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Adolescent Sleep Behavioral Interventions and Opportunities to Improve Cognitive Functioning: A Call for Action

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Public Health: Why Now and Why it Matters

The COVID-19 pandemic has led governments across the world to establish public health policies aimed at prevention of exposure to the virus and related health effects in the population. To date, the consequences of these policies (eg. schools and nonessential business closures) remain mixed, as these policies resulted in adverse impacts over many areas of adolescent development.[1,2] Specifically, social distancing and school closures caused disruption in routines affecting aspects of well-being including but not limited to sleep.[3] Studies have highlighted that distress resulting from isolation; changes in routines, including diet and physical activity along with decreased daylight exposure; and increased exposure to short-wavelength/blue-light from electronic devices has led to a disruption in sleep.[3–5] Recent research examining a number of studies on sleep suggests that prevalence of sleep problems has risen for nearly half of the adolescent population compared to pre-pandemic levels.[4] Other researchers also found that insufficient sleep and related changes in sleep patterns have led to chronic pathological presentations such as insomnia, affecting between 18% to 25% of the adolescent population.[6]

Research on sleep has been at the forefront of factors affecting adolescents' well-being in general. The COVID-19 pandemic has increased concerns about adolescent sleep, but sleep was a major public health concern before the

pandemic. The United States and other countries have implemented vital health policies (eg. National Healthy Sleep Awareness Project; Sleep Health Objective of Healthy People 2020; guidelines from the World Health Organization) since the early 2000s and 2010s paving the way to various health promotion and research-related efforts. Yet, 10 years later, rates for insufficient sleep remain a concern for adolescents.[6–9] According to the 2017 Youth Risk Behavior Surveillance System, nearly 3 out of 4 high school students in the US reported less than 8 hours of sleep on an average school night.[10] According to Donskoy and Loghmanee, self-report data for sleep among adolescents who reported more than 8 hours is often overestimated.[11] The authors also stated that adolescents mostly present their sleep concerns as secondary to other chief complaints and generally do not seek help for sleeping-related problems. During the formative years of adolescence, sleep problems have been associated with diminished psychological and physical health, behavioral risk-taking (eg. sports injuries and automobile crash accidents), and poor academic performance.[12–18] Additionally, sleep-related concerns have also been linked to deficits in cognitive functioning and academic performance.[14] As insufficient sleep and chronic presentations of sleep disorders such as insomnia persist among adolescents, it is argued that more research to understand sleep in adolescents is needed.[6]

Adolescents' Sleep and Cognition

An area of growing attention over the years has been the relationship between sleep and cognition, as sleep has been found to influence learning in adolescence. Early research between 1966 and 2008 found that the decline in cognitive performance among participants with insufficient sleep was mostly observed with abstract and more complex tasks in contrast to simple memory tasks.[19] Subsequent studies showed correlations between oscillations in sleep electroencephalogram (ie, EEG) and executive functioning for cognitive tasks in adolescents with diminished sleep; yet correlations between sleep and executive functioning varied on cognitive domains of working memory/executive, attention, and speed accuracy.[17,20] It is also argued that much of the relationship between sleep and cognitive functioning is moderated by an intersection of biological, psychological, and sociocultural factors inherent to development.[21] From pre-adolescence to adolescence, sleep function is impacted by age-related changes in the homeostatic regulation sleep, a circadian phase delay, and slow rise of sleep as a bioregulatory process[15,18,22]; psychosocial demands such as school and other societal expectations[11,21]; and structural barriers such as household income, built environment, and community environment.[23] The influence of these factors on sleep reveals unique challenges for the field of adolescent sleep.

Existing literature also focuses on identifying aspects of sleep that are critical to understanding the relationship between sleep and memory consolidation.[19] Research has found that sleepiness, sleep duration, and sleep quality are common indicators for memory consolidation and learning.[24] Many models have been proposed to explain the effects of insufficient sleep, with two models in particular emphasizing the relationship between sleep and cognitive functioning--the synaptic-homeostasis hypothesis and the active trace-reactivation hypothesis, both briefly discussed by de Bruin and collaborators.[25] The synaptic homeostasis hypothesis posits that the increased use of cellular energy needed for learning during waking episodes requires cellular restoration periods (sleep cycles) that help restore cellular homeostasis of neuronal networks.[26] The active trace-reactivation hypothesis suggests that sleep is necessary for consolidation of memories acquired during waking hours.[27] Generally, both hypotheses consider the effect of sleep on cognitive functioning; the main difference between these two models lies in the delineation of processes employed by synaptic and cortical networks involved in learning during adolescent development.[26,27] Furthermore, both suggest that insufficient sleep can be harmful as it hinders brain maturation and memory consolidation (ie, learning) in adolescents. Hence, it is vital to address the sleep-related needs of adolescents in general, and particularly now, while the present adolescent generation faces the COVID-19 global pandemic and its lingering effects on sleep and subsequent learning.[28] The current manuscript

aims to provide an overview of research on treatment of insomnia-related symptoms within the adolescent population, with a particular focus on sleep treatment as it relates to improvements in cognitive functioning. The authors also discuss relevant barriers and considerations for diagnosis and treatment with the adolescent's population affected by the pandemic.

Assessment and Treatment

The progress on sleep research continues to expand, simultaneously raising crucial questions regarding areas of assessment and treatment for sleep-wake disorders. Research has identified both best assessment tools for sleep and best practices for its treatment.[29] Professionals working with the adolescent population have noted concerns regarding identification of the severity of sleep-wake disorders specific to insomnia.[30,31]

Insomnia disorder has become increasingly common in adolescents.[32] One of the largest population studies conducted with adolescents ages 16 to 18 found that 18.5% met indicators for insomnia, with higher rates in girls (23.6%) than boys (12.5%).[33] Similar to other studies, the criteria used to determine insomnia symptoms focused on sleep onset and duration, which vary from school to non-school days.[14,18] Experts in the field noted that assessment of insomnia should consider these and other factors associated with age-related developmental changes that are not typically reported with the adult population.[32] These concerns

raised important questions for the accuracy of diagnosis and prevalence of insomnia in adolescents. An updated revision of literature focusing on sleep screening and diagnostic tools with the adolescent population documented similar concerns of accuracy of diagnosis. [31] In their findings, the authors also pointed out limitations related to sensitivity, and specificity affecting the reliability of classification of insomnia and related sleep problems. Despite a growing number of available measurement tools, the authors noted that significant improvements for sleep assessments are needed, including further validation and evaluation of psychometric properties, replication of studies, an increase in culturally unbiased content, and attention to potential confounding factors (eg, comorbidity with mental health, delayed sleep phase disorder, etc). In addition to these findings, most study designs utilize instruments that capture self-report data, not objective behavior via actigraphy, accelerometry, and/or polysomnography, often considered the gold standard in research.[34] Nonetheless, the consensus in the field of sleep research is that multiple sources of information (eg. quantitative and qualitative) can better inform the classification, decision making, and subsequent treatment of insomnia. [31,32,34,35]

The considerations posed here have several implications for the treatment of insomnia in adolescence as well as for outcomes on cognitive functioning. When referring to treatment, we will focus on behavior modification interventions

shown to be effective in treating insomnia and other sleeping problems. These interventions are often categorized as sleep extension, sleep improvement, and sleep restriction.[25] The most studied treatment approaches to sleeping concerns include relaxation therapy, stimulus control therapy, sleep restriction therapy, sleep hygiene education, paradoxical intention therapy, cognitive therapy, and cognitive behavior therapy for insomnia (CBTi) recently adapted to adolescents.[36–40] For cognitive functioning, we refer to executive functioning related domains focusing on cognitive flexibility, working memory, and inhibitory control/attention.

Research on behavior modification interventions has led to important findings adding valuable insight for sleep research. A study conducted between 1981 and 2015 examined the effectiveness of treatment for sleep-related problems and found that many of the behavioral interventions, including sleep extension, led to improvements in cognitive functioning, specifically on working memory and memory consolidation. Further treatment via sleep deprivation and partial restriction showed a steady decline in psychomotor vigilance tasks, yet effects were small for the adolescent population.[25] The authors also indicated some inconclusive results from the use of cognitive functioning measures, supporting the need for adequate testing approaches to accurately measure cognitive functioning domains including inhibition/interference control, working memory,

cognitive flexibility, declarative memory, and abstract reasoning. Similar to considerations discussed earlier with sleep assessment for insomnia, de Bruin and collaborators also emphasized the need to ensure appropriate tools for the assessment of cognitive functioning.[25] These observations can provide additional understanding on reported changes in cognitive functioning resulting from the interventions and inform clinical practice guidelines for adolescents. Therefore, we systematically synthesized emerging scientific work, aiming to fill this gap in the field of sleep studies as it relates to adolescents and interventions specific to treating insomnia.

Methods

Search Strategy

This is a systematic review, and narrative (descriptive) synthesis, informed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. [41] The review was registered on PROSPERO, under designated protocol # CRD42021227094. Based on record (eg. article, publication) relevancy, the following electronic databases were included in the search from late March to May 2021: MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), CINAHL, SCOPUS, and PsycINFO. PubMed and Web of Science abstracts were identified during the search. Active studies from Clinicaltrials.gov, and the World Health Organization's International Clinical

Trials Registry Platform were assessed and included if published. Cross-reference of citations from screened records and other secondary sources, including Google Scholar, was completed. There were no limitations on language for publication and publication period. Search criteria included a combination of keywords and terms related to the studies focusing on the relationship between sleep behavioral interventions for insomnia in adolescents and cognitive functioning. The inclusion of terms and Boolean operators along with other combinations were part of the search (Table 1). Search procedures and guidelines were established by a research librarian (JU) to ensure the appropriateness of the strategies implemented.

Study Selection

Eligible records included studies assessing the effectiveness of behavioral modification interventions for insomnia and the application of measures to assess cognitive functioning as additional treatment outcomes in adolescents of any sex and 10 to 21 years of age. This age range is based on guidelines by the American Academy of Pediatrics.[42] Non-institutionalized and institutionalized adolescent populations were part of the study. Settings included laboratories, home, clinical/hospital, or a combination. Studies included the administration of behavioral modification interventions used to (1) address insomnia; and administered (2) throughout daytime and hours before bedtime at night. Behavioral modification interventions were categorized as extension,

improvement, and restriction as described earlier by de Bruin and collaborators.[25] The present study focused on sublevel symptoms or indicators for insomnia (eg. duration, problems for initiating, maintaining, and awaking) and/or insomnia as primary or secondary presentation. Subjective (eg. self-report logs and self-report questionnaires) and objective measures (eg. actigraphy) were used to determined sub-threshold insomnia or related symptoms to severe insomnia. Secondary outcomes, including sleep onset latency (SOL), wake after sleep onset (WASO), total sleep time (TST), and sleep efficiency (SE%), for the assessment of sleep initiation, duration, and quality were also part of the variables of interest. Additional outcomes in treatment included at least one relevant outcome from an objective measure for cognitive functioning. Cognitive functioning measurements included the assessment for domains related to executive functioning including but not limited to inhibition/interference control, working, and declarative memory. Study designs included randomized controlled trials (RCTs, parallel-arm and crossover), as well as open-label, single group, or pre- vs. post- designs. Comparator groups varied depending on study design, including (1) control (separate group of participants or crossover condition) and (2) baseline levels (compared to post-treatment).

As exclusion criteria, the review restricted study designs that focused on behavioral interventions conducted with adults. Restrictions were considered in

studies that included pharmacological treatments impacting sleep outcomes. Studies with adolescent subjects reporting pre-levels of cognitive functioning impairment or neurological development disorders were also excluded. Table 2 presents an overview of the search strategy for the study. Both criteria listed above were discussed in collaboration with a team of researchers and entered as main procedures into Covidence, an online repository that helps with the extraction and subsequent production of systemic reviews. Individual records were screened independently and if there was any disagreement, another member of the team or all research members (if needed) discussed each item until consensus for inclusion or exclusion was reached. If information was missing, corresponding authors were reached or protocols were consulted to determine if inclusion criteria were met.

Data Extraction

Data extracted for the study consisted of the following key variables: author, year of publication, study design, participant conditions, sample size, participant age and sex, sample size, method employed for diagnosis, duration of the interventions, control details and outcome methods (for sleep and cognitive functioning). If during extraction there were questions regarding any of these variables, discrepancies were discussed with another researcher or a third researcher (if needed) until consensus was reached. Similar to steps taken for the

exclusion criteria, the leading researcher sought out corresponding authors of published studies where missing information was needed to establish inclusion or exclusion.

Risk of Bias Assessment

The assessment for risk of bias was completed in accordance with the Cochrane Risk of Bias Assessment Tool for RCTs and nonrandomized research designs as informed by the Cochrane Effective Practice and Organization of Care (EPOC) guidelines. The following criteria were assessed for RCTs: selection bias (improper sequence generation or allocation concealment), performance bias (lack of blinding of participants or personnel to intervention conditions), detection bias (blinding of assessors of sleep and cognitive outcomes), attrition bias (incomplete outcome data), selective outcome reporting, and other bias (groups similar at baseline). For non-RCTs, assessment for risk of bias followed the following criteria: selection bias (improper sequence generation or allocation concealment), baseline measures and characteristics similar, attrition bias, knowledge of intervention prevented, protection against contamination, and selective outcome reporting.

RESULTS

A total of 735 records were identified through databases (Figure 1). There were 175 records removed as duplicates by Covidence during identification, resulting in 560 records available for screening. During the screening procedure, 536 records were excluded for not meeting inclusion criteria. Twenty-four records were screened for eligibility. Cross-references of citations from screened records and other secondary sources, including Google Scholar, were completed. Only 2 records remained for the review after considering inclusion and exclusion criteria.

Data from Studies Included

The selection process led to 2 records-- 1 published study and 1 abstract discussing a study part of two clinical trial (Table 3). [43–46] Both identified studies varied in total number for participants in their samples (n=32 and n=147, respectively) and consisted of parallel-arm RCTs in design. Participants' mean ages ranged from 15.9 years to 19.8 years. The sample reported by de Bruin and collaborators consisted of healthy adolescents with no other psychiatric or medical diagnoses.[43] The sample study from Ling and co-authors at baseline included subsamples of healthy adolescents and other conditions with major depression.[44–46] Methods to determine insomnia and or/related symptoms consisted of validated self-report measures (eg. Holland Sleep Disorder Questionnaire, HSDQ and Insomnia Severity Index [ISI]), sleep logs, and secondary outcomes that encompassed sleep quality, duration, and initiation. The

duration for treatment (CBTi for both studies) ranged from 6 to 10 weeks. Both studies reported objective cognitive functioning measures at baseline and post treatment (eg. Amsterdam Neuropsychological Task [ANT]; Auditory Verbal Learning Test [AVLT], Psychomotor Vigilance Task [PVT], Digit Span, N-back Test, Go/No-go Task, Wisconsin Card Sorting Task [WCST], and Trail Making Task [TMT]). Results varied in regard to the treatment effects on insomnia symptoms and cognitive functioning. In the study by de Bruin, participants from the treatment conditions compared to controls (11 out of 18) showed improvements in symptoms of insomnia after 6 weeks. Interaction effects between time and condition were also found for several domains, mostly with visuospatial processing for reaction time, proportion correct, and efficiency. Other findings were reported for selective attention and working memory, only for improvement of efficiency (0.018) within these 2 domains. In the study by Ling and collaborators, sleep improvement was found among participants receiving treatment for insomnia. The study reported interaction effects for the TMT, which measures inhibition and interference control and cognitive flexibility. No additional data on time or efficiency was available. Outcomes for both studies with significant p-values, from small to large effect sizes, were included (Table 3).

Risk of Bias Assessment

In determining risk of bias in the assessment, it was found that several key criteria were unclear for both studies. Each study is discussed using the criteria for the assessment depicted by level and color coding (high risk of bias=red; low risk of bias=green; and unclear risk of bias=yellow) (Figure 2). While the study by de Bruin and colleagues failed to describe their randomization method, they pointed out that it was determined by characteristics of age and sex.[43] They also noted that following randomization, participants in the waiting list condition were significantly older than the ones in the treatment, which could have impacted the results. Allocation concealment was not described in both studies, including for respective protocols. The blinding of participants and personnel procedures varied by study. For de Bruin and co-authors, blinding was not clear for participants, and research personnel were aware of the conditions during trials.[43] Blinding procedures were not described in detail in Ling's work, including associated clinical trial protocols.[44–46] Both studies met the criteria on blinding for outcome assessors as described in either publication or protocol. Incomplete outcome data is reported by de Bruin's research adding that there was missing data for some participants due to malfunction on test, for actigraphy, and for some sleep measures.[43] As reported in their publication, the authors re-ran the analysis for these purposes. This data was not available for Ling's study and related protocols.[44–46] Information regarding other selective outcome reporting or other bias (groups different at baseline) is not specified or not available for both studies.

DISCUSSION

This systemic review of the literature focusing on insomnia resulted in findings similar to those in the 2017 review by de Bruin and collaborators.[25] This included the dearth of RCTs to assess the effectiveness of sleep-focused behavioral interventions on cognitive outcomes, inadequate selection of cognitive functioning measures, and study design limitations (eg. medications or treatments assumed to affect sleep, presentation of other chronic medical or psychological disorders, and limited to one behavior intervention). Furthermore, many of the articles reviewed from screening to eligibility had one method for assessing insomnia, mostly self-report or subjective, not a combination of both subjective and objective measures of insomnia. Two publications fitting the inclusion criteria were available for review; both, however, focusing on CBTi. The effect sizes for these intervention studies varied and were limited by sample and study design characteristics. This was the case for the study by Bruin and colleagues, where the sample was small and lacked power despite reporting changes over time with working memory (eg. visuospatial processing, selective attention and response inhibition, set shifting, and letter fluency as measured).[43] Changes in working memory were also consistent with the Ling study, particularly as observed with

the TMT, but not with other tasks.[44] These findings do not necessarily indicate that CBTi should not be considered as a treatment option. Quite the opposite is true, since both studies reported changes in certain domains for executive functioning as attained by several measures, including subtest. It is also stated that this intervention emphasized the cognitive and psychological aspect of insomnia, resulting in one of the most comprehensive options available.[47] Moreover, a large body of evidence supports the intervention.[32] Nevertheless, not much is known about how CBTi leads to improvement in cognitive functioning and how it compares with other interventions for adolescents with insomnia, reiterating the need to pursue more research in this field. Our study expands on the risk of bias assessment, arguing for the need for clarity in study designs for insomnia-related research in the adolescent population. Lastly, due to the insufficient number of appropriate studies available in the literature, we were unable to quantify effects on outcomes and combine similar intervention approaches to conduct a meta-analysis.

FUTURE DIRECTIONS AND CONCLUSIONS

While the return to school can provide a glimpse of normalcy for the life of many adolescents, it is also a time during which they may continue to struggle with emotional and sleep difficulties impacting cognitive processes related to learning. Besides the need to further the research in this area, as described in our article, it

is also imperative to continue raising awareness of the importance of sleep and the treatment of sleep disorders in adolescents. This could include extending offerings for training practitioners to gain a greater understanding of sleep and its short- to long-term consequences. In addition to this, best practices should be prioritized and geared toward adequate selection and utilization of up-to-date assessments to follow up with behavioral interventions. Such clinical advances alongside the emerging science on sleep can inform the design of social and educational strategies to help adolescents overcome sleep disorders and their consequential cognitive effects.

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Table 1. Search terms used in the study.

("Adolescent"[Mesh] OR "Young Adult"[Mesh] OR Adolescent* OR Teen OR Teens OR Teenager* OR “Young adult*” OR Youth*)	("Behavior Therapy"[Mesh] OR "Hypnosis"[Mesh] OR "Biofeedback, Psychology"[Mesh] OR "Breathing Exercises"[Mesh] OR "Phototherapy"[Mesh] OR “Behavioral intervention*” OR “Cognitive behavioral therap*” OR “CBT” OR “Cognitive behavioral therapy for insomnia” OR “CBTi” OR “Relaxation training*” OR “Stimulus control therap*” OR “Sleep restriction therap*” OR “Sleep hygiene” OR “Paradoxical intention therap*” OR “Cognitive restructuring” OR Desensitization OR Relaxation OR Hypnosis OR Biofeedback OR “Relaxation therap*” OR “Abdominal breath*” OR “Stimulus control” OR “Sleep restriction” OR “Paradoxical intention” OR “Cognitive therap*” OR “Cognitive behavioral intervention*” OR “Light exposure” OR “Brief behavioral therap*”)	("Sleep Initiation and Maintenance Disorders"[Mesh] OR Insomnia* OR “Delayed sleep phase disorder*”)	("Cognition"[Mesh] OR "Memory"[Mesh] OR "Executive Function"[Mesh] OR “Cognitive function*” OR “Cognitive gain*” OR Cognition OR Memory OR “Brain function*” OR “Cognitive control” OR “Cognitive impairment” OR “Executive function*” OR Attention OR “Working memory” OR “Episodic memory” OR Neuropsych* OR “Processing speed” OR “Executive attention” OR “Visual spatial” OR “Speed processing” OR “Declarative memory” OR “Procedural learning”)

Table 2. Spider Statement

SPIDER	ELEMENT	FOCUS OF PRESENT REVIEW
S	Sample	Adolescents between ages of 10 to 21
P OF I	Phenomenon of interest	Insomnia treatments and cognitive functioning measures
D	Design	Limited to experimental designs, pre-post; RCTs, intervention studies
E	Evaluation	Objective data regarding changes over time for insomnia treatments and secondary outcomes for cognitive functioning
R	Research type	Quantitative

Figure 1. PRISMA Flow Diagram

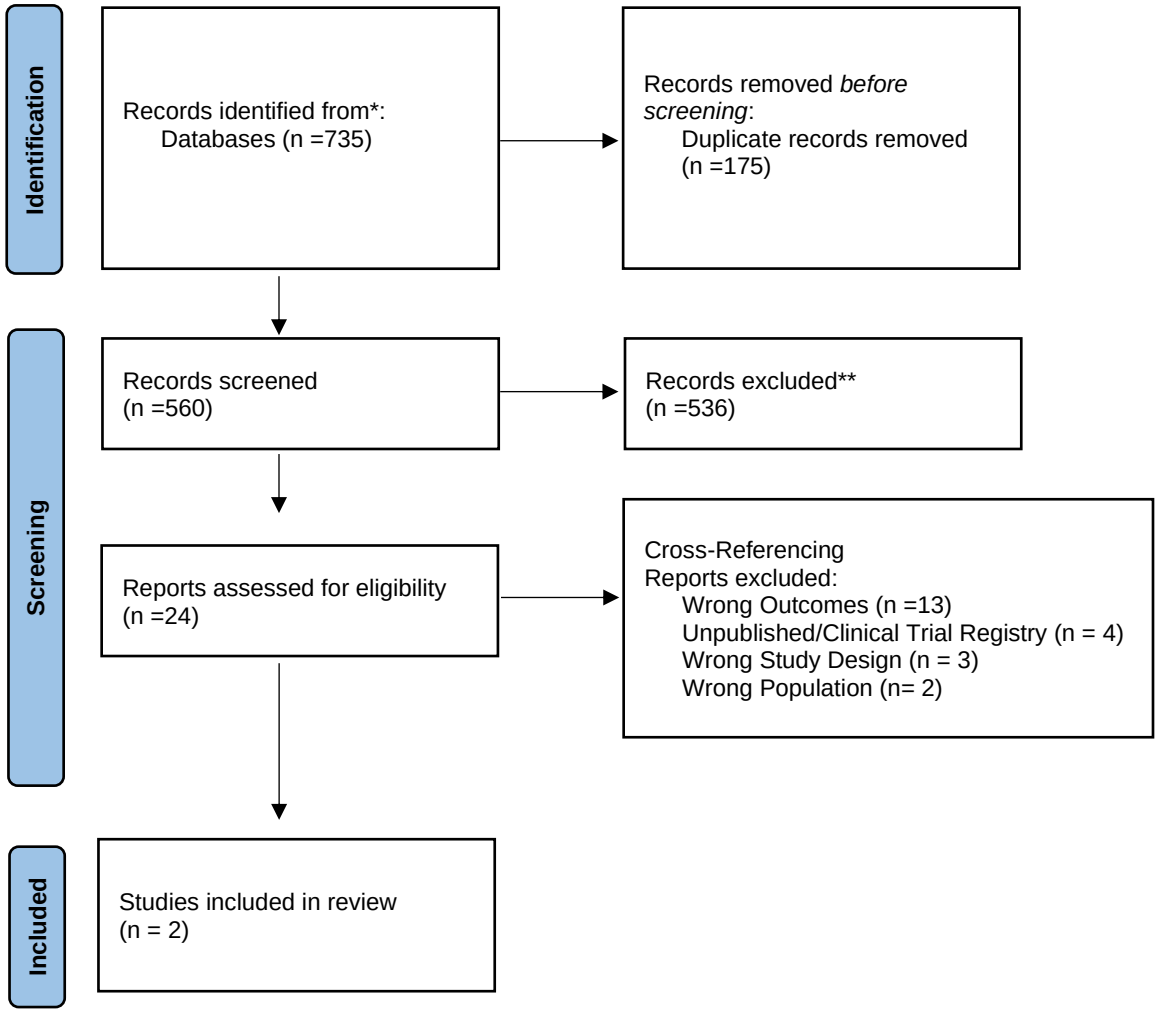

Table 3. Summary of Studies Included

Author, Year (ref #)	Study design	Participants	Sample size	Diagnosis Sleep	Age, (SD)	Sex, Female/ Male	Duration	Intervention Details	Control details	Outcomes Methods	Results	
											Sleep	Cognition
de Bruin et al, 2015 (43)	Parallel group RCT	Healthy adolescents	n=32	Diagnostic interview / self-report, actigraphy	15.9 (1.6)	81%♀	6 weeks	CBTi	Waiting list condition	Actigraphy, sleep logs, self-report measures for sleep and cognitive functioning measures	Improvements compared to control	Changes on response inhibition and set shifting, selective attention and working memory
Ling et al, 2020 (44)	Parallel group RCT	Healthy adolescents; and other conditions with MD	n=147	Self-report/ actigraphy	19.87 (2.4)	--	8 weeks	CBTi	Waiting list condition	Actigraphy, sleep logs, self-report measures for sleep and cognitive functioning measures	Improvements compared to control	Changes on inhibition and interference control and cognitive flexibility

NOTE: Abbreviations: RCT, randomized clinical trial; MD, major depression; CBTi, cognitive behavior therapy for insomnia.

Results included are only for interaction effects between time and condition.

Figure 2. Risk of Bias for Included RCTs