Journal of Affective Disorders 314 (2022) 259–262

Contents lists available at ScienceDirect

Journal of Affective Disorders

journal homepage: www.elsevier.com/locate/jad

Short communication

Seasonality and ADHD: Summer time is associated with less symptoms of inattention among children and adolescents with ADHD

María Fernanda Zerón-Rugerio [a,b], Jose A. Alda [c,f], Tannia Valeria Carpio-Arias [d], Maria Izquierdo-Pulido [a,b,1], Trinitat Cambras [e,*,1]

[a] *Department of Nutrition, Food Science and Gastronomy, Faculty of Pharmacy and Food Science, University of Barcelona, Barcelona, Spain*
[b] *Institut de Recerca en Nutrició i Seguretat Alimentaria (INSA-UB), University of Barcelona, Barcelona, Spain*
[c] *Children and Adolescent Mental Health Research Group, Institut de Recerca Sant Joan de Déu, Barcelona, Spain*
[d] *Research Group on Food and Nutrition (GIANH), Higher Polytechnic School of Chimborazo, Ecuador*
[e] *Department of Biochemistry and Physiology, Faculty of Pharmacy and Food Science, University of Barcelona, Barcelona, Spain*
[f] *Child and Adolescent Psychiatry and Psychology Department, Hospital Sant Joan de Deu Barcelona, Barcelona, Spain*

ARTICLE INFO

Keywords:
Light intensity
Motor activity
Circadian variables
ADHD

ABSTRACT

Background: Although alertness and activity status are related to light intensity, the effects of seasonal light variability on patients with Attention Deficit Hyperactivity Disorder (ADHD) have been scarcely studied. Our objective was to investigate the effect of seasonality (summer time vs. winter time) on ADHD symptomatology and on the circadian pattern of motor activity in children and adolescents with ADHD and healthy controls.

Methods: A total of 117 participants (56.4 % males; age [mean ± SD] 9.2 ± 2.8 years; 51 % patients with ADHD) were included in this cross-sectional study. For all participants we assessed ADHD symptomatology using the Conners Parents Rating Scale-Revised and the circadian pattern of motor activity using actigraphy. Data were collected when schools were in session. General linear models were used to test for differences in outcome variables based on seasonality and ADHD subtype.

Results: The results revealed that seasonality had a significant effect among ADHD-I patients. Particularly, we observed that inattention symptoms were ~8.1 points lower ($p = 0.002$) in summer time, relative to winter time. In addition, we observed that among patients with ADHD-I, the intradaily variability was also significantly lower in summer ($p = 0.024$).

Conclusion: The results from this preliminary study suggest that seasonal light variability could be a factor that modifies the behavior of children and adolescents with ADHD-I.

1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD), one of the most common psychiatric disorders in childhood and adolescence, is characterized by inattention and/or hyperactivity/impulsivity that interferes with every day functioning (Korman et al., 2020). Although its etiology remains poorly understood (Korman et al., 2020), ADHD has been shown to have high comorbidity with sleep disorders and alterations in circadian rhythms (Coogan and McGowan, 2017; Korman et al., 2020; Zerón-Rugerio et al., 2020).

The circadian system underpins the generation of near 24-h rhythms in physiological and behavioral variables. One of the main external synchronizers of the circadian system is the environmental light–dark cycle (LeGates et al., 2014). Light is necessary for image formation by the visual system, but is also essential for the regulation of numerous circadian non-image-forming functions, which include the direct improvement of alertness and performance (Gaggioni et al., 2014; LeGates et al., 2014; Lockley et al., 2006). These non-image-forming effects are distinct from classical visual system (which includes rods and cones), since they have the origin in the intrinsically photosensitive retinal ganglion cells (ipRGC), which express the photopigment melanopsin, that have a maximal sensitivity to blue light (Gaggioni et al., 2014). Thanks to this path, light information reaches the circadian clock, but also conveys a direct (exogenous) stimulating signal that

---

[*] Corresponding author at: Department of Nutrition, Food Science and Gastronomy, University of Barcelona, Av. Joan XXIII 27-31, 08028 Barcelona, Spain.
E-mail address: cambras@ub.edu (T. Cambras).

[1] Dr. Cambras and Dr. Izquierdo-Pulido share senior authorship.

https://doi.org/10.1016/j.jad.2022.07.036
Received 5 April 2022; Received in revised form 13 May 2022; Accepted 17 July 2022

impacts on alertness (LeGates et al., 2014; Lockley et al., 2006).

Although alertness and activity status could be related to light intensity and might influence behavior, the effects of light on ADHD have been scarcely studied (Korman et al., 2020). For instance, morning blue light therapy was an effective adjunctive treatment in the fall and winter periods in adult ADHD patients (Rybak et al., 2007). Notably, light therapy was associated with improvements in attentional functioning, impulsivity, and behavioral inhibition in this population (Rybak et al., 2007). Furthermore, Arns et al. (2013) found that 34–57 % of the variation in ADHD prevalence was explained by sunlight intensity. As such, those areas of the U.S. with the highest solar intensity had the lowest prevalence of ADHD. Thus, they hypothesized that a higher solar intensity could be related to improved circadian function. Taking into account the aforementioned, our aim was to investigate the effect of seasonality (summer time vs. winter time) on ADHD symptomatology and alterations in the circadian pattern of activity in children and adolescents with ADHD and healthy controls. Our hypothesis is based on the possibility that patients with ADHD could have a different sensibility to light that could influence their symptomatology and their circadian rhythmicity.

2. Methods

This is a secondary analysis of a case-control study comparing differences in the circadian pattern of activity between newly diagnosed (medication naïve) children and adolescents with ADHD ($n = 59$) versus healthy controls ($n = 58$). More details about the methodology are provided in Zerón-Rugerio et al. (2020). The study was conducted in accordance with the ethical guidelines of the Declaration of Human Studies of Helsinki and approved by the Ethical Committee of the Hospital of Sant Joan de Deu. Written informed consent was obtained from the parents of the participants and verbal assent from the participants.

2.1. Exposure variables

2.1.1. Seasonality

Participants were grouped according to the season in which they wore the actigraph, as follows:

i. Summer time or daylight saving time (GMT + 02), included participants who wore the actigraph during the last week of March until the third week of October.
ii. Winter time or standard time (GMT + 01), included participants who wore the actigraph during the last week of October, until the third week of March.

We excluded July and August since these months correspond to summer school holidays in Spain.

2.2. Outcome variables

2.2.1. ADHD symptomatology

The evaluation of ADHD symptomatology of children was assessed through the Conners Parents Rating Scale-Revised (Short Version) (CPRS-R:S) (Conners et al., 1998). This scale evaluates the domains of inattention and hyperactivity, oppositional behavior, and the ADHD index. Furthermore, according to the symptomatology, patients were diagnosed into two subtypes: ADHD-combined (ADHD-C) or ADHD-inattentive (ADHD-I).

2.2.2. Circadian pattern of motor activity

The 24 h-rhythm of activity was measured with the ActiSleep actigraph (ActiGraph, Pensacola, FL, USA), which was programmed to collect data every minute for 7 consecutive days [34]. Participants were required to wear the actigraph on the non-dominant wrist and only take it off while showering or bathing. Environmental light was detected by the same device.

From these data, we studied the circadian pattern of motor activity using "el Temps" (v293), an integrated package for chronobiological analysis. We calculated the mean value of motor activity fitted to a cosine function (Mesor), as well as circadian variables related to the stability (interdaily stability, and Rayleigh test) and the fragmentation (intradaily variability) of the circadian rhythm. Additionally, we calculated the average value of motor activity between 20:00 and 22:00 (Act20-22) as a measure of activity previous to sleep time.

2.3. Statistical analysis

Values are expressed as mean and standard deviation, unless stated otherwise. General linear models (GLMs) were used to test differences in outcome variables between seasons (summer time vs. winter time) in the following subgroups: ADHD-I, ADHD-C, and healthy controls. For those ADHD symptoms that differed between seasons (inattention), we calculated Cohen's d to describe the standardized mean difference of the effect (Becker, 1999). Effect size was considered as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$) (Lakens, 2013). All analyses were adjusted for age and performed with SPSS software v25.0 (IBM SPSS Statistics, Armonk, USA).

3. Results

Overall, 117 participants (56.4 % males; age [mean ± SD] 9.2 ± 2.8 years; 51 % patients with ADHD) were included in this study. Of which, 60 participants (33 control, 11 ADHD-I, and 16 ADHD-C) were studied during winter time and 57 participants (25 control, 11 ADHD-I and 21 ADHD-C) were studied during summer time. The mean values of environmental light measured during the study period are shown in the Fig. 1.

Our results revealed that seasonality was significantly associated with ADHD symptomatology among patients with ADHD-I (Table 1). Note that in this subgroup, inattention was, on average, 8.1 points lower [95 % CI: 3.4, 12.8] in summer time, relative to winter time. Accordingly, seasonality had a large effect on inattention symptoms among patients with ADHD-I (Cohen's $d = 1.4$). In addition, we observed that the total score of CPRS-R:S was also significantly lower in summer time ($p = 0.003$, Cohen's $d = 1.39$). Likewise, we observed that, in relation to winter time, the intradaily variability was significantly lower in summer ($p = 0.024$).

Regarding patients with ADHD-C, we observed that neither the symptoms, nor the rhythmic variables of motor activity differed between seasons (Table 1). In this case, we only observed that mean values of Act20-22 were higher in summer time, however this difference was only close to statistical significance ($p = 0.052$). Finally, we observed that among healthy controls, the Rayleigh test was slightly lower in summer time ($p = 0.049$).

4. Discussion

The results from this preliminary study showed that, among children and adolescents newly diagnosed with ADHD, symptomatology differs according to seasonality. Specifically, the results showed that compared with winter time, ADHD inattention symptoms were lower in summer time among patients with ADHD-I. Noteworthy, light exposure can trigger other neurobehavioral responses, including improved alertness and performance (Chellappa et al., 2011; Rybak et al., 2007). Additionally, the effects of light stimuli on the human sleep-wake cycle are well established in a variety of measures, including phase resetting and suppression of the sleep-promoting hormone melatonin (Korman et al., 2020).

Regarding the circadian pattern of motor activity, our results showed that winter time was associated with a higher fragmentation of this daily rhythm (given by a higher intradaily variability) among patients with

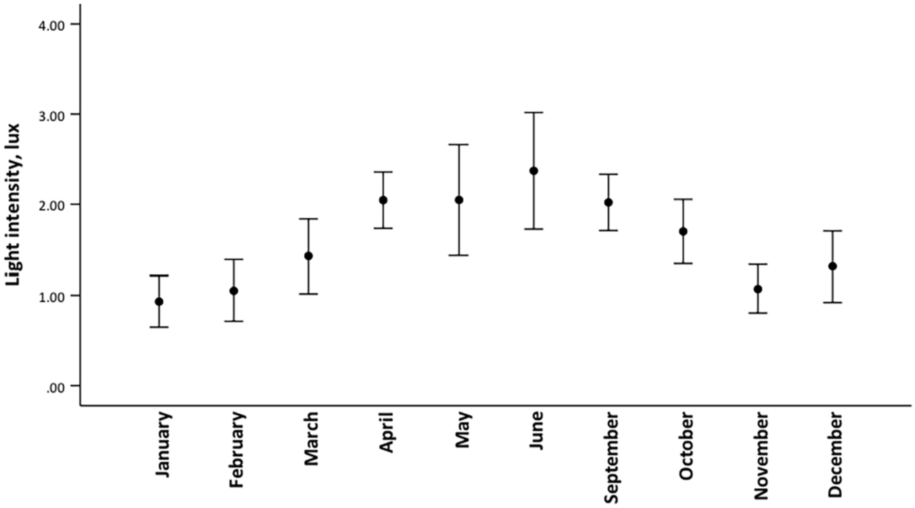

Fig. 1. Mean values of environmental light intensity measured during the study period. Values are expressed as mean and SEM.

Table 1

Comparison of ADHD symptoms and circadian variables in subjects with ADHD-Inattentive, ADHD-Combined, and healthy controls as a function of seasonality (summer time vs winter time).

	ADHD-inattentive			ADHD-combined			Controls		
	Summer time *n* = 11	Winter time n = 11	p-Value	Summer time (*n* = 21)	Winter time (*n* = 16)	p-Value	Summer time *n* = 25	Winter time *n* = 33	p-Value
ADHD symptoms[a]									
Inattention	70.7 (5.4)	78.7 (5.9)	**0.002**	70.4 (12.8)	68.4 (14.4)	0.701	44.9 (4.8)	46.9 (7.4)	0.244
Hyperactivity	56.0 (10.3)	58.8 (12.2)	0.570	78.4 (11.6)	73.2 (12.7)	0.184	47.7 (5.7)	46.7 (3.4)	0.311
Oppositional behavior	54.4 (12.3)	55.5 (12.8)	0.852	64.5 (14.4)	61.2 (13.0)	0.358	46.4 (6.6)	43.1 (5.5)	0.080
Total	67.7 (5.2)	75.7 (6.2)	**0.003**	70.8 (10.5)	71.1 (12.6)	0.932	44.5 (4.6)	45.2 (5.4)	0.615
Rhythmic variables of motor activity									
Mesor, AU	2435.0 (558.5)	2351.6 (452.6)	0.680	2781.5 (477.7)	2620.8 (749.3)	0.196	2316.7 (522.8)	2482.5 (432.7)	0.897
Intradaily variability, AU	0.38 (0.05)	0.43 (0.05)	**0.024**	0.37 (0.07)	0.40 (0.08)	0.208	0.38 (0.06)	0.39 (0.05)	0.119
Rayleigh test, AU	0.95 (0.05)	0.95 (0.03)	0.703	0.94 (0.05)	0.96 (0.03)	0.213	0.92 (0.07)	0.96 (0.04)	**0.049**
Interdaily stability, %	42.9 (6.4)	40.3 (4.3)	0.158	42.7 (7.4)	43.6 (7.1)	0.886	39.6 (6.9)	42.5 (6.2)	0.803
20:00–22:00, AU	2516.5 (589.1)	2838.0 (858.2)	0.266	3530.3 (1108.9)	2861.5 (949.2)	0.052	2271.5 (892.1)	2347.6 (640.8)	0.900

AU: Arbitrary units. Data are shown mean (SD).

[a] ADHD symptomatology of children was assessed through the Conners Parents Rating Scale-Revised (Short Version). Statistical tests: General linear models adjusted for age were used to compare differences. Significant *p*-values are shown in bold. NS: not significant.

ADHD-I. Notably, the intradaily variability is a marker of chronodisruption, which our group has recently showed it was associated with symptoms of inattention among patients with ADHD-I (Zerón-Rugerio et al., 2020). Furthermore, a higher fragmentation of the circadian pattern has been associated with other ADHD comorbidities, such as symptoms of depression and cognitive impairment (Luik et al., 2013; Oosterman et al., 2009). Thus, according to our findings, patients who are diagnosed with the inattentive subtype of ADHD could benefit from light therapy during those months with shorter photoperiods, specially wintertime, improving their attentional functioning (Rybak et al., 2007). We also observed that the stability of the circadian rhythm (given by the Rayleigh test) was lower during summer time when we studied among healthy controls. This could be due to the fact that relative to winter time, physical activity tends to be higher in summer time (Turrisi et al., 2021), but it could also be related to the effect of summer time on sleep (Quante et al., 2019).

5. Conclusion

In summary, our results suggest that light could be a factor that modifies the behavior of children and adolescents and that different subtypes of ADHD might be characterized by different sensitivity to light. Actually, seasonality alterations of mood and behavior have been related with gene polymorphisms of the core clock machinery or of retinal melanopsin cells (i.e. Garbazza and Benedetti, 2018) and this might generate the differences in season between the groups. Consequently, since summer time was associated with the improvement in ADHD-I symptoms, the need to implement light therapy in these patients during winter could be suggested. However, due to the observational nature of our study, future interventional studies are needed to confirm our findings.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

We are grateful to Dr. Ramírez, Dr. Hernández and Dr. Serrano for their assistance with material collection and to the patients and families for their collaboration and implication.

Funding

The study was supported by a grant from the Subdirección General de Evaluación y Fomento de la Investigación from the Instituto de Salud

Carlos III, Ministerio de Ciencia e Innovación, Spain [PI11/2009].

Author contributions

JAA and MIP designed the study; TVCA, JAA and MIP acquired the data; MFZR and TC analyzed the data; MFZR wrote the first draft; TC, JAA, and MIP revised the manuscript. All authors read and approved the final manuscript.

References

Arns, M., Van Der Heijden, K.B., Arnold, L.E., Kenemans, J.L., 2013. Geographic variation in the prevalence of attention deficit/hyperactivity disorder the sunny perspective. Biol. Psychiatry 1–6. https://doi.org/10.1016/j.biopsych.2013.02.010.

Becker, L., 1999. Effect Size Calculator. University of Colorado Springs. https://lbecker.uccs.edu/. (Accessed 9 May 2022).

Chellappa, S.L., Steiner, R., Blattner, P., Oelhafen, P., Götz, T., Cajochen, C., 2011. Non-visual effects of light on melatonin, alertness and cognitive performance: can blue-enriched light keep us alert? PLoS One 6. https://doi.org/10.1371/journal.pone.0016429.

Conners, C.K., Sitarenios, G., Parker, J.D., Epstein, J.N., 1998. The revised Conners'Parent Rating Scale (CPRS-R): factor structure, reliability, and criterion validity. J. Abnorm. Child Psychol. 26, 257–268.

Coogan, A.N., McGowan, N.M., 2017. A systematic review of circadian function, chronotype and chronotherapy in attention deficit hyperactivity disorder. ADHD Atten. Deficit Hyperact. Disord. 9, 129–147. https://doi.org/10.1007/s12402-016-0214-5.

Gaggioni, G., Maquet, P., Schmidt, C., Dijk, D.J., Vandewalle, G., 2014. Neuroimaging, cognition, light and circadian rhythms. Front. Syst. Neurosci. 8, 1–12. https://doi.org/10.3389/fnsys.2014.00126.

Garbazza, C., Benedetti, F., 2018. Genetic factors affecting seasonality, mood, and the circadian clock. Front. Endocrinol. (Lausanne) 23, 481. https://doi.org/10.3389/fendo.2018.00481.

Korman, M., Palm, D., Uzoni, A., Faltraco, F., Tucha, O., Thome, J., Coogan, A.N., 2020. ADHD 24/7: circadian clock genes, chronotherapy and sleep/wake cycle insufficiencies in ADHD. World J. Biol. Psychiatry 21, 156–171. https://doi.org/10.1080/15622975.2018.1523565.

Lakens, D., 2013. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front. Psychol. 4, 1–12. https://doi.org/10.3389/fpsyg.2013.00863.

LeGates, T.A., Fernandez, D.C., Hattar, S., 2014. Light as a central modulator of circadian rhythms, sleep and affect. Nat. Rev. Neurosci. 15, 443–454. https://doi.org/10.1038/nrn3743.

Lockley, S., Evans, E., Scheer, F., Brainard, G., Czeisler, C., Aeschbach, D., 2006. Short-wavelength sensitivity for the direct effects of light on alertness, vigilance, and the waking electroencephalogram in humans. Sleep 29, 161–168. https://doi.org/10.5665/sleep.2894.

Luik, A.I., Zuurbier, L.A., Hofman, A., Someren, E.J.W.Van, Tiemeier, H., 2013. Stability and fragmentation of the activity rhythm across the sleep-wake cycle: the importance of age, lifestyle, and mental health. Chronobiol. Int. 30, 1223–1230.

Oosterman, J.M., Van Someren, E.J.W., Vogels, R.L.C., Van Harten, B., Scherder, E.J.A., 2009. Fragmentation of the rest-activity rhythm correlates with age-related cognitive deficits. J. Sleep Res. 18, 129–135. https://doi.org/10.1111/j.1365-2869.2008.00704.x.

Quante, M., Wang, R., Weng, J., Kaplan, E.R., Rueschman, M., Taveras, E.M., Rifas-Shiman, S.L., Gillman, M.W., Redline, S., 2019. Seasonal and weather variation of sleep and physical activity in 12-14-year-old children. Behav. Sleep Med. 17, 398–410. https://doi.org/10.1080/15402002.2017.1376206.

Rybak, Y.E., McNeely, H.E., Mackenzie, B.E., Jain, U.R., Levitan, R.D., 2007. Seasonality and circadian preference in adult attention-deficit/hyperactivity disorder: clinical and neuropsychological correlates. Compr. Psychiatry 48, 562–571. https://doi.org/10.1016/j.comppsych.2007.05.008.

Turrisi, T.B., Bittel, K.M., West, A.B., Hojjatinia, Sarah, Hojjatinia, Sahar, Mama, S.K., Lagoa, C.M., Conroy, D.E., 2021. Seasons, weather, and device-measured movement behaviors: a scoping review from 2006 to 2020. Int. J. Behav. Nutr. Phys. Act. 18, 24. https://doi.org/10.1186/s12966-021-01091-1.

Van Someren, E.J.W., 2007. Improving actigraphic sleep estimates in insomnia and dementia: how many nights? J. Sleep Res. 16, 269–275. https://doi.org/10.1111/j.1365-2869.2007.00592.x.

Zerón-Rugerio, M.F., Carpio-Arias, T.V., Ferreira-García, E., Díez-Noguera, A., Cambras, T., Alda, J.Á., Izquierdo-Pulido, M., 2020. ADHD subtypes are associated differently with circadian rhythms of motor activity, sleep disturbances, and body mass index in children and adolescents: a case–control study. Eur. Child Adolesc. Psychiatry. https://doi.org/10.1007/s00787-020-01659-5.