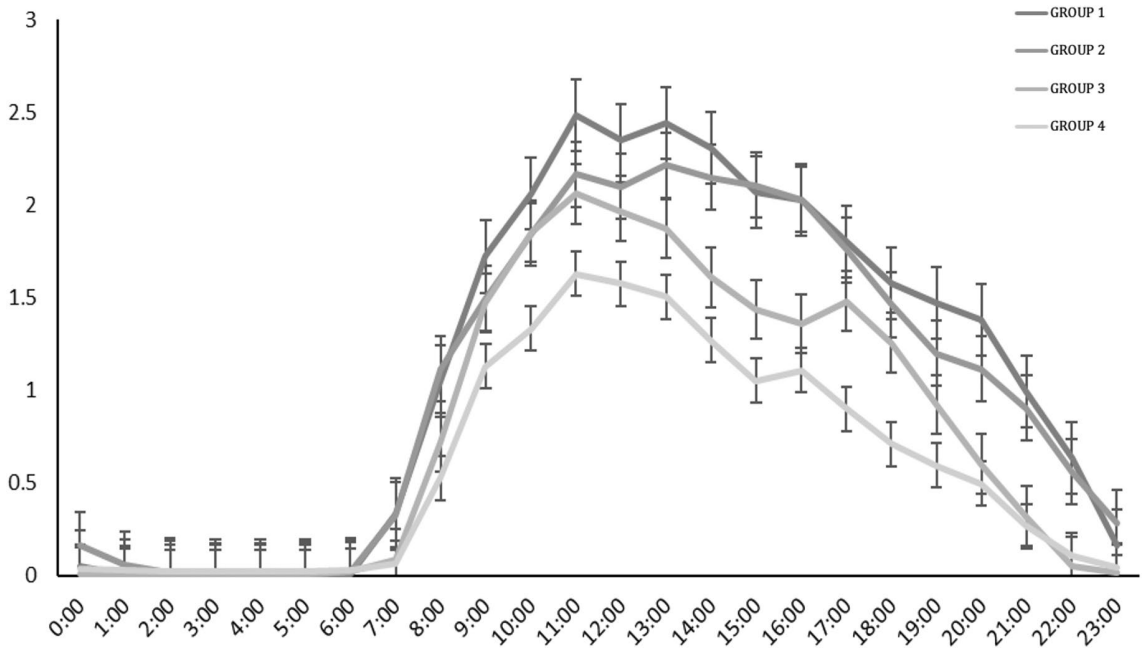

FIGURE 2 | Averaged 24 h wave of the light intensity exposure rhythm at the four groups 1 (between 0–9 years old), 2 (10–17 years old), 3 (18–27 years old) and 4 (28–65 years old).

The main strength of this study is that it uses a large sample of people with autism across the lifespan who have all had their sleep, as well as temperature and motor movements recorded objectively using ACM. The sample size for both children and adults exceeds previous published work using actimetry for children and adolescents (Miner et al. 2023; Wiggs and Stores 2004) and adults (Baker and Richdale 2015; Benson et al. 2019) with autism, giving us confidence in our results. The sex distribution in our sample is like that of other publications (e.g., (Yavuz-Kodat et al. 2019)). However, our small number of females did not allow us to replicate a recent finding that women with autism have poorer sleep outcomes (Jovevska et al. 2020). Other limitations include that our age groups differed in terms of medication and co-occurring conditions; however, this was examined in relation to sleep parameters and few differences were found. Also, only 17% of children and adolescents had ID, but all adults had ID; but recent publications suggest that ID is more strongly associated with sleep satisfaction, a dimension of sleep not assessed in the present study, rather than functional impairments (Gilbertson et al. 2021). Differences in our participants' living conditions potentially played a role in their sleep outcomes, as children and adolescents lived at home while our adults were in a supported residential setting. Thus, it will be important for future research to examine sleep in adults with autism in different living conditions to begin to tease out the effects of the environment on their sleep. Further studies designed

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as clinical trials also need to explore the effects of shifting light exposure and reducing TIB or sleep opportunities have for sleep and circadian parameters for adults with autism, with and without ID.

In conclusion, the present work indicates that sleep problems that appear during childhood in autism persist into adulthood, including abnormal sleep onset latency and wake after sleep onset, and reduced total sleep among children. Variation in total sleep reported across adults may be due to compensation mechanisms such as increased opportunity to sleep, due to a greater time in bed. Sleep parameters should not only be assessed by average times, but by also examining the proportion of participants who fall within normal sleep values adjusted by age, and by examining individual differences (e.g., ongoing medication). Sedentarism and light exposure in people with autism need to receive further attention, together with how living conditions, such as imposed schedules in residential facilities, shift the sleep midpoint. The consistent and increasing reports of poor sleep among individuals with autism over the last 40 years (e.g., see (Hoshino et al. 1984)) indicate a need for further studies of sleep trajectories longitudinally in this population to improve our understanding of causal and maintenance factors, and to target prevention and intervention strategies.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] While there has been a preference for identity first language in English speaking countries, a recent study reported a preference for person-first language in adults with an autism diagnosis living in Belgium and The Netherlands (De Laet et al. 2023). Thus, in this manuscript we use person-first language (i.e., person with autism).

References

Alder, M., C. Johnson, J. Zauszniewski, B. Malow, C. Burant, and L. Scahill. 2023. "Feasibility of Actigraphy for Evaluating Sleep and Daytime Physical Activity in Children With Autism Spectrum Disorder." *Journal of Autism and Developmental Disorders* 53, no. 9: 3670–3682.

American Psychiatric Association, D., & American Psychiatric Association, D. 2013. *Diagnostic and Statistical Manual of Mental Disorders: DSM-5*. Vol. 5. American psychiatric association.

Baker, E., A. Richdale, M. Short, and M. Gradisar. 2013. "An Investigation of Sleep Patterns in Adolescents With High-Functioning Autism Spectrum Disorder Compared With Typically Developing Adolescents." *Developmental Neurorehabilitation* 16, no. 3: 155–165.

Baker, E. K., R. J. Adams, S. L. Appleton, et al. 2017a. "Sleep Health of Australian Adults in 2016: Results of the 2016 Sleep Health Foundation National Survey." *Sleep Health* 3, no. 1: 35–42.

Baker, E. K., and A. L. Richdale. 2015. "Sleep Patterns in Adults With a Diagnosis of High-Functioning Autism Spectrum Disorder." *Sleep* 38, no. 11: 1765–1774.

Baker, E. K., and A. L. Richdale. 2017. "Examining the Behavioural Sleep-Wake Rhythm in Adults With Autism Spectrum Disorder and no Comorbid Intellectual Disability." *Journal of Autism and Developmental Disorders* 47: 1207–1222.

Baker, E. K., A. L. Richdale, and A. Hazi. 2019a. "Employment Status Is Related to Sleep Problems in Adults With Autism Spectrum Disorder and no Comorbid Intellectual Impairment." *Autism* 23, no. 2: 531–536.

Baker, E. K., A. L. Richdale, A. Hazi, and L. A. Prendergast. 2017b. "Assessing the Dim Light Melatonin Onset in Adults With Autism Spectrum Disorder and no Comorbid Intellectual Disability." *Journal of Autism and Developmental Disorders* 47: 2120–2137.

Baker, E. K., A. L. Richdale, A. Hazi, and L. A. Prendergast. 2019b. "Assessing a Hyperarousal Hypothesis of Insomnia in Adults With Autism Spectrum Disorder." *Autism Research* 12, no. 6: 897–910.

Ballester, P., M. J. Martínez, A. Javaloyes, et al. 2019. "Sleep Problems in Adults With Autism Spectrum Disorder and Intellectual Disability." *Autism Research* 12, no. 1: 66–79.

Benedetti, M., L. Maierová, C. Cajochen, J.-L. Scartezzini, and M. Münch. 2022. "Optimized Office Lighting Advances Melatonin Phase and Peripheral Heat Loss Prior Bedtime." *Scientific Reports* 12, no. 1: 4267.

Benson, S., A. M. Bender, H. Wickenheiser, et al. 2019. "Differences in Sleep Patterns, Sleepiness, and Physical Activity Levels Between Young Adults With Autism Spectrum Disorder and Typically Developing Controls." *Developmental Neurorehabilitation* 22, no. 3: 164–173.

Berard, M., M. Peries, J. Loubersac, et al. 2022. "Screen Time and Associated Risks in Children and Adolescents With Autism Spectrum Disorders During a Discrete COVID-19 Lockdown Period." *Frontiers in Psychiatry* 13: 1026191.

Bonmati-Carrion, M., B. Middleton, V. Revell, D. Skene, M. Rol, and J. Madrid. 2015. "Validation of an Innovative Method, Based on Tilt Sensing, for the Assessment of Activity and Body Position." *Chronobiology International* 32, no. 5: 701–710.

Buysse, D. J., K. E. Browman, T. H. Monk, C. F. Reynolds III, A. L. Fasiczka, and D. J. Kupfer. 1992. "Napping and 24-Hour Sleep/Wake Patterns in Healthy Elderly and Young Adults." *Journal of the American Geriatrics Society* 40, no. 8: 779–786. https://doi.org/10.1111/j.1532-5415.1992.tb01849.x.

Carmassi, C., L. Palagini, D. Caruso, et al. 2019. "Systematic Review of Sleep Disturbances and Circadian Sleep Desynchronization in Autism Spectrum Disorder: Toward an Integrative Model of a Self-Reinforcing Loop." *Frontiers in Psychiatry* 10: 456337.

Carrier, J., and T. H. Monk. 1997. "Estimating the Endogenous Circadian Temperature Rhythm Without Keeping People Awake." *Journal of Biological Rhythms* 12, no. 3: 266–277.

Carskadon, M. A. 2011. "Sleep in Adolescents: The Perfect Storm." *Pediatric Clinics* 58, no. 3: 637–647.

Carvalho Bos, S., J. Waterhouse, B. Edwards, R. Simons, and T. Reilly. 2003. "The Use of Actimetry to Assess Changes to the Rest–Activity Cycle." *Chronobiology International* 20, no. 6: 1039–1059.

Charlton, R. A., G. A. McQuaid, L. Bishop, N. R. Lee, and G. L. Wallace. 2023. "Predictors of Sleep Quality for Autistic People Across Adulthood." *Autism Research* 16, no. 4: 757–771.

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Cohen, S., B. D. Fulcher, S. M. Rajaratnam, et al. 2018. "Sleep Patterns Predictive of Daytime Challenging Behavior in Individuals With Low-Functioning Autism." *Autism Research* 11, no. 2: 391–403.

Cortese, S., F. Wang, M. Angriman, G. Masi, and O. Bruni. 2020. "Sleep Disorders in Children and Adolescents With Autism Spectrum Disorder: Diagnosis, Epidemiology, and Management." *CNS Drugs* 34, no. 4: 415–423.

Crowley, S. J., C. Acebo, and M. A. Carskadon. 2007. "Sleep, Circadian Rhythms, and Delayed Phase in Adolescence." *Sleep Medicine* 8, no. 6: 602–612.

Cvejic, R. C., S. R. Arnold, K.-R. Foley, and J. N. Trollor. 2018. "Neuropsychiatric Profile and Psychotropic Medication Use in Adults With Autism Spectrum Disorder: Results From the Australian Longitudinal Study of Adults With Autism." *BJPsych Open* 4, no. 6: 461–466.

De Laet, H., A. D. Nijhof, and J. R. Wiersema. 2023. "Adults With Autism Prefer Person-First Language in Dutch: A Cross-Country Study." *Journal of Autism and Developmental Disorders* 55, no. 6: 2027–2033. https://doi.org/10.1007/s10803-023-06192-3.

Deliens, G., R. Leproult, R. Schmitz, A. Destrebecqz, and P. Peigneux. 2015. "Sleep Disturbances in Autism Spectrum Disorders." *Review Journal of Autism and Developmental Disorders* 2: 343–356.

Deserno, M. K., D. Borsboom, S. Begeer, J. A. Agelink Van Rentergem, K. Mataw, and H. M. Geurts. 2019. "Sleep Determines Quality of Life in Autistic Adults: A Longitudinal Study." *Autism Research* 12, no. 5: 794–801.

Díaz-Román, A., J. Zhang, R. Delorme, A. Beggiato, and S. Cortese. 2018. "Sleep in Youth With Autism Spectrum Disorders: Systematic Review and Meta-Analysis of Subjective and Objective Studies." *BMJ Mental Health* 21, no. 4: 146–154.

Dietz, P. M., C. E. Rose, D. McArthur, and M. Maenner. 2020. "National and State Estimates of Adults With Autism Spectrum Disorder." *Journal of Autism and Developmental Disorders* 50: 4258–4266.

Duncan, A., M. Liddle, and L. J. Stark. 2021. "Iterative Development of a Daily Living Skills Intervention for Adolescents With Autism Without an Intellectual Disability." *Clinical Child and Family Psychology Review* 24, no. 4: 744–764.

Elrod, M. G., and B. S. Hood. 2015. "Sleep Differences Among Children With Autism Spectrum Disorders and Typically Developing Peers: A Meta-Analysis." *Journal of Developmental & Behavioral Pediatrics* 36, no. 3: 166–177.

Elrod, M. G., C. M. Nylund, A. L. Susi, et al. 2016. "Prevalence of Diagnosed Sleep Disorders and Related Diagnostic and Surgical Procedures in Children With Autism Spectrum Disorders." *Journal of Developmental & Behavioral Pediatrics* 37, no. 5: 377–384.

Esler, A., A. Hewitt, J. Hall-Lande, S. L. Pettingell, and J. Houseworth. 2019. "Psychotropic Medication Use for Adults With Autism Spectrum Disorder Who Receive Services and Supports Through Adult Developmental Disability Services in the United States." *Journal of Autism and Developmental Disorders* 49: 2291–2303.

Fazekas, C. L., M. Bellardie, B. Török, et al. 2021. "Pharmacogenetic Excitation of the Median Raphe Region Affects Social and Depressive-Like Behavior and Core Body Temperature in Male Mice." *Life Sciences* 286: 120037.

Fong, C. J., J. Taylor, A. Berdyyeva, A. M. McClelland, K. M. Murphy, and J. D. Westbrook. 2021. "Interventions for Improving Employment Outcomes for Persons With Autism Spectrum Disorders: A Systematic Review Update." *Campbell Systematic Reviews* 17, no. 3: e1185.

Frank, F., M. Jablotschkin, T. Arthen, et al. 2018. "Education and Employment Status of Adults With Autism Spectrum Disorders in Germany–a Cross-Sectional-Survey." *BMC Psychiatry* 18: 1–10.

Gao, F., S. Wei, L. Dang, et al. 2022. "Sleep Disturbance Is Associated With Mild Cognitive Impairment: A Community Population-Based Cross-Sectional Study." *BMC Public Health* 22, no. 1: 2000.

Ghanouni, P., S. Quirke, J. Blok, and A. Casey. 2021. "Independent Living in Adults With Autism Spectrum Disorder: Stakeholders' Perspectives and Experiences." *Research in Developmental Disabilities* 119: 104085.

Gilbertson, M., C. Richardson, P. Eastwood, et al. 2021. "Determinants of Sleep Problems in Children With Intellectual Disability." *Journal of Sleep Research* 30, no. 5: e13361.

Goldman, S., M. Alder, H. Burgess, et al. 2017. "Characterizing Sleep in Adolescents and Adults With Autism Spectrum Disorders." *Journal of Autism and Developmental Disorders* 47: 1682–1695.

Goldman, S. E., S. McGrew, K. P. Johnson, A. L. Richdale, T. Clemons, and B. A. Malow. 2011. "Sleep Is Associated With Problem Behaviors in Children and Adolescents With Autism Spectrum Disorders." *Research in Autism Spectrum Disorders* 5, no. 3: 1223–1229.

Goldman, S. E., A. L. Richdale, T. Clemons, and B. A. Malow. 2012. "Parental Sleep Concerns in Autism Spectrum Disorders: Variations From Childhood to Adolescence." *Journal of Autism and Developmental Disorders* 42: 531–538.

Gustemps, L. G., J. L. Marín, I. S. Ramos, et al. 2021. "Sleep Disturbances in Autism Spectrum Disorder Without Intellectual Impairment: Relationship With Executive Function and Psychiatric Symptoms." *Sleep Medicine* 83: 106–114.

Haugland, B. S., M. Hysing, V. Baste, et al. 2021. "Sleep Duration and Insomnia in Adolescents Seeking Treatment for Anxiety in Primary Health Care." *Frontiers in Psychology* 12: 638879.

Henderson, L. M., M. St Clair, V. Knowland, E. Van Rijn, S. Walker, and M. Gaskell. 2023. "Stronger Associations Between Sleep and Mental Health in Adults With Autism: A UK Biobank Study." *Journal of Autism and Developmental Disorders* 53, no. 4: 1543–1559.

Hirshkowitz, M., K. Whiton, S. M. Albert, et al. 2015. "National Sleep Foundation's Sleep Time Duration Recommendations: Methodology and Results Summary." *Sleep Health* 1, no. 1: 40–43.

Hodge, D., T. M. Carollo, M. Lewin, C. D. Hoffman, and D. P. Sweeney. 2014. "Sleep Patterns in Children With and Without Autism Spectrum Disorders: Developmental Comparisons." *Research in Developmental Disabilities* 35, no. 7: 1631–1638.

Hohn, V. D., D. M. de Veld, K. J. Mataw, E. J. van Someren, and S. Begeer. 2019. "Insomnia Severity in Adults With Autism Spectrum Disorder Is Associated With Sensory Hyper-Reactivity and Social Skill Impairment." *Journal of Autism and Developmental Disorders* 49: 2146–2155.

Hoshino, Y., H. Watanabe, Y. Yashima, M. Kaneko, and H. Kumashiro. 1984. "An Investigation on Sleep Disturbance of Autistic Children." *Psychiatry and Clinical Neurosciences* 38, no. 1: 45–51.

J Madrid-Navarro, C., R. Sanchez-Galvez, A. Martinez-Nicolas, et al. 2015. "Disruption of Circadian Rhythms and Delirium, Sleep Impairment and Sepsis in Critically Ill Patients. Potential Therapeutic Implications for Increased Light-Dark Contrast and Melatonin Therapy in an ICU Environment." *Current Pharmaceutical Design* 21, no. 24: 3453–3468.

Jovevska, S., A. L. Richdale, L. P. Lawson, M. Uljarević, S. R. Arnold, and J. N. Trollor. 2020. "Sleep Quality in Autism From Adolescence to Old Age." *Autism in Adulthood* 2, no. 2: 152–162.

Lawson, L. P., A. L. Richdale, A. Haschek, et al. 2020. "Cross-Sectional and Longitudinal Predictors of Quality of Life in Autistic Individuals From Adolescence to Adulthood: The Role of Mental Health and Sleep Quality." *Autism* 24, no. 4: 954–967.

Leader, G., A. Barrett, C. Ferrari, et al. 2021. "Quality of Life, Gastrointestinal Symptoms, Sleep Problems, Social Support, and Social

19393806, 2025, 7, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aur.70058 by Spanish Cochrane National Provision (Ministerio de Sanidad), Wiley Online Library on [09/01/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Functioning in Adults With Autism Spectrum Disorder." *Research in Developmental Disabilities* 112: 103915.

LeGates, T. A., D. C. Fernandez, and S. Hattar. 2014. "Light as a Central Modulator of Circadian Rhythms, Sleep and Affect." *Nature Reviews Neuroscience* 15, no. 7: 443–454.

Lever, A. G., and H. M. Geurts. 2016. "Psychiatric Co-Occurring Symptoms and Disorders in Young, Middle-Aged, and Older Adults With Autism Spectrum Disorder." *Journal of Autism and Developmental Disorders* 46: 1916–1930.

Liang, X., R. Li, S. H. Wong, R. K. Sum, and C. H. Sit. 2020. "Accelerometer-Measured Physical Activity Levels in Children and Adolescents With Autism Spectrum Disorder: A Systematic Review." *Preventive Medicine Reports* 19: 101147.

Maenner, M. J. 2023. "Prevalence and Characteristics of Autism Spectrum Disorder Among Children Aged 8 Years—Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2020." *MMWR Surveillance Summaries* 72, no. 2: 1–14. https://doi.org/10.15585/mmwr.ss7202a1.

Martinez-Cayuelas, E., T. Gavela-Pérez, M. Rodrigo-Moreno, et al. 2022. "Melatonin Rhythm and Its Relation to Sleep and Circadian Parameters in Children and Adolescents With Autism Spectrum Disorder." *Frontiers in Neurology* 13: 813692. https://doi.org/10.3389/fneur.2022.813692.

Martínez-Cayuelas, E., B. Rodríguez-Morilla, L. Soriano-Guillén, et al. 2022. "Sleep Problems and Circadian Functioning in Children and Adolescents With Autism Spectrum Disorder." *Pediatric Neurology* 126: 57–64. https://doi.org/10.1016/j.pediatrneurol.2021.09.009.

Martinez-Nicolas, A., E. Ortiz-Tudela, J. A. Madrid, and M. A. Rol. 2011. "Crosstalk Between Environmental Light and Internal Time in Humans." *Chronobiology International* 28, no. 7: 617–629.

Mazurek, M. O., K. Dovgan, A. M. Neumeyer, and B. A. Malow. 2019. "Course and Predictors of Sleep and Co-Occurring Problems in Children With Autism Spectrum Disorder." *Journal of Autism and Developmental Disorders* 49: 2101–2115.

Mazurek, M. O., and G. F. Petroski. 2015. "Sleep Problems in Children With Autism Spectrum Disorder: Examining the Contributions of Sensory Over-Responsivity and Anxiety." *Sleep Medicine* 16, no. 2: 270–279.

McGovney, K., A. Curtis, M. Mazurek, et al. 2020. "0922 Nightly Associations Between Pre-Bedtime Activity, Actigraphic Light, and Sleep in Children With ASD and Insomnia." *Sleep* 43, no. Supplement_1: A350–A351.

Miner, S., M. McVoy, and E. Damato. 2023. "Evaluation of the Relationship of Sleep Disturbances to Severity and Common Behaviors in Autism Spectrum Disorder." *Research Square*. https://doi.org/10.21203/rs.3.rs-2674526/v1.

Moore, M., V. Evans, G. Hanvey, and C. Johnson. 2017. "Assessment of Sleep in Children With Autism Spectrum Disorder." *Children* 4, no. 8: 72.

Morgan, B., F. Nageye, G. Masi, and S. Cortese. 2020. "Sleep in Adults With Autism Spectrum Disorder: A Systematic Review and Meta-Analysis of Subjective and Objective Studies." *Sleep Medicine* 65: 113–120.

Mormont, M.-C., J. Waterhouse, P. Bleuzen, et al. 2000. "Marked 24-h Rest/Activity Rhythms Are Associated With Better Quality of Life, Better Response, and Longer Survival in Patients With Metastatic Colorectal Cancer and Good Performance Status." *Clinical Cancer Research* 6, no. 8: 3038–3045.

Natale, V., G. Plazzi, and M. Martoni. 2009. "Actigraphy in the Assessment of Insomnia: A Quantitative Approach." *Sleep* 32, no. 6: 767–771.

Ohayon, M., E. M. Wickwire, M. Hirshkowitz, et al. 2017. "National Sleep Foundation's Sleep Quality Recommendations: First Report." *Sleep Health* 3, no. 1: 6–19.

Ohayon, M. M., M. A. Carskadon, C. Guilleminault, and M. V. Vitiello. 2004. "Meta-Analysis of Quantitative Sleep Parameters From Childhood to Old Age in Healthy Individuals: Developing Normative Sleep Values Across the Human Lifespan." *Sleep* 27, no. 7: 1255–1273.

Ortiz-Tudela, E., P. F. Innominato, M. A. Rol, F. Lévi, and J. A. Madrid. 2016. "Relevance of Internal Time and Circadian Robustness for Cancer Patients." *BMC Cancer* 16: 1–12.

Ortiz-Tudela, E., A. Martinez-Nicolas, J. Albares, et al. 2014. "Ambulatory Circadian Monitoring (ACM) Based on Thermometry, Motor Activity and Body Position (TAP): A Comparison With Polysomnography." *Physiology & Behavior* 126: 30–38.

Ortiz-Tudela, E., A. Martinez-Nicolas, M. Campos, M. Á. Rol, and J. A. Madrid. 2010. "A New Integrated Variable Based on Thermometry, Actimetry and Body Position (TAP) to Evaluate Circadian System Status in Humans." *PLoS Computational Biology* 6, no. 11: e1000996.

Øyane, N. M., and B. Bjorvatn. 2005. "Sleep Disturbances in Adolescents and Young Adults With Autism and Asperger Syndrome." *Autism* 9, no. 1: 83–94.

Richdale, A. L., L. P. Lawson, A. Chalmers, et al. 2023. "Pathways to Anxiety and Depression in Autistic Adolescents and Adults." *Depression and Anxiety* 2023, no. 1: 5575932.

Richdale, A. L., and K. A. Schreck. 2009. "Sleep Problems in Autism Spectrum Disorders: Prevalence, Nature, & Possible Biopsychosocial Aetiologies." *Sleep Medicine Reviews* 13, no. 6: 403–411.

Roenneberg, T., T. Kuehnle, P. P. Pramstaller, et al. 2004. "A Marker for the End of Adolescence." *Current Biology* 14, no. 24: R1038–R1039.

Sarabia, J. A., M. A. Rol, P. Mendiola, and J. A. Madrid. 2008. "Circadian Rhythm of Wrist Temperature in Normal-Living Subjects: A Candidate of New Index of the Circadian System." *Physiology & Behavior* 95, no. 4: 570–580.

Schreck, K. A., and A. L. Richdale. 2020. "Sleep Problems, Behavior, and Psychopathology in Autism: Inter-Relationships Across the Lifespan." *Current Opinion in Psychology* 34: 105–111.

Siraji, M. A., M. Spitschan, V. Kalavally, and S. Haque. 2023. "Light Exposure Behaviors Predict Mood, Memory and Sleep Quality." *Scientific Reports* 13, no. 1: 12425.

Souders, M. C., T. B. Mason, O. Valladares, et al. 2009. "Sleep Behaviors and Sleep Quality in Children With Autism Spectrum Disorders." *Sleep* 32, no. 12: 1566–1578.

Tani, M., C. Kanai, H. Ota, et al. 2012. "Mental and Behavioral Symptoms of Person's With Asperger's Syndrome: Relationships With Social Isolation and Handicaps." *Research in Autism Spectrum Disorders* 6, no. 2: 907–912.

Tordjman, S., D. Cohen, G. Anderson, et al. 2018. "Repint of "Reframing Autism as a Behavioral Syndrome and Not a Specific Mental Disorder: Implications of Genetic and Phenotypic Heterogeneity"." *Neuroscience and Biobehavioral Reviews* 89: 132–150.

Van Someren, E. J., and R. F. Van Der Riemersma- Lek. 2007. "Live to the Rhythm, Slave to the Rhythm." *Sleep Medicine Reviews* 11, no. 6: 465–484.

Vasa, R. A., and M. O. Mazurek. 2015. "An Update on Anxiety in Youth With Autism Spectrum Disorders." *Current Opinion in Psychiatry* 28, no. 2: 83–90.

Wallengren, J. 1997. "Vasoactive Peptides in the Skin." *Journal of Investigative Dermatology Symposium Proceedings* 2, no. 1: 49–55. https://doi.org/10.1038/jidsymp.1997.11.

19393806, 2025, 7, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aur.70058 by Spanish Cochrane National Provision (Ministerio de Sanidad), Wiley Online Library on [09/01/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Wang, F., Z. Sun, F. Lin, et al. 2024. "Nonlinear Relationships Between Sleep Duration, Mental Health, and Quality of Life: The Dangers of Less Sleep Versus More Sleep." *Sleep Medicine* 119: 565–573.

Wasdell, M. B., J. E. Jan, M. M. Bomben, et al. 2008. "A Randomized, Placebo-Controlled Trial of Controlled Release Melatonin Treatment of Delayed Sleep Phase Syndrome and Impaired Sleep Maintenance in Children With Neurodevelopmental Disabilities." *Journal of Pineal Research* 44, no. 1: 57–64.

Weitzman, E. D., D. F. Kripke, L. Johnson, D. Tepas, W. Colquhoun, and M. Colligan. 1981. "Experimental 12-Hour Shift of the Sleep-Wake Cycle in Man: Effects on Sleep and Physiological Rhythms." *Variations in Work-Sleep Schedules: Effects on Health and Performance. Advances in Sleep Research* 7: 125–149.

Wiggs, L., and G. Stores. 2004. "Sleep Patterns and Sleep Disorders in Children With Autistic Spectrum Disorders: Insights Using Parent Report and Actigraphy." *Developmental Medicine and Child Neurology* 46, no. 6: 372–380.

Witting, W., I. Kwa, P. Eikelenboom, M. Mirmiran, and D. F. Swaab. 1990. "Alterations in the Circadian Rest-Activity Rhythm in Aging and Alzheimer's Disease." *Biological Psychiatry* 27, no. 6: 563–572.

Yavuz-Kodat, E., E. Reynaud, M.-M. Geoffray, et al. 2019. "Validity of Actigraphy Compared to Polysomnography for Sleep Assessment in Children With Autism Spectrum Disorder." *Frontiers in Psychiatry* 10: 551.

Yoon, I., D. F. Kripke, S. D. Youngstedt, and J. A. Elliott. 2003. "Actigraphy Suggests Age-Related Differences in Napping and Nocturnal Sleep." *Journal of Sleep Research* 12, no. 2: 87–93.

19393806, 2025, 7, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/aur.70058 by Spanish Cochrane National Provision (Ministerio de Sanidad), Wiley Online Library on [09/01/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License