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RESEARCH ARTICLE

Differential effects of COVID-related lockdown on sleep–wake rhythms in adults with autism spectrum disorder compared to the general population

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Abstract

COVID-related lockdown led to a radical modification of daily activities and routines which are known to affect sleep. Compared to the general population, participants with autism may be particularly vulnerable to the repercussions of lockdown on sleep, given their intrinsic inflexible adherence to routines and the high overall prevalence of sleep disturbances in this population. The study is a French nation-wide online survey assessing sleep–wake rhythms and behaviors known to affect sleep (daily screen time, daylight exposure, and physical activity), before and during COVID-related lockdown. Respondents were 207 adults with autism (56% female) and 1652 adults of the general population (77% female), with a mean age 35.3 years (SD 11.3). Before lockdown, the adults with autism displayed on average later bedtime and waking hours, lower sleep quality, more evening screen time, less exposure to daylight, and less exercise (all $p < 0.01$). Lockdown affected all studied measures of sleep and related exposures in a similar way in both groups: poorer self-rated sleep quality as well as a less regular and delayed sleep–wake rhythm, longer screen time in the evening and less exposure to daylight (all $p < 0.001$). Adults with autism displayed significantly higher levels of sleep and circadian rhythm disturbances and less favorable daily routines known to regulate sleep. While the effect of confinement on sleep and sleep related behaviors was similar in both groups, the results highlight that the pre-existing shift in circadian rhythms and lifestyles in adults with ASD further deteriorated during lockdown.

Lay abstract: COVID-related lockdown led to a radical modification of daily activities and routines known to affect sleep. In a sample of 1800 adults, we observed that, before lockdown, participants with autism displayed significantly higher levels of sleep disturbances and less favorable daily routines known to regulate sleep, compared to the general population. While the deleterious effect of lockdown on sleep was similar in both groups, pre-existing difficulties in adults with autism reached worrying levels during lockdown.

KEYWORDS

autism spectrum disorder, circadian rhythm, insomnia, sleep, sleep hygiene

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic affected countries worldwide with the introduction of various strategies aiming to contain the outbreak. In

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France, the first wave of infection made a fast breakthrough with, on March 15, 2020, 6378 confirmed cases including 161 deaths reported (Santé Publique France, 2020). A first period of strict total lockdown was implemented on French territory from March 17 to May 11 2020. Similar to other countries, measures included mandatory remote work except for specified essential workers, closure of schools and non-essential stores, and restrictions on time (<1 h/day) and distance (perimeter of 1 km) of trips outside the home.

Unsurprisingly, the first studies on the repercussions of lockdown showed that the disruption of life routines, the stress induced by the pandemic and the associated consequences (economic, socio-professional, family, etc.), led to significant disturbances in general mental health, and particularly in anxiety and depression symptoms (Gualano et al., 2020; Hao et al., 2020; Marelli et al., 2020; Vindegaard & Benros, 2020; Wang et al., 2020). Although lockdown affects society as a whole, the repercussions in adults with autism spectrum disorder (ASD) are likely to differ.

ASD is a frequent neurodevelopmental disorder, with prevalences estimated between 1.1% (Brugha et al., 2016) and 2.2% (Dietz et al., 2020) in adults. It is characterized by the presence from childhood of social communication deficits associated with restricted, repetitive, and stereotypical behaviors and interests, responsible for major functional limitations in everyday life (American Psychiatric Association, 2013). Insistence on sameness is an important sign of autism, including an inflexible adherence to routines or ritualized patterns of behavior (e.g., extreme distress at small changes and need for predictable daily rituals). As a result, sudden drastic changes in daily routine dictated by the lockdown strategies might be expected to have a greater impact on people on the autism spectrum. An alternative hypothesis is that the decrease in social interactions resulting from lockdown might be experienced as a relief and reduce stress in this population. In a study including about 600 adults with autism and 400 controls across three European countries, Oomen et al. (2021) found some positive changes reported by adults with autism, such as reduced sensory and social overload with, however, an increase in depression and anxiety symptoms, which was significantly greater in adults with autism than controls. Interestingly, they also found that although adults with autism felt they had to make fewer changes in their daily routines than controls, they felt more stressed about those changes. Pellicano et al. (2021) found similar results in their qualitative study. On the one hand, adults with autism expressed some positive outcomes, such as "a release from the demands of conventional social challenges" during lockdown, however they reported at the same time negative effects with "a deep sense of social loss; and a deterioration of mental health."

Aside from mental health issues, the negative impact of population confinement may also include an effect on sleep and circadian rhythms. The master biological clock, located in the suprachiasmatic nucleus, orchestrates the endogenous sleep–wake cycle of a period close to 24 h, called the circadian sleep–wake rhythm. This rhythm determines propensities towards wakefulness or sleep and is entrained by external cues (also called "*Zeitgebers*," meaning "time giver" in German) (Stephenson et al., 2012) and internal cues (clock genes and neurohormones including melatonin) (Lalanne et al., 2021; Reppert & Weaver, 2002). Circadian sleep–wake rhythm disorders occur in cases of misalignment between the endogenous rhythm and external environment. The light/dark cycle is the most important Zeitgeber, although others exist, such as physical activity and social interactions. Light modulates the circadian rhythm through two distinct mechanisms: "(1) the acute suppression of melatonin in response to light exposure and (2) the ability of light exposure to shift circadian phase" (Blume et al., 2019). The effect of light on circadian rhythm and sleep is dependent on the timing, the intensity, and the wavelength of the light. While the exposure to natural daylight in the morning advances the circadian phase and has been shown to improve sleep quality and reduce sleep latency (Figueiro et al., 2017), an evening exposure to blue light (overly emitted by computers and smart-phone screens) lowers and delays melatonin secretion (Cajochen et al., 2011) and modifies sleep architecture (Münch et al., 2006). As the COVID-19 lockdown affected work and leisure routines, there were probable knock-on effects on key *Zeitgebers*, such as daylight exposure and physical activity, in turn affecting the organization and position of the sleep–wake cycle, and thus sleep duration and sleep quality. Indeed, most studies on the subject report a delayed rhythm and reduced sleep quality during lockdown, although discrepancies have been reported. An Italian online cross-sectional study of 1310 adults compared sleep quality, duration, and timing before lockdown and during the second week of lockdown. The results showed a delay in sleep–wake rhythms, an increase in time spent in bed and lower sleep quality (Cellini et al., 2020). Another Italian study of 400 adults found later bedtimes and wake-up times during lockdown, as well as a worsening of sleep quality and an increase in all insomnia symptoms assessed by the Insomnia Severity Index: sleep initiation, sleep maintenance, and early morning awakening (Marelli et al., 2020). An Argentinian online study (Leone et al., 2020) with 1021 participants found delayed sleep onset and wake time during lockdown but only on weekdays, with a greater effect on wake time compared to sleep onset. However, an online European study of 435 adults in Austria, Germany, and Switzerland from mid-March to end of April 2020 by Blume et al. (2020) found a reduction of the mismatch between external (social) and internal (biological) sleep–wake timing, an increase in sleep duration, but also a small reduction of sleep quality. These studies were all performed in the general population, and the effects of lockdown on sleep may be more pronounced in vulnerable populations such as people with neuro-developmental disorders, given the high prevalence of sleep disturbances as a co-occurring range of symptoms (Shelton & Malow, 2021).

Sleep disturbances are very common in ASD, affecting 50–80% of the concerned population in their lifetime (Ballester et al., 2020; Lai et al., 2014). Recent systematic reviews and meta-analyses show shorter sleep duration, lower sleep efficiency associated with longer sleep onset latency, and overall lower sleep quality compared to controls (Carmassi et al., 2019; Morgan et al., 2020). Differences have also been found in sleep architecture, with increased duration of stage 1 sleep and decreased non-REM sleep and slow-wave sleep (Limoges et al., 2005). Circadian sleep–wake disturbances have also been reported; studies based on actigraphy found that compared to neurotypical participants, participants with ASD had lower circadian rhythm amplitudes (Hare et al., 2006) and a higher prevalence of non 24-h sleep–wake rhythm (Baker & Richdale, 2017); studies based on melatonin and its metabolite reported lower secretion in general, especially in the hour before usual sleep time (Melke et al., 2008; Tordjman et al., 2012). The increased prevalence of sleep disturbances in ASD may be due to variations in clock genes and melatonin pathway genes (Yang et al., 2016) leading to abnormal melatonin production and secretion (Melke et al., 2008; Pagan et al., 2017). However behavioral modifications in participants with autism may also lead to inappropriate light exposure patterns, including screen use (Coutelle et al., 2021), and difficulties integrating social cues linked to daily rhythms and sleep timing (Ballester et al., 2020). Therefore, lockdown strategies may have led to greater sleep–wake disturbances in adults with autism compared to those in the general population.

One small Turkish study assessed the relationship between chronotype, sleep, and autism symptom severity in 46 children with autism during lockdown (Türkoğlu et al., 2020). Their results showed that children with autism reported more "eveningness" chronotype, sleep problems, and autism symptom scores during the lockdown period than before. They also showed that sleep problems mediated the relationship between chronotype and autism symptoms in that population. However, to the best of our knowledge, the effects of lockdown on sleep and chronotype have not been studied in adults with autism.

The aim of our study was to explore the effect of lockdown on sleep and circadian rhythms in adults with autism compared to the general population. Based on the scientific literature, we predicted (i) higher levels of sleep–wake rhythms disturbances and lower sleep quality and sleep regularity in the ASD group compared to the general population, and (ii) a differential impact of lockdown on sleep quality parameters and related behaviors (daily screen time, daylight exposure, and physical activity), in adults with autism compared to the general population.

METHODOLOGY

We conducted an observational cross-sectional study to assess sleep–wake rhythms and related behaviors before and during COVID-related lockdown in adults with autism compared to adults from the general population, referred to below as the comparison group.

Participants

The comparison group data were extracted from a French nation-wide survey, conducted by the "Morphée" Network (Hartley et al., 2020). In parallel, adults with a pre-established diagnosis of ASD were recruited via ASD expert centers nationwide. ASD expert centers ensure a diagnosis made by certified practitioners using the Diagnostic and Statistical Manual of Mental Disorders (DSM IV-TR, Bell, 1994 or DSM-5 criteria according to the year of diagnosis, American Psychiatric Association, 2013) and the Autism Diagnostic Observation Scale (Lord et al., 2000). The eligibility criteria were: age 18 or older, and capable of completing the online questionnaire independently. Participants received an email inviting them to participate in a web-based study using the same questionnaire as for the general population (Hartley et al., 2020). Participants provided consent in response to the first question of the form. The study was approved by the "Comité d'éthique pour la recherche" (CER) of the University of Strasbourg (Unistra/CER/2020-07).

Measures

The full questionnaire is available in the Supplementary material, in the original version (French) and an English translation. The time taken to fill the online questionnaire was estimated to be less than 10 min. It included 20 questions, four dealing with demographics and housing characteristics, five regarding circadian sleep–wake rhythms and three about related behaviors (exposure to daylight, screen time, and physical activity). Questions regarding circadian sleep–wake rhythms and related behaviors were asked twice, before and during lockdown.

Questions regarding demographic and housing characteristics were: age, sex, type of housing (house, apartment, with, or without outside space) and living arrangements (alone, with a partner, with one, or more children, with extended family).

Questions regarding the characteristics of sleep and circadian rhythms before and during lockdown were "quality of sleep" (Likert scale, scores from 0 to 10), "bedtime" (clock time range), "wake-up time" (clock time range), "day-to-day regularity of wake-up time" (varying less than an hour, between 1 and 2 h, more than 2 h), "weekly amount of physical activity," "daily exposure to natural light" (in hours), "daily exposure to screens (smartphone, TV, tablet, etc.) in the evening" (in hours). The mid-point of sleep (also called mid-sleep time), a proxy of the circadian phase (Kantermann & Burgess, 2017), was defined as the time point halfway between bedtime and wake-up time.

Statistical analysis

Intragroup differences before and during lockdown were tested using the Mantel–Haenszel test for qualitative variables and Wilcoxon rank test for quantitative variables. Intergroup (ASD vs. comparison group) differences in sleep and related variables before lockdown and during lockdown were explored using logistic regression (with group as the dependent variable), adjusted for sex and age. For all categorical independent variables, the reference category was defined as the most prevalent in the comparison group at T0 (before lockdown). Finally, intergroup differences between before and during lockdown (more, less, or equal sleep duration, regular wake-up time, screen duration, exercise frequency, and day-light exposure; as well as earlier, later or equal bed and wake-up time) were studied using logistic regression, adjusted for age, and sex.

RESULTS

Study population

Population demographics are described in Table 1. The study included 1859 adults, comprising 207 adults with autism (44.0% men), and 1652 participants of the general population (22.9% men). There was a significant overrepresentation of men in the ASD group compared to the comparison group ($p < 0.001$), and mean age was equivalent (34.5 (SD 10.3) years in the ASD group and 35.4 (SD 11.4) years in the comparison group). The type of housing was similar between groups; however, living arrangements were quite different, with 41.1% of the ASD group versus 14.6% of the comparison group being confined with extended family, and only 15.5% of the ASD group versus 38.7% of the comparison group being confined with their wife/husband and/or their underage children.

Before lockdown comparison between ASD and the general population (intergroup comparison)

Before lockdown, adults with autism had longer sleep duration (β 0.43 CI95% [0.29; 0.56]) but poorer sleep quality than the comparison group (β −0.30 CI95% [−0.38; −0.23]. They also had on average a later circadian rhythm (mid-point of sleep β 0.29 CI95% [0.16; 0.43]), but extremely early bedtime (between 21:00 and 22:00) was also more frequent in participants with autism, indicating a nonlinear association, with an overrepresentation of participants with autism at both extremes of the chronotype spectrum. In addition, waking times were less regular in adults with autism than in the comparison group: Odds ratio (OR) of varying waketime by 1 h 1.68 CI95% [1.20; 2.34], OR of varying waketime by 2 h 2.56 CI95% [1.65; 4.06], $p < 0.01$). Behavior was also different: compared to the comparison group, participants with autism had longer screen time during the evening, did less exercise and had a shorter daily exposure to light (Table 2). All results were adjusted for age and sex.

TABLE 1 Population description

	Comparison group 1652	ASD 207	P
Sex			**<0.0001**
Men	22.9% ($N = 379$)	44.0% ($N = 91$)	
Women	77.1% ($N = 1273$)	56.0% ($N = 116$)	
Age			
In years	Mean 35.4 (SD = 11.4)	Mean 34.5 (SD = 10.3)	0.495
Lockdown condition			**<0.0001**
Alone	18.8% ($N = 311$)	25.6% ($N = 53$)	
With partner	27.8% ($N = 459$)	17.9% ($N = 37$)	
With partner and children	38.7% ($N = 640$)	15.5% ($N = 32$)	
With extended family	14.6% ($N = 242$)	41.1% ($N = 85$)	
Type of housing			0.875
In an apartment	20.1% ($N = 332$)	20.8% ($N = 43$)	
In an apartment with balcony	26.2% ($N = 433$)	23.7% ($N = 49$)	
In a house without a garden	2.1% ($N = 34$)	2.4% ($N = 5$)	
In a house with a garden	51.6% ($N = 853$)	53.1% ($N = 110$)	

Note: p-values are marked in bold.

TABLE 2 Sleep, sleep–wake rhythms and related behaviors before (T0) and during (T1) lockdown, and group comparison by time

	Comparison group ($N = 1652$)			ASD ($N = 207$)			ASD versus comparison group			
	T0%(N) or mean (SD)	T1 %(N) or mean (SD)	p[a]	T0 %(N) or mean (SD)	T1 %(N) or mean (SD)	p[a]	T0 β [CI95%]	p[b]	T1 β [CI95%]	p[b]
Sleep duration			**<0.0001**			**<0.0001**				
<6 h	10.1% (167)	19.9% (329)		9.7% (20)	21.7% (45)		0.20 [−0.34;0.73]	0.47	0.43 [−0.01;0.87]	0.06
6–7 h	34.1% (564)	24.6% (407)		24.2% (50)	20.3% (42)		−0.14 [−0.53;0.25]	0.48	0.09 [−0.35;0.54]	0.69
7–8 h	43.1% (712)	29.1% (481)		33.3% (69)	22.2% (46)		Reference		Reference	
8–10 h	12.3% (204)	24.5% (404)		29.0% (60)	30.0% (62)		1.17 [0.78;1.56]	**<0.001**	0.51 [0.10;0.92]	**0.02**
>10 h	0.3% (5)	1.9% (31)		3.9% (8)	5.8% (12)		3.17 [2.02;4.32]	**<0.001**	1.53 [0.78;2.28]	**<0.001**
Bedtime			**<0.0001**			**<0.0001**				
[21:00–22:00[	9.5% (157)	4.5% (75)		19.8% (41)	10.1% (21)		1.40 [0.93;1.86]	**<0.001**	1.25 [0.68;1.83]	**<0.001**
[22:00–23:00[	36.6% (604)	18.9% (312)		31.9% (66)	16.4% (34)		0.52 [0.13;0.92]	**0.01**	0.30 [−0.17;0.76]	0.21
[23:00–00:00[	39.6% (655)	37.4% (618)		22.2% (46)	23.7% (49)		Reference		Reference	
[00:00–01:00[	10.7% (176)	20.4% (337)		13.5% (28)	17.4% (36)		0.77 [0.27;1.28]	**<0.001**	0.27 [−0.19;0.72]	0.25
[01:00–03:00[	3.0% (49)	14.9% (246)		9.2% (19)	22.7% (47)		1.59 [0.96;2.21]	**<0.001**	0.85 [0.42;1.29]	**<0.001**
> 3:00	0.7% (11)	3.9% (64)		3.4% (7)	9.7% (20)		1.99 [0.97;3.01]	**<0.001**	1.33 [0.73;1.93]	**<0.001**
Wake-up time			**<0.0001**			**<0.0001**				
<6:00	6.8% (113)	4.4% (72)		8.7% (18)	5.8% (12)		0.52 [−0.06;1.09]	0.08	0.36 [−0.41;1.13]	0.35
[6:00–7:00[	41.9% (693)	12.2% (202)		29.0% (60)	10.1% (21)		Reference		Reference	
[7:00–8:00[	36.0% (595)	29.6% (489)		27.1% (56)	18.4% (38)		0.05 [−0.33;0.44]	0.79	−0.29 [−0.85;0.28]	0.32
[8:00–9:00[	9.9% (163)	29.4% (486)		15.5% (32)	21.3% (44)		0.79 [0.32;1.25]	**<0.001**	−0.10 [−0.65;0.45]	0.71
[9:00–11:00[	4.7% (78)	19.5% (322)		14.0% (29)	25.6% (53)		1.48 [0.96;1.99]	**<0.001**	0.51 [−0.04;1.05]	0.07
> 11:00	0.6% (10)	4.9% (81)		5.8% (12)	18.8% (39)		2.48 [1.57;3.38]	**<0.001**	1.55 [0.94;2.17]	**<0.001**
Mid-point of sleep (h)	3:30 (0:54)	4:06 (1:16)	**<0.0001**	3.31 (1:26)	4:35 (1:40)	**<0.01**	0.29 [0.16;0.43]	**<0.001**	0.26 [0.16;0.37]	**<0.001**
Sleep Quality (score 0–10)	6.69 (1.79)	5.69 (2.25)	**<0.0001**	5.58 (2.08)	4.85 (2.49)	**<0.01**	−0.30 [−0.38;-0.23]	**<0.001**	−0.17 [−0.23;-0.11]	**<0.001**
Day-to-day wake time regularity			**<0.0001**			**0.0017**				
Varies less than1 h	72.4% (1196)	48.2% (797)		58.5% (121)	38.2% (79)		Reference		Reference	
Varies between 1 and 2 h	20.4% (337)	36.4% (601)		26.6% (55)	32.9% (68)		0.52 [0.18;0.87]	**<0.001**	0.16 [−0.18;0.51]	0.35
Varies more than 2 h	7.2% (119)	15.4% (254)		15.0% (31)	29.0% (60)		0.95 [0.50;1.40]	**<0.001**	0.87 [0.49;1.24]	**<0.001**
Screen time			**<0.0001**			**<0.0001**				
<1 h	11.9% (196)	4.1% (67)		12.1% (25)	7.7% (16)		0.29 [−0.21;0.80]	0.25	1.06 [0.42;1.69]	**<0.001**
1–2 h	32.8% (542)	14.7% (243)		22.7% (47)	13.0% (27)		−0.15 [−0.56;0.26]	0.46	0.25 [−0.26;0.76]	0.33
2–3 h	33.0% (545)	30.8% (508)		28.0% (58)	21.3% (44)		Reference		Reference	
3–4 h	12.8% (212)	23.0% (380)		16.4% (34)	19.3% (40)		0.33 [−0.13;0.79]	0.16	0.18 [−0.27;0.63]	0.44
>4 h	9.5% (157)	27.5% (454)		20.8% (43)	38.6% (80)		0.91 [0.47;1.35]	**<0.001**	0.64 [0.25;1.04]	**<0.001**

(Continues)

TABLE 2 (Continued)

	Comparison group ($N = 1652$)			ASD ($N = 207$)			ASD versus comparison group			
	T0%(N) or mean (SD)	T1 %(N) or mean (SD)	p^a	T0 %(N) or mean (SD)	T1 %(N) or mean (SD)	p^a	T0 β [CI95%]	p^b	T1 β [CI95%]	p^b
Exercise			**<0.0001**			**<0.0001**				
Never	29.9% (494)	35.5% (586)		45.9% (95)	58.5% (121)		Reference		Reference	
1 time/week	27.2% (450)	17.1% (283)		20.3% (42)	15.0% (31)		−0.71 [−1.10;-0.32]	**<0.001**	−0.67 [−1.09;-0.24]	**<0.001**
2 time/week	20.0% (331)	11.9% (196)		11.6% (24)	5.8% (12)		−1.01 [−1.48;-0.53]	**<0.001**	−1.24 [−1.86;-0.62]	**<0.001**
3 time a week	14.6% (241)	13.4% (221)		10.1% (21)	4.3% (9)		−0.80 [−1.31;-0.30]	**<0.001**	−1.66 [−2.35;-0.96]	**<0.001**
Almost every day	8.2% (136)	22.2% (366)		12.1% (25)	16.4% (34)		−0.01 [−0.5;0.48]	0.97	−0.74 [−1.15;-0.34]	**<0.001**
Light exposure			**<0.0001**			**<0.0001**				
<1 h	27.5% (454)	49.0% (810)		31.4% (65)	63.8% (132)		0.15 [−0.21;0.51]	0.41	0.42 [0.03;0.80]	**0.03**
1–2 h	34.4% (569)	20.9% (346)		35.3% (73)	18.8% (39)		Reference		Reference	
2–3 h	18.5% (306)	14.6% (242)		16.4% (34)	9.2% (19)		−0.16 [−0.60;0.28]	0.48	−0.26 [−0.84;0.32]	0.37
3–4 h	8.4% (138)	8.7% (143)		10.1% (21)	4.3% (9)		0.21 [−0.32;0.74]	0.44	−0.56 [−1.31;0.20]	0.15
>4 h	11.2% (185)	6.7% (111)		6.8% (14)	3.9% (8)		−0.64 [−1.25;-0.04]	**0.04**	−0.52 [−1.32;0.28]	0.2

Note: *p*-values are marked in bold.
[a]Before (T0) versus during (T1) lockdown paired analyses (Mantel–Haenszel or Wilcoxon rank test accordingly), separately by group.
[b]Logistic regression analyses of the ASD versus comparison group difference in sleep and associated behaviors, adjusted for age and sex, at T0 and T1.

Effect of lockdown, in ASD and the general population (intragroup before/after comparison)

All studied measures of sleep were significantly affected by the lockdown in both groups (Table 2). Compared to pre-lockdown, both the comparison group and participants with autism had poorer self-rated sleep quality as well as less regular and delayed sleep–wake rhythm, with later bed and wake-up time resulting in a delayed mid-point of sleep (all $p < 0.001$). However, modification in sleep duration was not linear, with an increase of extremes (less than 6 h and more than 10 h) in both groups. Behavioral measures were also affected by the lockdown, with longer screen time in the evening, and less exposure to daylight. In both groups, there was an increase of participants not doing any exercise but also an increase of participants exercising every day.

Lockdown affected sleep in a similar way in both groups, with an equivalent difference before and during lockdown in sleep duration, bedtime, wake-up time, and overall sleep quality (Table 3). Regarding behavioral measures, the comparison group was more likely to increase the frequency of physical activity and daylight exposure (see Figure 1). They were also more likely to increase evening screen time exposure. This could be explained by the fact adults with autism already had a very high screen exposure before lockdown, with 37% spending 3 h or more in front of a screen in the evening; there was thus less opportunity for them to increase even further this exposure, resulting in a ceiling effect..

During lockdown comparison between ASD and the general population (intergroup comparison)

Adults with autism presented the same differences with the comparison group noted prior to lockdown, with longer sleep duration, poorer sleep quality more irregular wake-times than the comparison group. Average bedtime and wake-up time remained later, resulting in a later mid-point of sleep (see Figure 2), although extremely early bedtimes, between 21:00 and 22:00, were still more present in participants with autism. Adults with autism also maintained worse sleep–wake rhythm related behaviors with less physical activity, less daylight exposure, and more screen time, although the "less than an hour" exposure to screen time was more frequent in the ASD group (Table 2, all $p < 0.001$).

DISCUSSION

To the best of our knowledge, this study is the first attempt to investigate the impact of lockdown strategies on sleep and circadian rhythms in an adult population with autism compared to a large sample of the general population. Our study shows that adults with autism had

TABLE 3 Change between before and during lockdown in sleep and associated behaviors

	Comparison group	ASD	β [CI95%][a]	p[a]
Sleep duration				
Less	29.4% (486)	35.7% (74)	0.3[−0.05;0.65]	0.09
Equal	37.7% (623)	38.2% (79)	(ref)	
More	32.9% (543)	26.1% (54)	−0.22[−0.59;0.16]	0.26
Bedtime				
Earlier	7.2% (119)	8.7% (18)	0.22[−0.34;0.77]	0.44
Equal	38.6% (638)	38.6% (80)	(ref)	
Later	54.2% (895)	52.7% (109)	0.07[−0.25;0.39]	0.66
Wake-up time				
Earlier	7.2% (119)	12.1% (25)	0.42[−0.1;0.93]	0.11
Equal	27.5% (455)	30.4% (63)	(ref)	
Later	65.3% (1078)	57.5% (119)	−0.2[−0.53;0.14]	0.24
Mid-point of sleep				
Mean difference (SD)	0.95 (1.12)	−1.07 (1.55)	0.10[−0.02;0.22]	0.11
Sleep quality				
Mean difference (SD)	−1.01 (2.27)	−0.73 (2.37)	0.05[−0.02;0.11]	0.14
Regular wake time				
Less	35% (578)	40.1% (83)	0.37[0.05;0.69]	**0.02**
Equal	56.6% (935)	45.4% (94)	(ref)	
More	8.4% (139)	14.5% (30)	0.82[0.36;1.28]	**<0.001**
Screen time				
Less	5.1% (85)	6.8% (14)	0.07[−0.68;0.54]	0.82
Equal	35.8% (591)	51.2% (106)	(ref)	
More	59.1% (976)	42% (87)	−0.69[−1.02;-0.37]	**<0.001**
Exercise				
Less	26.8% (442)	31.4% (65)	−0.11[−0.45;0.23]	0.52
Equal	38.3% (632)	51.2% (106)	(ref)	
More	35% (578)	17.4% (36)	−0.96[−1.36;-0.56]	**<0.001**
Light exposure				
Less	45.3% (749)	49.8% (103)	−0.19[−0.52;0.13]	0.24
Equal	27.6% (456)	36.7% (76)	(ref)	
More	27.1% (447)	13.5% (28)	−0.94[−1.39;-0.48]	**<0.001**

Note: *p*-values are marked in bold.
[a]Logistic regression of the group difference in change between before and during lockdown, adjusted on age and sex, "equal" category as reference. A positive β indicates a category which is more likely for the ASD group than the comparison group.

pre-existing sleep and circadian rhythm disturbances before the lockdown period, compared to the comparison group, including a phase shift with later bedtime and waking hours, and a longer sleep duration but lower sleep quality. In both groups, lockdown affected not only sleep, with poorer self-rated sleep quality, less regular and more delayed sleep–wake rhythms but also related behavioral measures, notably exposure to natural and artificial light, with longer screen time in the evening and less exposure to daylight. Though the effect of lockdown was similar in both groups, our results highlight that the pre-existing shift in circadian rhythms and lifestyles in adults with autism in relation to the general population was further amplified by lockdown.

Before lockdown

Our data before lockdown show that adults with autism had a longer sleep duration but a poorer sleep quality than the general population. Those results partially match with the existing literature, which is generally scarcer for adults than for children with autism. A recent meta-analysis found that adults with autism had a higher Pittsburgh Sleep Quality Index, meaning a poorer sleep quality, a longer total time spent in bed, and a higher sleep onset latency than controls; but no differences were found in total sleep time (Morgan et al., 2020). In their study based on polysomnography, Limoges et al. (2005) also found lower sleep quality (lower sleep efficiency, increased night-waking, and increased sleep onset latency) and no difference in total sleep time. In contrast, Baker and Richdale (2015) found a shorter sleep duration in adults with high functioning ASD and without co-occurring anxiety or depression diagnosis compared to neurotypical adults using actigraphy.

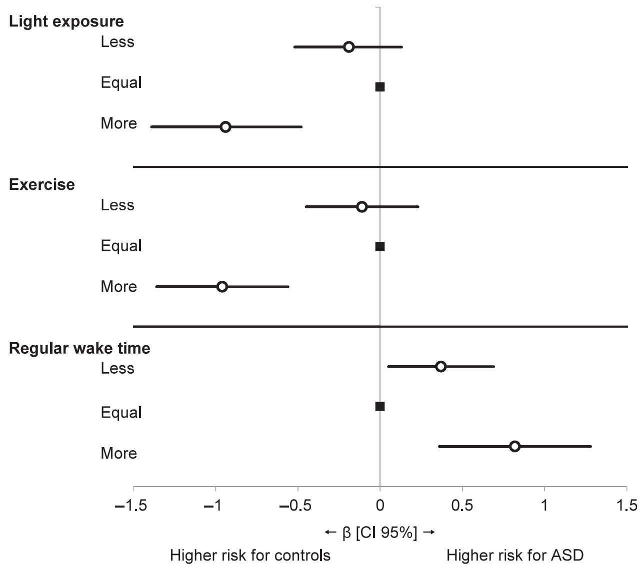

FIGURE 1 Changes between before and during lockdown in behaviors known to influence circadian rhythms ("*zeitgeber*") in ASD compared to the general population. Forest plot representing the logistic regression estimates (β and [CI 95%]) of the difference between ASD and comparison groups in the changes between before versus during lockdown regarding light exposure, exercise, and regularity of wake-time (adjusted for age and sex). The change between before and during lockdown is expressed as more, equal or less (exposure to light, quantity of exercise, and regularity of sleep), with the "equal" category as reference. A positive β indicates a category which is more likely for the ASD group than the comparison group

Regarding sleep–wake rhythm, the ASD group displayed less regular sleep patterns and, on average, a later circadian phase (later bedtime and wake-up time resulting in a later mid-point of sleep). However, this association is not linear, with an overrepresentation of both extremely early and extremely late bedtime in the ASD group. Our results are in line with the current literature reporting circadian rhythm disturbances in ASD, but with no clear direction of the phase shift. Hare et al. (2006) observed in their actigraphic study a lower relative amplitude, lower inter-daily stability and greater variability in sleep measures. On average, mean phase markers were equivalent in both groups but with variability in the ASD group indicating the presence of both phase advance and phase delay. Baker and Richdale (2017) found that adults with ASD were more likely to meet diagnosis criteria (based on actigraphy and sleep diary) for circadian rhythm sleep–wake disorder, with a significant proportion displaying delayed sleep–wake phase disorder, but also a non-significant proportion with advanced sleep–wake rhythms. In their study assessing circadian phase based on dim-light melatonin onset, Baker et al. (2017) observed no mean difference in circadian phase but advances and delays in individual profiles. In their meta-analysis, Morgan et al. (2020) did not find significant differences between the ASD and control populations in bedtime (weekend or weekday) and wake-up time (weekend or weekday). As previously suggested by Baker and Richdale (2017), it is likely that sub-groups of sleep phenotype and etiology exist within

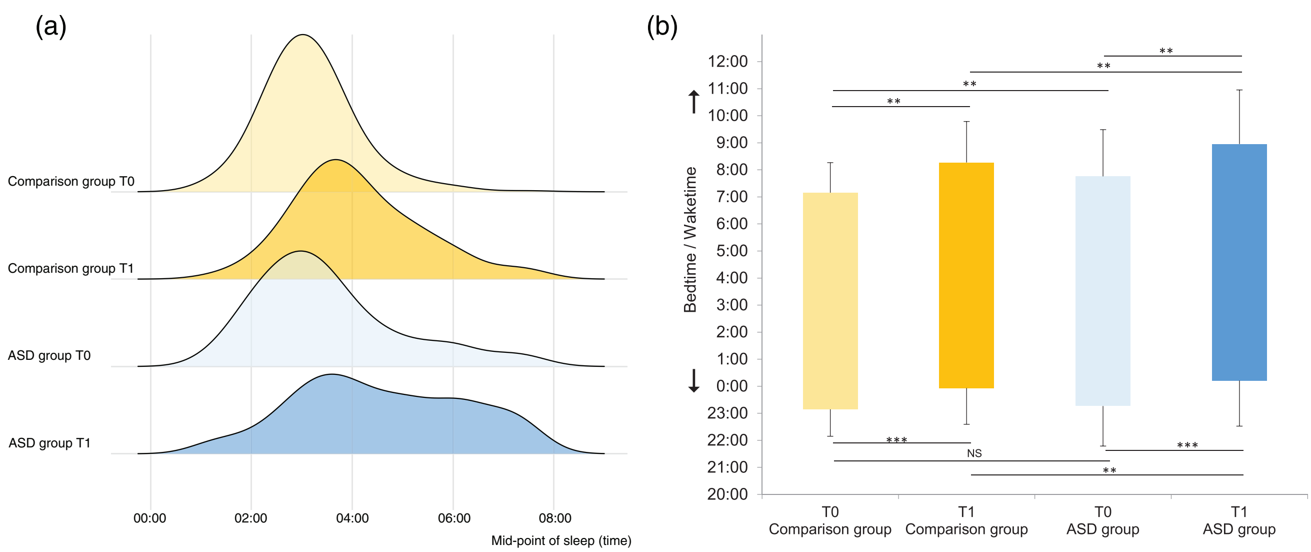

FIGURE 2 Circadian sleep–wake rhythm in ASD and comparison group before and during lockdown. (a) Ridgeline density plot of the mid-point of sleep in ASD and comparison group before (T0) and during (T1) lockdown. (b) Mean bedtime (bottom) and wake-up time (top) in ASD and comparison group before (T0) and during lockdown (T1). Error bars are Standard Deviations. Statistical comparisons between groups are logistic regressions between group, bedtime and wake time. Comparisons between T0 and T1 within a group are paired Wilcoxon rank test. ***$p < 0.001$, **$p \leq 0.01$, *$p \leq 0.05$. Abbreviation: NS, non-significant

ASD. Null findings could be explained by the presence of both extremes (i.e., very early and very late chronotypes) simultaneously in the ASD population, as the process of averaging the extremes would cancel the difference with a more normally distributed sleep duration in the general population.

The lower sleep quality and disturbed circadian rhythm found in participants with autism prior to lockdown could be partially explained by behaviors likely to negatively influence sleep and circadian rhythm. Participants with autism did indeed display longer screen times during the evening, less frequent physical exercise and a shorter daily exposure to light than the comparison group. These results are in line with the literature describing a more sedentary behavior in children with autism compared to their neurotypical peers (Jones et al., 2017), and although the literature is much more sparse, concordant results are found for adults with autism (Coutelle et al., 2021; Weir et al., 2021). In addition to these external factors, the irregular sleep–wake patterns or circadian rhythm sleep–wake disorders in ASD are also likely to be intrinsic to ASD pathophysiological mechanisms (Lorsung et al., 2021). As detailed in the Lorsung et al. (2021), studies have reported polymorphisms in genes that regulate circadian timing (called clock genes, Yang et al., 2016) as well as abnormal secretion of circadian biomarkers, including melatonin (Melke et al., 2008), serotonin (Melke et al., 2008) and cortisol (Corbett et al., 2006).

During lockdown

As expected, both the comparison group and ASD groups were impacted by lockdown, with poorer self-rated sleep quality, less regular and delayed sleep–wake rhythm, and a delayed mid-point of sleep compared to before lockdown. These results are in line with the existing literature on the effect of lockdown in various populations' sleep patterns. For example, Gualano et al. (2020) found that 42.2% of the 1515 participants of their Italian online survey had sleep disturbances during the last 14 days of lockdown and, among them, 17.4% reported moderate/severe insomnia. Another study found later bedtime hour, sleep onset latency, and wake-up time during lockdown compared to before in 400 participants, with a worsened sleep quality and an increase of insomnia symptoms (Marelli et al., 2020). Blume et al. (2020) found similar results, with an increase in sleep duration and a decrease in sleep quality A delayed chronotype during lockdown was also found in Argentina by Leone et al. (2020) with later going to sleep and waking up times on weekdays, resulting in a longer weekday sleep duration during the lockdown, without an impact on sleep quality.

Contrary to our initial hypothesis, participants with autism were not more impacted by lockdown than the general population in terms of differences in sleep patterns; in fact, both populations were equally affected. Indeed, the magnitude of the difference between before and during lockdown in sleep duration, bedtime, wake-up time, and overall sleep quality proved to be equivalent in participants with autism and the general population. But as significant sleep disturbances were present prior to lockdown in adults with autism compared to the general population, these difficulties worsened significantly during lockdown. We note that though sleep worsened, some aspects of lockdown may have been positive for some adults with autism, such as a relief from social demands (Oomen et al., 2021; Pellicano et al., 2021).

Limitations

Nevertheless, our study has some limitations. First, our sample of adults with autism is not representative of the general population of adults with autism, since the ability to take an online survey requires a preserved intelligence, which excludes de facto a population with moderate to severe intellectual deficiency. The comparison group wasn't representative of the general population either, especially regarding the sex ratio (77% women). Female preponderance happens to be common in online surveys where participation is based on a voluntary commitment; recent online surveys regarding COVID-19 (Sulistyawati et al., 2021; Zhang et al., 2021) as well as surveys conducted within the ASD population (Scattoni et al., 2021) have reported similar imbalance towards women. Second, due to the time-sensitive aspect of the research and lockdown circumstances, all data were self-reported. We were unable to conduct face-to-face interviews and collect objective measures. Results are thus to be interpreted rather as a perception of sleep than actual sleep. Lugo et al. (2020) report in their meta-analysis regarding sleep in adults with autism that subjective measures match those found in actigraphy studies, but not those of polysomnography. Also, in order to limit response burden, the questionnaire was designed to minimize completion time (Hartley et al., 2020). Thus, data regarding socio-demographic features of the population are scarce and we did not use validated questionnaires, which were deemed too lengthy to assess sleep and circadian rhythm. Third, we did not screen for other co-occurring conditions which are quite frequent in ASD, notably those that may have impacted sleep and sleep–wake rhythms (e.g., anxiety, depression, bipolar disorder, and ADHD, for review: Hossain et al., 2020). For example, a longer sleep duration may be associated with depression, while anxiety can lead to lower sleep quality or in dysregulated bedtime and waketime. As anxiety and depression symptoms appear to be associated with lockdown in ASD (Oomen et al., 2021; Pellicano et al., 2021) and the general population (Gualano et al., 2020; Hao et al., 2020; Marelli et al., 2020; Vindegaard & Benros, 2020; Wang et al., 2020) and are linked to sleep (Altena et al., 2016), it will be important to take those variables into account in future studies. Fourth, participants reported retrospectively on sleep and wake behavior "before lockdown," leading to a potential recall bias. Finally, we did not verify if our participants experienced a disruption in their health care provision. The reallocation of medical staff towards COVID-19 units restricted the access to health and psychiatric care for most people, which may have indirectly impacted sleep quality. As co-occurring medical and psychiatric conditions are more prevalent in people with autism (Lai et al., 2014, 2019), this population would be, like other psychiatric populations, more vulnerable to the interruption of health care (Hao et al., 2020; Lazzari et al., 2020; Talevi et al., 2020; Vindegaard & Benros, 2020).

Studies in children with autism and their families have shown that lockdown led to an increase in behavioral issues and autism symptoms (Asbury et al., 2020; Colizzi et al., 2020), but also a worsening of quality of life linked to higher levels of stress (Manning et al., 2020). Maintaining functioning mental health services during future lockdowns, especially for vulnerable populations, should be a priority for governments and may require innovative solutions. Telemedicine may represent an opportunity to maintain services, as some therapies and healthcare support are adaptable to new technologies (e.g., teleconsultation services and health care apps) some of which target sleep (Aji et al., 2021) (e.g., online cognitive and behavioral therapy for insomnia).

CONCLUSIONS

Our study has shed new light on circadian sleep–wake rhythms in adults with autism before and during the COVID-related lockdown. Lockdown had a negative impact on sleep–wake rhythms and related behaviors of both adults with autism and the general population. While adults with autism displayed significantly higher levels of sleep disturbances before lockdown, including delayed sleep phase, more irregular sleep–wake rhythms, and more behaviors known to affect sleep and circadian rhythms (lower daylight exposure, lower levels of physical activity, and higher screen time) compared to the general population, lockdown affected sleep in both populations in similar ways, leading to even higher sleep disturbances in the ASD population. Given the known vulnerability of this population, innovative support strategies should be sought in case of future lockdowns.

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DATA AVAILABILITY STATEMENT

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

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