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REVIEW ARTICLES

Sleep Characteristics in Children with Attention Deficit Hyperactivity Disorder: Systematic Review and Meta-Analyses

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Study Objectives: Sleep disturbances have been associated with attention deficit hyperactivity disorder (ADHD), but such relationship is still unclear. The results from the studies conducted do not provide enough evidence to support a sleep physiology inherent to ADHD. This study tries to determine if that sleep physiology really exists by comparing children with ADHD and control children in some sleep parameters.
Methods: A search was conducted in several databases (Web of Science, Scopus, Pubmed and PsycINFO), and a manual search, to retrieve all the articles available from 1987 until March 2014. Of 8,678 non-duplicate studies retrieved, 11 studies met the inclusion and methodological quality criteria. Two meta-analyses were performed with eight of those studies, depending on data provided by them: polysomnographic or actigraphic. A fixed-effects model, and the standardized mean difference (SMD) as the index of effect size, were used in both meta-analyses.
Results: Significant differences were found only in the meta-analysis with polysomnography as outcome. Children with ADHD were found to spend more time in stage 1 sleep than controls (pooled SMD = 0.32, 95% CI = 0.08–0.55, p value = 0.009).
Conclusions: Although few differences in sleep between children with ADHD and controls have been found in this review, further studies are required on this matter. Those studies should consider some variables discussed in this review, in order to obtain useful and reliable conclusions for research and clinical practice. Particularly, the influence of assessment criteria and ADHD subtypes in the sleep characteristics of children with ADHD should be addressed.
Keywords: sleep, attention deficit hyperactivity disorder, ADHD, children, systematic review, meta-analysis.
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INTRODUCTION

Attention deficit hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders in childhood and adolescence, with a worldwide prevalence rate of about 5.3% and 5% in Europe.[1,2] The considerable increase in ADHD diagnosis for the last few years (around 24% between 2001 and 2010),[3] has made this disorder a topic of great interest for many researchers and clinicians. Mainly because of its numerous effects on the social, emotional, and cognitive functioning. ADHD symptomatology interferes negatively with academic performance, levels of self-esteem and quality life, and social and family relationships of children who suffer from it.[4–6] In addition, ADHD is related to numerous comorbid conditions in childhood and adolescence, including bipolar disorder, oppositional defiant disorder, behavioral and substance use disorders, and eating disorders.[7–10] It has been also associated with depression and anxiety symptoms and even identified as a major risk factor for suicide.[11,12]

Other problems related to this disorder have been sleep disturbances. Although rates estimated have varied over the years, it has been reported that up to 55% of children with ADHD may have sleep problems.[13] In general, sleep disturbances have negative consequences in different areas of a child's life. For instance, sleep problems have a negative impact on attention and/or behavior and on daytime sleepiness levels of children.[14,15] Given that these factors have repercussions on academic or cognitive performance, which were already affected in children with ADHD, sleep disturbances in these children might be acting as a positive feedback mechanism, exacerbating their symptomatology. Therefore, the relationship between sleep characteristics and ADHD in children needs to be examined for the development of effective intervention or treatment programs for ADHD that could improve their quality of life. Nevertheless, such relationship is not totally determined yet, because the results obtained until now have been contradictory.

Although numerous authors have found differences between children with and without ADHD in several sleep descriptors, such differences have not been consistent. Whereas some authors have found differences on sleep continuity and architecture,[16,17] other authors have found them regarding motor activity during sleep,[18,19] and others in daytime sleepiness levels.[20] However, the discrepancies between the results of the previous studies might be due to the differences between them with regard to: (a) the type of measure (objective or subjective) employed to obtain data, and the little comparison between both information sources; (b) the age ranges covered; (c) the consideration of sex differences in the clinical symptomatology of ADHD; (d) the control of participants' medication and of their comorbid conditions; (e) the distinction made between the three subtypes of ADHD; and (f) the ADHD assessment itself, because there is not a common assessment protocol to all the studies.[19,21–24]

Besides the limitations resulting from those differences between the studies, another important limitation is the lack of rigorous inclusion and exclusion criteria for participants in several studies. For instance, participants with primary sleep disorders, like apnea or restless legs syndrome, were not excluded in some studies.[25–30] This limitation makes it difficult to conclude if sleep disturbances in those children with ADHD were actually due to ADHD symptomatology, or if their primary sleep disorders might be biasing the results; for instance, regarding sleep physiology. Given that those primary sleep disorders suffered from children with ADHD may be changing their sleep architecture regardless their ADHD symptoms, it is not possible to ensure that the sleep architecture found in such studies is a distinctive feature of ADHD. This question was not taken into account either in the reviews and/or meta-analyses conducted until now.[23,31,32] Therefore, the results of these reviews should be also interpreted with a certain caution.

Considering these aspects, the main goal of this study is to determine the relationship between sleep and ADHD, taking into account the limitations of earlier studies. Particularly, we analyze if there are differences in sleep characteristics between children with and without ADHD. Furthermore, we study if the possible differences between them might be influenced by variables inherent to participants or methodology followed in the studies included: sex, subtypes, medication use, comorbidities, assessment measures and inclusion criteria for participants.

METHODS

This systematic review was conducted according to a previously established protocol drawn up following the recommendations of the MOOSE statement.[33]

Search Strategy

A search was conducted in Pubmed, Web of Knowledge, PsycINFO and Scopus, entering the following search terms in Spanish or in English depending on the database: < < *ADHD OR "attention deficit" OR hyperactivity AND sleep** > > . Search fields were title, abstract and keywords. No search limit was established by language, but by publication year, in or after 1987. This is the year in which the third revised edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-III-R) was published and sleep disturbances stopped being one of the diagnostic criteria of ADHD.[34]

Subsequently, the literature search was completed with a manual search, reviewing the references included in the selected articles, and the citations that they had received.

We employed the RefWorks bibliographic management program to manage the references found.

Selection Criteria

Studies available from 1987 until March 2014 were selected if they: (a) included children with ADHD, according to the diagnostic criteria of DSM or any other diagnostic manual, in which sleep disturbances were not one of the symptoms of the disorder; (b) were comparative studies (randomized or non-randomized) in which the control group was composed of children without ADHD and the evaluation had been performed simultaneously in both groups by the research team itself (what guarantees an identical and less biased assessment for both groups); (c) did not include children with primary sleep disorders; (d) assessed differences in sleep between children with and without ADHD; (e) provided data in relation to age, sex, medication use, and comorbid diseases of participants; and (f) were not just abstracts or conference papers.

Titles and abstracts of all the articles retrieved, after excluding duplicates, were examined to check if they fulfilled the inclusion criteria previously described; those in which there were some doubts were assessed in full text length.

Selected studies were assessed in terms of risk of bias or methodological quality through the Scottish intercollegiate guidelines network (SIGN 50) scale designed for cohort studies that has a wide acceptance.[35,36] The assessment was performed blindly, as a mean of guaranteeing the preciseness of this process. This scale enables three assessment categories—high quality, medium quality, and low quality—on the basis of risk of bias. Due to the fact that some items of the scale were not applicable to the type of studies selected (1.3–1.6 and 1.12), we decided to obtain a weighted score by subtracting one degree of quality from each of the studies. Thus, we made sure that the assessment was not biased due to the loss of items.[37] Only those studies that, after subtracting that degree of quality, belonged to the second category (medium quality) were included in the review.

From each study included, the following data were collected: first author and publication year of the article, country in which the study was performed, number of participants in each group (along with age, sex, medication use, subtypes, and comorbidities), study design, assessment measures employed, and main results obtained.

Studies were assessed for inclusion criteria and methodological quality, and the data extracted, by two of the three authors independently, and discrepancies between them were resolved by a third author.

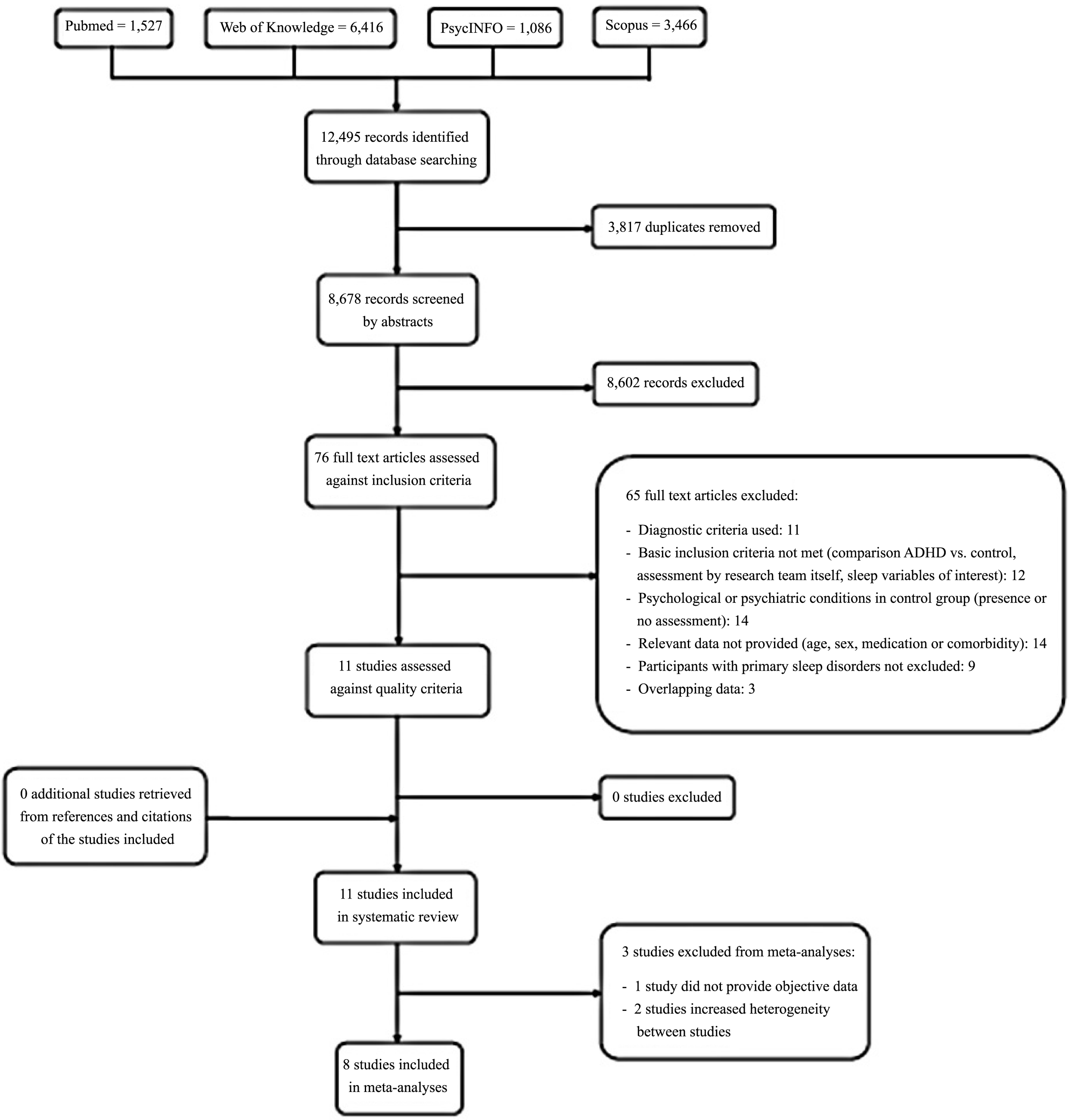
Data Analysis

Two meta-analyses were performed following the steps proposed by Botella and Gambara[38]—one of them with polysomnographic data and the other with actigraphic data. The most common variables among studies were selected as dependent variables: total sleep time, sleep latency, sleep efficiency, wake time, stage 1 NREM sleep, stage 2 NREM sleep, slow wave sleep, REM sleep, and REM latency. The independent variable was always the presence or absence of ADHD.

Both meta-analyses were carried out using Review Manager 5.3. software, with a fixed-effects model and a 95% confidence interval (CI). The index of effect size used was the standardized mean difference (SMD), applying the correction proposed by Hedges[39] to avoid bias due to sample size. The weighted mean effect size (pooled SMD) was obtained through the inverse variance method, and its statistical significance by the Z statistic. Heterogeneity between studies was also analyzed by means of the χ^2 and I^2 statistics,[40] interpreting the percent value of this last one according to the levels suggested by Higgins et al.[41]: low ($I^2 < 25\%$), medium ($25\% < I^2 < 50\%$), and high heterogeneity ($I^2 > 50\%$).

Sensibility and publication bias analyses could not be performed because the number of studies included was not

Figure 1—Results of the search and selection of studies.



enough.[42] Such circumstance did not allow us to carry out any other analysis according to the variables of interest mentioned in our goals (age, sex, ADHD subtypes, medication use, comorbidities and assessment measures employed), being only possible to describe them by means of a narrative synthesis.

RESULTS

Studies Included

We retrieved 12,495 studies through databases (**Figure 1**). From 8,678 non-duplicate studies, only 11 were included in the review, after removing those that did not meet the inclusion criteria or presented overlapping data. Those 11 studies[18,22,43–51] passed the assessment of risk of bias, obtaining a medium methodological quality level. No new study was retrieved through the manual search.

The main characteristics of the studies included and their participants are shown in **Tables 1** and **2**. In all the studies, a cross-sectional assessment of participants had been performed, 6 performed it with objective measures of sleep uniquely, one study used subjective measures, while 4 employed both.

For the meta-analyses, studies were considered according to the measure employed for sleep assessment. At first time, 8 studies were included in the first meta-analysis that performed a sleep assessment through polysomnography (PSG),

Table 1—Characteristics of the included studies.

Author, year	Country	Measure	Main results found (95% CI)
Galland, 2010 [43,a]	New Zealand	PSG, subjective	↑ SL and restless sleep according to a sleep questionnaire
Gruber, 2004 [44,a]	Canada	ACTG	↑ intraindividual variability of sleep-onset time, sleep duration and true sleep time
Gruber, 2012 [22,a]	Canada	PSG, subjective	↑ evening tendency (↓ score on the child morning-evening preference scale) ↑ total CSHQ score ↑ scores on the CSHQ subscales of sleep onset delay, sleep duration, sleep anxiety, night wakings, and daytime sleepiness
Konofal, 2001 [18,a]	France	PSG, video analysis	↑ number of limb movements ↑ movements associated with behavioral awakening ↓ motionless episodes
Mullin, 2011 [45,a]	USA	ACTG, subjective	No significant differences were found between both groups
Owens, 2000 [46]	UK	Subjective	↑ total CSHQ score ↑ scores on all the CSHQ subscales (except on the sleep-disordered breathing subscale) ↓ average of sleep amount (CSHQ) ↑ disturbed sleep (sleep self-report)
Prehn-Kristensen, 2011 [47]	Germany	PSG	↑ sleep onset latency and REM sleep ↓ SWS latency and SE
Prehn-Kristensen, 2013 [48,a]	Germany	PSG	No significant differences were found between both groups
Příhodová, 2012 [49,a]	Czech Republic	PSG	No significant differences were found between both groups
Ringli, 2013 [50]	Switzerland	PSG	↓ amount of S1
Wiebe, 2013 [51,a]	Canada	PSG, ACTG, MSLT, subjective	No significant differences were found between both groups

PSG, polysomnography; ACTG, actigraphy; MSLT, Multiple Sleep Latency Test; CI, confidence interval; ↑, higher in ADHD group; ↓, lower in ADHD group; SL, sleep latency; CSHQ, Children Sleep Habit Questionnaire; REM, rapid eye movement; SWS, slow wave sleep; SE, sleep efficiency; S1, stage 1 sleep. [a] Studies included in the meta-analyses.

and 3 studies in the second meta-analysis that used actigraphy to assess sleep. One study employed both objective measures to assess to the participants, so it was included in both meta-analyses.[51] On the contrary, the study that only provided subjective measures[46] was not included in any meta-analysis, because no meta-analysis was carried out on the basis of subjective measures, since subjective measures were too varied between studies to be summarized in a meta-analysis. Thus, only 10 of the 11 studies included in the review were included in the meta-analyses. However, from those 10 studies included initially, 2 studies were excluded from the meta-analysis with PSG as outcome,[47,50] because they increased significantly the heterogeneity between the studies. In particular, when those studies were included, the percent values of heterogeneity according to the I^2 statistic ranged between 53% and 76% in 5 of the 9 sleep variables considered. The decision of excluding those studies was taken because it was not possible to employ a random-effects model or to perform a meta-regression because of the sparse number of studies included.[42]

The final sample of each meta-analysis was composed of 133 (PSG) and 58 (actigraphy) children with ADHD, and 169 (PSG) and 92 (actigraphy) controls, whose most relevant characteristics are shown in **Table 3**. Regarding the meta-analysis with PSG as outcome, the Rechtschaffen and Kales criteria[52] were applied as scoring rules in all the studies included, except for one of the studies[22] in which the American Academy of Sleep Medicine criteria[53] were applied. A difference between both scoring rules that could have affected our results is the consideration of stage 3 and stage 4 sleep as the stage of slow wave sleep as a whole, but this last variable was also provided by the studies in which the Rechtschaffen and Kales criteria had been applied. In addition, although some significant differences have been pointed out between both scoring systems in sleep data,[54] there are no reasons to think that such differences might have affected our results. Mainly because, besides the fact a different system criterion was applied only in one study of the meta-analysis at issue,[22] the same procedure of scoring was also followed in all the studies for both children with ADHD and control children. Differences in sleep data depending on scoring criteria would have affected both groups of children equally, with no repercussion on the differences found between them in sleep parameters.

In all the studies, the proper procedure was carried out in order not to include children with primary sleep disorders (even snoring or sleep-disordered breathing). Both in the studies with PSG and in the studies with actigraphy, children with ADHD and controls were excluded if they displayed some sleep disorder or if this disorder was known before taking part in the study. Even in the study in which only subjective measures were employed to obtain sleep data,[46] parents

Table 2—Participant characteristics of the included studies.

Study	Sex and mean age (SD)	Subtype [b]	Medication	Comorbidity [d]
Galland, 2010 [43,a]	ADHD = 21M/6F, 10 years 6 months; age range: 6 years 7 months – 12 years 4 months Control = 21M/6F, 10 years 4 months; age range: 6 years 6 months – 12 years 3 months	6 Inattentive, 21 combined	No [c]	Nine had ODD and one had a specific phobia
Gruber, 2004 [44,a]	ADHD = 24M, 8.94 (1.25) Control = 25M, 8.83 (1.01)	2 Inattentive, 4 hyperactive-impulsive, 18 combined	No	No
Gruber, 2012 [22,a]	ADHD = 17/9, 8.46 (1.5) Control = 30M/19F, 8.69 (1.2)	8 Inattentive, 1 hyperactive-impulsive, 17 combined	No [c]	Eight had ODD and two had conduct disorder
Konofal, 2001 [18,a]	ADHD = 30M, 7.8 (1.6) Control = 19M, 8.4 (1.4)	11 Inattentive, 5 hyperactive-impulsive, 14 combined	No	No
Mullin, 2011 [45,a]	ADHD = 11M/3F, 15.1 (2.1) Control = 11M/10F, 14.1 (2.0)	14 Combined	Some children	No
Owens, 2000 [46]	ADHD = 34M/12F, 89.4 (18.7) months Control = 32M/14F, 86.5 (16.9) months	Not provided	No	Three had ODD and one had conduct disorder
Prehn-Kristensen, 2011 [47]	ADHD = 12M, 12.99 (0.52) Control = 12M, 12.64 (0.24)	Not provided	No [c]	Three had ODD
Prehn-Kristensen, 2013 [48,a]	ADHD = 16M, 10.6 (0.95) Control = 16M, 11.1 (0.95)	8 Inattentive, 8 combined	No [c]	Four had ODD
Příhodová, 2012 [49,a]	ADHD = 12M/2F, 9.6 (1.6) Control = 8M/4F, 9.0 (1.6)	2 Inattentive, 12 combined	No	No
Ringli, 2013 [50]	ADHD = 8M/1F, 11.9; age range: 9.7–13.4 Control = 8M/1F, 11.6; age range: 9.6–14.2	9 Combined	Two children	No
Wiebe, 2013 [51,a]	ADHD = 13M/7F, 9.2 (1.6) Control = 28M/18F, 8.7 (1.1)	13 Inattentive, 3 hyperactive-impulsive, 4 combined	No [c]	No

SD, standard deviation; ADHD, attention deficit hyperactivity disorder; M, males; F, females; ODD, oppositional defiant disorder. [a] Studies included in the meta-analyses. [b] All the diagnoses were based on the DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition) or on its text revision (DSM-IV-TR). [c] Medication was cut off at least 48 hours before evaluation. [d] Disorders with no direct effects on sleep, such as learning disability, were not taken into account in our data extraction.

of children were interviewed on this matter prior to their participation.

Meta-Analyses

In the meta-analysis with PSG as outcome, only 1 of the 9 variables assessed approached statistical significance, the stage 1 sleep (pooled SMD = 0.32, 95% CI = 0.08–0.55, p value = 0.009). Children with ADHD spend more time in that sleep stage than control children (**Table 4**, **Figure 2**). In the rest of the variables, although the differences between both groups were not significant, that tendency is also observed, primarily in the case of sleep latency, so a higher sleep latency is observed in children with ADHD compared with the control group (pooled SMD = 0.23, 95% CI = −0.01–0.46, p = 0.06). The heterogeneity percent between the studies was zero in all the variables, except for the wake time ($I^2 = 3\%$, p = 0.38), slow wave sleep ($I^2 = 13\%$, p = 0.33), and sleep efficiency ($I^2 = 54\%$, p = 0.05) variables. Although the heterogeneity found in those sleep parameters could be supposed to affect to the proportion of stage 1 sleep, the I^2 values obtained are into the limits considered for low heterogeneity.[41] Only the heterogeneity percent found in sleep efficiency is considered high.[41] This high heterogeneity, although requires the results in sleep efficiency to be interpreted with extreme caution, cannot affect to the proportion of stage 1 sleep. Basically, because sleep efficiency is a parameter obtained as the result of (TST/TIB) × 100, considering all sleep stages (1, 2, 3, 4, and REM) in TST as a whole.[53]

Otherwise, in the meta-analysis with actigraphy as outcome, significant differences between children with ADHD and controls were not observed in any variable (**Table 5**). The heterogeneity degree between the studies of this meta-analysis was always within the acceptable limits ($I^2 = 0\%–21\%$, $p > 0.05$).

DISCUSSION

This study aimed at determining the relationship between sleep characteristics and ADHD in children, analyzing the differences in sleep physiology between children with and without ADHD through the meta-analysis, and defining strict inclusion and exclusion criteria that considered the limitations from preceding studies previously mentioned. In particular, we intended to compare children with ADHD and control children in sleep, excluding of them those who suffered from primary sleep disorders. This is a novel criterion in this study, in comparison with previous systematic reviews and meta-analyses, and that was adopted to determine the sleep architecture of ADHD itself, distinguishing it from the sleep architecture inherent to primary sleep disorders.

In this regard, it is observed that just the percent of stage 1 sleep approaches the statistical significance when the assessment is performed by PSG. Thus, these results enable to conclude that children with ADHD spend more time in stage 1 NREM sleep than children without this pathology. It means that children with ADHD show a lighter sleep than controls. These results are not consistent with the results corresponding to the 2 studies that were not included in the meta-analyses (because of heterogeneity) but they were in this review.[47,50] In one of those studies,[47] differences in stages of NREM sleep between children with ADHD and controls were not found. Moreover, in that study, children with ADHD, besides a higher sleep onset latency and a lower sleep efficiency, spent more time in stage REM sleep than controls.[47] According to that study, children with ADHD would have a deeper sleep that controls and not the opposite. In the other study included,[50] children with ADHD were found to spend less time in stage 1 NREM sleep than controls. Definitely, results from both studies were contrary to what we have found. However, these inconsistencies between our results and the results from those 2 studies mentioned may be due to some aspects that are discussed below.

We also wanted to determine if other variables might be having an impact on sleep characteristics, such as age, sex, ADHD subtypes, medication use, comorbidities, and assessment measures employed. In this sense, a certain similarity was observed between the studies included in the meta-analyses regarding age, medication use (children who were taking medication stopped taking it at least 48 hours before evaluation, with the exception of 4 children in one study[45]), comorbidities of participants, and the type of objective assessment employed (PSG-actigraphy) (**Tables 1**, **2**, and **3**). In addition, even though a greater number of boys than girls is observed in all the studies included in the meta-analyses, this superiority of masculine sex is found both in children with ADHD and in control children (**Table 3**). Therefore, it is just possible to discuss the influence of ADHD subtypes in sleep disturbances.

In fact, although few studies have analyzed the differences between the ADHD subtypes regarding sleep patterns, the results found indicate that sleep disturbances are different depending on the subtype or the predominant symptomatology in ADHD. Children with the inattentive subtype appear to have fewer sleep problems, being those children with the hyperactivity-impulsivity subtype who show more problems in this area.[55,56] In this regard, the distribution of ADHD subtypes between the participants of the studies included in the 2 meta-analyses of this review was not homogeneous. The number of children with ADHD with the inattentive subtype was higher than the number of children with the hyperactivity-impulsivity

Table 3—Main characteristics of children included in the meta-analyses.

Characteristics	Meta-Analyses PSG (n)	Meta-Analyses ACTG (n)
ADHD sex		
Male	109	48
Female	24	10
Control sex		
Male	122	64
Female	47	28
Subtype		
Inattentive	48	15
Hyperactive-impulsive	9	7
Combined	76	36
Medication		
Yes	0	4 [a]
No	133	54
Comorbidity		
No	109	58
ODD	21	0
Conduct disorder	2	0
Other	1	0

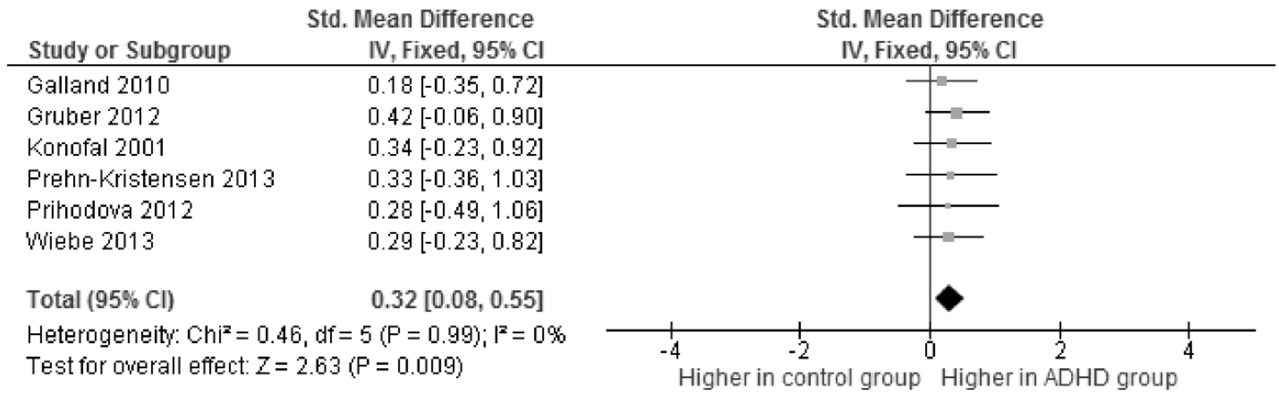
ADHD, attention deficit hyperactivity disorder; ODD, oppositional defiant disorder; PSG, polysomnography; ACTG, actigraphy. [a] This is an approximate number because the exact number of children taking medication in one study[45] was not reported.

Table 4—Results of the meta-analysis with polysomnography as outcome (n = 302).

Variable	SMD (95% CI) [a]	χ^2	p value [b]	I^2	Z	p value	k
TST	0.14 (−0.12, 0.40)	0.82	0.94	0	1.09	0.28	5
SL	0.23 (−0.01, 0.46)	0.91	0.97	0	1.89	0.06	6
SE	−0.12 (−0.35, 0.12)	10.95	0.05	54	0.98	0.33	6
TA	0.05 (−0.27, 0.37)	3.10	0.38	3	0.30	0.77	4
S1	0.32 (0.08, 0.55)	0.46	0.99	0	2.63	0.009	6
S2	0.10 (−0.13, 0.34)	3.18	0.67	0	0.85	0.40	6
SWS	−0.08 (−0.35, 0.19)	4.58	0.33	13	0.61	0.54	5
REM sleep	0.08 (−0.15, 0.31)	1.52	0.91	0	0.68	0.50	6
REM latency	0.15 (−0.20, 0.49)	0.44	0.80	0	0.81	0.42	3

TST, total sleep time; SL, sleep latency; SE, sleep efficiency; TA, time awake; S1, stage 1 sleep; S2, stage 2 sleep; SWS, slow wave sleep; REM, rapid eye movement; SMD, pooled standardized mean difference; CI, confidence interval; χ^2, heterogeneity test; I^2, heterogeneity index (%); Z, test for overall standardized mean difference; k, number of studies included. [a] A negative SMD indicates that this variable was higher in the control group. [b] This p value corresponds to the heterogeneity degree found between the studies included.

Figure 2—Forest plot of the standardized mean differences (SMD) obtained in the meta-analysis with polysomnography as outcome for stage 1 sleep.



IV, inverse variance method; Fixed, fixed-effects model; CI, confidence interval; Chi^2, heterogeneity test; df, degrees of freedom; I^2, heterogeneity index; Z, test for overall standardized mean difference; ADHD, attention deficit hyperactivity disorder.

Table 5—Results of the meta-analysis with actigraphy as outcome (n = 150).

Variable	SMD (95% CI) [a]	χ^2	p value [b]	I^2	Z	p value	k
TST	−0.09 (−0.43, 0.24)	1.33	0.51	0	0.53	0.59	3
SL	0.23 (−0.11, 0.57)	2.52	0.28	21	1.34	0.18	3
TA	0.09 (−0.32, 0.51)	0.04	0.85	0	0.45	0.66	2

TST, total sleep time; SL, sleep latency; TA, time awake; SMD, pooled standardized mean difference; CI, confidence interval; χ^2, heterogeneity test; I^2, heterogeneity index (%); Z, test for overall standardized mean difference; k, number of studies included. [a] A negative SMD indicates that this variable was higher in the control group. [b] This p value corresponds to the heterogeneity degree found between the studies included.

subtype (**Table 3**), mainly in the meta-analysis with PSG as outcome. Therefore, if children with the inattentive subtype predominate, who show fewer sleep problems, the results might be under the influence of this variable. With regard to the other 2 studies that did not distinguish between subtypes,[46,47] these were not included in the meta-analyses, so they cannot have influenced our results.

In summary, on the basis of all the above, it seems plausible that the differences in sleep found in this review between control children and children with ADHD were affected by the ADHD subtypes of the children included. Or, moreover, that the absence of greater significant differences in sleep between both groups has been conditioned by this variable.

Other variable that may have had an influence in the results obtained in the meta-analysis is the sample size in each study. Although the total sample of each meta-analysis was composed of an acceptable number of participants in each group (**Table 3**), undoubtedly the sample sizes of each study included were not too high (**Table 2**). Noteworthy, above all, the studies of Mullin,[45] Prehn-Kristensen,[48] and Prihodova,[49] with 14, 16, and 14 participants with ADHD, respectively. This low sample size might have determined the lack of statistical significance in other variables, because although not significant, some tendencies are appreciated in the rest of the variables (**Tables 4** and **5**).

In addition, there are other variables also related to sleep that have not been taken into account in our meta-analyses. In this sense, some of the studies included in this review provided subjective sleep data. Due to the lack of analogy between those studies with regard to the sleep variables considered and the subjective assessment measures employed, no meta-analysis could be performed with subjective sleep measures. Nevertheless, significant differences were found in those studies included between children with ADHD and controls in some subjective sleep variables that are important to be noted. For instance, one of these variables is daytime sleepiness. Children with ADHD showed a higher daytime sleepiness than controls in 2 of the studies,[22,46] according to their scores in the Children Sleep Habit Questionnaire (CSHQ). Conversely, daytime sleepiness was not found to be affected by ADHD in 2 other studies included, according to a sleep questionnaire[43] or a modified Epworth Sleepiness Scale.[51] Such discrepancies, even in this subjective variable, deserves a deeper analysis in future studies. For that reason, although both meta-analyses presented in this review were performed focused on nocturnal sleep characteristics, further research is needed to pay attention to some other sleep variables, such as daytime sleepiness, that might be also affected by ADHD symptomatology.

Finally, although ADHD is currently a topic of great interest, there is a debate in relation to the disorder, leading some authors even to question its own existence.[57] Other authors suggest that the big problem might be an overdiagnosis of the disorder[58,59] that would be the responsible for the increase in the number of children diagnosed with ADHD, increasing the number of false positives. Although the latter is not totally clear,[60] in that case, this could be a factor that impacts on the controversy about the existence of sleep disturbances in children with ADHD. Since a high number of false positives in the group with ADHD would lead the differences between the groups with regard to sleep disturbances to disappear. This requires that the future studies include an assessment of the child by a specialist that covers different areas (school, social, and family), to corroborate the diagnosis. In this sense, there were not enough data provided in all the studies included in this review in order to confirm that the diagnosis of children with ADHD had been appropriately corroborated (example, Mullin et al.[45]), and in the cases in which it was corroborated, nor was a common assessment protocol.

In general, this systematic review has several limitations; among them, the small sample size of the studies, like the sparse number of studies included in the review and in the meta-analyses. The other limitation is the unequal distribution of ADHD subtypes between the participants of those studies. These limitations do not enable to generalize the results, not even make possible to obtain convincing conclusions. On the contrary, such limitations highlight the importance of further studies on this topic.

This review has also some strengths to be noted. In the first place, the development of a previous protocol guaranteed the methodological rigor of the following review. Secondly, a very complete search of all the studies available in the literature was carried out, avoiding bias by publication language. In the way, the blind assessment of the quality of the studies avoided the presence of methodological bias in them and in the evaluation itself. Also, rigorous inclusion criteria were followed, which enabled to obtain valid and feasible results. For instance, those studies in which some participants showed primary sleep disorders were excluded, along with those in which a control group composed of children with no disorders was not included. These two criteria meant that if differences in sleep between children with ADHD and controls were found, these could not be attributed to other factors different from the pathology studied itself. Finally, when meta-analyses were performed, the opportune corrective measures were taken in order to avoid that the results obtained were conditioned by the heterogeneity between the studies or the different assessment measures of sleep parameters.

CONCLUSIONS

The results obtained with this systematic review and meta-analyses suggest that children with ADHD show few differences in sleep with regard to children without this pathology. However, such differences might be stressed if some of the limitations previously discussed would be taken into account. For that reason, a higher number of studies on the relationship between sleep and ADHD are still required. Above all, these studies will have to: (a) assess if the predominant subtype or symptomatology in these children leads to particular sleep patterns; (b) count on an appropriate sample size that enables to generalize the results; (c) consider both objective and subjective sleep variables and perform a comparison between them; (d) avoid the presence in the sample of children with primary sleep disorders, or control children with medical or psychological problems, which affect the results obtained; and (e) confirm the ADHD diagnosis, guaranteeing the absence of false positives in the group with ADHD.

ABBREVIATIONS

↑, higher in ADHD group
↓, lower in ADHD group
ACTG, actigraphy
ADHD, attention deficit hyperactivity disorder
χ^2, heterogeneity test
CI, confidence interval
CSHQ, Children Sleep Habit Questionnaire
df, degrees of freedom
DSM, Diagnostic and Statistical Manual of Mental Disorders
DSM-III-R, DSM, Third Edition Revised
DSM-IV, DSM, Fourth Edition
DSM-IV-TR, DSM, Fourth Edition Text Revision
F, females
Fixed, fixed-effects model
I^2, heterogeneity index (%)
IV, inverse variance method
k, number of studies included
M, males
MSLT, Multiple Sleep Latency Test
NREM, non-rapid eye movement
ODD, oppositional defiant disorder
PSG, polysomnography
S1, stage 1 sleep
S2, stage 2 sleep
SD, standard deviation
SE, sleep efficiency
SIGN-50, Scottish Intercollegiate Guidelines Network
SL, sleep latency
SMD, standardized mean difference
SWS, slow wave sleep
TA, time awake
TST, total sleep time
Z, test for overall standardized mean difference

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