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Sleep Disorders as a Risk to Language Learning and Use

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Structured Abstract

Clinical Question—Are people with sleep disorders at higher risk for language learning deficits than healthy sleepers?

Method—Scoping Review

Study Sources—PubMed, Google Scholar, Trip Database, ClinicalTrials.gov

Search Terms—sleep disorders AND language AND learning; sleep disorders language learning –deprivation –epilepsy; sleep disorders AND verbal learning

Number of Included Studies—36

Primary Results—Children and adults with sleep disorders were at a higher risk for language problems than healthy sleepers. The language problems typically co-occurred with problems of attention and executive function (in children and adults), behavior (in children), and visual–spatial processing (in adults). Effects were typically small. Language problems seldom rose to a level of clinical concern but there were exceptions involving phonological deficits in children with sleep-disordered breathing and verbal memory deficits among adults with sleep-disordered breathing or idiopathic REM sleep behavior disorder.

Conclusions—Case history interviews should include questions about limited sleep, poor-quality sleep, snoring, and excessive daytime sleepiness. Medical referrals for clients with suspected sleep disorders are prudent.

Clinical Scenario

When we were speech-language pathologists (SLPs) in training—one many years ago, the other mere months ago—we were taught to include questions about sleep in diagnostic interviews. But we were never sure whether reports of sleep problems were meaningful to the clinical decision making at hand. What do sleep problems entail? How does poor sleep affect language learning and use? When is a medical referral needed? This uncertainty prompted us to ask whether individuals with sleep disorders are at higher risk for language learning deficits than healthy sleepers. Our primary goal was to inform clinical protocol.

Background Information

Two lines of evidence support a link between sleep and language learning. The first involves experimental manipulations of sleep intervals relative to learning intervals in the general population. In these experiments, sleep affected adults' memory consolidation as demonstrated by enhanced retention of word forms (Drummond et al., 2000; Ficca, Lombardo, Rossi, & Salzarulo, 2000), stabilization of improvement in word recognition (Fenn, Nusbaum, & Margoliash, 2003), and integration of newly-learned words into the mental lexicon (Gaskell & Dumay, 2003). The effect of sleep on verbal learning and memory is not limited to adults nor is it exclusive to the lexical domain. Infants who slept after exposure to an artificial language derived abstract grammatical patterns; those who remained awake did not (Gómez, Bootzin, & Nadel, 2006).

The second line of evidence is the observation that people with disabilities that affect language learning and memory frequently experience sleep problems. For example, difficulty initiating or maintaining sleep affects 77 to 81% of children with severe intellectual disabilities (Bartlett, Rooney, & Spedding, 1985). Children with autism spectrum disorders exhibit longer sleep onset times, greater fragmentation of sleep, and less overall sleep than unaffected age-mates (Honomichl, Goodlin-Jones, Burnham, Gaylor, & Anders, 2002; Patzold, Richdale, & Tonge, 1998). Snoring, which can be a sign of sleep-disordered breathing, is a common problem among children with ADHD, with a prevalence of 33% compared to a prevalence of 10% among unaffected peers (Chervin, Dillon, Bassetti, Ganoczy, & Pituch, 1997). Moreover, sleep problems are not exclusive to developmental disorders. It is estimated, for example, that up to 98% of adults with Parkinson's disease present with sleep disturbances (Partinen, 1997).

Our clinical question prompts exploration of a third line of evidence. Are people with diagnosed sleep disorders at increased risk for language deficits? Pursuit of this question is an important step in understanding the sleep-language connection. In studies designed to answer this question, sleep problems are examined in otherwise healthy people, thereby isolating sleep as a variable. The question is not esoteric as sleep disorders are commonplace. An estimated 25% of all children are affected by sleep disorders at some point during childhood (Owens, 2008). The prevalence is even higher in adults. In an epidemiologic study of 2,187 adults, 41% reported at least one symptom of disturbed sleep. Women are more often affected than men and older adults are more often affected than younger adults (Klink & Quan, 1987).

Sleep disorders are diagnosed through a combination of sleep history and sleep log information, polysomnography, and/or multiple sleep latency testing. Polysomnography is a procedure that involves measurement of brain activity, oxygen levels in the blood, heart rate, respiration, and movements of the eyes and legs during sleep. Multiple sleep latency testing determines how quickly a patient falls asleep when given a chance to nap and how quickly the patient reaches REM sleep during the nap (National Library of Medicine, National Institutes of Health [NLM, NIH], 2012).

There are seven major categories of sleep disorders (see Table 1). Any and all types of sleep disorders can reduce the amount or quality of sleep, limiting the opportunities available for consolidation of newly learned material. Furthermore, they can increase daytime sleepiness and fatigue, limiting the resources available for adequate language processing. Some sleep disorders reduce oxygen levels in the blood and, over time, alter brain morphology (Torelli et al., 2011) with consequences for language learning and memory. For these reasons, we searched for evidence on a wide range of sleep disorder types.

Clinical Question

Questions of risk are, fundamentally, questions about relationships between two variables: Does the presence of factor P (sleep disorder) mean that factor O (language learning deficit) is more likely? Many levels of evidence are relevant to the question. Therefore, we developed the question in a flexible PO/PECO/PICO format:

Problem	diagnosed sleep disorders
Exposure	severity or duration of sleep disorder (observational studies only)
Intervention	treatment to improve sleep (treatment studies only)
Comparison	healthy sleep
Outcome	language learning deficit

Search for the Evidence

Inclusion Criteria

To ensure a focused and manageable search, we established three inclusion criteria: 1) Each study must include participants with primary sleep disorders so that we could disentangle the effects of sleep problems from other neurological or physiological problems; 2) The study must include at least one verbal outcome measure. Any aspect of language learning, knowledge, memory, or use was acceptable. Finally, as a first pass at ensuring quality, 3) the study must be published in a peer-reviewed journal.

Search Strategy

Because of its comprehensive nature, we conducted our first search in PubMed, which also searches the Cochrane Database of Systematic Reviews. We searched with the MeSH terms sleep disorders AND language AND learning while applying the filters human and English. The search resulted in 106 papers; review of the abstracts revealed that 20 were relevant. Irrelevant studies largely involved sleep as a secondary disorder (especially secondary to epilepsy). Also, to prevent biasing the weight of the evidence, we did not review any single study papers already considered in two systematic reviews we identified.

Next we searched Google Scholar with the terms sleep disorders language learning–deprivation–epilepsy. There were 11,700 results so we limited the search to papers published since 2010 and sorted by decreasing relevance. We reviewed the first 200 results and found 7 nonduplicative, relevant papers. We next searched Trip Database (which also searches DARE and PubMed) using the population search term sleep disorders AND the outcome search term verbal learning. There were 55 results. Three were duplicates of previous finds and 51 were irrelevant; these were largely guidelines for treatment of various sleep disorders. There was one new relevant paper. We also searched after replacing the outcome search term with language learning. No new papers were recovered. Finally, a search of ClinicalTrials.gov revealed only a single relevant study but the study was not yet complete. Therefore, we proceeded to appraise 28 papers. After reading these, we found eight additional papers in the reference lists. A total of 36 papers were included in this review.

Evaluating the Evidence

To evaluate single studies, we selected the Quality Assessment Tool for Quantitative Studies (Effective Public Health Practice Project, 2009). This tool guides ratings of selection bias, study design, confounders, blinding, data collection, and treatment of withdrawals and dropouts. We added to this an assessment of effect size and precision. To judge effect sizes consistently across studies, we did not rely on the individual authors' stated interpretations, but rather referred to Ferguson (2009). To evaluate systematic reviews, we selected the Assessment of Multiple Systematic Reviews (AMSTAR; Shea et al., 2007). We evaluated all papers independently and then resolved disagreements by consensus.

As a group, the single study papers were of good quality with the majority earning global ratings of moderate or above. The most consistent reasons for loss of points were a) employing a descriptive rather than experimental design (although the descriptive studies were highly relevant to the question); b) failing to indicate whether participants were blinded to the study questions; and c) failing to provide information on the reliability of data collection procedures. Reliability was often discussed related to sleep measures but not language measures. There were two systematic review papers, one moderate and one weak. Common strengths included using an a priori design; listing the studies included and describing the publication types in the inclusion criteria. Vagueness about the method of assessing quality and failure to state conflicts of interest were common weaknesses.

In the 18 papers that concerned children, five did not report effect sizes. Effect sizes that were reported were typically small but there were three moderate effects and one large effect. Precision was reported in only three papers. In the 18 papers on adults, nine did not report effect sizes and none reported precision. The reported effect sizes were typically small; there was a single moderate effect. The studies are summarized in the Appendix and explored below.

Language profiles of children with sleep disorders

The cycle of wake and sleep undergoes dramatic changes over the first years of life. Wake and sleep segments become less fragmented and more in sync with the light and dark hours of the day. Dionne et al. (2011) queried the association between day/night sleep ratios at 6, 18, and 30 months and vocabulary outcomes at 18, 30, and 60 months in a cohort of 1,029 twins. Smaller ratios are indicative of more mature sleep patterns. The 6- and 18-month ratios, but not the 30-month ratios, were negatively correlated with vocabulary size at 30 and 60 months; the effect remained after accounting for a large number of potential confounds. Children who scored more poorly than -1 *SD* on the vocabulary measures at 18 and 60 months or at 60 months only (persistent or late delays) had less mature sleep development at 6 and 18 months than those with no delays or with transient delays.

Four papers concerned children with sleep problems as identified via parent questionnaires. In three of these (de Carvalho et al., 2013; Liu et al., 2012; Quach, Hiscock, Canterford, & Wake, 2009), children with sleep problems were compared to children who were healthy sleepers. In all three, children with sleep problems presented with poorer language as measured by parent and teacher reports (Quach et al., 2009), grades in language courses (de

Carvalho et al., 2013), or a standardized test of verbal IQ (Liu et al., 2012). The effect remained after potential confounding factors were controlled (Quach et al., 2009). Verbal IQs were roughly two points lower for those with sleep problems, although for children whose sleep problem manifested as difficulty maintaining nighttime sleep, the difference was nearly five points. That said, the mean scores for both groups were within normal limits (Liu et al., 2012). The only language measure that failed to differentiate poor from healthy sleepers was the Peabody Picture Vocabulary Test™ (Quach et al., 2009). Group differences were not exclusive to language; measures of mathematics, performance IQ, and behavior also predicted lower performance by the poor sleepers.

The fourth paper on children's sleep problems took a different tact. Only children with sleep problems were enrolled and half of them were randomly assigned to a sleep hygiene intervention. The intervention improved children's sleep and behavior but not their language. Children in both intervention and control groups scored within normal limits on a test of word reading and spelling six months after the intervention and the two groups did not differ on these measures (Quach, Hiscock, Ukoumunne, & Wake, 2011).

Thirteen papers reported studies of children with sleep-disordered breathing, a common problem in childhood. Prevalence in the school years is estimated at 1.2% and nasal abnormalities, snoring, obesity, and African American race are risk factors (Bixler et al., 2009). Prevalence estimates for younger children are more difficult to find but it is thought that the prevalence peaks between the ages of 2- and 8-years-old when tonsils and adenoids are largest relative to the airway (Marcus, 2001). Affected children experience intermittent airway obstructions during REM sleep. These do not often result in cortical arousal; therefore, sleep architecture is preserved and excessive daytime sleepiness is avoided (Marcus, 2001). Nonetheless, the 13 reviewed papers indicated that sleep-disordered breathing in childhood does pose a risk to language learning.

Three papers used grades in language classes as an outcome measure. Grades were lower for those with sleep-disordered breathing than for healthy sleepers in two studies (Brockmann et al., 2012; Perez-Chada et al., 2007) but not the third (Ting et al., 2011). The first two involved adolescents while the third involved younger children; this difference could be pertinent to the inconsistent outcomes.

Standardized tests constituted the language outcome measures in 10 studies comparing children with sleep-disordered breathing to children who were healthy sleepers of the same age. Three sets of outcomes emerged. First, there was no consistent evidence across studies that sleep-disordered breathing was related to problems in narrative memory, memory for names, sentence comprehension, or sentence repetition. Second, the bulk of the evidence revealed statistically lower—but not clinically significant— performance on the part of the children with sleep disorders in three language domains: auditory working memory, phonological processing, and verbal IQ. The children with sleep-disordered breathing scored lower on auditory working memory in both studies that reported this measure (Friedman et al., 2003; Kurnatowski, Putynski, Lapienis, & Kowalska, 2006). The children with sleep-disordered breathing scored lower on phonological processing in two studies (Kohler et al., 2009; O'Brien et al., 2004) but not a third (Jackman et al., 2012). In Jackman et al. (2012)

there was a numerical difference between the groups with $p = .02$, but this was not significant after Bonferroni correction for multiple comparisons. It should be noted that Kohler et al. (2009) and O'Brien et al. (2004) did not apply Bonferroni corrections. Verbal IQ was lower in four of six studies (Aronen et al., 2009; Bourke et al., 2011; Kennedy et al., 2004; Kohler et al., 2009). There were no numerical differences in verbal IQ in the Friedman et al. (2003) or Jackman et al. (2012) studies.

The third and final finding involved the domain of expressive phonology. The evidence came from a single study that yielded both statistically and clinically significant differences between 146 children with and without sleep-disordered breathing (Lundeborg, McAllister, Samuelsson, Ericsson, & Hultcrantz, 2009). In this study, children with sleep-disordered breathing were randomly assigned to one of two types of surgical intervention. Prior to surgery they demonstrated more frequent and more severe phonological processes than unaffected peers. Six months after surgery, both groups demonstrated improved expressive phonology, but they still lagged behind (a different control group of) unaffected peers. A comparison group of children with sleep-disordered breathing, but no surgical intervention, was not included so we cannot determine whether the improvements in phonology resulted from surgical correction of the sleep disorder or the natural course of development over the six-month period.

Twelve of the 13 papers on sleep-disordered breathing in children also measured outcomes unrelated to language. In 11 of the papers, problems in nonverbal domains such as executive function, attention, and behavior characterized the sleep-disordered breathing group. Therefore, any relationship between sleep-disordered breathing and language development is not exclusive; rather, it is likely part of a more general lag in cognitive development.

Language profiles of adults with sleep disorders

In one of the 18 papers that addressed adults with sleep disorders, Nebes, Buysse, Halligan, Houck, and Monk (2009) administered a sleep quality questionnaire to a community sample of 157 older adults. Those with poor sleep did not differ from those with good sleep on immediate or delayed recall of a story (the only language measure), processing speed, or inhibitory function. They did perform more poorly on measures of working memory, attentional set shifting, and abstract problem solving.

Two systematic reviews and seven single-study papers addressed sleep-disordered breathing sequelae in adults. This is a common problem affecting 13% of all men and 6% of all women in the U.S. (Peppard et al., 2013). People who are elderly, who snore, or who are obese are at increased risk (Marcus, 2001) and this problem affects adults differently than children. In adults, the intermittent obstructions of the airway can occur during REM or nonREM sleep. There is cortical arousal at the end of each apneic event and, as a result, sleep architecture is disrupted and daytime sleepiness is common (Marcus, 2001).

Both systematic reviews reported consistent evidence of poor verbal memory among adults with sleep-disordered breathing as tapped by recall of word lists or narratives. Performance on naming and semantic fluency tasks was largely spared. The single-study papers provided converging support for this conclusion. Semantic fluency was assessed in four single-study papers and was never found to differentiate adults with and without sleep-disordered breathing. Five of five studies that required recall of word lists or narratives reported poorer verbal memory performance on the part of adults with sleep-disordered breathing than adults with healthy sleep (Kloepfer et al., 2009; Nikodemova, Finn, Mignot, Salzieder, & Peppard, 2013; Salorio, White, Piccirillo, Duntley, & Uhles, 2002; Torelli et al., 2011; Twigg et al., 2010). The effect size was reported in only one case and it was small (Kloepfer et al., 2009). However, Hrubos-Strøm et al. (2012) compared scores earned by patients with sleep-disordered breathing to norms on the Rey Auditory Verbal Learning Test™ and found the patients to average -1.3 *SD*, suggesting that at least some presented with clinically significant concerns. Again problems were not specific to language; performance on executive function and attention tasks was frequently compromised.

Valencia-Flores, Bliwise, Guilleminault, Cilveti, and Clerk (1996) examined verbal memory among 37 patients who received Continuous Positive Airway Pressure (CPAP) intervention. Those who increased daytime alertness following CPAP also improved verbal recall. This suggests a direct link between sleep or sleepiness and verbal memory. All other studies that measured this sort of link found converging evidence: verbal recall correlated with number of REM cycles in overnight sleep (Kloepfer et al., 2009); oxygen saturation levels during sleep (Hrubos-Strøm et al., 2012); and daytime sleepiness (Torelli et al., 2011).

Each of three single studies dealt with one of three other conditions known to disrupt sleep and cause daytime sleepiness. Mazzetti et al. (2006) compared 24 adults with and without narcolepsy-cataplexy. There were no differences in verbal IQ, but those with narcolepsy-cataplexy took longer to decide lexical status on a lexical decision task, and they were less influenced by the strength of a preceding semantic prime than those without, suggesting subtle differences in semantic processing. Fulda, Beitinger, Reppermund, Winkelmann, and Wetter (2010) compared 46 adults with and without restless leg syndrome and found those affected to be poorer at semantic fluency. Receptive single-word vocabulary and verbal memory were unaffected but attention was compromised. Finally, Haimov and Shatil (2013) presented a cognitive intervention to 34 adults with insomnia and compared their outcomes to an active control group of 17 adults with insomnia. Following the intervention, sleep, naming, and verbal memory (as well as executive function and visual memory) improved, and the improvement in naming correlated with improvement in sleep. Whereas we focused on the role of sleep in language learning and memory, these authors provided evidence of a reciprocal relationship; a cognitive “workout” can also improve sleep.

Five studies concerned idiopathic REM sleep behavior disorder (iRBD) in older adults. This disorder manifests as abnormal and sometimes violent muscle activity while dreaming (Gagnon, Postuma, Mazza, Doyon, & Montplaisir, 2006). It is widely considered an early sign of neurodegeneration (Fantini et al., 2011) and in one longitudinal study, 38% of adults with iRBD eventually developed Parkinson’s disease (Schenck, Bundlie, & Mahowald, 1996). All five studies reviewed here were cohort studies that compared older adults with iRBD to unaffected adults of similar age. All included a measure of semantic fluency and a measure of verbal memory for either word lists (Gagnon et al., 2009; Massicotte-Marquez et al., 2008; Terzaghi et al., 2008) or narratives (Fantini et al., 2011; Ferini-Strambi et al., 2004; Terzaghi et al., 2008). There was no consistent evidence of a deficit in semantic fluency, but evidence in support of a verbal memory deficit was more compelling. Two studies reported deficits in recall of word lists (Gagnon et al., 2009; Massicotte-Marquez et al., 2008). A third did not (Terzaghi et al., 2008), but the two groups in that study were numerically different with $p = .008$. This difference was not significant after Bonferroni corrections for multiple testing. Gagnon et al. (2009) and Massicotte-Marquez et al. (2008) did not correct for multiple comparisons. Two studies reported deficits in recall of narratives (Fantini et al., 2011; Terzaghi et al., 2008) and both of these corrected for multiple comparisons. In Fantini et al. (2011), a profile of problematic narrative recall with preserved semantic fluency was stable over two years. Ferini-Strambi et al. (2004) found a numerical difference between iRBD patients and controls on a measure of narrative recall but $p = .02$ was not significant following Bonferroni correction. None of these studies reported effect sizes; however, Massicotte-Marquez et al. (2008) explored the clinical significance of the list recall deficit in the iRBD patients. They found that five of 14 adults with iRBD presented with mild or moderate deficits while none of the control participants scored outside of normal limits. As with all other disorders reviewed above, the relation to language was not specific. In the majority of studies, adults with iRBD also presented with problems in visuospatial and/or executive function.

The Evidence-Based Decision

There is consistent evidence that children with sleep disorders are at higher risk for language problems than healthy sleepers. With the exception of expressive phonology (in a single study), these problems are subtle. Effect sizes were typically small and the low scores earned on standardized tests of language were still within normal limits. Although it is clear that sleep disorders do increase the risk of at least subclinical language problems, the risk is not limited to language. Children with sleep disorders also presented with poor behavior, attention, and executive function. The SLP should consider this evidence when taking case histories and making appropriate referrals. If parents report that their child consistently exhibits limited sleep, poor quality sleep, snoring, or excessive daytime sleepiness, a referral to a physician is warranted. The child who presents with mild or subclinical deficits in language, along with problematic attention, executive function, or behavior, might be more accurately diagnosed with a sleep disorder than a language learning deficit. That said, given the current evidence, it is not clear that treatment for the child's sleep disorder will remediate subclinical language problems.

The bulk of research on the risks that sleep disorders impose on language function in adults concerns patients diagnosed with sleep-disordered breathing or iREM. Tasks tapping memory for word lists or narratives consistently revealed that adults with either condition present with poorer verbal memory than adults with healthy sleep. As in the pediatric studies, effects were typically small but, for some individual adult participants, the verbal memory problem was of clinical concern. There was also consistent evidence that verbal memory problems are linked to severity of the sleep disorder. Again, when suspecting sleep disorders because patients complain of consistently limited sleep, poor quality sleep, snoring, or excessive daytime sleepiness, a medical referral is prudent. Although limited to a single study (Valencia-Flores, Bilwise, Guilleminault, Cilveti, & Clerk, 1996), there was evidence that sleep interventions can improve verbal memory; therefore, management of sleep might be a useful complement to management of language deficits in adults.

Ours was a general query. We were not concerned with a specific client but, rather, with a clinical protocol. The evidence revealed risks to language learning, memory, and use associated with sleep disorders so we retained questions about sleep on diagnostic intake interviews. We now know more about the importance of these questions and how better to act on the answers. For SLPs who wish to consider the "whole patient" at any age, an enhanced understanding of normal sleep behavior in infancy, childhood, and younger and older adulthood is useful. Lee and Rosen (2012) provide a comprehensive overview of sleep development over the lifespan.

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Table 1

Categories of sleep disorders with definitions and subtypes as specified in the American Academy of Sleep Medicine's International Classification of Sleep Disorders, 3rd ed. (2014).

Category	Definition	Subtypes
Insomnia	Difficulty initiating or maintaining sleep, poor quality sleep	Short-term insomnia, chronic insomnia
Sleep-disordered breathing	Abnormal respiration during sleep characterized by intermittent partial or complete upper airway obstruction	Central sleep apnea, obstructive sleep apnea, sleep-related hypoventilation, sleep-related hypoxemia
Central disorders of hypersomnolence	Daytime sleepiness not associated with disturbed sleep or misaligned circadian rhythms	Narcolepsy w/cataplexy, narcolepsy w/out cataplexy, idiopathic hypersomnia, Kleine-Levin syndrome, insufficient sleep syndrome, hypersomnia due to medical or psychiatric disorders or due to substances
Circadian rhythm sleep-wake disorders	Sleep disturbance due to misalignment between the environment and the individual's sleep-wake cycle	Shift work/jet lag disorder, delayed sleep-wake phase disorder, advanced sleep-wake phase disorder, irregular sleep-wake rhythm disorder, non-24-hour sleep-wake rhythm disorder, circadian rhythm disorders associated with medical, psychiatric, or neurological disorder
Parasomnias	Undesirable movements, behaviors, perceptions, or dreams that occur during sleep or arousals from sleep without conscious awareness	Nonrapid eye movement related parasomnias, rapid eye movement sleep behavior disorder, other parasomnias that bear no specific relationship to sleep stage
Sleep-related movement disorders	Simple, stereotypic movements that disrupt sleep	Restless leg syndrome, periodic limb movement disorder, sleep-related leg cramps, sleep-related bruxism, sleep-related rhythmic movement disorder
Other	Sleep disorders that cannot be appropriately classified elsewhere	

Appendix 1

Sleep Problem	Age	Specific Dx	Country	Study Design	Verbal Outcome Measure	Main Findings	Effect Size	Precision	Global Rating	Citation
Circadian rhythm sleep disorder	6 months to 5 years (longitudinal, *n* = 1,029)	Immature sleep-wake rhythms	Canada	Descriptive study of groups	MacArthur Communicative Development Inventory™ (parent report of child's vocabulary), Peabody Picture Vocabulary Test™ (taps comprehension of single words)	Children w/ language delays at age 5 had less mature sleep-wake rhythms at 6 and 18 months than those w/out delays and those with transient (resolved by 5 years) delays.	Small	NA	Mod.	Dionne et al., 2011
Sleep problems broadly defined	5.7 years (mean) (*n* = 108)	Sleep problems broadly defined	Australia	RCT	Word functioning and spelling subtests of the Wechsler Individual Achievement Test™	Children whose families received a sleep hygiene intervention did not differ from children w/out the intervention on word functioning or spelling at 6 months post intervention.	NA	NA	Strong	Quach et al., 2011
	5.7 years (mean) (*n* = 1,656)	Sleep problems broadly defined	China	Descriptive study of groups	Verbal subtest of the Wechsler Preschool and Primary Scale of Intelligence™	Compared to children w/healthy sleep, those w/ sleep problems characterized by sleep resistance, difficulty maintaining sleep, or sleep talking had lower verbal IQs.	Not reported	Not reported	Mod.	Liu et al., 2012
	6.8 years (mean) (*n* = 4,460)	Sleep problems broadly defined	Australia	Descriptive study of groups	Peabody Picture Vocabulary Test- III, composite of language subscales on the Child Communication Checklist 2™, teacher-reported language and literacy learning from a published rating scale	Children w/ moderate or severe sleep problems had lower parent- reported language on the CCC and lower teacher-reported language and literacy than children w/out sleep problems. PPVT did not differ between groups. Children w/ persistent problems (reported at age 4 to 5 and age 6 to 7 years) had lower parent and teacher reported language than children whose previous sleep problems had resolved.	Small for all group differences except for parent-reported language in persistent cases vs. no history of sleep problems where the effect was large	Good	Weak	Quach et al., 2009
	7-to 10-year-olds (*n* = 2,384)	Symptoms of sleep disorders broadly defined	Brazil	Descriptive study of groups	Academic grades in Portuguese	Those w/SSD had lower mean Portuguese grades than those w/out SSD; 13% of those w/SSD were failing vs. 9% of those w/ out SSD.	Not reported	Not reported	Weak	de Carvalho et al., 2013
Sleep- disordered breathing	3 to 5 years (*n* = 153)	Sleep- disordered breathing	Australia	Cohort	The vocabulary subtest of the Abbreviated Battery IQ from the Stanford- Binet Intelligence Scales for Early Childhood™ (5th ed), the phonological processing and comprehension of instructions subtests of the NEPSY™, and the story recall subtest of the Rivermead Behavioral Memory Test for Children™	Children w/SDB did not differ from those w/out on any measure of language regardless of diagnosis (primary snoring, mild OSAS, mod/severe OSAS).	NA	NA	Strong	Jackman et al., 2012

Sleep Problem	Age	Specific Dx	Country	Study Design	Verbal Outcome Measure	Main Findings	Effect Size	Precision	Global Rating	Citation
	3- to 6-year- olds (*n* = 89)	Snoring	Finland	Cross- sectional	Verbal subtest of the Wechsler Preschool and Primary Scale of Intelligence-R, body part naming, speeded naming, comprehension of instructions, narrative memory, memory for names subtests of the NEPSY	Those who snore demonstrated lower verbal IQ than children who do not snore but both group means were within normal limits. Snorers also earned lower scores on the comprehension of instructions and speeded naming subtests of the NEPSY. The groups did not differ on memory for names or narratives.	Small for verbal IQ, not reported for NEPSY subtests	Not reported	Mod.	Aronen et al., 2009
	3- to 12-year- olds (*n* = 92)	Sleep- disordered breathing	Australia	Controlled trial	Verbal IQ subtest of the Stanford- Binet Intelligence Scale™, phonological processing, speeded naming, comprehension, memory for names, and narrative memory subtests of the NEPSY	Both before and after surgical intervention, those w/SDB demonstrated lower scores on verbal IQ (10 points lower on average), phonological processing, naming, comprehension and narrative memory; however, these low scores were not clinically significant.	Moderate for phonological processing and verbal IQ; small for naming, comprehen- sion, and narrative memory	Not reported	Mod.	Kohler et al., 2009
	4- to 5-year- olds (*n* = 146)	Obstructive sleep- disordered breathing	Sweden	RCT	Published Swedish phonology test analyzed in terms of phonological processes	Children w/SDB randomly assigned to one of two types of surgical interventions. Compared to children w/ out SDB, they demonstrated more and more severe phonological deficits before surgery. Despite improvement 6 months post- op, the group level differences in performance remained.	Not reported	Not reported	Mod.	Lundeborg et al., 2009
	5- to 9-year- olds (*n* = 75)	Obstructive sleep apnea	USA	Descriptive study of groups	Memory for names, narrative memory, and sentence repetition subtests of the NEPSY	Those w/OSA did not differ from those w/out on any NEPSY measure but a subset of children w/OSA who had concomitant deficits did demonstrate a different pattern of change across three learning trials on the memory for names subtest.	Small	Not reported	Mod.	Spruyt et al., 2009
	5- to 9-year- olds (*n* = 59)	Obstructive sleep apnea	Israel	Controlled trial	The word order subtest of the Kaufman Assessment Battery for Children™ (taps verbal working memory), the vocabulary subtest of the Wechsler Intelligence Scale for Children-R™	Those w/OSA demonstrated poorer performance on word order than those w/ out. The groups did not differ on vocabulary.	Moderate	Not reported	Strong	Friedman et al., 2003
	6.7 years (mean) (*n* = 70)	Sleep- disordered breathing	USA	Cohort	The phonological processing, speed naming, comprehension of instructions, memory for names, narrative memory, and sentence repetition subtests of the NEPSY	Children w/OSA scored lower on phonological processing than children w/ out. There were no other group differences on language/ verbal memory subtests. There were no correlations between language/ verbal memory performance and a variety of sleep indices measured during polysomnography.	Small	Not reported	Strong	O'Brien et al., 2004

Sleep Problem	Age	Specific Dx	Country	Study Design	Verbal Outcome Measure	Main Findings	Effect Size	Precision	Global Rating	Citation
	6.9 years (mean) (*n* = 26)	Snoring	Australia	Cohort	Verbal subtest of the Wechsler Preschool and Primary Scale of Intelligence-R/ Wechsler Intelligence Scale for Children–III	Children who snore scored a mean of 17 points lower on verbal IQ. Verbal IQ scores were associated with a high number of >3% oxygen desaturations per hour of REM sleep.	Moderate	Not reported	Strong	Kennedy et al., 2004
	6- to 11-year- olds (*n* = 138)	Sleep- disordered breathing	Taiwan	Descriptive study of groups	Academic grades in Chinese and English	Grades did not vary w/presence or severity of apnea.	NA	NA	Weak	Ting et al., 2011
	6 to 9 years (*n* = 161) and 10 to 13 years (*n* = 64)	Sleep apnea	Poland	Cohort	The Token Test™ (taps comprehension of instructions), Luria Auditory Verbal Learning Test™	Children w/OSA scored lower on both tests than children w/out at both ages.	Not reported	Not reported	Mod.	Kurnatowski et al., 2006
	7- to 12-year- olds (*n* = 137)	Sleep- disordered breathing	Australia	Case control	Verbal subtest of the Wechsler Abbreviated Scale of Intelligence™, the word reading and spelling subtests of the Wide Range Achievement Test-3™	Regardless of severity, children w/SDB scored lower on verbal IQ than those w/ out. 16% of those w/SDB scored in the impaired range which is roughly the expectation in the general population. There were no differences between those w/ and w/out SDB on the WRAT-3 but a higher percentage of children w/primary snoring (mild form of SDB) had scores in the impaired range.	Not reported	Not reported	Strong	Bourke et al., 2011
	7 to 17 years (*n* = 523)	Snoring	Chile	Descriptive study of groups	Academic grades in Spanish	Children w/habitual snoring earned lower grades in Spanish than other children. Those who also presented with sleep disordered breathing were at greater risk for failing Spanish than others.	Small	Good	Mod.	Brockmann et al., 2012
	13.3 years (mean) (*n* = 2884)	Sleep- disordered breathing	Argentina	Descriptive study of groups	Academic grades in language	Those whose parents reported SDB problems had lower language grades than those w/out and a larger proportion of those w/SDB were failing language.	Small	Good	Mod.	Perez-Chada et al., 2007
Sleep problems broadly defined	65 to 80 years (*n* = 157)	Sleep problems broadly defined	USA	Descriptive study of groups	The logical memory test from the Wechsler Memory Scale™-Revised (taps immediate and delayed narrative memory)	Poor and good sleepers did not differ on the immediate or delayed recall of narratives.	NA	NA	Weak	Nebes et al., 2009
Sleep- disordered breathing	Adults (number of papers = 5)	Obstructive sleep apnea		Systematic review	Various neuropsychological measures of language (semantic fluency and naming) and verbal memory (immediate and delayed)	Delayed verbal memory was lower for those w/OSA than those w/out in 4 of 4 review papers. Results re the impact of OSA on naming and semantic fluency were inconsistent.	NA	NA	Mod.	Bucks et al., 2013
	Older adults (number of papers = 18)	Sleep- disordered breathing		Systematic review	Various neuropsychological measures of verbal memory	The majority of studies reported poorer delayed verbal memory in those with SDB than those w/out.	NA	NA	Weak	Zimmerman & Aloia, 2012

Sleep Problem	Age	Specific Dx	Country	Study Design	Verbal Outcome Measure	Main Findings	Effect Size	Precision	Global Rating	Citation
	44 years (mean) (*n* = 52)	Obstructive sleep apnea	USA	Cohort	California Verbal Learning Test™ (taps memory for word lists), semantic fluency	Those w/apnea demonstrated significantly poorer encoding of word lists on the CVLT than those w/out. The groups did not differ on fluency.	Not reported	Not reported	Mod.	Salorio et al., 2002
	46.4 years (mean) (*n* = 35)	Obstructive sleep apnea	Germany	Controlled trial	Verbal subtest of the Visueller und Verbaler Merkfähigkeitstest™ (standardized test tapping narrative memory)	Those w/and w/out OSA did not differ in immediate recall but after a night of sleep, those w/OSA retained less relative to their immediate baseline than those w/out. Number of REM cycles was positively correlated with verbal retention rate.	Small for group difference in retention; moderate for correlation between REM and retention	Not reported	Strong	Kloepfer et al., 2009
	48.2 years (mean) (*n* = 290	Obstructive sleep apnea	Norway	Descriptive study of groups	Rey Auditory-Verbal Learning Test™ (taps immediate recall, retention, delayed recall, and recognition of a list of words)	Those w/OSA scored 1.3 SD below the normative mean on the RAVLT. Performance was related to severity as indicated by a relation between scores and oxygen saturation levels recorded during polysomnography	Small	NA	Weak	Hrubos- Strøm et al., 2012
	48.5 years (mean) (*n* = 37)	Sleep apnea	USA	Controlled trial	Rey Auditory Verbal Learning Test	Those w/apnea whose alertness increased following CPAP intervention demonstrated significant improvement on verbal recall.	Not reported	Not reported	Mod.	Valencia- Flores et al., 1996
	51 years (mean) (*n* = 60)	Sleep apnea	England	Cohort	Examiner-made probes of semantic fluency, naming, and narrative memory	Those w/apnea demonstrated significantly poorer narrative recall than those w/out. The groups did not differ on fluency or naming.	Not reported	Not reported	Mod.	Twigg et al., 2010
	53.9 years (mean) (*n* =755)	Sleep- disordered breathing	USA	Descriptive study of groups	Rey Auditory Verbal Learning Test	Those w/o SDB scored better than those w/mild or mod/severe SDB on all RAVLT measures. Mod/ severe SDB was associated with poorer performance on the recognition subtest but only in those who were APOE4 positive (APOE4 carriers are at genetic risk for late-onset Alzheimer).	Small	NA	Weak	Nikodemova et al., 2013
	55.8 years (mean) (*n* = 30)	Obstructive sleep apnea	USA	Cohort	Rey Auditory-Verbal Learning Test, semantic fluency	Those w/OSA demonstrated lower immediate and delayed recall on the RAVLT. The groups did not differ on semantic fluency. Delayed recall scores were positively correlated w/total hippocampal volume and were inversely correlated with daytime sleepiness.	Not reported for group difference in recall; small for correlations	NA	Strong	Torelli et al., 2011
Narcolepsy- cataplexy	31.25 years (mean) (*n* = 24)	Narcolepsy- cataplexy	Italy	Controlled trial	Weschler Adult Intelligence Scale-R™ verbal IQ; examiner- made lexical decision probe	Those w/and w/ out NC did not differ in verbal IQ. Compared to those w/out NC, those w/NC were longer to make lexical decisions and their RTs varied less with associative strength of the semantic prime.	Not reported	Not reported	Strong	Mazzetti et al., 2006

Sleep Problem	Age	Specific Dx	Country	Study Design	Verbal Outcome Measure	Main Findings	Effect Size	Precision	Global Rating	Citation
Restless leg syndrome	54.91 years (mean) (*n* = 46)	Restless leg syndrome	Germany	Cohort	California Verbal Learning Test, Regensburg™ (standardized test of semantic fluency), Mehrfachwahl-wortschatztest™ (standardized test of vocabulary)	Those w/RLS demonstrated lower semantic fluency than those w/out. The groups did not differ on the CVLT or the vocabulary test.	Small	Not reported	Strong	Fulda et al., 2010
Insomnia	73.2 years (mean) (*n* = 51)	Insomnia	Israel	RCT	Naming and working linguistic-auditory memory subtests of the CogniFit computerized neurocognitive evaluation	Those who received cognitive training demonstrated improved sleep, naming and linguistic memory; those in the active control group did not. In the training group, improvement in naming correlated with improvement in number of awakenings after sleep onset.	Small for group difference in naming; moderate for group difference in linguistic memory; small for correlation	Not reported	Weak	Haimov & Shatil, 2013
REM sleep behavior disorder	65.7 years (mean) (*n* = 112)	Idiopathic REM sleep behavior disorder	Canada	Cohort	Rey Auditory-Verbal Learning Test, semantic fluency	Those w/RSBD demonstrated poorer immediate recall, retention, and semantic fluency on the RAVLT than those w/out. RAVLT recognition did not differ.	Not reported	Not reported	Mod.	Gagnon et al., 2009
	66.6 years (mean) (*n* = 28)	Idiopathic REM sleep behavior disorder	Canada	Cohort	Semantic fluency subtest of the Dementia Rating Scale™, the Rey Auditory Verbal Learning Test	Those w/RSBD demonstrated poorer immediate recall, retention, recognition, and semantic fluency, on the RAVLT than those w/out.	Not reported	Not reported	Strong	Massicotte-Marquez et al., 2008
	67 years (mean) (*n* = 46)	Idiopathic REM sleep behavior disorder	Italy	Cohort	Published probes of semantic fluency, word span, word list recall, and narrative memory	Those w/RSBD demonstrated significantly poorer word span and narrative recall than those w/out. The groups did not differ on semantic fluency or word list recall.	Not reported	Not reported	Strong	Terzaghi et al., 2008
	69.5 years (mean) (*n* = 36)	Idiopathic REM sleep behavior disorder	Italy	Cohort (longitudinal)	Published probes of semantic fluency and narrative memory	Those w/RSBD demonstrated significantly poorer narrative recall than those w/out. The groups did not differ on semantic fluency. This pattern held at a two-year- follow-up.	Not reported	Not reported	Strong	Fantini et al., 2011
	70 years (mean) (*n* = 34)	Idiopathic REM sleep behavior disorder	Italy	Cohort	A probe of semantic fluency, a probe of narrative memory	Those w/RSBD did not differ from those w/out on semantic fluency or narrative recall.	Not reported	Not reported	Mod.	Ferini- Strambi et al., 2004