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CLINICAL REVIEW

# Cognitive dysfunction in sleep disorders

**S. Fulda[1] and H. Schulz[2]**

[1]Krankenhaus der Barmherzigen Brüder, München, Germany, and [2]Department of Neurology, Klinikum Erfurt, Erfurt, Germany

**KEYWORDS**
neuropsychology, sleep-related breathing disorders, insomnia, narcolepsy, driving, attention, memory, cognitive, psychomotor, daytime functioning

**Summary** Fifty-six studies were reviewed that explored cognitive dysfunctions in people with sleep-related breathing disorders (SRBD, 24 studies), insomnia (18 studies), or narcolepsy (14 studies). Individual study outcomes were grouped according to neuropsychological functions. Available evidence was reviewed separately for SRBD, insomnia and narcolepsy. Consistent evidence was found for impaired driving simulation performance in SRBD patients (92.9% of comparisons with control subjects). Other neuropsychological functions with less pronounced impairment included (i) attention span, divided attention and sustained attention for SRBD patients; (ii) attention span, verbal immediate memory and vigilance for insomniac patients, and (iii) sustained attention, vigilance and driving simulation performance for narcoleptic patients. Reduced performance in tasks measuring attention was found to be higher for SRBD and narcoleptic patients (35.9% and 44.2% of all comparisons, respectively) while this rate was lower for insomniac patients (22.8%). Impairment of memory performance in comparison with control subjects was less pronounced for all three groups, with 20.0% for insomnia, 17.1% for SRBD and 15.6% for narcolepsy. In other areas of cognitive functioning, the data did not allow definite conclusions for any of the patient groups. 

## INTRODUCTION

Impairment of daytime functioning is a key element in major diagnostic groups of sleep disturbances. This may present as exaggerated sleepiness as in narcolepsy and sleep-related breathing disorders (SRBD), or as increased tiredness associated with reduced sleep propensity as in insomnia. Perhaps as a direct consequence of sleep-wake dysregulation, cognitive and psychomotor functions may be impaired either objectively or subjectively. There are quite recent reviews from studies with SRBD patients [1–3], narcolepsy patients [4, 5] and patients with insomnia [6]. The aim of this review is to update present knowledge and to compare results on cognitive dysfunction in patients with either SRBD, insomnia or narcolepsy. Since testing of cognitive functions in other sleep disorders is extremely rare, such studies were not considered for this review. An additional aim of the review was to explore the pattern of cognitive dysfunction in greater detail by grouping individual tasks into neuropsychological functions and subfunctions and to examine convergence of evidence across studies.

Correspondence should be addressed to: Stephany Fulda, Krankenhaus der Barmherzigen Brüder, Abtl. für Geriatrische Rehabilitation, Romanstr. 93, 80639 München, Germany. Fax: +49 89 1797 3302, Email: StephFulda@compuserve.com

## METHOD

We conducted a systematic search of electronic databases, hand-searched several journals and

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screened references in major publications. We considered all those studies that compared performance in sleep-disordered people to that of control subjects who showed neither signs or symptoms of sleep disturbances nor complained about poor sleep. Our search yielded 24 studies in the area of SRBD [7–30], 18 studies for insomnia [31–48], and 14 studies for narcolepsy [49–62]. To keep the three areas somewhat balanced, for SRBD, where most data are available, we integrated only those studies which were published as full journal articles, discarding abstracts or other non-peer reviewed material.

Cognitive functions were studied with a wide array of neuropsychological tasks and test procedures. All tasks were grouped according to Lezak's [63] taxonomy of neuropsychological functions, which we used throughout as standard reference. Tasks are listed in Table 1. Summary tables for the three patient groups (Tables 2 to 4) use the same format to allow easy comparison across diagnostic groups, and to indicate areas which were adequately investigated, or neglected. Since most tasks have more than one, or even multiple outcome measures, the number of comparisons in Tables 2 to 4 is substantially larger than the number of tasks applied.

# RESULTS

## Sleep-related breathing disorders

The literature search yielded a total of 24 studies [7–30]. Five studies reported results for multiple patient groups [7–10] or control groups [11]. In two cases [7, 8] results from two different studies were reported in one publication. They were treated as separate studies. Two studies compared two patient groups to one control group [9, 10], and one study compared the same patient group with two different control groups [11]. Taken together, the studies compared 28 patient groups with a total of 893 patients with SRBD to either normal control groups or clinical control groups that were sampled within the sleep laboratory and comprised a total of 1281 persons. The clinical control groups considered in the present review included non-apnoeic patients referred for evaluation of sleep apnoea [8a, 8b, 11]. To study the effect of apnoea severity on neuropsychological performance measures, patient groups were divided into three categories regarding their average apnoea severity: nine patient samples [9, 10, 12, 15, 18, 20, 23, 29, 30] were classified as being mildly affected with apnoea severity indices between 10 and 30; eleven patient samples were moderately affected with severity indices between 31 and 50 [8, 10, 13, 14, 16, 19, 22, 24, 26–28], and for eight groups of patients severity indices exceeded 50 (severely affected patients [7a, 7a, 8b, 9, 11, 17, 21, 25]). Neuropsychological task performance was grouped according to basic areas of attention, motor performance, constructional performance, driving simulation, memory, concept formation, reasoning and executive function, verbal functions and composite measures of general intellectual functioning. Each area of cognitive performance will be reviewed separately. Table 2 shows the main results.

### *Perception*

Perception was investigated in four studies by means of skin writing [12], the Hooper visual organization test [9], and the Thurstone visual matching test [9], all of which showed no difference between mildly [9, 12] or severely [9] affected SRBD patients and controls. In addition, Lee *et al.* [13] employed a sensory motor task, where subjects were asked to point to a figure on a touch-sensitive screen after being otherwise engaged for a couple of seconds [13]. The number of correct responses, which was improved in SRBD patients, was considered as a measure of basic perception, whereas reaction time on this task was considered a measure of motor performance and will be reviewed in the respective section. Overall, there is no evidence that SRBD patients show reduced perceptual functions.

### *Attention*

Six studies have compared attentional performance of patients with mild forms of SRBD [9, 10, 12, 15, 18, 20] to that of normal controls. Patients did not differ from controls in measures of alertness [10], attention span [12], complex focused attention like the Trail-Making Test (TMT) A [15, 20], the TMT B [9, 15, 18], the Symbol Digit Substitution Test (SDST) [15, 18], the Digit Symbol Substitution Test (DSST) [9, 15, 20], and various cancellation tests [9, 12, 15, 18]. Furthermore, no difference was reported for measures of divided attention [10, 15, 20], selective attention [10], sustained attention [9, 10, 15] and vigilance [10]. Only in one study [15] was reversed digit span reduced, which was not,

**Table 1 Neuropsychological tasks**

**Perception (1–6)**
1- Graphesthesia [12], 2- Hooper Visual Organization Test [9], 3- Thurstone Visual Matching Test [9], 4- Sensory motor task, no. correct [13], 5- Line judgement [42], 6- Physical match [49]

**Attention (7–72)**
*Alertness* (7–11)
7- Critical Flicker Fusion Test (CFF) [10, 22, 33, 35, 50], 8- Simple reaction time [19, 31–37, 49, 51], 9- Simple auditory reaction time [38], 10- Choice reaction time [13], 11- reaction time, targets missed, false positive, P300 paradigm [52]

*Attention span* (12–19)
12- Digit span, forward [13, 14, 34, 39, 40, 55], 13- Digit span, reversed [12–15, 39, 40, 55], 14- Digit span, combined [12, 16, 53, 54], 15- Corsi Block Tapping Task [14], 16- Spatial span, forward [40], 17- Spatial span, reversed [40], 18- Knox Cube Imitation Test [55], 19- Double-encoding task, visual span, verbal span, double span [14]

*Focused attention* (20–33)
20- Trail Making Test (TMT), TMT A [13–15, 19, 20, 39, 56], 21- TMT B [8, 9, 13–16, 18, 39, 56], 22- Symbol Digit Substitution Test (SDST) [15, 18, 39, 53], 23- Digit Symbol Substitution Test (DSST) [9, 15, 20, 34, 38, 41–43, 49], 24- Letter cancellation [9, 12, 15, 16, 35, 44], 25- d2 cancellation task [49], 26- Digit cancellation [14, 18], 27- Memory And Search Task (MAST), 1, 2, and 3 letter search [41, 43], 28- Strub And Black's List Of Letters [53], 29- Visual search [42], 30- Serial search task [57], 31- Selective attention [19], 32- Q11 (Wiener Test Battery) [10], 33- Selective attention task [51]

*Divided attention/mental tracking* (34–48)
34- Divided attention (Wiener Test Battery) [22], 35- Divided attention (TAP, Test Battery for Measuring Attention) [19, 51], 36- Divided attention task [34], 37- Paced Auditory Serial Addition Task (PASAT) [8, 49, 54], 38- Stroop Color Word Test [14, 20, 49, 56], 39- Digit subtraction [13, 15], 40- Mental tracking subtraction [56], 41- Serial addition [10, 22], 42- Wilkinson Addition Task [38], 43- Memory addition task [32]. 44- Addition [42], 45- Letter number sequencing [40], 46- Mental tracking alphabet [56], 47- Continuous tracking task [37], 48- Word list monitoring [44]

*Other complex attention tasks* (49–56)
49- General response latency (combined measure) [45], 50- Switching Attention Test [31], 51- Complex reaction time [33, 34], 52- Go-No Go test [56], 53- Shifting of attention [51], 54- Krakau Visual Acuity [50], 55- Two choice reaction time [50], 56- reaction time after warning tone, anticipatory responses, CNV paradigm [52]

*Sustained attention* (57–64)
57- Modified sustained attention test [10], 58- Continuous Performance Test (CPT) [15, 31, 37, 59], 59- Four-Choice Reaction Time Test (FCRTT) [8, 9, 39, 58], 60- Continuous Attention Test [19], 61- Psychomotor Vigilance Device (PVT) [17, 21], 62- Continuous Attention Test [47], 63- Wilkinson Addition Task (20 min) [57], 64- DSST (20 min) [57]

*Vigilance* (65–72)
65- Mackworth clock [61], 66- Müggeburg Test (variant of the Mackworth Clock) [10, 22], 67- Vigilance test [19], 68- Visual vigilance [37, 41, 43], 69- Auditory vigilance [34], 70- Auditory vigilance test [46, 60], 71- Wilkinson auditory vigilance test [42, 54], 72- CFF (10 hours) [62]

**Motor functions (73–80)**
73- Finger tapping task [12, 20, 36, 44, 59], 74- Grooved Pegboard Task [18], 75- Purdue Pegboard Task [9, 16, 38, 39, 57], 76- Pegboard [44], 77- Grünberger Fine-Motor Activity Test [35], 78- Sensory motor task, reaction time [13], 79- Hand tremor [41, 43], 80- Line tracing [42]

**Driving simulation (81–87)**
81- Steer Clear [8, 11, 17, 21, 23, 24], 82- Divided Attention Driving Task (DADT) [25], 83- Carsim Driving Simulator [28], 84- Driving simulator [27], 85- Driving simulator [26], 86- Computer driving simulator [7], 87- Film driving simulator [7]

**Table 1** *continued*

**Constructional performance (88–91)**
*Copying* (88, 89)
88- Rey-Osterrieth figure [9], 89- Bender Gestalt Test [16]

*Building and assembling* (90, 91)
90- WAIS-R Block Design [9, 12, 16], 91- WAIS-R Object Assembly [9]

**Memory (92–138)**
*Visual immediate recall* (92, 93)
92- WMS Figural Memory [8, 12, 16, 39, 53, 55], 93- Rey-Osterrieth figure [9, 53]

*Verbal immediate recall* (94–99)l
94- WMS Logical Memory [8, 9, 12, 16, 40, 53, 55], 95- California Verbal Learning Test (CVLT), trial 1 [13], 96- WMS Verbal Paired Associates [39, 40, 53], 97- Williams Word Memory Test [38, 41, 43], 98- Selective Reminding Test [47], 99- Word List Recall [44, 59]

*Learning* (100–107)
100- CVLT List learning [15], 101- WMS Associate learning [12, 55], 102- Auditory verbal learning test (AVLT) [18, 34, 53], 103- Verbal learning test, selective reminding procedure [14], 104- WMS Verbal paired associates, learning rate [39, 40], 105- Selective reminding test [44, 47], 106- Verbal learning [44, 51, 56], 107- Visual learning test [14]

*Visual delayed free recall* (108, 109)
108- Rey-Osterrieth figure [9, 20], 109- WMS Figural memory [8, 16, 29, 39, 55]

*Verbal delayed free recall* (110–114)
110- CVLT [15], 111- WMS Logical memory [8, 9, 16, 29, 40, 53, 55], 112- AVLT [34, 53], 113- WMS Verbal Paired Associates [39, 40, 55], 114- Verbal delayed recall [51, 56]

*Forgetting* (115–119)
115- Visual Learning Test, % forgetting [14], 116- Verbal Learning Test, % forgetting [14], 117- WMS Figural Memory, % retained [16], 118- WMS Logical Memory, % retained [16], 119- AVLT, % retained [18]

*Others* (120–138)
120- WMS Logical Memory [20], 121- WMS Figural Memory [20], 122- CVLT [12], 123- Factor memory [18], 124- AVLT recognition [18], 125- Verbal Learning And Memory Test [19], 126- Pursuit Rotor Learning (3 trials) [15], 127- Spatial Working Memory Task [13], 128- Word list recognition [44, 51, 56], 129- Word recognition [36, 55], 130- Figure recognition [36, 55], 131- Numerical memory test [35], 132- Delayed word list relearning [56], 133- Difference between recall and recognition [56], 134- Short-term memory [49], 135- Long-term memory [49], 136- Word list frequency estimation, incidental memory [57], 137- Sternberg Memory Scanning Task [59], 138- WMS Paired Associates Cued Recall [55]

**Concept formation (139–141)**
139- WAIS-R Similarities [9, 20], 140- Wisconsin Card Sorting Task (WCST) [13–14, 39], 141- Card sorting [38, 48]

**Reasoning (142–148)**
142- WAIS-R Picture arrangement [9], 143- WAIS-R Comprehension [9], 144- 20 question task [14], 145- Optimal telegram task [40], 146- Logical reasoning [38], 147- Baddeley's Logical Reasoning Task [42], 148- Complex reasoning [49, 57]

**Executive functions (149–152)**
149- Mazes [9, 12, 56], 150- Tower puzzles [13], 151- Tower of Toronto [14], 152- Porteus Mazes [40]

**Verbal functions and language skills (153–164)**
*Verbal fluency* (153, 154)
153- Controlled Oral Word Association Test (COWAT) [12, 13, 16, 18, 56], 154- Verbal fluency [9, 14, 44, 49, 55]

**Table 1** *continued*

*Others* (155–164)
155- WAIS-R Vocabulary [12, 16], 156- WAIS-R Information [16, 23], 157- Boston Naming Test [12, 56], 158- Proofreading [41, 43], 159- Word detection [42], 160- Revised Token Test [56], 161- Stroop Test, color naming [49], 162- Semantic match [49], 163- Naming test – visual verbal [55], 164- Naming test – auditory verbal [55]

**Composite measures (165–170)**
165- WAIS-R Full scale [9], 166- WAIS-R Verbal scale [9, 29, 30], 167- WAIS-R Performance scale [9, 29, 30], 168- WAIS-R Vocabulary and Block Design [8], 169- Mini Mental Status Examination (MMSE) [20, 29], 170- Factor psychomotor efficiency [18]

however, confirmed by Knight *et al.* [12]. The former study [15] also found a reduction of the signal detection parameter in a 10-min continuous performance test (CPT), albeit only for the last 2 min. Taken together, the evidence suggests that patients with mild forms of SRBD show little or no impairment in diverse functions of attention.

Attention performance of patients with moderate levels of SRBD was compared in seven studies [8, 10, 13, 14, 16, 19, 22] to that of normal controls. Here the pattern of performance is more complex. Measures of alertness showed a reduced performance of patients in one study [19] but did not differ from that of controls in three other studies [10, 13, 22]. The forward and reversed digit span was found to be reduced in two studies [14, 16] and unchanged in another [13]. Similarly, the TMT A showed a reduced performance of patients in one study [19] and was not different to that of controls in two other studies [13, 14]. Performance in the TMT B, however, which is more complex than the TMT A, showed no differences between moderately affected SRBD patients and normal controls in all four studies [8, 13, 14, 16]. Only two studies have used cancellation tests, one reported a reduced performance [16] and the other did not [14]. However, two studies have found that SRBD patients differed from controls in two German tasks of selective attention [10, 19]. Tasks measuring divided attention and mental tracking were found to be reduced in two studies [8, 14] and unimpaired in four studies [10, 13, 19, 22], with one [19] reporting an increased error rate for patients. Sustained attention did not differ between patients and controls in two studies [8, 10] and was reduced in one [19]. Finally, vigilance performance was found reduced in one study [22] and not different to that of controls in another two [10, 19], with one of them reporting an increased error rate for SRBD patients [19]. In summary, with the exception of one study [13] which found no reduction in attention functions, all others reported a reduced performance in at least one attentional task. Across studies however, these deficits do not converge, so that attention functions may be impaired in some but not all patients with moderate forms of SRBD.

Only three studies have included samples of severely affected SRBD patients [9, 17, 21]. All three studies assessed sustained attention with the Psychometer Vigilance Device (PVD) test [17, 21] or the Four Choice Reaction Time test (FCRRT) [9] and all three reported reduced performance of patients when compared with controls, though not for all task parameters. Bédard *et al.* [9] furthermore found a reduced performance in short-term focused attention with the TMT B, the DSST and a cancellation task. Taken together, the studies support the assumption that severely affected SRBD patients show impaired sustained attention. However, for other areas of attention, conclusions will have to await further evidence.

### *Motor functions*

Motor functions in SRBD patients have been investigated by means of the Purdue pegboard [9, 16], the grooved pegboard [18], finger tapping [12, 20] and a sensory motor task [13]. Finger tapping performance did not differ between mildly affected SRBD patients and controls in two studies that employed this measure [12, 20]. The grooved pegboard was employed in a large population-based study. Kim *et al.* [18] found no difference between persons with or without SRBD, defined by an apnoea–hypopnoea index (AHI) of less than five. For the Purdue pegboard, on the other hand, two studies reported reduced performance of patients

with mild [9], moderate [16] or severe [9] forms of SRBD when compared to controls. Lee *et al.* [13] employed a sensory motor task and reported prolonged reaction times of moderately affected patients when compared to controls. Overall, finger tapping and grooved pegboard performance was found to be unimpaired in SRBD patients, while Purdue pegboard performance was reduced. The number of studies, however, is too small to draw any firm conclusions.

### *Driving simulation*

Driving simulation performance has been investigated with different devices (see Table 1) in twelve studies in comparison to normal controls. With the exception of Ingram *et al.* [23] and Findley *et al.* [24], all other studies consistently showed that driving simulation performance was reduced in moderately [26–28] and severely [7, 8, 11, 17, 21, 25] affected SRBD patients when compared with controls. There is strong evidence that driving simulation performance is reduced in patients with SRBD in at least moderate or severe forms.

### *Constructional performance*

Constructional performance in SRBD patients has been investigated in only three studies for copying [9, 16] and building and assembling [9, 12, 16]. Both areas were unimpaired in patients with mild forms of SRBD [9, 12]. Moderately affected patients showed reduced copying performance but did not differ from controls on the Wechsler Adult Intelligence Scale (WAIS-R) Block Design task [16]. One group of 10 patients [9] with severe SRBD did exhibit reduced copying as well as building and assembling performance. Although the studies suggest that constructional performance of SRBD patients varies with apnoea severity, more studies are needed before any conclusions can be drawn.

### *Memory*

Memory performance consists of several, largely independent functions [63] that can be selectively impaired in neuropsychological patients. Immediate recall, learning, retention, and retrieval have all been repeatedly assessed in patients with SRBD, whereas other memory functions like working memory [13] or procedural memory [15] have received less attention [3].

Patients with mild SRBD did not differ from controls in verbal immediate recall [9, 12], learning performance [12, 15, 18], verbal delayed recall [9, 15, 29], relative measures of forgetting [18], and various global memory scores [12, 15, 18, 20]. Only in one study of Bédard *et al.* [9] was immediate visual recall of the Rey–Osterrieth figure reduced. Immediate visual recall of the Wechsler memory scale (WMS) subtest figural memory was found to be, unimpaired in another study [12]. Likewise, Berry *et al.* [29] found a reduced delayed recall of the WMS figural memory, which was not confirmed by two other studies [9, 20]. Taken together, there is only limited evidence that memory functions are impaired in patients with mild forms of SRBD.

Memory performance of patients with moderate forms of SRBD was comparable with that of normal controls [8, 13, 14, 16, 18, 19] for most areas of memory functions: immediate visual [16, 18] and verbal recall [8, 13, 16] as well as delayed visual and verbal retrieval [8, 16], relative measures of forgetting [14, 16], and other memory tasks [13, 19]. Only one study [14] has explored learning performance in moderately affected SRBD patients and reported reduced visual as well as verbal learning capacity. In summary, patients with moderate SRBD show no impairment in absolute and relative measures of memory retention and immediate recall performance but might experience reduced learning capacity.

Only one study [9] has explored memory functions in a group of 10 severely affected SRBD patients. These authors found reduced visual immediate and delayed recall performance and reduced delayed verbal performance, while immediate verbal recall did not differ between patients and controls. Any conclusion about memory performance in severely affected patients requires additional evidence.

### *Concept formation*

Concept formation denotes the ability to form concepts, to use categories, to generalize from single instances or applying procedural rules and general principles [63]. It has been assessed using the WAIS-R subtest Similarities [9, 20] and the Wisconsin Card Sorting Test (WCST), with special emphasis on sorting and shifting. SRBD patients and controls did not differ in the WAIS-R Similarities subtest [9, 20] regardless of severity. For the WCST, all three control group studies that employed this test reported an increase in perseverative errors for mildly [15] and moderately [14, 15] affected

SRBD patients while other parameters of the WCST (like the number of errors [14] or categories achieved [13, 14]) showed no difference between patients and controls. In summary, the results suggest that, whereas the basic ability to form concepts is unimpaired in SRBD patients, the shifting of concepts or inhibition of responses might be impaired even in milder forms of the disorder.

### *Reasoning*

Reasoning involves logical thinking, comprehension of relationships and practical judgement [63] and has been assessed in three studies by means of the WAIS-R subtests Picture Arrangement [9, 14] and Comprehension [9], and the 20-question procedure [14]. Performance in WAIS-R Picture Arrangement or the 20-question task did not differ between mildly [9], moderately [14], or severely [9] affected SRBD patients and controls, but two groups with mild and severe SRBD showed reduced performance in the WAIS-R Comprehension subtest [9]. More research is needed before drawing any conclusions.

### *Executive functions*

Executive functions involve the four components: volition, planning, purposive action and effective performance [63]. Among these components, planning was mainly studied in SRBD patients. Planning activities were assessed by various tower tasks [13, 14] and maze tracing [9, 12]. Lee *et al.* [13] as well as Naëgelé *et al.* [14] compared tower task performance of moderately affected SRBD patients to that of normal controls. Whilst one study [13] found no difference in performance, a second study [14] reported reduced performance in the three-disk but not the four-disk task. For maze tracing, one study [12] with elderly subjects and mild forms of SRBD found no performance differences when compared with controls, whereas Bédard *et al.* [9] reported an increase in impulsive errors for both mildly and severely affected patients. Again, more studies are needed to clarify whether executive functions are impaired in SRBD patients.

### *Verbal functions and language skills*

Those that have been assessed in SRBD patients include verbal fluency, vocabulary, confrontation naming, knowledge acquisition and retention (verbal academic skills). With one exception [9], patients with mild [9, 12, 18, 23] or moderate [12–14, 16] forms of SRBD did not differ from normal controls on measures of verbal fluency [12–14, 16, 18], confrontation naming [12], vocabulary [12, 16], or knowledge acquisition and retention [16, 23]. Only Bédard *et al.* [9] reported reduced verbal fluency for a subgroup of severely affected SRBD patients when compared with controls. In summary, the evidence suggests that verbal functions are unimpaired in patients with SRBD, with the possible exception of very severely affected patients.

### *Composite measures*

These are those measures that combine performance on widely different tasks into a single score. The best-known composite measures are the WAIS-R verbal, performance and full-scale IQ scores. We found one study with two patient groups comparing the full-scale WAIS-R of SRBD patients to that of normal controls [9]. While mildly affected patients did not differ from controls, the group of severely affected patients showed reduced WAIS-R full-scale scores [9]. This was due to a reduced performance IQ, whereas the verbal IQ was found not to differ from that of control subjects. Indeed, verbal IQ scores have been shown to be comparable to that of normal controls in all three studies that have reported this measure [9, 29, 30]. The performance IQ, on the other hand, was unimpaired in two groups of mildly affected patients [9, 30], but reduced in two other groups of mildly [29] and severely affected patients [9]. Other composite measures included the Mini-Mental Status Examination (MMSE) which did not differ between patients and controls in two studies [20, 29], a combination of the WAIS-R subtests Vocabulary and Block Design which did likewise not differ between patients and controls [8], and a factor-analytically derived psychomotor efficiency measure [18]. In contrast to all other composite measures, the factor was derived empirically by Kim *et al.* [18] and discriminated between SRBD patients and controls.

### *Summary*

Cognitive dysfunctions in SRBD patients show a complex pattern. There is strong evidence that driving simulation performance is reduced in patients as compared with controls. For other areas of neuropsychological functions, comparisons between patients and controls are less conclusive.

Attention span, divided attention, sustained attention, and composite measures show some evidence of reduced performance in SRBD patients, although findings do not converge easily across studies. In the areas of complex focused attention, visual immediate memory and delayed memory, study results suggest little impairment. Apnoea severity and task complexity might be moderating factors. In the areas of basic perceptual function, verbal immediate memory, forgetting and verbal function there is no evidence that SRBD patients show reduced performance. In the areas of vigilance performance, motor function, construction, learning, concept formation, reasoning and executive functions, further research is needed as the number of studies is too small to draw any firm conclusions.

## Insomnia

Research into neuropsychological functions of insomniac patients was mainly focused on attention and memory (Table 3). We located 18 studies that compared the cognitive performance of insomniac patients to that of non-sleep disturbed control subjects [31–48]. Taken together, the studies compared 17 patient groups with a total of 374 patients with insomnia to 17 normal control groups which comprised a total of 347 persons.

### *Alertness*

Alertness has been investigated by means of simple reaction time tasks [31–38] and the Critical Flicker Fusion test (CFF) [33, 35]. Measures of alertness did not differ between insomniac patients and controls in the majority of studies [31–33, 36–38]. However, there were two exceptions [34, 35]. Hauri [34] reported that in a simple reaction time task insomniac patients showed prolonged initiation and total reaction times, whereas movement time was not different from controls. Similarly, Saletu-Zyhlarz *et al.* [35] found prolonged reaction times in patients with insomnia related to mild generalized anxiety disorder (GAD) when compared with controls. Interestingly, both studies [34, 35] employed comparatively large samples of 26 [34] and 44 [35] insomniac patients.

### *Attention span*

Attention span has been investigated in three studies by Hauri [34], Vignola *et al.* [39] and Randazzo *et al.* [40]. The forward digit span was found reduced by Hauri [34] and Vignola *et al.* [39], but not by Randazzo *et al.* [40] who additionally reported that the forward spatial span did not differ between insomniacs and controls. The reversed digit span was likewise reduced in both studies employing this task [39, 40], while the reversed spatial span did not differ between insomniacs and controls [40]. Overall, the studies favour the conclusion that verbal attention span in insomniacs might be reduced although the number of studies is too small to reach firm conclusions.

### *Complex focused attention*

Complex focused attention has been investigated by means of the TMT [39], the DSST [34, 38, 39, 41–43] and various cancellation or visual search tasks [35, 41–44]. Performance in the TMT did not differ between insomniacs and controls in the study by Vignola *et al.* [39]. Five studies found no difference between insomniac patients [34, 38, 39, 42] or patients with sleep state misperception (SSM) [43] and controls in the DSST. Cancellation tasks or visual search similarly did not differ between insomniac patients [42, 44], insomniac patients with mild GAD [35], and patients with SSM [43] and controls. Only Bonnet and Arand [41] found that performance in a one-letter, but not a two- or three-letter search task was reduced in insomniac patients when compared with controls, suggesting that perceptual speed but not memory load may be impaired in insomniac patients. Taken together, there is only little evidence that complex focused attention is impaired in insomniac patients.

### *Divided attention and mental tracking*

These functions have been investigated by means of addition tasks [32, 38, 42], a divided attention task [34], word list monitoring [44], a continuous tracking task [37], and letter number sequencing [40]. With the exception of letter number sequencing, which was reduced in insomniac patients when compared with controls [40], no other differences have been reported for these attention tasks. Again, there is little overall indication that divided attention performance is reduced in insomniacs, although summarizing across these very diverse tasks may be problematic.

### *Other complex attention tasks*

Other tasks include complex reaction time tasks [31, 34, 45], the Switching Attention Test [31] and a combined measure of general response latency

[45]. Complex reaction times did not differ between insomniac patients and controls in three studies of Edinger *et al*. [31], Crenshaw and Edinger [45], and Adam *et al*. [33], whereas Hauri [34] found prolonged initiation and total reaction times when insomniacs were compared with controls. One study [31] also found that performance on the first part of the Switching Attention test was improved in insomniac patients while performance on the second part did not differ between insomniacs and controls. Finally, Crenshaw and Edinger [45] computed a general measure of response latency, which did not differ between elderly insomniacs and controls. More research is needed before conclusions can be drawn.

### *Sustained attention*

Sustained attention in insomniac patients has been investigated in four studies using the Continuous Performance test (CPT) [31, 37], the Wilkinson Four Choice Reaction Time Test [39] and a continuous attention test [47]. While Mendelson *et al*. [37] and Vignola *et al*. [39] found no difference between insomniacs and controls, Szelenberger and Niemcewicz [47] found that performance was improved in insomniac patients. Edinger *et al*. [31] showed that performance was significantly different between insomniac patients and controls depending on the setting of the previous night, with insomniacs showing superior performance after a night in the sleep lab and controls showing superior performance after home polysomnography. Taken together, sustained attention did not differ consistently between insomniac and controls after sleep lab polysomnography. Although the setting of the previous night might influence sustained attention, the finding by Edinger *et al*. [31] needs replication.

### *Vigilance*

Vigilance performance has been investigated in six studies with insomniac patients [34, 37, 41, 42, 46] and patients with SSM [43, 46]. In the two studies that included a sample of patients with SSM [43, 46], vigilance performance was found to be reduced when compared with controls [43, 46] or insomniac patients with objective findings [46]. For other groups of insomniac patients only Schneider-Helmert [42] reported reduced vigilance performance while the remaining four studies [34, 37, 41, 46] found no difference between insomniac patients and controls. Further research is needed to replicate vigilance impairments in patients with SSM.

### *Memory*

Memory performance of insomniac patients has been investigated with measures of immediate visual [39] and verbal recall [38, 40–43, 47], learning performance [40, 44, 47], delayed visual [39] and verbal recall [34, 40] and other measures [35, 36, 44]. **Immediate verbal recall** did not differ between insomniacs [39, 38, 44, 47] or patients with SSM [43] and controls in the majority of studies with two exceptions: Bonnet and Arand [41] and, more recently, Randazzo *et al*. [40] both found reduced immediate recall performance in insomniac patients. **Learning** performance has been investigated in four studies [34, 40, 44, 47] with only Szelenberger and Niemcewicz [47] reporting reduced learning performance of insomniac patients when compared to controls. Measures of **delayed verbal recall** have been included in three studies. Hauri [34] and Vignola *et al*. [39] found no difference between insomniacs and controls, while Randazzo *et al*. [40] reported that delayed story recall was reduced in insomniac patients, but delayed recall of verbal pairs showed no difference between insomniacs and controls in the same study. Immediate and delayed visual recall has only been investigated by Vignola *et al*. [39], who found that insomniacs and controls did not differ on these measures. Other measures of memory performance including word [36, 44] and figure [36] recognition and a numerical memory test [35] did not differ between insomniacs and controls. Taken together, the studies suggest that the memory performance of insomniac patients is comparable to that of controls. Verbal immediate recall might be an exception, especially when considering that there is some evidence that basic verbal attention span might be reduced in insomniacs. Further research is needed to explore this question.

### *Motor performance*

Motor performance has been investigated by means of finger tapping [36, 44], the pegboard task [39, 38, 44], the Grünberger fine-motor activity test [35], a hand tremor task [41, 43], and a line tracing task [42]. Finger tapping did not differ between insomniac and controls in a study of Broman *et al*. [36], while Mendelson *et al*. [44] reported a reduced tapping rate of insomniac patients, but only for the

first of four trials. Performance on the pegboard task did not differ between insomniacs and controls in three studies employing this task [39, 38, 44]. The hand tremor task did not differ between insomniacs [41] or patients with SSM [43] and controls in the studies of Bonnet and Arand. On the other hand, Saletu-Zyhlarz *et al.* [35] found that fine-motor activity in insomniac patients was reduced for the right, left, and both hands when compared to that of controls. Schneider-Helmert [42], likewise, reported that insomniacs showed reduced line tracing performance compared with controls. Overall, basic motor performance in insomniac patients does not appear to differ from that of controls. It seems worthwhile to explore if this is also true for more complex tasks.

### *Other neuropsychological functions*

Other neuropsychological functions in insomniac patients have received comparably less attention. **Verbal functions** were assessed by means of proofreading [41, 43], a word detection task [42], and verbal fluency [44]. Among these tasks **verbal fluency** is the only one that was found to be reduced by Mendelson *et al.* [44]. Although they observed that insomniacs consistently produced fewer words at all five test times during the day, this finding needs replication. **Concept formation** was assessed by means of a card sorting task [38, 48] and the WCST [39] and did not differ between insomniacs and controls. **Reasoning** has been investigated in three studies with logical reasoning tasks [38, 42] and the optimal telegram task [40]. While Bonnet [38] found no difference in logical reasoning between elderly insomniacs and controls, Schneider-Helmert [42] reported that the reasoning performance of insomniacs was reduced in the morning, but not at noon or in the afternoon. Finally, Randazzo *et al.* [40] found that insomniacs were significantly faster in generating an optimal telegram but showed reduced accuracy when compared to controls. Randazzo *et al.* [40] are also the only ones who assessed **executive function** using the Porteus mazes and found that insomniacs performed significantly worse than controls.

### *Summary*

There is no consistent or unequivocal evidence of cognitive dysfunction for any neuropsychological functions in insomniac patients. Nevertheless, there appears to be an elusive pattern of cognitive dysfunctions in insomniac patients that is not consistent across studies and functions. Attention span and vigilance performance in SSM patients are the two areas where the available evidence tentatively points to reduced performance in insomniacs. Measures of alertness, focused, divided and sustained attention did not show consistent differences between patients and controls. Verbal functions, concept formation, reasoning, and executive functions all need to be explored further since only a small number of studies have been conducted looking at these tasks. Finally, there may be; (i) a statistical power effect with a higher probability of significant group differences with larger sample sizes [38, 40, 45]; (ii) an effect of situational factors, like the setting of the previous night [31]; and (iii) a time-of-day effect with group differences being more apparent in the morning [42, 44].

## Narcolepsy

Narcolepsy is a life-long neurological disorder that is characterized by excessive daytime sleepiness (EDS) and cataplexy. Hypnagogic hallucinations, sleep paralysis and automatic behaviour are experienced by a subgroup of patients. Research into cognitive dysfunction in narcoleptic patients has mainly focused on the effects of daytime sleepiness on attention and memory using a variety of research protocols and neuropsychological tasks. The literature search yielded 15 studies [24, 25, 49–61] that compared 15 groups with a total of 213 narcoleptic patients to 15 control groups with 204 persons. Study results are summarized in Table 4.

### *Perception*

Perception has only been investigated by Hood and Bruck [49] with a physical matching task. They found no evidence that narcoleptic patients differed from normal controls under conditions of high arousal after a daytime nap.

### *Alertness*

Alertness has been assessed by means of the CFF [50], simple reaction times [49, 51], and reaction times within the P300 paradigm [52]. Both Levander and Sachs [50] and Rieger [51] found that narcoleptic patients show reduced alertness compared with controls. Aguirre and Broughton [52] and Hood and Bruck [49], on the other hand, found no difference between patients and controls. Overall,

evidence of short-term measures of alertness is inconclusive and must await further research.

### *Attention span*

Attention span has been assessed in three studies [53–55]. Combined [53, 54] as well as single [55] verbal span and forward spatial span [55] did not differ between narcoleptic patients and controls in all three studies.

### *Focused attention*

Focused attention has been investigated with the TMT [56], the SDST [53], the DSST [49], various cancellation tasks [49, 53] and other tasks [51, 57]. No single measure has been employed in more than one study. Hood and Bruck [49] found that performance on the DSST was reduced in narcoleptic patients under conditions of low arousal. Rogers and Rosenberg [53] reported that patients had more perseverations but not omissions or errors of commission in a cancellation task. Pollak *et al*. [57] found that narcoleptic patients were consistently less accurate but not slower than controls in a visual search task. All other tasks did not differ between narcoleptic patients and controls. Further research is needed to explore the relative importance of different task parameters to overall performance.

### *Divided attention and mental tracking*

Both divided attention and mental tracking have been investigated with the Stroop test [49, 56], the PASAT [49, 54], backwards alphabetical tracking [56], serial subtraction [56], and a divided attention task [51]. The Stroop test, the Paced Auditory Serial Addition Task (PASAT), and both mental tracking task did not differ in two studies [54, 56] that did not manipulate sleepiness in narcoleptic patients. Hood and Bruck [49] on the other hand, showed that Stroop and PASAT performance were reduced in narcoleptic patients under conditions of experimentally induced low arousal. Finally, Rieger [51] found that patients showed reduced divided attention performance when compared with controls. Overall, acute sleepiness seems to reduce divided attention performance in narcoleptic patients significantly.

Other complex attention tasks include the Go-No-Go test [56], the Krakau visual acuity test [50], and two-choice reaction time [50], which did not differ between patients and controls. However, reaction time after a warning tone and number of anticipatory responses within the CNV paradigm [52] as well as a task requiring subjects to flexibly shift attention [51] showed reduced performance of narcoleptic patients as compared to controls. Again, no single task has been employed twice.

### *Sustained attention*

Sustained attention was measured by the FCRTT [52, 58], the CPT [59], a 20-min DSST [60], and a 20-min version of the Wilkinson addition test [60]. In the FCRTT narcoleptic patients showed more gaps and prolonged reaction times but not more errors than controls [52, 58]. Narcoleptic patients also showed reduced performance in the extended DSST but not the Wilkinson addition task [60]. Finally, Henry *et al*. [59] found that narcoleptics and controls did not differ in the CPT. Overall, the number of four studies is too small to draw any conclusions.

### *Vigilance*

Longer and more tedious tasks measuring vigilance yielded more converging findings. Valley and Broughton [54] showed that in the 60-min Wilkinson Auditory Vigilance test (WAVT) narcoleptic patients had fewer hits but made as many false-positive responses as controls. Hood and Bruck [49] used a 15-min version of the WAVT to successfully induce low arousal in narcoleptic patients, although results were not reported. Likewise, Meier-Ewert [61] found that performance of narcoleptic patients in the 30-min Mackworth clock was reduced compared to controls. Schulz *et al*. [62] repeatedly administered the CFF over a 10-h test period and found that although average CFF thresholds did not differ between patients and controls, narcoleptic patients showed significantly greater variability in performance, a finding that has also been noted by others [52, 57]. Taken together, vigilance performance in narcoleptic patients has repeatedly been shown to be reduced, but as in the other areas of cognitive functions, more studies are needed to replicate these findings.

More recently, **driving simulation** performance of narcoleptic patients has repeatedly been shown to be reduced compared to controls [24, 25].

### *Memory*

Memory performance in narcoleptic patients did not differ from controls in most measures of

## Table 2 Neuropsychological functions in patients with SRBD: summary of study results

| Neuro-psychological functions | Tasks[a] | SEVERITY OF SRBD: MILD — Total No. of studies | MILD — No. of: Studies | MILD — No. of: Comparisons | MILD — No. of comparisons showing: Reduced performance | MILD — No. of comparisons showing: No difference | MODERATE — No. of: Studies | MODERATE — No. of: Comparisons | MODERATE — No. of comparisons showing: Reduced performance | MODERATE — No. of comparisons showing: No difference | SEVERE — No. of: Studies | SEVERE — No. of: Comparisons | SEVERE — No. of comparisons showing: Reduced performance | SEVERE — No. of comparisons showing: No difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Perception** | 1–4 | *3* | 2 | 3 | | 3 [9, 12] | 1 | 1 | | 1 [13][b] | 1 | 1 | | 1 [9] |
| **Attention** | | | | | | | | | | | | | | |
| – Alertness | 7, 8, 10 | **4** | 1 | 1 | | 1 [10] | 4 | 4 | 1 [19] | 3 [10, 13, 22] | | | | |
| – Attentional span | 14 | **2** | 1 | 1 | | 1 [12] | 1 | 1 | 1 [16] | | | | | |
| forward | 12, 15, 19 | **2** | | | | | 2 | 6 | 5 [14] | 1 [13] | | | | |
| reversed | 13 | **4** | 2 | 2 | 1 [15] | 1 [12] | 2 | 2 | 1 [14] | 1 [13] | | | | |
| – Focused attention | | | | | | | | | | | | | | |
| TMT A | 20 | **5** | 2 | 2 | | 2 [15, 20] | 3 | 3 | 1 [19] | 2 [13, 14] | | | | |
| TMT B | 21 | **7** | 3 | 3 | | 3 [9, 15, 18] | 4 | 4 | | 4 [8, 13, 14, 16] | 1 | 1 | 1 [9] | |
| SDST | 22 | **2** | 2 | 2 | | 2 [15, 18] | | | | | | | | |
| DSST | 23 | **3** | 3 | 3 | | 3 [9, 15, 20] | | | | | 1 | 1 | 1 [9] | |
| Cancellation tests | 24, 26 | **6** | 4 | 4 | | 4 [9, 12, 15, 18] | 2 | 2 | 1 [16] | 1 [14] | 1 | 1 | 1 [9] | |
| Other tasks | 32, 33 | **2** | 1 | 1 | | 1 [10] | 2 | 2 | 2 [10, 19] | | | | | |
| – Divided attention/mental tracking | 34, 35, 37–39, 41 | **8** | 3 | 3 | | 3 [10, 15, 20] | 6 | 6 | 3 [8, 14, 19] | 5 [10, 13, 19, 22] | | | | |
| – Other complex attention tasks | | | | | | | | | | | | | | |
| – Sustained attention | 57–59, 61, 62 | **7** | 3 | 6 | 1 [15] | 5 [9, 10, 15] | 3 | 3 | 1 [19] | 2 [8, 10] | 3 | 6 | 3 [9, 17, 21] | 3 [9, 17] |
| – Vigilance | 65, 67 | **3** | 1 | 1 | | 1 [10] | 3 | 5 | 3 [19, 22] | 2 [10, 19] | | | | |
| **Motor functions** | | | | | | | | | | | | | | |
| – Finger tapping | 73 | 2 | **2** | 2 | | 2 [12, 20] | | | | | 1 | 1 | 1 [9] | |
| – Pegboard | 74, 75 | **3** | 2 | 2 | 1 [9] | 1 [18] | 1 | 3 | 3 [16] | | | | | |
| – Other | 78 | **1** | | | | | 1 | 1 | 1 [13] | | | | | |
| **Driving simulation** | 81–87 | **12** | 1 | 1 | | 1 [23] | 4 | 8 | 7 [26–28] | 1 [24] | 7 | 12 | 12 [7, 8, 11, 17, 21, 25] | |
| **Constructional performance** | | | | | | | | | | | | | | |
| – Copying | 88, 89 | **2** | 1 | 1 | | 1 [9] | 1 | 1 | 1 [16] | | | | | |
| – Building and assembling | 90, 91 | **4** | 2 | 3 | | 3 [9, 12] | 1 | 1 | | 1 [16] | 1 | 2 | 2 [9] | |
| **Memory** | | | | | | | | | | | | | | |
| – Immediate recall | | | | | | | | | | | | | | |
| Visual recall | 92, 93 | **4** | 2 | 2 | 1 [9] | 1 [12] | 2 | 2 | | 2 [18, 16] | 1 | 1 | 1 [9] | |
| Verbal recall | 95, 96 | **5** | 2 | 2 | | 2 [9, 12] | 3 | 3 | | 3 [8, 13, 16] | 1 | 1 | | 1 [9] |
| – Learning | 100–103, 107 | **4** | 3 | 3 | 3 [12, 15, 18] | 1 | 2 | 2 [14] | | | | | | |

**Table 2** *continued*

| Neuro-psychological functions | Tasks | Total No. of studies | SEVERITY OF SRBD: MILD No. of: Studies | MILD No. of: Comparisons | MILD No. of comparisons showing: Reduced performance | MILD No. of comparisons showing: No difference | MODERATE No. of: Studies | MODERATE No. of: Comparisons | MODERATE No. of comparisons showing: Reduced performance | MODERATE No. of comparisons showing: No difference | SEVERE No. of: Studies | SEVERE No. of: Comparisons | SEVERE No. of comparisons showing: Reduced performance | SEVERE No. of comparisons showing: No difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| – Retrieval | | | | | | | | | | | | | | |
| Visual retrieval | 108, 109 | **5** | 3 | 3 | 1 [29] | 2 [9, 20] | 1 | 1 | | 1 [16] | 1 | 1 | 1 [9] | |
| Verbal retrieval | 110, 111 | **5** | 3 | 3 | | 3 [9, 15, 29] | 2 | 2 | | 2 [8, 16] | 1 | 1 | 1 [9] | |
| – Forgetting | 115–119 | **3** | 1 | 1 | | 1 [18] | 2 | 4 | | 4 [14, 16] | | | | |
| – Other | 120–127 | **6** | 4 | 6 | | 6 [12, 15, 18, 20] | 2 | 3 | | 3 [13, 19] | | | | |
| **Concept formation** | 139 | **2** | 2 | | | 2 [9, 20] | | | | | 1 | 1 | | 1 [9] |
| – WCST | 140 | **3** | 1 | 1 | 1 [15] | | 2 | 5 | 2 [13, 14] | 3 [13, 14] | | | | |
| **Reasoning** | 142–144 | **2** | 1 | 2 | 1 [9] | 1 [9] | 1 | 1 | | 1 [14] | 1 | 2 | 1 [9] | 1 [9] |
| **Executive functions** | 149–151 | **4** | 2 | 2 | 1 [9] | 1 [12] | 2 | 4 | 1 [14] | 3 [13, 14] | 1 | 1 | 1 [9] | |
| **Verbal functions/Language skills** | | | | | | | | | | | | | | |
| – Verbal fluency | 153, 154 | **6** | 3 | 3 | | 3 [9, 12, 18] | 3 | 3 | | 3 [12–14] | 1 | 1 | 1 [9] | |
| – Other | 155–157 | **3** | 2 | 3 | | 3 [12, 23] | 1 | 2 | | 2 [16] | | | | |
| **Composite measures** | | | | | | | | | | | | | | |
| WAIS-R full scale | 165 | **1** | 1 | 1 | | 1 [9] | | | | | 1 | 1 | 1 [9] | |
| WAIS-R verbal scale | 166 | **3** | 3 | 3 | | 3 [9, 29, 30] | | | | | 1 | 1 | | 1 [9] |
| WAIS-R performance scale | 167 | **3** | 3 | 3 | 1 [29] | 2 [9, 30] | | | | | 1 | 1 | 1 [9] | |
| Other | 168–170 | **4** | 3 | 3 | 1 [18] | 2 [20, 29] | 1 | 1 | | 1 [8] | | | | |

Number of comparisons that exceeds number of studies result from multiple patients groups, tasks or task parameters. TMT: Trail Making Test; DSST: Digit Symbol Substitution Test; SDST: Symbol Digit Substitution Test, WCST: Wisconsin Card Sorting test; WAIS-R: Wechsler Adult Intelligence Scales – Revised.

[a] Numbers in the task column refer to neuropsychological tests as listed in Table 1.

[b] Improved performance.

**Table 3 Neuropsychological functions in patients with insomnia: summary of study results**

| Neuropsychological functions | Tasks[a] | No. of studies | No. of comparisons | No. of comparisons showing: Reduced performance of patients | No. of comparisons showing: No difference between patients and controls |
|---|---|---|---|---|---|
| **Perception** | 5 | 1 | 1 | | 1 [42[b]] |
| **Attention** | | | | | |
| – Alertness | 7–9 | 8 | 14 | 4 [34, 35] | 10 [31–38] |
| – Attentional span | | | | | |
| forward | 12 ,16 | 3 | 4 | 2 [34, 39] | 2 [40] |
| reversed | 13, 17 | 2 | 3 | 2 [39, 40] | 1 [40] |
| – Focused attention | | | | | |
| TMT A | 20 | 1 | 1 | | 1 [39] |
| TMT B | 21 | 1 | 1 | | 1 [39] |
| SDST | | | | | |
| DSST | 23 | 5 | 6 | | 6 [34, 38, 39, 42, 43] |
| Cancellation tests | 24 | 2 | 6 | | 6 [35, 44] |
| Other tasks | 27, 29 | 3 | 7 | 1 [41] | 6 [41–43] |
| – Divided attention/mental tracking | 36, 42, 43–45, 47, 48 | 7 | 9 | 1 [40] | 8 [32, 34, 37, 38, 42, 44, 37] |
| – Other complex attention tasks | 49–51 | 4 | 7 | 2 [34] | 5 [31[b]],33, 34, 45] |
| – Sustained attention | 58, 59, 62 | 4 | 5 | 1 [31] | 4 [31, 37, 39, 47[b]] |
| – Vigilance | 68–71 | 6 | 7 | 3 [42, 43, 46] | 4 [34, 37, 41, 46] |
| **Motor functions** | | | | | |
| – Finger tapping | 73 | 2 | 6 | 1 [44] | 5 [36, 44] |
| – Pegboard | 75, 76 | 3 | 3 | | 3 [39, 38, 44] |
| – Other | 77, 79, 80 | 3 | 5 | 4 [35, 42] | 1 [43] |
| **Driving simulation** | | | | | |
| **Constructional performance** | | | | | |
| – Copying | | | | | |
| – Building and assembling | | | | | |
| **Memory** | | | | | |
| – Immediate recall | | | | | |
| Visual recall | 92 | 1 | 1 | | 1 [39] |
| Verbal recall | 94–99 | 7 | 9 | 3 [40, 41] | 6 [38–40, 43, 44, 47] |
| – Learning | 101, 102, 105, 106 | 4 | 5 | 1 [47] | 4 [34, 40, 44] |
| – Retrieval | | | | | |
| Visual retrieval | 109 | 1 | 1 | | 1 [39] |
| Verbal retrieval | 111–113 | 3 | 5 | 1 [40] | 4 [34, 39, 40] |
| – Forgetting | | | | | |
| – Other | 128–131 | 3 | 4 | | 4 [35, 36, 44] |
| **Concept formation** | 141 | 2 | 2 | | 2 [38, 48] |
| – WCST | 140 | 1 | 2 | | 2 [39] |
| **Reasoning** | 145–147 | 3 | 6 | 2 [40, 42] | 4 [38, 40, 42] |
| **Executive functions** | 152 | 1 | 2 | 2 [40] | |
| **Verbal functions/Language skills** | | | | | |
| – Verbal fluency | 154 | 1 | 1 | 1 [44] | |
| – Other | 158, 159 | 3 | 3 | | 3 [41–43] |
| **Composite measures** | | | | | |
| WAIS-R full scale | | | | | |
| WAIS-R verbal scale | | | | | |
| WAIS-R performance scale | | | | | |
| Other | | | | | |

Number of comparisons that exceeds number of studies result from multiple patients groups, tasks or task parameters. References are indicated by numbers in square brackets. TMT: Trail Making Test; DSST: Digit Symbol Substitution Test; SDST: Symbol Digit Substitution Test, WCST: Wisconsin Card Sorting test; WAIS-R: Wechsler Adult Intelligence Scales – Revised.

[a] Numbers in the task column refer to neuropsychological tests as listed in Table 1.

[b] Improved performance.

immediate [51, 55, 59] and delayed recall [51, 53, 55, 56, 59] or recognition [51, 56]. Rogers and Rosenberg [53] found reduced delayed recall of a 30 word list, and Smith *et al*. [56] found the learning performance of narcoleptic patients to be reduced compared with controls. Furthermore, Rogers and Rosenberg [53] reported that narcoleptic patients showed reduced performance in automatic incidental memory, and noted that patients showed reduced general reaction times in all task sets of the Sternberg Memory Scanning task, which they interpreted as a perceptual encoding deficit. Smith *et al*. [56] found a greater gap between recall and recognition performance in narcoleptic patients. Hood and Bruck [49], however, found no difference in short- and long-term memory between patients and controls, even under conditions of low arousal. As in the area of short-term attention, deficits in narcoleptic patients have only been demonstrated in singular studies with widely different tasks and must await replication.

Other areas of neuropsychological functioning in narcoleptic patients have received only little attention. No difference in performance between patients and controls was found in the areas of motor function [59, 57], reasoning [57], executive function [56], and verbal function [56, 59]. Constructional performance and concept formation have not been investigated in narcoleptic patients.

### *Summary*

Experimental research protocols have demonstrated that cognitive performance of narcoleptic patients is greatly influenced by varying degrees of daytime sleepiness. Although Hood and Bruck [49] showed that task complexity is most susceptible to the effects of sleepiness, vigilance performance is the one area where narcoleptic patients show consistently reduced performance when compared with controls. If this is due to an inability to sustain attention over a longer period of time or in situations of low stimulation, or both, is not entirely clear since both factors have not been varied independently. Studies that have investigated sustained attention (for a shorter period of time but with higher stimulation) showed mixed results, but generally favour the hypotheses that time-on-task is a significant contributor to performance decrements in narcoleptic patients. Although reduced performance has been reported for some areas of short-term attention and memory, this represents single-study evidence with small groups of patients and have not been replicated so far.

## DISCUSSION

Summed up across all neuropsychological tasks and task parameters from 57 studies which were reviewed, patients with SRBD and narcolepsy showed reduced performance in one third (36.9% and 34.6%, respectively) of all comparisons to control subjects, while performance of insomniac patients was reduced to a lesser degree (22.9% of all comparisons). The most consistent finding was impaired driving simulation performance (92.9% of all comparisons), with a total of 22 comparisons in SRBD patients, six in narcoleptic patients and none in insomniac patients. Sleep-disordered patients performed worse than control subjects on tasks measuring attention (33.5%) or motor functions (42.3%). Memory performance was comparatively less impaired with reduced performance of patients in only 17.3% of all comparisons. Although reasoning and executive functions appeared to be considerably impaired, the number of studies in these areas was too small to draw meaningful conclusions.

When the performance of the three diagnostic groups was compared within each area of neuropsychological functions, SRBD and narcoleptic patients showed reduced performance in attention tasks in one third to half of all comparisons made (35.9% and 44.2%, respectively), which is substantially higher than the 22.9% rate of impairment of insomniac patients. Driving simulation performance was reduced in SRBD patients in 90.1% of the comparisons, and in all six comparisons from a total of only two studies in narcoleptic patients. Given the suggested high sensitivity of tasks measuring driving performance, exploration of driving simulation performance would also be of interest in insomniac patients, where we found no study in the literature.

Concerning mnestic functions, insomniacs showed reduced memory performance in 20.0% of the comparisons, which is slightly above the ratio for SRBD and narcoleptic patients (17.1% and 15.6%, respectively). This suggests that either the applied measures of memory performance are rather insensitive to the effects of various sleep disorders, or, alternatively, mnestic functions are afflicted to a lesser degree than attention and motor tasks in patients with sleep disorders.

**Table 4 Neuropsychological functions in patients with narcolepsy: summary of study results**

| Neuropsychological functions | Tasks[a] | No. of studies | No. of comparisons | No. of comparisons showing: Reduced performance of patients | No. of comparisons showing: No difference between patients and controls |
|---|---|---|---|---|---|
| **Perception** | 6 | 1 | 1 | | 1 [49] |
| **Attention** | | | | | |
| – Alertness | 7, 8, 11 | 4 | 4 | 2 [50, 51] | 2 [49, 52] |
| – Attentional span | 14 | 2 | 2 | | 2 [53, 54] |
| forward | 12, 18 | 1 | 2 | | 2 [55] |
| reversed | 13 | 1 | 1 | | 1 [55] |
| – Focused attention | | | | | |
| TMT A | 20 | 1 | 1 | | 1 [56] |
| TMT B | 21 | 1 | 1 | | 1 [56] |
| SDST | 22 | 1 | 1 | | 1 [53] |
| DSST | 23 | 1 | 1 | 1 [49] | |
| Cancellation tests | 25, 28 | 2 | 4 | 1 [53] | 3 [49, 53] |
| Other tasks | 30, 33 | 2 | 3 | 1 [57] | 2 [51, 57] |
| – Divided attention/mental tracking | 36, 37, 38, 40, 46 | 4 | 7 | 3 [49, 51] | 4 [54, 56] |
| – Other complex attention tasks | 52–56 | 4 | 6 | 3 [51, 52] | 3 [50, 56] |
| – Sustained attention | 58, 59, 71, 72 | 4 | 14 | 7 [54, 58, 60] | 7 [54, 58–60] |
| – Vigilance | 65, 71, 72 | 3 | 5 | 5 [54, 61, 62] | 2 [54, 62] |
| **Motor functions** | | | | | |
| – Finger tapping | 73 | 1 | 1 | | 1 [59] |
| – Pegboard | 75 | 1 | 2 | | 2 [57] |
| – Other | | | | | |
| **Driving simulation** | 81, 82 | 2 | 6 | 6 [24, 25] | |
| **Constructional performance** | | | | | |
| – Copying | | | | | |
| – Building and assembling | | | | | |
| **Memory** | | | | | |
| – Immediate recall | | | | | |
| Visual recall | 92, 93 | 2 | 3 | | 3 [53, 55] |
| Verbal recall | 94, 96, 99 | 3 | 4 | 1 [59] | 3 [53, 55] |
| – Learning | 102, 104, 106 | 4 | 4 | 1 [56] | 3 [51, 53, 55] |
| – Retrieval | | | | | |
| Visual retrieval | 109 | 1 | 1 | | 1 [55] |
| Verbal retrieval | 111–114 | 4 | 7 | | 7 [51, 53, 55, 56] |
| – Forgetting | | | | | |
| – Other | 128–130, 132–138 | 5 | 13 | 3 [56, 59] | 10 [49, 51, 55, 56, 59] |
| **Concept formation** | | | | | |
| – WCST | | | | | |
| **Reasoning** | 148 | 2 | 3 | 1 [49] | 2 [57] |
| **Executive functions** | 149 | 1 | 1 | | 1 [56] |
| **Verbal functions/Language skills** | | | | | |
| – Verbal fluency | 153, 154 | 3 | 3 | 1 [49] | 2 [55, 56] |
| – Other | 157, 160–164 | 3 | 6 | 1 [49] | 5 [49, 55, 56] |
| **Composite measures** | | | | | |
| WAIS-R full scale | | | | | |
| WAIS-R verbal scale | | | | | |
| WAIS-R performance scale | | | | | |
| Other | | | | | |

Number of comparisons that exceeds number of studies result from multiple patients groups, tasks or task parameters. References are indicated by numbers in square brackets. TMT: Trail Making Test; DSST: Digit Symbol Substitution Test; SDST: Symbol Digit Substitution Test, WCST: Wisconsin Card Sorting test; WAIS-R: Wechsler Adult Intelligence Scales – Revised.

[a] Numbers in the task column refer to neuropsychological tests as listed in Table 1.

Reviewing the evidence for each patient group separately, we found that SRBD patients showed most pronounced deficits in the areas of attention (35.9%) and driving simulation (90.1%) while memory performance was considerably less impaired (17.1%). Evidence suggests potential impairment of motor functions, concept formation, reasoning and executive functions, however, the number of studies was too small to reach firm conclusions. Taken together, the present results, which are simply based on the proportion of controlled studies showing significantly impaired performance of patients, are very similar to the quantitative analyses of Engleman *et al.* [2] in patients with breathing disorders during sleep. These authors calculated weighted average impairment effect sizes of 0.4 standard deviation (SD) for attention and psychomotor performance including driving simulation, 0.2 SD for memory scores, and 0.7 for executive and frontal scores. Although we found evidence too sparse to conclude impairment of executive function, we agree with these authors that SRBD appears to be more closely related to impairments in attention than memory performance.

In the area of SRBD, studies were also summarized separately for mild, moderate and more severe forms of SRBD. Patients with mild forms of SRBD showed reduced performance in only 11.9% (10 out of 84 comparisons) while this percentage increased to 44.2% (38 out of 86 comparisons) in patients with moderate forms of SRBD and reached a value of 78.4% (29 out of 37 comparisons) in severely affected patients. This highlights the importance of distinguishing between patients with different degrees of severity in future research. However, as has already been mentioned by Englemann and Joffe [1] and applies to other sleep disorders as well, at present we have little knowledge what constitutes meaningful severity criteria.

Insomniac patients showed less pronounced differences to controls. For attention tasks 22.9% of all comparisons showed reduced performance while for memory performance, this percentage was 20.0%. Motor performance and "higher-order" functions seem to be an area of possible impairment (cf. Table 3), but this was investigated in a limited number of studies. The results are in agreement with the recent review by Riedel and Lichstein [6] who found that 76% of a total of 54 comparisons showed no difference between insomniacs and controls. Only one deficit was replicated in an independent study. One reason for non-replication may be the diversity of tasks and measures employed.

Patients with narcolepsy were most often found to differ from controls in the areas of attention (44.2%) and driving simulation performance (100%, two studies only) while evidence was less conclusive in the area of memory performance (15.6%). Again, higher order functioning and motor functions have received only little research effort. In this, like in other sleep disorders, the percentage of patients showing objective cognitive impairment is much lower than those rating their performance on such tasks as impaired [36, 39, 64]. Sleepiness may be an essential interfering factor when the performance of cognitive functions is either rated by the patient, or measured in a standardized test situation. Hood and Bruck [49] could show that the presence and extent of cognitive deficits was dependent on the degree of arousal, which was experimentally manipulated in their study. Apart from the above conclusions, our review has identified a number of problems which may be considered in future research. These include: (i) lack of available evidence in several areas of neuropsychological functions; (ii) methodological considerations; and (iii) the problem of comparability across studies.

For several areas of neuropsychological functioning the number of studies was too small to reach meaningful conclusions. In particular, "higher-order" functions like concept formation, reasoning and executive function are underrepresented in the literature. Further research is needed, especially as the available evidence suggests that sleep-disordered patients might experience considerable difficulties in these areas.

Methodological problems arise predominantly from the small sample sizes of the individual studies. Statistical power analysis [65] suggests that in order to attain a significant effect (type I error below .05) with moderate effect size and adequate test power (type II error of 0.20), sample sizes in the order of $n_1 = n_2 = 50$ participants are required. Considering that the majority of studies included only 10 to 20 participants per group, one may conclude that the effects reported in the present review are large. The sample size problem has also been addressed by Riedel and Lichstein [6] for insomnia. Engleman *et al.* [2] have undertaken a quantitative analysis in the area of SRBD where they computed impairment effect sizes. As mentioned above, they reported that average weighted effect sizes varied between

0.2 and 0.7. Given the size of these effects, a quantitative review might be more appropriate to summarize the available small-scale studies. For this reason, we agree with the recommendation to report effect sizes in original publications, which has been proposed for several years [66].

Summarizing evidence across single studies relies on the assumption that these studies can be meaningfully compared. The 57 studies reviewed in this paper employed a total of 170 different tasks for the measurement of cognitive performance. One could seriously question the comparability across studies in many areas. To overcome the problem of non-compatibility, Décary *et al.* [3] have proposed a standard battery of neuropsychological tests for the assessment of cognitive deficits in SRBD. A similar, but less elaborate test battery was also proposed for narcolepsy [4]. The implementation of standards for selecting and performing neuropsychological tests in sleep-disordered patients would clearly improve comparability of results across studies.

Another problem is the use of multiple outcome parameters for the same task, especially in case of conflicting results. The most frequently encountered case was a difference between parameters of speed and accuracy [e.g. 9, 13, 19, 40, 57]. For many areas of task performance it is still unclear which task parameter should be considered as indicative for a specific cognitive performance [3].

Performance of patients with SRBD, insomnia or narcolepsy differed repeatedly from that of non-sleep disturbed controls. Even if results may not always be consistent within or across diagnostic groups this suggests that the observed degree of cognitive dysfunction is clinically relevant.

A main topic which needs clarification is the question whether neuropsychological laboratory based assessments are related to meaningful or significant outcomes in everyday life. Among those that are frequently recognized as important belong in first place quality of life, accident rates and economic variables like absenteeism or medical costs. People with sleep disorders as a group show impaired quality of life [64, 67–71], have a higher prevalence of absenteeism [64, 72, 73] and are more likely to experience traffic and household accidents [71, 74–78]. They also frequently complain of memory and other cognitive problems [70, 71, 79]. This documents that these patients experience significant impairment. The question is, whether these are mediated by cognitive deficits.

Quality of life, which has repeatedly been shown to be reduced in patients with sleep disorders [64, 67–71], can not be easily regressed into cognitive deficits. Although the construct of quality of life has been difficult to define precisely [80] and has been operationalized with different components and dimensions [81, 82] there is a general agreement that quality of life is neither exclusively equivalent to external conditions nor to internal perceptions of these conditions but encompasses both [83]. The internal perception of cognitive deficits in patients with sleep disorders is well documented. Memory and attention problems and impaired ability to perform are among the most frequent symptoms that are brought forward by sleep-disordered patients [70, 71, 79] and might indeed be their chief complaint. The external basis of these complaints is more difficult to determine. This review shows that patients with sleep disorders differed from non-sleep disordered control subjects in a number of studies and a number of tasks. On a group level this provides evidence that sleep-disordered patients do indeed experience cognitive dysfunction. Summarizing these results, there are good reasons to assume that the objectively impaired and perceived cognitive dysfunction is part of the impaired quality of life in patients with different sleep disorders.

Patients with sleep disorders also exhibit a higher rate of accidents [71, 74–78], and patients with narcolepsy are not even allowed to drive a vehicle in some countries [71]. In large-scale population-based studies subjective sleepiness has been linked with higher accident rates [84], as has sleep-disordered breathing [85]. Retrospective self-reported accident rates are significantly higher in patients with SRBD [75] and narcolepsy [78] and in individuals with poor sleep [76, 77] when compared with control groups. Driving a car requires vigilance but also involves complex tasks like monitoring the road and the flow of traffic, and motor performance to control for lane position and speed. In patients with SRBD and narcolepsy [78] the association of traffic accidents with laboratory-based assessments of sleepiness or alertness by the MSLT or MWT is relatively poor [11, 25, 53, 78]. Findley *et al.* [11] have directly compared driving simulation performance with accident rates from official driving records.

They found that patients with SRBD or narcolepsy who showed a poor driving simulation performance had higher accident rates than patients with normal performance. However, this finding could not be replicated in a later study by Barbé *et al.* [17] with a different analytical approach. The present review has identified driving simulation performance as being exceptionally sensitive in discriminating between patients with SRBD, or narcolepsy and control subjects. One reason for this may be that driving and driving simulation performance is a highly complex process which requires not only the co-ordination of many cognitive functions but also the effective sustainment of these processes for a longer period of time. Although more studies are needed to explore the ecological and predictive value of driving simulation performance, this appears to be a particularly promising avenue of research for linking laboratory-based cognitive assessment to highly relevant real-life impairments.

The experimental manipulation of sleep with total, partial, or selective sleep deprivation, sleep restriction and sleep disruption [86–89] shows that sleep duration, sleep stages and sleep continuity all are related to cognitive function in non-sleep disturbed persons. This accumulated evidence provides a solid link between sleep and cognitive functions. Unfortunately the applicability to sleep disorders remains limited by several factors. The most important limitation is probably the difference in time frame between experiments and the studies reviewed here. While the experiments use acute manipulation of sleep, patients present a condition of chronically disturbed sleep. To date we know little about the time-course of chronic sleep disorders and nearly nothing on the development of cognitive dysfunction in the patients' career.

Another approach to cognitive functioning in sleep-disordered patients relies on correlational analysis or the comparison of subgroups within the group of sleep-disordered patients. The most straightforward approach would be to hypothesize that cognitive dysfunction is related to the severity of the respective sleep disorder. Our review has shown that patient groups with SRBD that we have post-hoc classified as mild, moderate, and severe, show different degrees of cognitive dysfunction in a dose-dependent manner, but for severe SRBD this is based on very limited data. Furthermore this approach did not differentiate between different indices of sleep-related breathing. In addition diagnostic severity criteria are not strict in defining cutpoints due to the consideration that "a single numerical cutpoint (such as the apnoea index) is often not an appropriate division between levels of severity, and clinical judgement of several indices of severity is considered superior" [90]. Research into cognitive function in sleep-disordered patients could profit greatly from the development and application of standardized research diagnostic criteria. There have been various studies that relate sleep parameters, measures of night-time sleep, daytime sleepiness and oxygenation to cognitive performance in patients with SRBD [2, 91, 92]. In insomniac patients at least one study [47] associated severity of insomnia to cognitive function. In narcoleptic patients, neuropsychological test performance was related to severity of ocular and muscular symptoms, although not in an entirely consistent way [56]. To date, however, none of these proposed relationships have been independently cross-validated which is needed because correlation models bear the danger of overfitting, especially in small samples. Progress is further limited by our lack of knowledge about the intercorrelation of the different proposed factors [1].

In summary, persons with SRBD, insomnia, or narcolepsy experience clinically significant impairment. Indicators for this are cognitive impairment, driving behaviour and accidents and reduced quality of life.

**Practice Points**

1. Sleep-disordered patients as a group show cognitive dysfunction. Major dysfunctions appear in the areas of attention, vigilance and driving behaviour. Results suggest a relationship between the severity of sleep-disordered breathing and cognitive impairment.
2. Patients with SRBD show reliable performance deficits in driving simulation performance. This may be a predictor for real-life behaviour because for this group of patients an increased rate of traffic accidents has been documented.
3. Cognitive deficits are less pronounced in insomniac patients but there is a clear lack of studies in this patient group.

4. Patients with narcolepsy experience profound cognitive difficulties in situations that provide little stimulation and last for longer periods of time. For these patients it has also been shown that performance strongly depends on the acute level of sleepiness.

### Research Agenda

1. The development of a standardized neuropsychological test battery, as has been proposed for SRBD patients, should also be considered for research and evaluation in patients with other sleep disorders.
2. There is a need for Research Diagnostic Criteria for the main diagnostic groups of sleep disorders to allow a better definition and comparison of patient groups.
3. There is a need for formalized severity criteria to allow a better comparison of patient samples within and between diagnostic groups.
4. There is a need for predictive models of daytime impairment, based on disturbed sleep.

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## APPENDIX 1. ABBREVIATIONS

AHI = apnoea–hypopnoea index; CFF = Critical Flicker Fusion test; CPT = Continuous Performance test; DSST = Digit Symbol Substitution Test; FCRRT = Four-Choice Reaction Time test; GAD = generalized anxiety disorder; MMSE = Mini-Mental Status Examination; PASAT = Paced Auditory Serial Addition Task; PVD = Psychometer Vigilance Device; SDST = Symbol Digit Substitution Test; SRBD = sleep-related breathing disorders; SSM = sleep-state misperception; TMT = Trail Making test; WAIS-R = Wechsler Adult Intelligence Scales – Revised; WAVT = Wilkinson Auditory Vigilance test; WCST = Wisconsin Card Scoring Test; WMS = Wechsler Memory Scale.