HHS Public Access

Author manuscript

Behav Sleep Med. Author manuscript; available in PMC 2017 May 01.

Published in final edited form as:

Behav Sleep Med. 2016 ; 14(3): 295–310. doi:10.1080/15402002.2014.1002034.

Changes in Cognitive Performance are Associated with Changes in Sleep in Older Adults with Insomnia

Kristine A. Wilckens,
University of Pittsburgh School of Medicine, Department of Psychiatry

Martica Hall,
University of Pittsburgh School of Medicine, Department of Psychiatry

Robert D. Nebes,
University of Pittsburgh School of Medicine, Department of Psychiatry

Timothy H. Monk, and
University of Pittsburgh School of Medicine, Department of Psychiatry

Daniel J. Buysse
University of Pittsburgh School of Medicine, Department of Psychiatry

Abstract

The present study examined sleep features associated with cognition in older adults and examined whether sleep changes following insomnia treatment were associated with cognitive improvements. Polysomnography and cognition (recall, working memory, and reasoning) were assessed before and after an insomnia intervention (Brief Behavioral Treatment of Insomnia (BBTI) or information control (IC)) in 77 older adults with insomnia. Baseline wake-after-sleep-onset (WASO) was associated with recall. Greater NREM (non-rapid eye movement) delta power and lower NREM sigma power were associated with greater working memory and reasoning. The insomnia intervention did not improve performance. However, increased absolute delta power and decreased relative sigma power were associated with improved reasoning. Findings suggest that improvements in executive function may occur with changes in NREM architecture.

INTRODUCTION

The negative consequences of sleep loss on cognition in young adults are well established. Total and partial sleep deprivation consistently lead to impairments in cognition, especially attention (Durmer & Dinges, 2005; Goel, Rao, Durmer, & Dinges, 2009) and higher-order executive functions (Harrison & Horne, 1998, 2000; Harrison, Horne, & Rothwell, 2000). Because sleep often changes with advancing age (Ancoli-Israel, 1997; Carrier & Bliwise, 2003; Carrier, Land, Buysse, Kupfer, & Monk, 2001; Ohayon, Carskadon, Guilleminault, & Vitiello, 2004; Vitiello, 2006), age-related sleep changes and sleep disorders might contribute to the cognitive deficits prevalent in older adulthood (Carrier, 2009; Mander et

Correspondence concerning this article should be addressed to: Kristine A. Wilckens, University of Pittsburgh, 3811 O'Hara St. Room E1132, Pittsburgh PA 15213. wilckenska@upmc.edu, Telephone: (412) 246-6144, Fax: (412) 246-5300.

al., 2013; Pace-Schott & Spencer, 2011; Wilckens, Erickson, & Wheeler, 2012). Much of the literature to date has focused on the role of sleep in memory consolidation in older adults (Mander et al., 2013; Pace-Schott & Spencer, 2011; Spencer, Gouw, & Ivry, 2007; Tucker, McKinley, & Stickgold, 2011; Wilson, Baran, Pace-Schott, Ivry, & Spencer, 2012). However, other aspects of cognition, including controlled memory processes and executive functions, show dramatic decline into older adulthood (Braver & West, 2008; Buckner, 2004; Verhaeghen & Cerella, 2002), and age-related changes in sleep may affect these domains of cognition (Anderson & Horne, 2003; Pace-Schott & Spencer, 2011; Terry, Anderson, & Horne, 2004; Wilckens et al., 2012; Wilckens, Woo, Erickson, & Wheeler, 2014). Notably, it remains an open question as to whether *improving* age-related sleep changes may lead to improvements in executive abilities.

Specific aspects of sleep are commonly associated with cognition across various age groups and clinical populations. Sleep continuity, total sleep time (TST), slow-wave sleep, sleep spindles, and rapid eye movement (REM) sleep have all been associated with some aspects of cognition. Sleep continuity is a particularly interesting sleep variable from the perspective of cognitive aging, given that sleep continuity decreases in older adulthood, and habitual and experimentally manipulated sleep continuity are associated with executive function (Blackwell et al., 2006; Martin, Engleman, Deary, & Douglas, 1996; Nebes, Buysse, Halligan, Houck, & Monk, 2009; Verstraeten & Cluydts, 2004; Wilckens, Woo, Erickson, et al., 2014; Wilckens, Woo, Kirk, Erickson, & Wheeler, 2014). Insomnia, which is often associated with poor sleep continuity, has been associated with poorer executive abilities relative to good-sleeping controls (Altena, Van Der Werf, Strijers, & Van Someren, 2008; Caplette-Gingras, Savard, Savard, & Ivers, 2013; Fortier-Brochu, Beaulieu-Bonneau, Ivers, & Morin, 2012; Fulda & Schulz, 2001). Further, sleep continuity has been shown to have specific benefits to controlled and executive abilities, compared with other domains of cognition, such as processing speed (Wilckens, Woo, Kirk, et al., 2014), simple response time, or motor aspects of cognition (Fulda & Schulz, 2001).

TST is commonly thought to be important for cognitive performance given that sleep deprivation has severe effects on cognition in young adults. However, sleep deprivation is less detrimental for older adults relative to young (Duffy, Willson, Wang, & Czeisler, 2009; Philip et al., 2004), and habitual TST is rarely associated with cognition in the cognitive aging literature (Blackwell et al., 2006; Nebes et al., 2009; Wilckens, Woo, Kirk, et al., 2014). In fact, a number of studies have shown that *longer* TST is associated with *poorer* performance in older adults (Devore et al., 2014; Loerbroks, Debling, Amelang, & Stürmer, 2010; Schmutte et al., 2007). Combined with evidence that sleep continuity supports executive abilities, this raises the question of whether more *continuous* and *condensed* sleep is beneficial for cognition in older adults.

More continuous and condensed sleep is associated with deep sleep (slow-wave sleep). Slow-wave sleep, characterized by delta frontal EEG (electroencephalogram) activity (0.5–4 Hz) has been associated with executive function and memory consolidation across healthy young adults (Diekelmann, Wilhelm, & Born, 2009; Ferrara, Gennaro, Casagrande, & Bertini, 2000; Walker, 2009), healthy older adults (Anderson & Horne, 2003; Mander et al., 2013) and those with insomnia (Backhaus et al., 2006; Crenshaw & Edinger, 1999). Delta

activity reflects homeostatic sleep drive and is therefore highest within the first NREM periods. Greater delta power within the first NREM period has been associated with better executive function in healthy older adults (Anderson & Horne, 2003). Delta activity reflects neural synchrony primarily within the prefrontal cortex, which may enhance cortical connections important for cognition (Mander et al., 2013; Muzur, Pace-Schott, & Hobson, 2002; Picchioni, Duyn, & Horovitz, 2013; Terry et al., 2004).

Sleep spindles (sigma frequency band 12–16 Hz) and REM sleep have been implicated in various aspects of cognition. Spindles are posited to promote synaptic plasticity and, in turn, benefit intellectual abilities and memory consolidation (Fogel et al., 2012; Fogel & Smith, 2011), but few studies have empirically examined this in older adults (Fogel & Smith, 2011; Guazzelli et al., 1986). While there is evidence that REM sleep is associated with certain aspects of cognition, such as memory consolidation (Diekelmann & Born, 2010; Maquet et al., 2000; Rauchs et al., 2004), and progression of dementia (Ferman et al., 1999; Iranzo et al., 2006; Reynolds et al., 1985), there is little evidence that REM sleep is important for controlled or executive abilities in cognitively healthy adults (see Prinz (1977) for most relevant exception).

Despite the promising evidence that older adults with better sleep (i.e., greater sleep continuity and slow-wave sleep) have better cognitive abilities (Pace-Schott & Spencer, 2011), the literature has yet to identify whether behavioral improvements in sleep may improve cognitive performance. The present report was based on secondary analysis of a study investigating the efficacy of an insomnia intervention, Brief Behavioral Treatment for Insomnia (BBTI) compared to an information only control (IC) (Buysse et al., 2011). The present aims were to examine 1) whether sleep continuity and NREM delta and sigma activity were associated with controlled and executive functions in older adults with insomnia at baseline, and 2) whether improvements in these sleep features were associated with improvements in controlled and executive functions at follow-up.

We hypothesized that higher baseline sleep continuity (wake after sleep onset), delta activity, and sigma activity would be associated with better controlled and executive abilities. Because delta within the first NREM period has been associated with better cognition (Anderson & Horne, 2003) and spindles tend to be reciprocally associated with delta across the night (De Gennaro & Ferrara, 2003), greater sigma activity within the first half of the night could be associated with lower delta. Therefore, we examined the effect of NREM period on relationships involving delta and sigma power. We hypothesized that higher delta power in the first half of the night, and higher sigma power in the second half of the night would be associated with higher cognitive performance. We hypothesized that longer TST would be associated with poorer performance as habitually longer TST may be associated with less condensed sleep and less deep sleep. Exploratory analyses assessed whether higher percent REM was also associated with controlled memory and executive function.

In terms of change analyses, we first examined whether BBTI improved cognitive performance relative to IC to determine if insomnia treatment improved performance. We subsequently examined whether changes in specific sleep features were associated with

changes in cognitive performance. We hypothesized that increases in sleep continuity and delta activity within the first NREM period from baseline to follow-up would be positively associated with increases in cognitive performance.

METHODS

Overview

Participants were recruited as part of the AgeWise program project, focused on sleep challenges in older adults (AG020677) (Buysse et al., 2011). Participants were randomly assigned to either BBTI or IC following recruitment, screening, and baseline assessments. Outcomes measured at baseline and follow-up included neuropsychological performance (episodic memory, working memory, and abstract reasoning) and objective sleep measured with PSG.

Participants

Participants were community dwelling older adults (n = 79) ages 60–87 (mean age 71.67, 54 female). Seventy-seven of these participants completed the cognitive battery. Participants completed the battery at a time of day that was convenient for the participant, ranging from morning to afternoon times. Thus the time of day for testing was not fixed across participants. Demographic information and clinical characteristics are displayed in Table 1. Baseline age-normed standardized scores on one of the cognitive assessments (Test of Non-Verbal Intelligence, (Brown, Sheronbenou, & Johnsen, 1997)) were approximately average for this sample of participants (*mean* = 105.42, *sd* = 12.60), where a score of 100 reflects the true population average, suggesting potential for performance improvement. Seventy-three of the participants returned at follow-up to complete the same PSG and cognitive measures collected at baseline. One BBTI participant dropped out during treatment. For the present analyses, participants with missing data in the measures of interest or unusable PSG/spectral data due to technical issues were excluded. This resulted in 76 participants at baseline and 70 at follow-up for WASO, TST, and percent REM sleep analyses, and 69 participants at baseline and 60 at follow-up for delta and sigma analyses. All participants were included in treatment group analyses. Participants met criteria for chronic insomnia based on the Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition, Text Revision) (DSM-IV-TR) (Szelenberger & Niemcewicz, 2000) and criteria for general insomnia disorder in the International Classification of Sleep Disorders (2nd Edition, ICSD-2). Diagnoses were verified by self-report questionnaires and structured clinician interviews. The criteria specified a sleep complaint lasting for at least 1 month with adequate opportunity for sleep and significant distress or daytime impairment (Buysse et al., 2011). The DSM-IV primary insomnia criteria relating to exclusions for medical, sleep, and psychiatric disorders were not applied. Thus, our sample could be considered to be one of comorbid insomnia, since all participants had some type of other chronic stable medical condition. However, all participants indicated their insomnia was not felt to be due to other medical conditions. Inclusion criteria for the present analyses included completion of all neuropsychological tasks at baseline. Exclusion criteria for the original study included dementia, untreated psychiatric disorders, substance use, ongoing chemotherapy or cancer treatment, recent hospitalization, periodic limb movements, sleep apnea, or other untreated

sleep disorder. All participants had mini-mental state exam scores above 24. Participants provided informed consent as required by the University of Pittsburgh Institutional Review Board.

Intervention

The intervention has been described elsewhere (Buysse et al., 2011). Briefly, participants with insomnia were randomly assigned to either BBTI (experimental treatment group) or IC (control group) by permuted block design, stratified by age (≤ 75 vs ≥ 75) and sex. BBTI consisted of a 45–60 minute individual intervention session, followed by a 30 minute session 2 weeks later and 20 minute telephone calls after 1 and 3 weeks. The IC condition was designed to emulate the behavioral treatment information generally available to patients and practitioners, and comprised instructions to read 3 publications from the American Academy of Sleep Medicine: *Insomnia*, (American Academy of Sleep Medicine, 2000) *Sleep as We Grow Older*, (American Academy of Sleep Medicine, 2001) and *Sleep Hygiene* (American Academy of Sleep Medicine, 2002). Both interventions were administered by a mental health nurse practitioner (Buysse et al., 2011). Follow-up assessments were recorded 4 weeks following the start of the intervention. Efficacy of the intervention is reported in Buysse et al. (2011).

Assessments and sleep measures

Demographic information collected at baseline included age, sex, and highest education level. Sleep and depression questionnaires (Pittsburgh Sleep Quality Index (PSQI) and Hamilton Depression Scale) were collected at both baseline and follow-up. The 17-item Hamilton Depression Scale, excluding questions regarding sleep, was used to characterize depressive symptoms. Participants underwent an in-home PSG study using Compumedics Siesta (Compumedics Limited, Abbotsford, Victoria, Australia) for three consecutive nights at baseline and two consecutive nights at follow-up. The first night of PSG data collection served to screen for untreated sleep apnea and periodic leg movements. This screening night was not used in analyses presented here. The two non-screening nights at baseline and follow-up were averaged to analyze sleep in relation to cognition. The in home PSG assessments took place on the nights immediately following the cognitive assessments in the clinic. Thus, for the present study, we assume that the average across the two PSG nights reflects the participants' habitual sleep at baseline and follow-up. To ensure that current sleep problems were specific to insomnia, participants who met criteria for significant sleep apnea (Apnea-Hypopnea Index >20/hr) or restless legs syndrome (based on clinical diagnosis) were excluded from the study. EEG was recorded from C3 and C4 electrodes, referenced to A1–A2. Epochs identified as movement artifact by automated algorithm (Brunner et al., 1996) and visual inspection were rejected. The sleep record was visually scored in 20-second epochs using Rechtschaffen and Kales criteria (Rechtschaffen & Kales, 1968) since the study was completed prior to the revised American Academy of Sleep Medicine criteria. Spectral analysis was performed on the EEG data using epochs scored as NREM sleep (Vasko et al., 1997). Spectral density data from the C4 channel within the 0.5–4 Hz (delta) and 12–16 Hz (sigma) bins were analyzed for the present study. Absolute and relative NREM delta and sigma powers were calculated for each NREM period to test hypotheses regarding effects of delta and sigma power across the night. Absolute and

relative powers were analyzed based on the rationale that absolute delta and sigma power were hypothesized to relate to cognitive performance, but additionally, the interventions may increase homeostatic sleep drive and in turn increase delta power relative to sigma power, which may be relevant to cognition (Mander et al., 2010). Relative power was calculated by dividing the area under the curve within the 0.5 to 4 Hz and 12 to 16 Hz bandwidths by the area under the curve within the 0.5 to 32 Hz bandwidth.

Cognitive measures

Three paper-and-pencil-based neuropsychological tasks were chosen to measure 3 distinct cognitive domains (episodic memory, working memory, and abstract reasoning). Episodic memory was assessed with the Logical Memory Test (Wechsler, 1997b) (immediate recall, delayed recall, and retention). In the Logical Memory Test, participants were read aloud two short stories, each 3–4 sentences long, and were asked to recall as much of the story as they could remember immediately after hearing it, and again 30 minutes later (delayed recall). Recall of key phrases was scored for accuracy. This test has been shown to have a reliability estimate of approximately 0.72 (Theisen, Rapport, Axelrod, & Brines, 1998). Retention was defined as delayed recall/immediate recall. These Logical Memory Test measures were highly correlated, $r > 0.5$. In order to limit the number of comparisons between cognition and sleep, we chose delayed recall to represent the episodic memory domain, given that delayed recall is a controlled memory process (Frankland & Bontempi, 2005; Mangels, Gershberg, Shimamura, & Knight, 1996; Shimamura, 2002) and more likely to be sensitive to sleep (Wilckens et al., 2012). For the present report, we distinguish delayed memory recall from the other cognitive domains as a controlled memory process, rather than an executive function. Abstract reasoning was assessed with the Test of Non-verbal Intelligence III (TONI) (Brown et al., 1997). The TONI is a language-free measure of abstract reasoning and figural problem solving that requires no retrieval of previously learned information. In this abstract reasoning task, participants were shown a set of 4 black and white abstract figures representing a pattern with one space missing. Participants were asked to choose from a set of 6 options, which symbol would complete the pattern for a given symbol set. The TONI has been shown to have reliability estimates ranging from 0.71 to 0.92 (Goldberg, Timmons, & Edelson, 1998; McGhee & Lieberman, 1991). Working memory was assessed with Letter-Number Sequencing (Wechsler, 1997a), which has been shown to have a reliability estimate of approximately 0.98 (Jeyakumar, Warriner, Raval, & Ahmad, 2004). In this working memory task, the participant was read aloud a series of letters and numbers. Immediately after, the participant was asked to first recall the digits in numerical order and then the letters in alphabetical order. The number of items in a series started with 2 and increased to a maximum of 8 items with each correct response. Thus participants were required to maintain and manipulate the alpha-numeric information in working memory. Abstract reasoning and working memory served as two measures of executive function. Abstract reasoning was significantly associated with working memory, $r = 0.39$, $p = 0.001$, and delayed recall, $r = 0.43$, $p < 0.001$. Working memory and delayed recall were not associated with one another, $r = 0.1$, $p = 0.38$. Stimuli were different in each of the neuropsychological tasks between baseline and follow-up sessions. Each of these tasks was designed to be repeatable with no practice effects across repetitions.

Statistical analyses

Specific sleep outcomes included sleep continuity (assessed with log transformed WASO), TST, percent REM, and NREM absolute and relative EEG delta and sigma power. Regression analysis was used to determine whether whole-night sleep variables (WASO, TST, and REM) were associated with cognitive performance (after adjusting for age, sex, and education), for baseline analyses as well as baseline to follow-up change analyses. Because long TST, but also very short TST, have been associated with poorer cognition, we tested both linear and quadratic regression models for TST. As delta and sigma activity change across NREM periods (Aeschbach & Borbely, 1993; De Gennaro & Ferrara, 2003), and these changes may be relevant to cognition (Anderson & Horne, 2003; Mander et al., 2010), mixed model analyses were used to assess main effects of delta and sigma power and interactions between spectral power and NREM period. NREM periods 1–5 were included in the analysis. The mixed models approach accounted for differences in the number of NREM periods among participants. For mixed model analyses, spectral power and covariates (age, sex, and education) were included in the model, NREM period was included as a fixed factor, subject as a random factor, and cognitive performance was the dependent variable. To avoid issues with multicollinearity, separate analyses were performed for each sleep measure.

Each of the analyses mentioned above assessed bivariate relationships between sleep and cognition. We also examined one multifactorial model to determine whether there is a potential combined benefit of high NREM delta activity and low WASO to performance. We reasoned that continuous, deep sleep characterized by the combination of low WASO and high NREM delta power may be associated with greater performance. This mixed models analysis included main effects of WASO, NREM delta power (separately for absolute and relative powers) and the interaction between WASO and NREM delta power, after adjusting for age, sex, and education. NREM period was included as a fixed factor, and subject as a random factor. Cognitive performance was the dependent variable.

To identify whether change in sleep was related to a change in cognitive performance, change scores were calculated for cognitive and sleep variables. T-tests and multivariate analysis of variance (MANOVA) were used to determine main effects of time on cognitive outcomes and main effects of treatment group on sleep and cognition change scores before and after adjusting for age, sex, education. Regression and mixed models analyses were used to test the association between changes in sleep features and changes in cognition, as well as moderating effects of treatment group on change relationships (after adjusting for age, sex, and education). Sleep-cognition change relationships were tested with- and without treatment group as a factor to ensure the stability of the model in light of potential collinearity between treatment group and change in sleep measures. To avoid issues with multiple comparisons, only associations that were significant at baseline were tested in baseline to follow-up change analyses.

Although participants were excluded if they had an Apnea-Hypopnea Index (AHI) >20, or had major depression, it is possible that sleep-cognition relationships could be influenced by the level of subclinical apnea (Fulda & Schulz, 2001; Naëgelé, Thouvard, Pépin, & Lévy, 1995; Verstraeten, Cluydts, Pevernagie, & Hoffmann, 2004) or depression (Newman,

Enright, Manolio, & Haponik, 1997). We therefore followed up all significant effects at baseline with sensitivity analyses including apnea-hypopnea index and the Hamilton Depression Scale (minus sleep items) as additional covariates to ensure that effects were not driven by these factors. Medications that could potentially influence sleep EEG power spectra (benzodiazepines and anti-depressants) (Ancoli-Israel, 1997; Bastien, LeBlanc, Carrier, & Morin, 2003; Kupfer et al., 1994) were also included as covariates in these sensitivity analyses.

RESULTS

Baseline associations between sleep and cognitive performance

Associations between sleep and cognition at baseline are displayed in Table 2. Lower WASO was associated with higher delayed recall performance. Other whole night sleep measures (TST and percent REM) were not significantly associated with any cognitive measure. Neither linear nor quadratic TST models revealed significant relationships with any cognitive measures, all p's > 0.25. Higher NREM delta power and lower NREM sigma power across NREM periods were both significantly associated with higher abstract reasoning and working memory performance. Contrary to our hypothesis that relationships involving delta power would be greatest in the first NREM periods and relationships involving sigma would be greatest in later NREM periods, there were no significant interactions involving NREM period, F's < 1. Sensitivity analyses revealed that associations among cognitive performance with WASO, delta, and relative sigma power were unchanged after further adjusting for possible confounding symptoms of sleep-disordered breathing, depression, antidepressant medication, and benzodiazapines. Relationships with absolute sigma power remained significant after accounting for depression and medications, but were no longer significant after accounting for sleep disordered breathing (abstract reasoning, F = 1.678, p = 0.196; working memory, F = 1.92, p = 0.167). Multifactorial analyses examining the interaction between WASO and NREM delta power revealed marginally significant interactions for delayed recall and abstract reasoning; the combination of lower WASO and greater absolute delta power was associated with better performance (Table 2). This effect did not interact with NREM period, F < 1.

Effects of the intervention on sleep and cognitive performance

Effects of the intervention are displayed in Table 3. There was a significant decrease in TST from baseline to follow-up across treatment groups, t = 2.7, p = 0.01. There were no significant changes over time in any other sleep measure across treatment groups. Participants in the BBTI group exhibited significantly greater improvements in WASO relative to those in the IC condition. There were no other significant differences between BBTI and IC in any sleep measures. There were no significant overall changes in cognitive performance from baseline to follow-up across treatment groups, (Recall: t = 0.404, p = 0.69; Reasoning: t = 1.01, p = 0.32; Working Memory: t = 1.1, p = 0.27). There were no main effects of treatment group on change in performance (Table 3). This remained the case after adjusting for age, sex, and education, (Recall: F = 0.74, p = 0.39; Reasoning: F = 0.43, p = 0.84; Working Memory: F = 0.55, p = 0.46).

Associations between sleep improvement and cognitive improvement

Changes in EEG power pre-post intervention were associated with improvement in cognitive performance (Table 4). Specifically, there was a significant positive association between increased absolute delta power and improved abstract reasoning. A similar relationship was found for relative delta power, but this association was marginally significant. Contrary to our hypotheses regarding effects of NREM period, these relationships did not interact with NREM period, (Absolute: $F(1, 53.2) = 1.4$, $p = 0.26$; Relative: $F(1, 75.2) = 1.5$, $p = 0.22$). Additionally, decreased relative sigma power was significantly associated with improvement in abstract reasoning and this was not moderated by NREM period. None of these relationships were moderated by treatment group (all F values < 1). There were no significant findings for change in delayed recall or working memory.

Given that delta and sigma power showed opposite relationships with cognition, we explored whether there was an inverse relationship between these two oscillations at baseline and in terms of change from baseline to follow-up for whole night NREM sleep. Delta and sigma *relative* power were indeed negatively correlated both at baseline, $r = -0.77$, $p < 0.001$, and in terms of change from baseline to follow-up, $r = -0.822$, $p < 0.001$. However, *absolute* delta and sigma power were *positively* associated at baseline, $r = 0.31$, $p = 0.009$, and in terms of change, $r = 0.342$, $p = 0.007$. Thus, the inverse relationship between delta and sigma power for whole night NREM sleep only applied to relative power.

To explore whether enhanced sleep continuity was associated with greater delta power, we also examined the correlations between WASO and delta power at baseline and from baseline to follow-up. This revealed significant baseline relationships whereby lower WASO was significantly associated with greater absolute ($p = 0.03$) and relative ($p = 0.001$) delta power regardless of NREM cycle. An increase in absolute delta power from baseline to follow-up was only marginally associated with a decrease in WASO ($p = 0.067$).

DISCUSSION

Delayed recall and executive function were associated with objective measures of sleep in older adults with chronic insomnia. Participants with greater WASO had lower delayed recall. Higher delta power and lower relative sigma power were associated with better performance on abstract reasoning and working memory. These findings are in line with the view that controlled memory processes and executive functions may be benefitted by sleep continuity and delta activity (Muzur et al., 2002; Wilckens et al., 2012) and that more condensed and continuous sleep is beneficial for cognition in older adults. In addition, we found that WASO and delta power were associated with one another, and a marginally significant interaction such that the combination of lower WASO and higher delta power were marginally associated with greater delayed recall and abstract reasoning. These findings suggest that these two factors together may contribute to cognitive performance. Notably, an increase in delta power from baseline to follow-up was associated with improved abstract reasoning performance. Conversely, a decrease in relative sigma power was associated with an increase in abstract reasoning performance. Contrary to our hypothesis, these effects were not moderated by NREM period. This is one of the first reports, to our knowledge, to reveal how improvements in sleep may be associated with

improvements in cognitive performance among older adults with insomnia. Nonetheless, improvements in sleep continuity and allocation to BBTI were not associated with improvements in performance. Based on these findings, future work will examine whether interventions designed to increase NREM delta power in older adults may reveal improvements in executive function.

Neither TST nor percent REM were associated with any cognitive measure. The negative TST findings combined with the sleep continuity and delta findings are consistent with the view that more condensed and continuous sleep is associated with better cognition. Combined with prior studies demonstrating that longer TST is associated with *poorer* performance, our results have public health implications suggesting that sleep continuity and sleep depth should be the goal for older adults' sleep, rather than increasing TST at the expense of sleep continuity.

The role of REM sleep in controlled and executive function has not been studied extensively in healthy older adults. Although disruptions in REM are associated with progression of dementia (Reynolds et al., 1985), the lack of associations with REM in present study suggest that REM sleep may be less important for cognitive performance in older adults without dementia. However, further research is needed to understand the influence of REM on cognition and its interaction with aging. Overall, the lack of effects for REM and TST suggest that benefits of sleep to executive functions in older adults may be specific to sleep continuity and slow-wave sleep.

Delta activity reflects synchronized neural activity, which may enhance cortical connections (Bódizs et al., 2005; Mander et al., 2013; Pace-Schott & Spencer, 2011). Thus, one potential mechanism underlying the association between delta and executive functions may be enhanced connectivity within cortical networks relevant to cognition (Terry et al., 2004). This may, in turn, benefit cognitive processes dependent on these networks, including controlled and executive processes. While not tested in the present study, this hypothesis is consistent with the view that delta during NREM sleep preferentially benefits brain regions such as the prefrontal cortex, and in turn executive function (Anderson & Horne, 2003; Mander et al., 2010; Muzur et al., 2002; Terry et al., 2004; Wilckens et al., 2012). Nonetheless, as the cognitive abilities assessed here were correlated with one another (with the exception of delayed recall and working memory), it remains unclear whether effects of sleep on a single underlying cognitive process (i.e. attention or working memory) or a range of cognitive functions dependent on the prefrontal cortex, could have driven these results. Future work should aim to specify the underlying cognitive process or processes that ultimately benefit from sleep continuity and sleep architecture.

Our findings regarding changes from baseline to follow-up are consistent with one prior study (Mander et al., 2010) which reported that, following recovery from sleep deprivation, an increase in delta power and a decrease in sigma power was associated with better inhibitory control performance. Given that TST decreased across intervention groups and restricted time in bed is a major component of BBTI (Buysse et al., 2011) and was included in the IC information, it is plausible that our findings reflect similar process reported by Mander and colleagues (2010). Reduced time in bed may increase delta power and decrease

relative sigma power in some individuals, although this pattern did not apply across participants in the present study. Future work should examine whether improvements in cognition are driven by delta power specifically, or if the combination of a delta increase and a sigma decrease is beneficial to cognition.

Relationships between sleep changes and cognitive changes were not stronger in the experimental intervention group (BBTI) than the control group. Allowing additional time (beyond 4 weeks) for the sleep treatment to take effect may produce a greater effect on the brain, and in turn, cognitive performance. Overall, our results suggest that better cognitive performance may have more to do with individual differences in sleep or changes in sleep rather than the particular insomnia treatment given.

We found no main effects of treatment group on performance. This finding suggests that increased sleep continuity with treatment for insomnia does not in itself improve cognition. Thus, it is a limitation of the present study that we are unable to speak to causality for specific interventions. Ancillary results, however, suggest that follow-up relationships involving change in abstract reasoning did not simply reflect the passage of time: there were no main effects of time point on cognitive performance. As this study was designed to treat insomnia, rather than change sleep architecture, developing behavioral interventions aimed at increasing delta power is important for future studies focused on improving cognition through sleep. Nonetheless, it is possible that the tasks used here were not adequately sensitive to detect improvements in cognitive abilities following insomnia treatment. Further, a recent study demonstrated *decreased* performance in attention following behavioral sleep restriction insomnia therapy (Kyle et al., 2014). Future studies should examine effects of insomnia treatment on a range of tasks and domains of cognition. Indeed, one study that manipulated task demands and used a multi-component sleep intervention (Altena et al., 2008), found improvements in response time measures in a vigilance task in patients with insomnia.

Accounting for demographic factors, such as age, sex, and education did not alter the absence of a treatment effect on cognition in the present study. Nonetheless, future studies may examine moderating effects of demographic and clinical variables on sleep treatment effects on cognition to examine whether factors that affect sleep may influence whether cognitive improvements are found with sleep treatment.

In addition to the study's limitations described above, the PSG assessment took place on the nights following the cognitive assessment. Thus, we assumed for the present study that the PSG assessment reflected the participants' habitual sleep and the cognitive assessment, their habitual cognitive abilities during baseline and follow-up. Future studies may manipulate the timing and duration of PSG and cognitive assessments to determine whether the aspects of sleep measured here have acute and/or chronic effects on cognitive processing. Finally, we did not control time of cognitive testing in the present study, but effects of time-of-day on cognitive performance have been found in older adults (Carrier & Monk, 2000; May, Hasher, & Foong, 2005; Winocur & Hasher, 1999). Future studies should examine how effects of sleep are modulated based on the time of day in which testing takes place.

Conclusion

Objective indices of sleep continuity and sleep architecture are associated with controlled and executive functions in older adults with primary insomnia. Improvements in sleep continuity and the experimental intervention were not associated with improved performance. Regardless of intervention, participants who showed the greatest increase in absolute delta power and the greatest decrease in relative sigma power across NREM periods exhibited the greatest improvements in abstract reasoning. Thus, increased delta throughout NREM sleep may benefit cognitive performance in older adults with insomnia. These findings have therapeutic implications for targeting modifiable factors aimed at benefitting cognition in older adults with insomnia.

Acknowledgments

This work was supported by the National Institutes of Health grants AG020677, RR024153, and T32 MH019986-16. The authors thank the AgeWise program staff of the Sleep and Chronobiology Center and the Neuroscience Clinical and Translational Research Center.

References

Aeschbach D, Borbely AA. All night dynamics of the human sleep EEG. Journal of Sleep Research. 1993; 2(2):70–81. [PubMed: 10607074]

Altena E, Van Der Werf YD, Strijers RL, Van Someren EJ. Sleep loss affects vigilance: effects of chronic insomnia and sleep therapy. Journal of Sleep Research. 2008; 17(3):335–343. [PubMed: 18844819]

American Academy of Sleep Medicine. Insomnia: The Inability to Fall Asleep or Stay Asleep. Westchester, IL: American Academy of Sleep Medicine; 2000.

American Academy of Sleep Medicine. Sleep as We Grow Older. Westchester, IL: American Academy of Sleep Medicine; 2001.

American Academy of Sleep Medicine. Sleep Hygiene. Westchester, IL: American Academy of Sleep Medicine; 2002.

Ancoli-Israel S. Sleep problems in older adults: putting myths to bed. Geriatrics. 1997; 52(1):20–30. [PubMed: 9003201]

Anderson C, Horne JA. Prefrontal cortex: links between low frequency delta EEG in sleep and neuropsychological performance in healthy, older people. Psychophysiology. 2003; 40(3):349–357.10.1111/1469-8986.00038 [PubMed: 12946109]

Backhaus J, Junghanns K, Born J, Hohaus K, Faasch F, Hohagen F. Impaired Declarative Memory Consolidation During Sleep in Patients With Primary Insomnia: Influence of Sleep Architecture and Nocturnal Cortisol Release. Biological Psychiatry. 2006; 60(12):1324–1330.10.1016/j.biopsych.2006.03.051 [PubMed: 16876140]

Bastien CH, LeBlanc M, Carrier J, Morin CM. Sleep EEG power spectra, insomnia, and chronic use of benzodiazepines. Sleep. 2003; 26(3):313–317. [PubMed: 12749551]

Blackwell T, Yaffe K, Ancoli-Israel S, Schneider JL, Cauley JA, Hillier TA, Stone KL. Poor sleep is associated with impaired cognitive function in older women: the study of osteoporotic fractures. Journal of Gerontology, Series A: Biological Sciences & Medical Sciences. 2006; 61(4):405–410.

Bódizs R, Kis T, Lázár AS, Havrán L, Rigó P, Clemens Z, Halász P. Prediction of general mental ability based on neural oscillation measures of sleep. Journal of Sleep Research. 2005; 14(3):285–292. [PubMed: 16120103]

Braver, TS.; West, R. Working memory, executive control, and aging. In: Craik, FI.; Salthouse, TA., editors. The handbook of aging and cognition. Vol. 3. 2008.

Brown, R.; Sheronbenou, RJ.; Johnsen, SK. Patent No. San Antonio, TX, USA: Pearson; 1997.

Brunner D, Vasko R, Detka C, Monahan J, Reynolds C III, Kupfer D. Muscle artifacts in the sleep EEG: Automated detection and effect on all-night EEG power spectra. Journal of Sleep Research. 1996; 5(3):155–164.10.1046/j.1365-2869.1996.00009.x [PubMed: 8956205]

Buckner RL. Memory and executive function in aging and AD: multiple factors that cause decline and reserve factors that compensate. Neuron. 2004; 44(1):195–208. [PubMed: 15450170]

Buysse DJ, Germain A, Moul DE, Franzen PL, Brar LK, Fletcher ME, Monk TH. Efficacy of brief behavioral treatment for chronic insomnia in older adults. Archives of Internal Medicine. 2011; 171(10):887–895.10.1001/archinternmed.2010.535 [PubMed: 21263078]

Caplette-Gingras A, Savard J, Savard MH, Ivers H. Is insomnia associated with cognitive impairments in breast cancer patients? Behavioral Sleep Medicine. 2013; 11(4):239–257. [PubMed: 23181706]

Carrier J. Possible mechanisms and consequences of age-related changes in the middle years of life. Principles and Practice of Geriatric Sleep Medicine. 2009; 10:22.

Carrier, J.; Bliwise, D. Sleep. Springer; 2003. Sleep and circadian rhythms in normal aging; p. 297-332.

Carrier J, Land S, Buysse DJ, Kupfer DJ, Monk TH. The effects of age and gender on sleep EEG power spectral density in the middle years of life (ages 20–60 years old). Psychophysiology. 2001; 38(2):232–242. [PubMed: 11347869]

Carrier J, Monk T. Circadian rhythms of performance: new trends. Chronobiology international. 2000; 17(6):719–732. [PubMed: 11128289]

Crenshaw MC, Edinger JD. Slow-wave sleep and waking cognitive performance among older adults with and without insomnia complaints. Physiology & Behavior. 1999; 66(3):485–492. [PubMed: 10357438]

De Gennaro L, Ferrara M. Sleep spindles: an overview. Sleep Medicine Reviews. 2003; 7(5):423–440. [PubMed: 14573378]

Devore EE, Grodstein F, Duffy JF, Stampfer MJ, Czeisler CA, Schernhammer ES. Sleep Duration in Midlife and Later Life in Relation to Cognition. Journal of the American Geriatrics Society. 2014

Diekelmann S, Born J. The memory function of sleep. Nature Reviews Neuroscience. 2010; 11(2): 114–126. [PubMed: 20046194]

Diekelmann S, Wilhelm I, Born J. The whats and whens of sleep-dependent memory consolidation. Sleep Medicine Reviews. 2009; 13(5):309–321. [PubMed: 19251443]

Duffy JF, Willson HJ, Wang W, Czeisler CA. Healthy older adults better tolerate sleep deprivation than young adults. Journal of the American Geriatrics Society. 2009; 57(7):1245–1251.10.1111/j.1532-5415.2009.02303.x [PubMed: 19460089]

Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Seminars in Neurology. 2005; 25(1):117–129.10.1055/s-2005-867080 [PubMed: 15798944]

Ferman T, Boeve B, Smith G, Silber M, Kokmen E, Petersen R, Ivnik R. REM sleep behavior disorder and dementia Cognitive differences when compared with AD. Neurology. 1999; 52(5):951–951. [PubMed: 10102411]

Ferrara M, Gennaro L, Casagrande M, Bertini M. Selective slow-wave sleep deprivation and time-of-night effects on cognitive performance upon awakening. Psychophysiology. 2000; 37(4):440–446. [PubMed: 10934902]

Fogel SM, Martin N, Lafortune M, Barakat M, Debas K, Laventure S, Carrier J. NREM sleep oscillations and brain plasticity in aging. Frontiers in neurology. 2012; 3

Fogel SM, Smith CT. The function of the sleep spindle: a physiological index of intelligence and a mechanism for sleep-dependent memory consolidation. Neuroscience & Biobehavioral Reviews. 2011; 35(5):1154–1165. [PubMed: 21167865]

Fortier-Brochu É, Beaulieu-Bonneau S, Ivers H, Morin CM. Insomnia and daytime cognitive performance: a meta-analysis. Sleep Medicine Reviews. 2012; 16(1):83–94. [PubMed: 21636297]

Frankland PW, Bontempi B. The organization of recent and remote memories. Nature Reviews Neuroscience. 2005; 6(2):119–130. [PubMed: 15685217]

Fulda S, Schulz H. Cognitive dysfunction in sleep disorders. Sleep Medicine Reviews. 2001; 5(6): 423–445. [PubMed: 12531152]

Goel N, Rao H, Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Seminars in Neurology. 2009; 29(4):320–339.10.1055/s-0029-1237117 [PubMed: 19742409]

Goldberg M, Timmons D, Edelson SM. Factors predicting intelligence scores on the TONI in individuals with autism. Focus on autism and other developmental disabilities. 1998; 13(1):17–26.

Guazzelli M, Feinberg I, Aminoff M, Fein G, Floyd T, Maggini C. Sleep spindles in normal elderly: comparison with young adult patterns and relation to nocturnal awakening, cognitive function and brain atrophy. Electroencephalography and Clinical Neurophysiology. 1986; 63(6):526–539. [PubMed: 2422002]

Harrison Y, Horne JA. Sleep loss impairs short and novel language tasks having a prefrontal focus. Journal of Sleep Research. 1998; 7(2):95–100. [PubMed: 9682180]

Harrison Y, Horne JA. The impact of sleep deprivation on decision making: a review. Journal of Experimental Psychology: Applied. 2000; 6(3):236–249.10.1037/1076-898X.6.3.236 [PubMed: 11014055]

Harrison Y, Horne JA, Rothwell A. Prefrontal neuropsychological effects of sleep deprivation in young adults--a model for healthy aging? Sleep. 2000; 23(8):1067–1073. [PubMed: 11145321]

Iranzo A, Molinuevo JL, Santamaria J, Serradell M, Marti MJ, Valldeoriola F, Tolosa E. Rapid-eye-movement sleep behaviour disorder as an early marker for a neurodegenerative disorder: a descriptive study. The Lancet Neurology. 2006; 5(7):572–577.10.1016/S1474-4422(06)70476-8 [PubMed: 16781987]

Jeyakumar SL, Warriner EM, Raval VV, Ahmad SA. Balancing the need for reliability and time efficiency: Short forms of the Wechsler Adult Intelligence Scale-III. Educational and Psychological Measurement. 2004; 64(1):71–87.

Kupfer DJ, Ehler CL, Frank E, Grochocinski VJ, McEachran AB, Alhaji B. Persistent effects of antidepressants: EEG sleep studies in depressed patients during maintenance treatment. Biological Psychiatry. 1994; 35(10):781–793. [PubMed: 8043708]

Kyle SD, Miller CB, Roger Z, Siriwardena M, Mac Mahon KM, Espie CA. Sleep restriction therapy for insomnia is associated with reduced objective total sleep time, increased daytime somnolence, and objectively-impaired vigilance: implications for the clinical management of insomnia disorder. Sleep. 2014

Loerbroks A, Debling D, Amelang M, Stürmer T. Nocturnal sleep duration and cognitive impairment in a population-based study of older adults. International Journal of Geriatric Psychiatry. 2010; 25(1):100–109. [PubMed: 19548221]

Mander BA, Rao V, Lu B, Saletin JM, Lindquist JR, Ancoli-Israel S, Walker MP. Prefrontal atrophy, disrupted NREM slow waves and impaired hippocampal-dependent memory in aging. Nature Neuroscience. 201310.1038/nn.3324

Mander BA, Reid KJ, Baron KG, Tjoa T, Parrish TB, Paller KA, Zee PC. EEG measures index neural and cognitive recovery from sleep deprivation. Journal of Neuroscience. 2010; 30(7):2686–2693.10.1523/JNEUROSCI.4010-09.2010 [PubMed: 20164352]

Mangels JA, Gershberg FB, Shimamura AP, Knight RT. Impaired retrieval from remote memory in patients with frontal lobe damage. Neuropsychology. 1996; 10(1):32.

Maquet P, Laureys S, Peigneux P, Fuchs S, Petiau C, Phillips C, Meulemans T. Experience-dependent changes in cerebral activation during human REM sleep. Nature Neuroscience. 2000; 3(8):831–836. [PubMed: 10903578]

Martin SE, Engleman HM, Deary IJ, Douglas NJ. The effect of sleep fragmentation on daytime function. American Journal of Respiratory and Critical Care Medicine. 1996; 153(4):1328–1332. [PubMed: 8616562]

May CP, Hasher L, Foong N. Implicit Memory, Age, and Time of Day Paradoxical Priming Effects. Psychological Science. 2005; 16(2):96–100. [PubMed: 15686574]

McGhee RL, Lieberman LR. Test-retest reliability of the Test of Nonverbal Intelligence (TONI). Journal of School Psychology. 1991; 28(4):351–353.

Muzur A, Pace-Schott EF, Hobson JA. The prefrontal cortex in sleep. Trends in Cognitive Science. 2002; 6(11):475–481.

Naëgelé B, Thouvard V, Pépin J-L, Lévy P. Deficits of cognitive executive functions in patients with sleep apnea syndrome. Sleep: Journal of Sleep Research & Sleep Medicine. 1995; 18(1)

Nebes RD, Buysse DJ, Halligan EM, Houck PR, Monk TH. Self-reported sleep quality predicts poor cognitive performance in healthy older adults. Journal of Gerontology, Series B: Psychological and Social Science. 2009; 64(2):180–187.10.1093/geronb/gbn037

Newman AB, Enright PL, Manolio TA, Haponik EF. Sleep disturbance, psychosocial correlates, and cardiovascular disease in 5201 older adults: the Cardiovascular Health Study. Journal of the American Geriatrics Society. 1997

Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. Sleep. 2004; 27(7):1255–1273. [PubMed: 15586779]

Pace-Schott, EF.; Spencer, RM. Age-related changes in the cognitive function of sleep. In: Green, AM.; Chapman, CE.; Kalaska, JF.; Lepore, F., editors. Progress in Brain Research. Vol. 191. New York, NY: Elsevier; 2011.

Philip P, Taillard J, Sagaspe P, Valtat C, Sanchez-Ortuno M, Moore N, Bioulac B. Age, performance and sleep deprivation. Journal of Sleep Research. 2004; 13(2):105–110.10.1111/j.1365-2869.2004.00399.x [PubMed: 15175089]

Picchioni D, Duyn JH, Horovitz SG. Sleep and the functional connectome. Neuroimage. 2013; 80:387–396. [PubMed: 23707592]

Prinz PN. Sleep patterns in the healthy aged: relationship with intellectual function. Journal of Gerontology. 1977; 32(2):179–186.

Rauchs G, Bertran F, Guillery-Girard B, Desgranges B, Kerrouche N, Denise P, Eustache F. Consolidation of strictly episodic memories mainly requires rapid eye movement sleep. Sleep. 2004

Rechtschaffen A, Kales A. A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. 1968

Reynolds CFI, Kupfer DJ, Taska LS, Hoch CC, Spiker DG, Sewitch DE, Martin D. EEG sleep in elderly depressed, demented, and healthy subjects. Biological Psychiatry. 1985; 20(4):431–442. [PubMed: 3978175]

Schmutte T, Harris S, Levin R, Zweig R, Katz M, Lipton R. The relation between cognitive functioning and self-reported sleep complaints in nondemented older adults: results from the Bronx aging study. Behavioral Sleep Medicine. 2007; 5(1):39–56. [PubMed: 17313323]

Shimamura AP. Memory retrieval and executive control. Principles of frontal lobe function. 2002:210.

Spencer RM, Gouw AM, Ivry RB. Age-related decline of sleep-dependent consolidation. Learning & Memory. 2007; 14(7):480–484. [PubMed: 17622650]

Szelenberger W, Niemcewicz S. Severity of insomnia correlates with cognitive impairment. Acta Neurobiologiae Experimentalis. 2000; 60(3):373. [PubMed: 11016080]

Terry JR, Anderson C, Horne JA. Nonlinear analysis of EEG during NREM sleep reveals changes in functional connectivity due to natural aging. Human brain mapping. 2004; 23(2):73–84. [PubMed: 15340930]

Theisen ME, Rapport LJ, Axelrod BN, Brines DB. Effects of practice in repeated administrations of the Wechsler memory scale-revised in normal adults. Assessment. 1998; 5(1):85–92. [PubMed: 9458344]

Tucker M, McKinley S, Stickgold R. Sleep optimizes motor skill in older adults. Journal of the American Geriatrics Society. 2011; 59(4):603–609. [PubMed: 21410442]

Vasko RC, Brunner DP, Monahan JP, Doman J, Boston JR, El-Jaroudi A, Kupfer DJ. Power spectral analysis of EEG in a multiple-bedroom, multiple-polygraph sleep laboratory. International Journal of Medical Informatics. 1997; 46(3):175–184. [PubMed: 9373779]

Verhaeghen P, Cerella J. Aging, executive control, and attention: a review of meta-analyses. Neuroscience & Biobehavioral Reviews. 2002; 26(7):849–857. [PubMed: 12470697]

Verstraeten E, Cluydts R. Executive control of attention in sleep apnea patients: theoretical concepts and methodological considerations. Sleep Medicine Reviews. 2004; 8(4):257–267. [PubMed: 15233954]

Verstraeten E, Cluydts R, Pevernagie D, Hoffmann G. Executive function in sleep apnea: controlling for attentional capacity in assessing executive attention. Sleep. 2004; 27(4):685–693. [PubMed: 15283003]

Vitiello MV. Sleep in Normal Aging. Sleep Medicine Clinics. 2006; 1:171–176.

Walker MP. The role of slow wave sleep in memory processing. Journal of Clinical Sleep Medicine. 2009; 5(2 Suppl):S20. [PubMed: 19998871]

Wechsler, D. Wechsler Adult Intelligence Scale. WAIS-III. Administration and scoring manual. 3. San Antonio: The Psychological Corporation; 1997a.

Wechsler, D. Wechsler Memory Scale (WMS-III). Psychological corporation; 1997b.

Wilckens KA, Erickson KI, Wheeler ME. Age-related decline in controlled retrieval: The role of the PFC and sleep. Neural Plasticity. 201210.1155/2012/624795

Wilckens KA, Woo SG, Erickson KI, Wheeler ME. Sleep continuity and total sleep time are associated with task-switching and preparation in young and older adults. Journal of Sleep Research. 2014

Wilckens KA, Woo SG, Kirk AR, Erickson KI, Wheeler ME. The role of sleep continuity and total sleep time in executive function across the adult lifespan. Psychology & Aging. 2014; 29(3)

Wilson JK, Baran B, Pace-Schott EF, Ivry RB, Spencer R. Sleep modulates word-pair learning but not motor sequence learning in healthy older adults. Neurobiology of aging. 2012; 33(5):991–1000. [PubMed: 22244090]

Winocur G, Hasher L. Aging and time-of-day effects on cognition in rats. Behavioral neuroscience. 1999; 113(5):991. [PubMed: 10571481]

Table 1

Baseline demographic and clinical characteristics by treatment group.

	BBTI		IC	
	Mean/N	**SD/%**	**Mean/N**	**SD/%**
Mean Age	72.61	6.69	70.45	7.56
N Female	25	65.8%	28	71.8%
N White/Caucasian	35	92.1%	37	94.9%
N Currently taking sleep medication	15	39.5%	16	41%
Mean number of current medications	5.40	2.46	4.95	2.04
Mean Hamilton Depression Scale	3.37	2.45	3.64	2.41
Mean Pittsburgh Sleep Quality Index Total Score	10.32	2.56	10.38	3.31

BBTI = Brief Behavioral Treatment of Insomnia, IC = Information only Control.

Table 2

Baseline associations between sleep and cognition.

	Delayed Recall	Abstract Reasoning	Working Memory
TST	0.031	0.021	−0.14
WASO	**−0.25***	−0.13	−0.03
Percent REM	0.039	−0.062	0.051
Delta			
Absolute	−0.03 (0.3)	**0.06 (0.03)***	0.01 (0.01)
Relative	−2.9 (4.5)	**9.01 (4.0)***	**3.43 (1.7)***
Sigma			
Absolute	−1.7 (0.88)†	**−1.67 (.80)***	**−0.96 (0.33)****
Relative	−14.91 (20.02)	**−62.07 (17.96)*****	**−23.66 (7.57)****
WASO* Delta			
Absolute	−0.17 (0.1) †	−0.16 (0.08) †	−0.02 (0.03)
Relative	−14.56 (13.80)	−2.75 (12.24)	−7.08 (5.24)

Associations between sleep and cognition at baseline across BBTI and IC. Regression model beta values are displayed for TST (linear), WASO, and Percent REM. Mixed model unstandardized parameter estimates (standard errors in parentheses) are displayed for Delta, Sigma, and WASO*Delta across NREM periods. Significant effects are in bold type.

† $p < 0.10$;

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$.

Table 3

Pre and post intervention means and (standard deviations) for sleep and cognitive scores by treatment group and significance of group difference change score.

	Pre BBTI	**Post**	**Pre IC**	**Post**	**Change score**	***t***	***p***
Delayed Recall	19.6 (7.7)	20.4 (6.8)	19.9 (7.2)	19.0 (7.7)	1.4	0.98	0.33
Abstract Reasoning	25.1 (6.9)	25.8 (6.3)	26.4 (7.6)	27.4 (6.0)	0.09	0.06	0.95
Working Memory	10.6 (2.6)	11.1 (2.6)	10.4 (2.5)	10.4 (2.5)	0.45	0.9	0.37
TST (mins)	353.3 (59.3)	324.0 (52.1)	351.3 (48.5)	337.7 (61.8)	7.65	0.51	0.61
WASO (mins)	100.4 (60.9)	79.6 (44.5)	89.4 (48.0)	92.3 (46.9)	**22.9**	**2.1**	**0.04***
REM (%)	22.7 (5.4)	23.0 (5.0)	22.9 (5.7)	22.3 (5.5)	1.29	1.06	0.29
Absolute Delta (Hz)	25.4 (12.0)	23.34 (8.4)	26.3 (11.3)	30.7 (13.3)	3.5	1.7	0.10
Absolute Sigma (Hz)	0.79 (0.4)	0.76 (0.4)	0.90 (0.5)	0.88 (0.5)	0.01	0.3	0.77

Change score statistics reflect analyses without standard covariates. Significant effects are in bold type.

$^{\dagger}p < 0.10$;

$^{*}p < 0.05$;

$^{**}p < 0.01$;

$^{***}p < 0.001$.

Table 4

Baseline to follow-up associations between changes in sleep and changes in cognition.

	Delayed Recall	Abstract Reasoning	Working Memory
WASO	−0.06		
Delta			
Absolute		**1.0 (0.03)****	
Relative		9.9 (5.6)†	−0.55 (1.7)
Sigma			
Absolute		−1.70 (2.0)	−0.12 (0.63)
Relative		**−69.84 (29.24)***	−1.54 (8.58)

Associations between change in sleep and change in cognition at baseline across BBTI and IC. Regression model beta values are displayed for WASO. Mixed model unstandardized parameter estimates (standard errors in parentheses) are displayed for Delta and Sigma across NREM periods. Significant effects are in bold type.

† $p < 0.10$;

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$.