Insomnia and daytime cognitive performance: a meta-analysis

Émilie Fortier-Brochu*, Simon Beaulieu-Bonneau, Hans Ivers, Charles M. Morin

École de Psychologie, Université Laval, Québec, Canada

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Correspondence: Tel.: +1 418 656 2131x12580; fax: +418 656 5152, e-mail address: emilie.fortier-brochu.1@ulaval.ca (É. Fortier-Brochu).

Abstract

Objectives: Individuals with insomnia consistently report difficulties pertaining to their cognitive functioning (e.g., memory, concentration). However, objective measurements of their performance on neuropsychological tests have produced inconsistent findings. This meta-analysis was conducted to provide a quantitative summary of evidence regarding the magnitude of differences between individuals with primary insomnia and normal sleepers on a broad range of neuropsychological measures.

Methods: Reference databases (PubMed, PsycInfo, Dissertation Abstracts International) were searched for studies comparing adults with primary insomnia to normal sleepers on neuropsychological measures. Dependent variables related to cognitive and psychomotor performance were extracted from each study. Variables were classified independently by two licensed neuropsychologists according to the main cognitive function being measured. Individual effect sizes (Cohen's *d*) were weighted by variability and combined for each cognitive function using a fixed effects model. Average effect sizes and their 95% confidence intervals were computed for each cognitive function.

Results: Twenty-four studies met inclusion criteria, for a total of 639 individuals with insomnia and 558 normal sleepers. Significant impairments ($p < 0.05$) of small to moderate magnitude were found in individuals with insomnia for tasks assessing episodic memory (ES ¼ -0.51), problem solving (ES ¼ -0.42), manipulation in working memory (ES ¼ -0.42), and retention in working memory (ES ¼ -0.22). No significant group differences were observed for tasks assessing general cognitive function, perceptual and psychomotor processes, procedural learning, verbal functions, different dimensions of attention (alertness, complex reaction time, speed of information processing, selective attention, sustained attention/vigilance) and some aspects of executive functioning (verbal fluency, cognitive flexibility).

Conclusion: Individuals with insomnia exhibit performance impairments for several cognitive functions, including working memory, episodic memory and some aspects of executive

functioning. While the data suggests that these impairments are of small to moderate magnitude, further research using more ecologically valid measures and normative data are warranted to establish their clinical significance.

Keywords: Insomnia, Cognitive impairment, Meta-analysis

Introduction

Insomnia is a widespread health problem, with recent reports estimating that 25e30% of adults in the general population experience occasional sleep problems, while 10% suffer from sleep disturbance severe enough to meet diagnostic criteria for insomnia.[1e3] As a chronic condition, insomnia entails significant personal and social costs: individuals with insomnia consistently report decreased quality of life[4] and are at greater risk for depression.[5] Insomnia is also associated with higher rates of absenteeism and loss of productivity,[6,7] and recent health economic analyses suggest that more than 90% of insomnia-related costs result from these occupational consequences.[8] The burden of insomnia thus lies predominantly in the impact it produces on daytime functioning rather than in nighttime sleep disturbances per se.

The most commonly reported daytime symptoms in individuals with insomnia are fatigue and mood disturbances, experienced as difficulty handling minor irritations, reduced interest and decreased satisfaction in leisure activities and relationships.[9e11]

Complaints related to altered cognitive functioning are also frequent and involve memory and concentration problems, difficulty making decisions and frequent work-related mistakes.[9e11] However, these complaints have not been unequivocally corroborated by objective performance-based measures. Over 30 studies have been published on the matter but only a small proportion has found differences between individuals with and without insomnia. For example, a recent review suggests that performance of individuals with insomnia and normal sleepers is comparable for different tasks assessing psychomotor function (e.g., finger tapping, Purdue Pegboard), some aspects of attentional function (e.g., Digit Symbol Substitution Test, vigilance tasks, Trail Making

Test) and episodic memory (e.g., Hopkins Verbal Learning Test, Verbal Paired Associates, Auditory Verbal Learning Test).[12] On the other hand, tests measuring working memory (e.g., Digit Span, Letter-Number Sequencing) and executive function (e.g., Wisconsin Card Sorting Test, verbal fluency, maze tasks) have yielded contradictory findings. The lack of consistent

evidence has led some to question the existence of daytime cognitive impairments in insomnia [13] and to attribute daytime complaints to other mechanisms such as excessive attention toward expected consequences of poor sleep.[14]

While these equivocal findings could suggest that cognitive functioning is well preserved in individuals with insomnia, they could also result from a number of methodological issues related to lack of statistical power, heterogeneity of subjects, and use of insensitive measures to detect mild defitics. Indeed, many of the studies in this domain were conducted with fairly small samples (<20 participants per group), which may have limited statistical power to detect subtle differences between normal sleepers and individuals with insomnia. In addition, participants in some of these studies were not always adequately characterized with regard to insomnia diagnosis and severity of sleep disturbances (e.g., unclear selection criteria, lack of valid diagnostic measures), thus potentially introducing heterogeneity in the samples and further decreasing statistical power. Also, the use of measures not specifically designed for this population may preclude adequate sensitivity to detect cognitive deficits. Given these limitations, it appears premature to conclude that the lack of consistent significant group differences in available studies (i.e., negative findings) is evidence of preserved cognitive functioning in individuals with insomnia. This meta-analysis was intended to circumvent the problem of low statistical power by pooling individual studies and conducting a quantitative review of the evidence. The aim was to estimate the magnitude of differences in cognitive performance between individuals with insomnia and normal sleepers.

Methods

Identification of eligible studies

The MedLine, PsycInfo and Dissertation Abstract International databases were searched using “insomnia” or “sleep initiation and maintenance disorders” as keywords or major descriptors. The results were then crossed with the following keywords: “cognitive”, “assessment”, “psychological tests”, “psychomotor performance”, “performance”,

“neuropsychology”, “memory”, “attention”, “cognitive disorders”, “neurobehavioral manifestations” or “mental processes”. The search was conducted in January 2009. There were no further restrictions regarding date of publication. Reference lists of relevant articles were also carefully reviewed. Published conference proceedings were included if they met all inclusion criteria and did not duplicate another included study.

Selection of studies

References were retrieved and screened for relevance using a standard method. To be included in the meta-analysis, studies had to 1) be conducted in a sample of adults (18 years and older) with primary insomnia, 2) involve a cross-sectional comparison to a control group without sleep problems, 3) assess daytime performance using face-to-face or computerized cognitive/neuropsychological tests, 4) include sufficient information to derive effect sizes, and 5) be published in either English or French.

Data extraction

Information extracted during coding included descriptive demographic attributes of samples, diagnostic procedures, methodological characteristics, neuropsychological tests and dependent variables that were used as well as information required to compute effect sizes. Demographic characteristics extracted were the following: number of participants in the insomnia and the control groups, number of women in each group, mean age and number of years of education in each group and mean duration of insomnia for the insomnia group. Information regarding diagnostic procedure included: criteria used to identify participants with insomnia and controls, exclusion criteria, as well as the assessment methods used to make the diagnosis and exclude other conditions. Methodological characteristics included : variables used to match participants (i.e., age, education, gender, etc.), if any, time of neuropsychological testing and control for alcohol and caffeine intake. Studies were also searched for measures assessing the subjective perception held by participants regarding their cognitive functioning.

Quantitative data synthesis

Among the 24 studies included, the number of dependent variables on which individuals with insomnia and controls were compared varied between 1 and 36 (mean ¼ 8.19 ± 7.42), yielding a total of 209 comparisons. Dependent variables were first classified according to the main cognitive function they were considered to assess. This process was undertaken independently by two licensed neuropsychologists (E.F.B. and S.B.B.) and any disagreement was resolved by consensus. The result of this categorization suggests that 17 cognitive processes are represented among the tasks included in the meta-analysis: general cognitive functioning, perceptual processes, psychomotor functions, attentional functions (i.e., alertness, choice reaction time, speed of information processing, selective attention, divided attention, sustained attention/ vigilance), episodic memory, working memory (i.e., retention and manipulation), procedural memory, executive functions (i.e., verbal fluency, cognitive flexibility and problem solving) and verbal functions.

A general description of cognitive processes, tasks and specific variables included in each category is provided in Table 1.

The standardized mean difference (Cohen's *d*) was derived for each of the 209 comparisons by subtracting the mean for control groups from the mean for insomnia groups and dividing the result by the pooled standard deviation.[15] The direction of effect size values was adjusted so that a negative value would always indicate a poorer performance in insomnia groups compared to controls. A correction for small sample bias was subsequently applied.[16] When the mean and standard deviations were not available, effect sizes were estimated from either *t* or *F* statistics or exact *p* values. Effect sizes were not estimated from graphs or from categorical *p* values.

Whenever two or more comparisons were reported for the same cognitive function in a study, effect sizes were pooled for that specific cognitive function. This yielded a maximum of one effect size per cognitive function per study, thus avoiding dependency among effects sizes.

In the cases where participants were tested on more than one occasion during the study, results from the different assessments were all included in the averaged effect size. The final number of effect sizes was 86.

Effect sizes were then weighted by variability and combined for each cognitive function using a fixed model. The *Q* homogeneity statistic was derived for each cognitive function. A significant *Q* statistic suggests that there is heterogeneity among the effect sizes used to compute the average effect size, indicating that factors related to differences between studies (i.e., methodological considerations) instead of sampling error alone may account for the variability encountered. In addition, to assess the possibility of a publication bias affecting the results, a funnel plot was constructed by plotting study-level effect sizes by sample sizes. The publication bias refers to the file drawer effect, according to which non-significant findings (with smaller effect sizes) are less likely to be published than significant findings (with larger effect sizes), thus resulting in an overrepresentation of significant findings in the literature. If such a bias is present in a given study, the resulting funnel plot will likely be asymmetrical, suggesting that only studies with effect sizes in the desired direction are available and that smaller or null effect sizes may be missing. On the other hand, a symmetrical funnel plot indicates that effect sizes are normally distributed around the averaged effect size, and suggests that a strong publication bias is less likely to have affected findings.

Results

Flow of included studies

The flow chart of study selection is presented in Fig. 1. Of the 866 studies initially retrieved using the search criteria, 24 were included in the meta-analysis. A total of 627 papers were excluded from the title or abstract (i.e., were not empirical papers, did not include a sample of individuals with primary insomnia, did not report a cross-sectional comparison to individuals without sleep problems, etc.). Among the remaining studies, the main reasons for exclusion were: being written in a language other than English or French (*n* ¼ 168), not including a cross-

sectional comparison with a group of individuals without sleep problems (*n* ¼ 18), not using face-to-face or computerized cognitive or neuropsychological measures (*n* ¼ 17), duplicating data from another study (*n* ¼ 4) and not including sufficient information to compute effect sizes (*n* ¼ 5). Five studies[17e21] assessed attentional bias in insomnia by comparing reaction time to sleep-related and neutral stimuli. In these tasks, the dependent variable is a measure of the tendency of individuals with insomnia to attend selectively to sleep-related stimuli, which is considered a cognitive mechanism contributing to insomnia rather than performance impairment per se. In this context, only measures of reaction time to neutral stimuli, for which the attentional bias was not considered to be involved, were included in the meta-analysis. Another study investigated prefrontal activation in individuals with insomnia using functional magnetic resonance imaging (fMRI) during a verbal fluency task.[22] In order to limit movement artifacts during the imaging procedure,

a covert adaptation of the verbal fluency task was used during which participants generated words silently and pressed a button whenever they were thinking of a word. While this is a common and useful adaptation for examining patterns of cerebral activation with fMRI during verbal fluency, it compromises the interpretability of the behavioral performance measure, as it becomes impossible to distinguish valid responses from set loss or perseveration errors.[17] For this reason, the behavioral data from this study were not included in the meta-analysis.

Study characteristics

Table 2 summarizes methodological characteristics of included studies. The 24 studies included a total of 1197 participants (59.0% women, mean age ¼ 46.7 ± 15.4 years). Of these, 639 were participants with insomnia (59.2% women, mean age ¼ 47.3 ± 14.9 years, mean insomnia duration ¼ 11.4 ± 5.0 years) and 558 were controls (58.4% women, mean age ¼ 46.1 ± 15.3 years).

Sample sizes of included studies varied between 7 and 177 participants. Sixteen studies matched participants with insomnia and control participants on age, 12 matched them on

gender and 8 on education or intellectual ability. Eight studies did not match diagnostic and statistical manual for mental disorders (DSM) participants with insomnia to controls. Most studies reported using and/or international classification of sleep disorders (ICSD) criteria to diagnose insomnia in their participants, and many added additional criteria (e.g., scoring above a given threshold on an insomnia questionnaire or meeting quantitative criteria on measures of sleep latency, wake after sleep onset, or total sleep time). There was great diversity in the methods used to verify these criteria, which ranged from self-reported checklists to clinical interviews, sleep diaries and polysomnography. Twenty-one studies mentioned at least one exclusion criterion for psychiatric comorbidity, 18 mentioned exclusion criteria on for medical comorbidity, 18 had criteria to exclude hypnotic use at the time of testing and 14 had explicit criteria pertaining to exclusion of other sleep disorders. Again, the stringency of these criteria and the procedures used to verify them varied greatly from one study to the other. A total of 10 studies conducted the cognitive assessment on more than one occasion during the day, whereas one conducted it in the early morning, three in the morning, three in the afternoon, three in the evening and one either in the morning or afternoon.

Quantitative data synthesis

Average effect sizes by cognitive function and their respective 95% confidence intervals are displayed in Fig. 2. Individuals with insomnia performed significantly worse than controls for tasks assessing retention in working memory (ES ¼ -0.22, 95%CI: -0.39 to -0.05), manipulation in working memory (ES ¼ -0.42, 95%CI: -0.66 to -0.18), episodic memory (ES ¼ -0.51, 95%CI :-0.70 to -0.32) and problem solving (ES ¼ -0.42, 95%CI: -0.71 to -0.12). Individuals with insomnia also tended to perform more poorly, although not significantly so ($0.05 < p < 0.10$), for tasks measuring complex reaction time (ES ¼ -0.19, 95%CI: -0.39 to 0.01), information processing (ES ¼ -0.25, 95%CI: -0.54 to 0.05) and selective attention (ES ¼ -0.19, 95%CI: -0.39 to 0.02). Performance did not differ between individuals with insomnia and healthy controls for tasks assessing general cognitive functioning (ES ¼ -0.12, 95%CI: -0.42 to 0.18), perceptual

processes (ES ¼ -0.10, 95%CI: -0.36 to 0.17), psychomotor functions (ES ¼ -0.13, 95%CI: -0.32 to 0.05), verbal functions (ES ¼ -0.11, 95% CI: -0.34 to 0.12), alertness (ES ¼ -0.04, 95%CI: -0.23 to 0.16), divided attention (ES ¼ -0.12, 95%CI: -0.54 to 0.30), sustained attention/ vigilance (ES ¼ -0.16, 95%CI: -0.37 to 0.04), procedural memory (ES ¼ 0.26, 95%CI: -0.34 to 0.86), cognitive flexibility (ES ¼ -0.16, 95% CI: -0.47 to 0.16) and verbal fluency (ES ¼ -0.19, 95%CI: -0.66 to 0.30).

Subjective assessment of cognitive functioning

Eight of the 24 studies included measures assessing the participants' subjective perception of their cognitive functioning.[23e30] Effect sizes for these measures are presented in Table 3. A correction for small sample size was applied.[16] These measures varied greatly in nature and included global retrospective subscales of existing questionnaires (e.g., confusion scale from the Profile of Mood States (POMS), mental fatigue scale from the Multidimensional Fatigue Inventory (MFI)), single retrospective items assessing either severity or frequency of cognitive impairment in a given domain (e.g., visual analogue scales for concentration or memory), prospective measures of a given cognitive function on a two-week diary, or different items assessing perceived performance on the specific neuropsychological tests used in the experiment (e.g., visual analogue scales of perceived performance compared to one's own capacity or to others). Effect sizes for subjective perception of cognitive deficits on these different measures vary considerably, from moderate to very large in magnitude.

Heterogeneity and publication bias

As shown in Fig. 2, there was significant heterogeneity among the effects sizes for the following cognitive functions: psychomotor functions ($Q(5)$ ¼ 13.6, p ¼ .018), perceptual processes ($Q(4)$ ¼ 11.9, p ¼ .018), sustained attention/vigilance ($Q(5)$ ¼ 16.5, p ¼ .006) and retention in working memory ($Q(7)$ ¼ 21.4, p ¼ .003). This suggests that factors other than sampling error may have produced variation among studies that examined these functions (e.g., differences in tasks, methodology or samples used). Because of the small number of effect

sizes included for these cognitive functions (i.e., between 5 and 8 effect sizes), moderator analysis could not be conducted to identify the source of heterogeneity. Heterogeneity tests did not reach significance for other cognitive functions.

Visual examination of the funnel plot suggests reasonable symmetry around the averaged effect size, indicating a lower probability of publication bias (i.e., file drawer problem).

Discussion

The aim of this meta-analysis was to summarize evidence regarding the magnitude of differences in cognitive performance between individuals with primary insomnia and individuals without sleep disturbances. Results suggest that insomnia is associated with mild to moderate impairments on specific cognitive functions. Individuals with insomnia performed more poorly on tasks assessing working memory (retention and manipulation), episodic memory and problem solving. They also tended to exhibit a mild to moderate impairment for several attentional processes, namely choice reaction time, information processing and selective attention. However, their performance was comparable to that of normal sleepers for other aspects of attention (alertness, divided attention, sustained attention and vigilance), perceptual and psychomotor processes, verbal functions, procedural memory and some aspects of executive functioning (verbal fluency, flexibility) as well as on general cognitive functioning.

The nature of cognitive impairment in insomnia

Previous studies have generally concluded that individuals with insomnia exhibit either selective and subtle cognitive deficits or no deficit at all (for reviews see [12,13,31]). However, most studies included small and heterogeneous samples, which may have limited statistical power to detect small differences between individuals with insomnia and healthy sleepers. By pooling results of multiple studies together, this limitation was at least partly circumvented. Nonetheless, there was considerable variability in the number of studies examining each cognitive function and low power remains a plausible explanation for the lack of group differences on functions for which few studies were available (e.g., verbal fluency, procedural memory). Further

investigation of these cognitive functions remains necessary before more definite conclusions can be drawn.

Findings of impairments in working memory, episodic memory and problem solving are consistent with those of recent studies indicating that insomnia seems to affect performance on complex rather than simple tasks (e.g.,[32,33]). Performance on these more complex tasks is dependent on the integrity of the prefrontal cortex.[34,35] Similar cognitive processes were also impaired following experimental induction of partial chronic sleep deprivation[36] or shallow sleep,[37] which are both present in at least some individuals with insomnia and may be related to decreased cognitive performance. A recent study found that individuals with insomnia and short sleep duration were impaired on tasks tapping the executive control of attention, while those with longer sleep duration were not.[38] However, other studies have also shown performance deficits in individuals with insomnia not confirmed by polysomnography (e.g.,[30]), sometimes even more severe than in individuals whose insomnia was confirmed by polysomnography.[39] This suggests that although poor sleep may contribute to cognitive deficits in individuals with insomnia, other mechanisms may play a role as well. Fatigue, anxiety and negative mood, which are well documented in insomnia, have all been associated with deficits affecting functions associated with the prefrontal cortex.[40e44]

The magnitude of cognitive impairment in insomnia

As a group, individuals with insomnia exhibit subclinical elevations of depression and anxiety symptoms. The mild to moderate differences inperformance found in this meta-analysis could similarly reflect subclinical cognitive impairments. Individual variability in cognitive impairments could also account for these findings. Incidentally, the distribution of daytime symptoms in epidemiological studies of insomnia suggests that not all individuals experience the same consequences. Trait-like individual differences in the cognitive vulnerability to sleep deprivation have been identified,[45] and similar differences may also exist for other consequences of sleep loss such as fatigue.[46] In this context, it seems reasonable to predict

that the contribution of sleep loss, fatigue and other psychological variables to cognitive impairment, as well as the level of cognitive impairment per se, may differ among individuals with insomnia. To complicate matters, studies of chronic sleep restriction indicate a dose-response effect inwhich impairment increases after each additional day of sleep restriction,[36] but also suggest that individuals are able to recover from sleep restriction after a night of normal sleep.[47] Because of the extensive night-to-night variability in the sleep of individuals with insomnia,[48] their cognitive performance may also be modulated by the quality of sleep on the night just before testing or, more generally, by the number of prior consecutive nights of poor sleep. In short, cognitive functioning in individuals with insomnia may be expected to vary across individuals depending on individual vulnerability to sleep loss, fatigue, mood, and may also vary across days for a given individual depending on the quality and duration of their recent sleep.

The clinical significance of cognitive impairments in insomnia

The presence of deficits involving working memory, episodic memory and problem solving in individuals with insomnia is consistent with their subjective report of difficulty concentrating, memory problems and difficulty making decisions.[9,10] Although no formal meta-analysis was conducted on subjective measures of cognitive functioning, the few effect sizes that were derived suggest the presence of moderate to very large subjective deficits. A plausible explanation for the discrepancies between objective and subjective measures of cognitive functioning is that individuals with insomnia exaggerate or overestimate their daytime deficits.[28] However, such discrepancies are not specific to individuals with insomnia as they have been found in various clinical populations including individuals with mild cognitive impairment,[49] schizophrenia[50] and multiple sclerosis,[51] as well as in healthy individuals.[52] While they can be influenced by many factors (e.g., fatigue, mood), subjective impairments have been shown, at least in some studies, to predict structural brain damage or cognitive decline better than objective performance.[53,54] Whether actual day-to-day functioning is better predicted from

objective or self-reported cognitive problems remains a matter of debate.[55,56] Objective cognitive deficits identified in the current study are consistent with daytime activities typically reported as impaired by individuals with insomnia. Because working memory, episodic memory and problem solving are very much involved in carrying on complex tasks,[56] even mild impairment of these functions may contribute to the increased frequency of non motor vehicle accidents (e.g., falls, work-related, etc.) or decreased work productivity associated with insomnia (e.g., [6, 9,57]). For comparative purposes, the magnitude of cognitive deficits found in this study appears similar to that which is found in psychiatric conditions known to be associated to mild cognitive problems, such as post-traumatic stress disorder and obsessive-compulsive disorder.[58] It is also comparable to the impact of chemotherapy on cognitive function in breast cancer patients,[59] but smaller than that found in obstructive sleep apnea.[60]

Limitations

Several methodological issues must be considered when interpreting the findings of this this meta-analysis. In addition to the issue of power already mentioned, the heterogeneity of participants with insomnia may have introduced some confound in the results. While many studies matched participants for age and a few others also considered education or intellectual potential, a significant number did not match participants at all. These variables are known to influence performance on a broad range of cognitive tests. In addition, there was much variability in selection criteria and in the assessment methods used to verify these criteria, raising some questions about comparability of results across studies and their generalizability to individuals with primary insomnia. Another important issue is that most performance tests used were developed and validated to assess major deficits in people with brain injury or neurological disorders. Such tasks may not have sufficient sensitivity to detect subtle differences in cognitive functioning of individuals with insomnia. An additional concern was the lack of details about some cognitive tests and the dependent variables derived from these tasks, which posed particular challenges for identifying the main cognitive functions assessed. Reporting of results

was also insufficient in many studies: five studies were excluded because they did not report sufficient information to allow extraction of effect sizes and, in studies that were included, some reported only partial data to compute effect sizes, which resulted in partial inclusion of their results.

The procedure used to categorize cognitive tests in this study also entails a few limitations. Because most cognitive tests assess different cognitive processes, attributing a single cognitive process to any given task remains a risky endeavor. It is possible that a different classification would have yielded different results. The strategy adopted was to create categories that were as pure as possible. This approach had the advantage of limiting unwanted variability specifically due to differences in the nature of the tasks, but it also yielded several cognitive functions that were assessed in only a small number of studies. The use of broader categories might have allowed for an increased sample of effect sizes, which may have permitted an analysis of moderators of cognitive performance. However, most of the variability among these effect sizes would likely result from differences in cognitive processes assessed, as suggested by the small number of “purer” cognitive functions presenting significant variability. In the end, we believe the strategy to examine more discrete cognitive functions remains preferable to derive the most informative interpretation.

As in any meta-analysis, a publication bias may have affected the representativity of included studies through an overrepresentation of significant findings. To attenuate this potential bias from published studies, abstracts from conference proceedings and academic work databases were searched to include all relevant studies whenever they met inclusion criteria. A visual analysis of the distribution of effect sizes also argued against the hypothesis of a strong publication bias in this study.

Future studies and clinical implications

Results of this meta-analysis suggest that non-significant differences in studies comparing individuals with insomnia and normal sleepers could mask mild but reliable deficits in

cognitive performance. Improving statistical power in future studies of cognitive function in insomnia will increase the probability of detecting subtle differences in performance. As previously suggested,[12] this could be achieved through larger and better characterized samples, as well as better methodological control of factors that may introduce variability among participants (e.g., matching of participants, use of reliable and sensitive tests, control of compensatory mechanisms, etc.). Although significant impairments were identified in several domains, some cognitive processes were poorly represented in this quantitative review of the literature. Additional studies assessing these underrepresented functions are needed before definitive conclusions are reached regarding the specific nature and extent of cognitive deficits associated with insomnia. To allow for an accurate interpretation of findings, these studies should report effect sizes and include a complete description of the instruments and the dependent variables derived from each test. Greater standardization in cognitive measures used would also facilitate comparisons across studies and improve interpretability of findings. Future studies should also investigate the clinical significance of cognitive impairments using normative data or examining their relationship to actual everyday functioning. Strategies such as ecological momentary assessment,[61] qualitative analysis or daytime monitoring using diaries[62] may improve understanding of how performance on cognitive tests in the laboratory relates to day-to-day functioning.

Additional studies are also needed to examine the correlates of daytime impairments in order to shed some light on their underlying mechanisms. These correlates should extend beyond sleep continuity variables and include sleep quality as well as other daytime symptoms of insomnia such as fatigue, arousal, anxiety and negative mood. As perceived daytime deficits is an important determinant of treatment seeking, it is important to include measures assessing cognitive functioning in intervention studies in order to evaluate the clinical significance of treatment outcomes.

Identification of reliable cognitive impairments in chronic insomnia has implications for clinical practice as well. On one hand, it emphasizes the need to inquire about cognitive functioning along with other daytime symptoms of insomnia (e.g., irritability, fatigue, excessive worry, etc.). Systematic assessment using validated measures may also be warranted. From a treatment perspective, recognizing the presence of cognitive deficits while reappraising and decatastrophizing their functional impact may prove useful to attenuate distress and excessive worry about daytime functioning. Care should be taken not to deny nor trivialize these cognitive problems, as this might increase feelings of frustration and isolation.[62] As a complement to standard cognitive-behavioral therapy for insomnia, individuals with significant cognitive complaints or deficits may also benefit from additional cognitive remediation strategies to improve daytime performance. Environmental strategies for decreasing distraction, improving problem solving and decision making abilities or increasing memory performance are available in rehabilitation settings. Adapting these interventions for individuals with insomnia may contribute to optimize their daytime functioning. The presence of cognitive deficits in individuals with insomnia also emphasizes the importance of inquiring about sleep when conducting neuropsychological assessment in clinical practice, and suggests that the presence of insomnia symptoms may need to be taken into consideration when interpreting test results.

Table 1
Description of cognitive domains, studies, tasks and dependent variables included.

Domain	Study	Tasks/Dependent variables
General cognitive functioning: measures assessing intelligence and screening measures for dementia	Altena et al. (2008)[32]	Mini mental status examination (MMSE), Groningen intelligence test, Dutch adult reading test
	Lundh et al. (1997)[18]	Vocabulary (WAIS-R)
	MacMahon (2006)[19]	National adult reading test
	Nissen et al. (2006)[27]	Full scale IQ
	Vignola et al. (2000)[30]	Vocabulary (WAIS), Information (WAIS), MMSE
Psychomotor functions: measures assessing motor speed or ability in motor tasks not involving higher order cognitive processes	Broman et al. (1992)[25]	Finger tapping
	Haimov et al. (2008)[63]	Psychomotor skill – % time accurate
	Rosa and Bonnet (2000)[24]	Hand tremor
	Schneider-Helmert (1987)[64]	Line tracing
	Seidel et al. (1984)[65]	Card sorting – time to deal 4 or 10 piles
	Vignola et al. (2000)[30]	Purdue pegboard
Perceptual functions: measures assessing ability to perceive	Bonnet and Arand (1995)[23]	Visual vigilance – sensory sensitivity
	Boyle et al. (2008)[66]	Critical flicker fusion
	Lundh et al. (1997)[18]	Emotional stroop – naming latency for control stimuli
	Schneider-Helmert (1987)[64]	Line judgment
	Seidel et al. (1984)[65]	Card sorting test – time to sort by suit or by value
Attention – Alertness: simple reaction time (RT) (no decision between stimuli and response). Max duration: 10 min.	Altena et al. (2008)[32]	Simple vigilance task – lapses
	Backhaus et al. (2006)[67]	Simple alertness task – RT and nb. correct, Simple reaction task – RT and nb. correct
	Boyle et al. (2008)[66]	Brake reaction time
	Broman et al. (1992)[25]	Reaction time – RT and variability
	Crenshaw et al. (1999)[68]	Simple RT test – RT and variability
	Edinger et al. (2000)[69]	Simple RT test – RT
	Haimov et al. (2008)[63]	Baseline RT
	Hauri et al. (1997)[70]	Simple RT
	Orff et al. (2006)[28]	Sustained attention (PVT)

Attention – complex RT: reaction time tasks with different stimuli associated to different responses (when one response requires inhibition, task is classified as measuring selective attention). Max duration: 10 min.	Backhaus et al. (2006)[67]	Complex RT – RT and nb. correct
	Boyle et al. (2008)[66]	Choice RT – motor RT, recognition RT, total RT
	Crenshaw et al. (1999)[68]	Continuous performance test – RT and variability, Switching attention test – part I & II
	Edinger et al. (2000)[69]	Continuous performance test – RT, Switching attention test – part I & II
	Pedrosi et al. (1995)[71]	Choice RT – RT
	Sagaspe et al. (2007)[72]	Stop-signal procedure – GO RT, % correct and missed responses
	Varkevisser et al. (2007)[29]	4-choice RT – RT and accuracy
Attention – Information processing : Digit symbol substitution test (DSST)	Boyle et al. (2008)[66]	DSST – nb. correct
	Orff et al. (2007)[28]	DSST – total
	Schneider-Helmert (1987)[64]	DSST
	Vignola et al. (2000)[30]	DSST – standard score
Attention – selective: reaction time tasks requiring inhibition of a response (e.g., go/no-go) or tasks requiring identification of relevant stimuli among distractors	Altena et al. (2008)[32]	Complex vigilance task – false positives
	Backhaus et al. (2006)[67]	Go/No-go task – RT and nb. correct
	Crenshaw et al. (1999)[68]	Continuous performance test – latency and variability
	Edinger et al. (2000)[69]	Continuous performance test – latency
	Haimov et al. (2008)[63]	Integration of 2 dimensions – % correct, Sustained attention task – RT
	Szelenberger and Niemcewicz (2001)[73]	Continuous attention test – omissions, commissions and RT for correct responses
	Vignola et al. (2000)[30]	Trail making – part A
Attention – divided: dual tasks	Boyle et al. (2008)[66]	Continuous tracking test – mean deviation and peripheral RT
	Pedrosi et al. (1995)[71]	Divided attention

(*continued on next page*)

Table 1 (*continued*)

Domain	Study	Tasks/Dependent variables
Attention – sustained/vigilance: tasks involving attention sustained over a prolonged period of time. Min duration: >10 min.	Altena et al. (2008)[32]	Complex vigilance task – false negatives
	Backhaus et al. (2006)[67]	Vigilance task
	Rosa and Bonnet (2000)[24]	Visual vigilance – hit rate (%)
	Schneider-Helmert (1987)[64]	Auditory vigilance
	Varkevisser et al. (2007)[29]	Vigilance detection task – RT and accuracy
	Vignola et al. (2000)[30]	Wilkinson 4-choice RT
Working memory – retention/capacity: Tasks involving retaining material in short term memory without performing any operation on it	Bonnet and Arand (1995)[23]	Memory and search task – 1 target – nb. correct
	Boyle et al. (2008)[66]	Sternberg short term memory scanning – RT
	Broman et al. (1992)[25]	Recognition of words – nb. correct, nb. incorrect, latency for correct, latency for incorrect, Recognition of figures – nb. correct, nb. incorrect, latency for correct, latency for incorrect
	Haimov et al. (2008)[63]	Memory span
	Orff et al. (2007)[28]	Digit span – forward, Brief test of attention – numbers & letters
	Randazzo et al. (2000)[74]	Digit span – forward
	Rosa and Bonnet (2000)[24]	Memory and search task – hit rate (%)
	Vignola et al. (2000)[30]	Digit span – forward
Working memory – manipulation: tasks involving retaining material in short term memory and performing an operation on it	Boyle et al. (2008)[66]	Rapid visual information processing – RT and nb. valid responses
	Orff et al. (2007)[28]	Digit span – backward, Letter-number sequencing
	Randazzo et al. (2000)[74]	Digit span – backward, Letter-number sequencing
	Varkevisser et al. (2007)[29]	2-back working memory task – RT and accuracy
	Vignola et al. (2000)[30]	Digit span – backward

Episodic memory: tasks involving learning material and recalling it after either a short or long delay	Backhaus et al. (2006)[67]	Declarative memory task – nb. trials to reach criterion and nb. words recalled in last trial
	Bonnet and Arand (1995)[23]	Williams word memory test
	Orff et al. (2007)[28]	Hopkins verbal learning test – trial 1, trial 2, delayed recall, recognition
	Pedrosi et al. (1995)[71]	16-item memory task – nb. correct
	Randazzo et al. (2000)[74]	Verbal paired associates – immediate recall
	Rosa and Bonnet (2000)[24]	Williams word memory test – nb. words
	Szelenberger and Niemcewicz (2001)[73]	Selective reminding test – nb. trials to learn all words
	Vignola et al. (2000)[30]	Verbal paired associates – immediate and delayed recall, Visual reproduction – immediate and delayed recall
Procedural memory: Tasks involving learning new skills or abilities	Backhaus et al. (2006)[67]	Mirror tracing task – total time, error count, error time, nb. trials to reach criterion
	Nissen et al. (2006)[27]	Mirror tracing task – time, error count, error time, nb. trials to reach criterion
Executive functions – verbal fluency: tasks requiring participants to name words beginning by a given letter or belonging to a given category	Mendelson et al. (1984)[75]	Verbal fluency – nb. words
	Orff et al. (2007)[28]	Verbal fluency – total, intrusions, perseverations
Executive functions – flexibility: tasks involving switching between two modes of response or two sets of stimuli	Edinger et al. (2000)[69]	Switching attention test – Parts IIIA and IIIB – latency
	Lundh et al. (1997)[18]	Emotional stroop – naming latency for color names
	Orff et al. (2007)[28]	Stroop color-word test – total and error, Trail B – time
	Sagaspe et al. (2007)[72]	Stop-signal procedure – stop signal RT
	Vignola et al. (2000)[30]	Trail making B – time
Executive functions – problem solving: tasks requiring to find a solution to a novel or unstructured problem	Fang et al. (2008)[26]	Wisconsin Card Sorting Test – perseverative responses, perseverative errors, conceptual level responses, nb. categories completed, failure to maintain set, learning to learn
	Haimov et al. (2008)[63]	Executive functioning (Maze)

Table 1 (*continued*)

Domain	Study	Tasks/Dependent variables
	Vignola et al. (2000)[30]	Wisconsin Card Sorting Test – nb. categories, nb. errors
Verbal functions: tasks involving verbal material but not classified within previous categories	Bonnet and Arand (1995)[23]	Proofreading task – nb. lines
	Haimov et al. (2008)[63]	Naming – % correct
	Rosa & Bonnet (2000)[24]	Proofreading task – nb. lines

DSST: digit symbol substitution test; IQ: intelligence quotient; MMSE: mini mental status examination; nb.: number; PVT: psychomotor vigilance task; RT: reaction time; WAIS: Wechsler's adult intelligence scale.

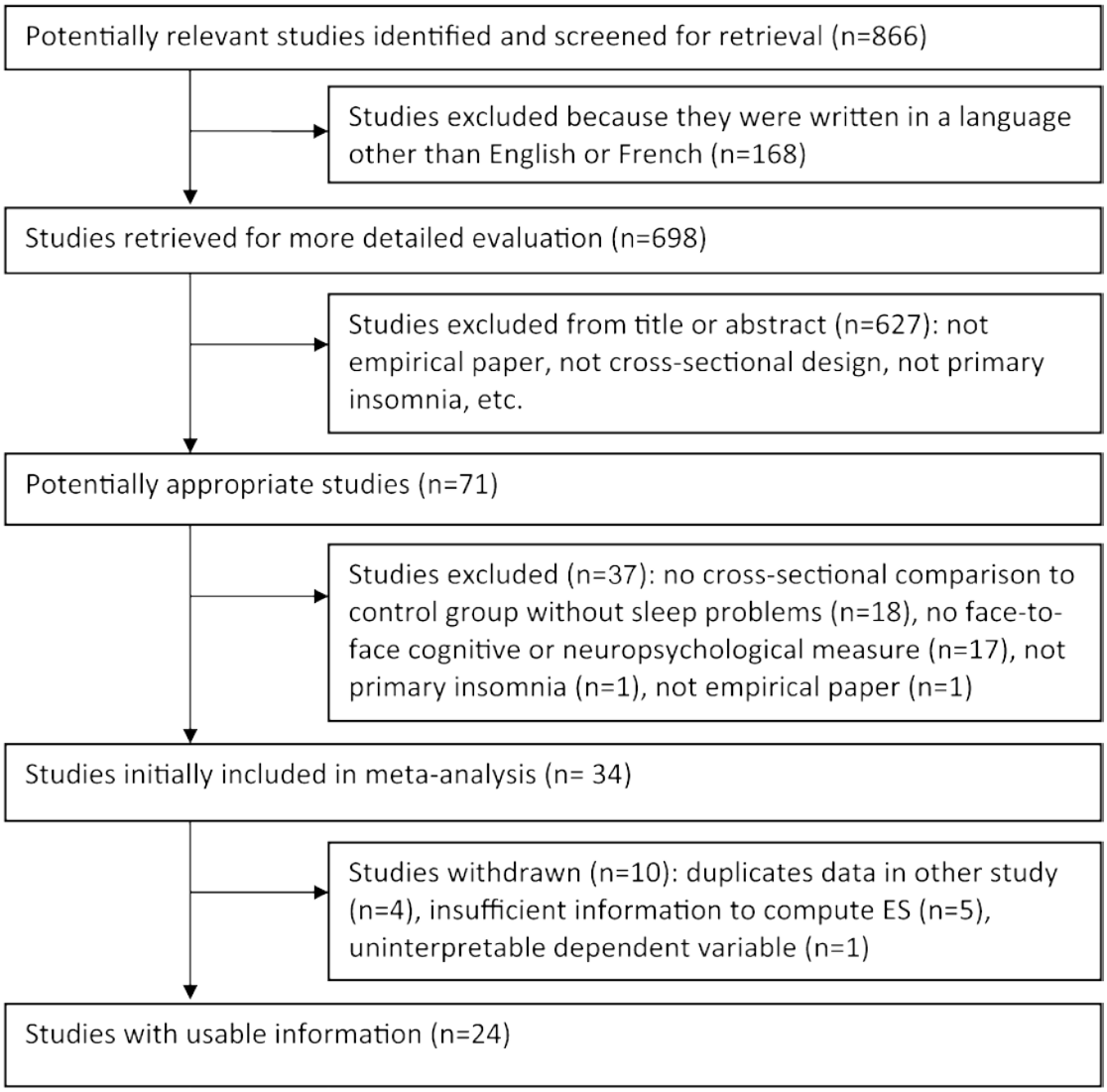

Fig. 1. Flow chart of study selection

Table 2
Methodological characteristics of included studies.

Study	*N*		Gender % women	Matching variables	Insomnia criteria	Exclusion criteria				Time of testing
	INS	CTL				Psychiatric comorbidity	Medical comorbidity	Hypnotic/ substance	Sleep disorders	
Altena et al. (2008)[32]	25	13	71	Age, gender, education	DSM-IVþ	Yes	Yes	Yes	Yes	PM
Backhaus et al. (2006)[67]	16	13	55	Age	DSM	Yes	Yes	Yes	Yes	Evening
Bonnet and Arand (1995)[23]	10	10	N/S	Age, gender, time in bed	Other	Yes	Yes	Yes	Yes	Repeated testing
Boyle et al. (2008)[66]	32	32	55	None	DSMþ	N/S	Yes	Yes	N/S	AM
Broman et al. (1992)[25]	20	20	75	Age, gender, time of testing	N/S (primary insomnia)	N/S	N/S	Yes	N/S	AM or PM
Crenshaw and Edinger (1999)[68]	32	32	50	Age, gender	DSMþ	Yes	Yes	Yes	Yes	Repeated testing
Edinger et al. (2000)[69]	27	31	53	Age, gender	DSM þ	Yes	Yes	Yes	Yes	Repeated testing
Fang et al. (2008)[26]	18	21	69	None	DSMþ	Yes	Yes	Yes	Yes	AM
Haimov et al. (2008)[63]	35	64	64	None	Quantitative criteria[76]	Yes	Yes	Yes	N/S	PM
Hauri (1997)[70]	26	26	73	Age, gender, education, occupation	Other	Yes	Yes	Yes	N/S	Repeated testing
Lundh et al. (1997)[18]	20	20	80	Age, gender, education	N/S (verified dx of insomnia)	Yes	N/S	N/S	N/S	N/S
MacMahon et al. (2006)[19]	21	20	61	None	DSMþ ICSDþ	Yes	N/S	N/S	Yes	N/S
Mendelson et al. (1984)[75]	10	10	90	Age, education	Other	Yes	Yes	N/S	Yes	Repeated testing
Nissen et al. (2006)[27]	7	7	57	Age, gender, handedness, IQ	DSM	Yes	Yes	Yes	Yes	Evening
Orff et al. (2007)[28]	32	30	71	Age, gender, education, IMC, race	Other	Yes	Yes	Yes	Yes	Evening
Pedrosi et al. (1995)[71]	12	12	N/S	None	Other	Yes	Yes	Yes	N/S	Repeated testing
Randazzo et al. (2000)[74]	35	35	74	Age, education	DSM	Yes	Yes	N/S	N/S	N/S
Rosa and Bonnet (2000)[24]	121	56	39	None	Other	Yes	N/S	Yes	Yes	Repeated
Sagaspe et al. (2007)[72]	13	13	39	Age, gender	ICSDþ	Yes	N/S	N/S	N/S	PM
Schneider-Helmert (1987)[64]	16	16	56	Age, gender	ICSD	N/S	N/S	Yes	N/S	Repeated testing
Seidel et al. (1984)[65]	38	36	61	Age	ICSDþ	Yes	Yes	Yes	Yes	Repeated testing
Szelenberger and Niemcewicz (2000)[73]	14	14	57	Age, gender, education, handedness	DSM	Yes	Yes	Yes	N/S	AM
Varkevisser et al. (2007)[29]	39	20	56	None	ICSD	Yes	Yes	No	Yes	Repeated testing
Vignola et al. (2000)[30]	20	20	50	None	DSMþ ICSDþ	Yes	Yes	Yes	Yes	Early morning

DSM ¼ diagnostic and statistical manual for mental disorders (DSM) criteria; ICSD ¼ international classification of sleep disorders (ICSD) criteria; DSM þ ICSD ¼ combined criteria from DSM and ICSD nosologies; DSMþ ¼ DSM criteria plus additional criteria (other than ICSD); ICSDþ ¼ ICSD criteria plus additional criteria (other than DSM); DSMþICSDþ ¼ Combined criteria from DSM and ICSD nosologies plus additional criteria; AM: morning, CTL: controls; dx: diagnostic; INS: insomniacs; N/S ¼ not specified; PM: afternoon.

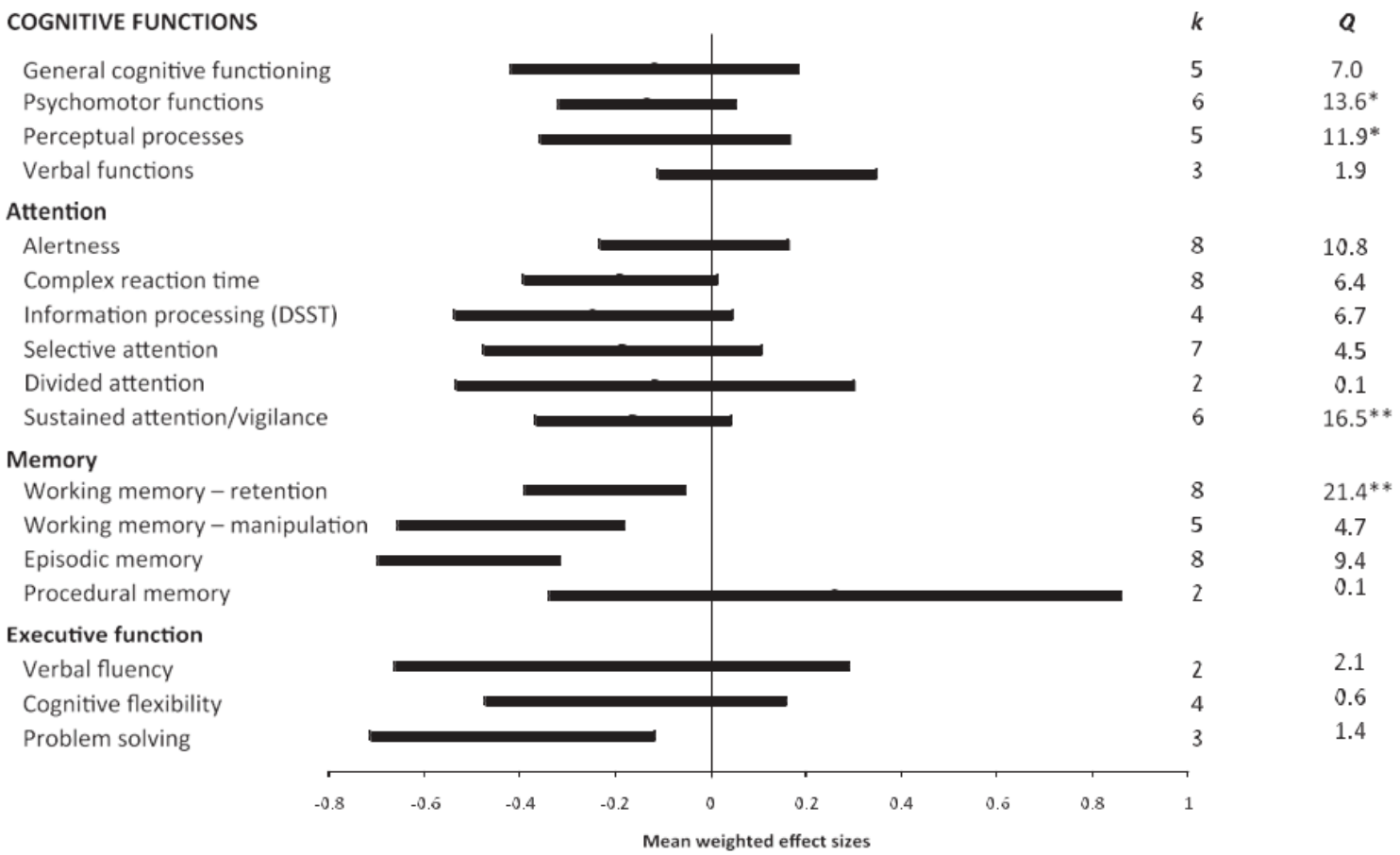

Fig. 2. Average effect sizes and 95% confidence intervals by cognitive domain. Note. *k* ¼ number of effect sizes available; *Q* ¼ *Q* statistic of homogeneity. *p<.05. **p<.01. DSST; digit symbol substitution test.

Table 3
Effect sizes for subjective measures of cognitive functioning in studies included in the meta-analysis.

Study	Measure	INS			CTL			*t*	*d*
		N	*M*	SD	*N*	*M*	SD		
Bonnet and Arand (1995)[23]	POMS Confusion scale	10	5.40	4.20	10	3.1	3.2		-0.59
Broman et al. (1992)[25]	Performance evaluation VAS	20			20			-2.03	-0.65
	Comparison with others VAS	20			20			-1.90	-0.61
	Comparison with own capacity VAS	20			20			-2.66	-0.84
Fang et al. (2008)[26]	Frequency of problems concentrating (days/week)	18	0.80	0.89	21	0.35	0.61		-0.59
Nissen et al. (2006) [27]	Subjective memory VAS	7	49.60	9.70	7	0.35	0.61		-0.42
Orff et al. (2007)[28]	MFI Mental Fatigue Score	32	10.95	3.40	30	5.44	4.58		-1.36
	Concentration (2 week prospective measure on diary e 5 pt scale)	32	3.73	1.06	30	4.52	1.40		-0.63
Rosa and Bonnet (2000)[24]	POMS confusion scale	121	6.26	4.19	56	4.38	3.23		-0.48
Varkevisser et al. (2007)[29]	CIS concentration	39	21.60	52.40	20	9.20	22.67		-0.27
	Concentration (rating 1e5)	39	2.60	1.14	20	3.98	0.72		-1.34
Vignola et al. (2000)[30]	Performance evaluation VAS	20	61.40	13.95	20	71.07	13.56		-0.69
	Satisfaction vs. performance VAS	20	59.77	14.03	20	71.97	12.90		-1.77
	Performance vs. others VAS	20	55.54	16,67	20	70.47	12.15		-3.01
	Performance vs. own capacity VAS	20	63.40	16.85	20	76.45	12.12		-3.49
	Concentration VAS	20	57.70	18.62	20	70.90	21.86		-3.19

CIS ¼ checklist individual strength; CTL: controls; INS: insomniacs; MFI ¼ multidimensional fatigue inventory; POMS ¼ profile of mood states; VAS ¼ visual analogue scale.

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