Sleep Medicine 87 (2021) 46–55

Contents lists available at ScienceDirect

Sleep Medicine

journal homepage: www.elsevier.com/locate/sleep

Original Article

Impact of daytime sleepiness and insomnia on simple and complex cognitive task performances

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ARTICLE INFO

Article history:
Received 25 May 2021
Received in revised form
17 July 2021
Accepted 4 August 2021
Available online 12 August 2021

Keywords:
Insomnia disorder
Hyperarousal
Daytime alertness
Cognitive performance
MSLT

ABSTRACT

Objective: To examine the individual and combined effects of daytime sleepiness and insomnia disorder (ID) on measures of cognitive functioning.
Design and setting: This study was conducted at a medical center using a cross-sectional research design.
Participants: 35 persons with ID (Mage = 40.6 years; 25 women) and 54 normal sleepers (NS; Mage = 31.5 years; 38 women).
Methods and measures: Participants underwent two nights of home-based polysomnography (PSG) followed by daytime testing with a four-trial Multiple Sleep Latency Test (MSLT). Before each MSLT nap, they completed a computer-administered battery of reaction time tasks. Measures of response latencies and response accuracy were tabulated and used as dependent measures. The ID and NS groups were each subdivided into "alert" (eg, MSLT mean latency > 8 min) and "sleepy" (eg, MSLT mean latency ≤ 8 min) subgroups to identify hyperaroused persons with ID and allow for their comparisons with the other participant subgroups.
Results: Multivariate analyses of variance showed a significant main effect for level of daytime sleepiness ($F[1, 84] = 8.52$, $p = 0.0045$) on simpler performance tasks and a significant main effect for presence vs. absence of ID ($F[1,84] = 6.62$, $p = 0.012$) on complex tasks. A lack of significant participant type x MSLT alertness level interactions in study analyses suggested those ID participants with presumed hyperaousal were not relatively more impaired than the other participant subgroups.
Conclusions: Daytime performance deficits on simple tasks seem most dependent on individuals' levels of daytime sleepiness, whereas performance deficits on more complex tasks appears related to the presence of ID. Therefore, it seems best to use complex performance measures both to document cognitive deficits among those with ID and to determine if insomnia treatments reduce such impairments.
Trial registration: ClinicalTrials.gov Identifier: NCT02290405.

Patients with insomnia disorder (ID) typically complain of daytime impairments including reduced attention, concentration, memory and global mental acuity. Moreover, epidemiological studies have shown insomnia contributes to reduced productivity, work and traffic accidents, and serious falls among the elderly [1–4]. Despite such findings, laboratory-based efforts to corroborate the cognitive complaints of ID sufferers have produced mixed results. Previous studies comparing ID sufferers with non-complaining normal sleepers across a range of neuropsychological tests have failed to show any relative deficits among the ID group [5–7]. Such findings, in turn, have led to the impression that ID patients' cognitive complaints may be over-stated and result from their attentional bias toward minor cognitive errors, dysfunctional beliefs about the impact of insomnia on functioning, a reduced ability to muster the effort to maintain attention on tasks or excessive self-focus rather than from any measurable daytime impairment [7–9].

However, many of these previous studies were underpowered due to small sample sizes and they used neuropsychological tests designed for detecting impairment resulting from brain disease/

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https://doi.org/10.1016/j.sleep.2021.08.004
1389-9457/

damage rather than the subtler, albeit significant, impairments of which ID patients complain. In recent research, we [10] and others [11–14] have shown that those with ID do indeed show deficits in measures of working memory, episodic memory and some aspects of executive functioning, particularly on complex tasks. Moreover, there is some preliminary evidence that an ID subgroup with elevated levels of physiological hyperarousal is more prone to suffer from neurocognitive performance deficits than both persons with ID who are not physiologically hyperaroused and normally alert individuals without ID. For example, Fernandez-Mendoza [11] showed that ID sufferers with a hyperarousal pattern, as suggested by their objective short sleep duration on serial polysomnograms (PSG), performed more poorly on a complex attention switching task than did both normal sleepers and ID sufferers with normal objective sleep durations.

In our efforts to follow up on this latter work, we [15] examined the error rates among groups of alert (ie, hyperaroused) and sleepy ID sufferers and normal sleepers (NS) across a series of simple and complex reaction time tasks. Using their performance on a daytime Multiple Sleep Latency Test (MSLT), we were able to group individuals into one of four groups: alert ID, sleepy ID, alert NS, and sleepy NS. Those classified as "alert" had a mean MSLT latency >8 min and those classified as "sleepy" had a mean MSLT latency $\leq$. 8 min. Our subsequent performance test comparisons showed the ID group as a whole had fewer correct responses on performance testing than did NS. However, we found a significant group $\times$ alertness interaction with greater error rates occurring among alert (presumably hyperaroused) ID sufferers (Mean = 4.5 $\pm$ 3.6 errors per trial) than among alert NS (Mean = 2.6 $\pm$ 1.9 errors per trial). This was particularly true for the complex attention switching task.

Our work [10,15] and the of the others mentioned above [11–14] serve to confirm that ID is associated with measureable, objective neurocognitive deficits and provides some preliminary suggestion for the types of testing approaches that should be used to detect them. The identification of tests sensitive to cognitive deficits reported by those with ID are particularly relevant for studies designed to determine whether current and future insomnia therapies actually improve objective daytime functioning in such individuals. Unfortunately, prior studies [16] have shown very modest benefits of insomnia therapy for patients' cognitive functioning. Nonetheless, measures of daytime dysfunction can and should serve as endpoints for assessing the benefits and detriments of insomnia therapies. In addition, our recent work suggests that ID subgroups may differ in their daytime deficits, with those showing physiological hyperarousal being most prone to make errors. This finding suggests that different types or doses of treatment may be needed to reverse the daytime impairments of the hyperaroused and non-aroused ID patients. Consistent with this speculation, several [17–20], albeit not all [21–23] studies have recently shown that ID patients with short sleep duration or other objective sleep deficits show a poorer response to cognitive behavioral insomnia therapy than do those without objective markers of sleep disturbance. However, our line of research concerning the performance deficits of hyperaroused ID patients would benefit by replication and extension of findings to (1) further confirm the detrimental effects of physiological hyperarousal on ID sufferer's neurocognitive functioning; and (2) identify a broader range of tests that can be used for assessing diurnal cognitive impairments in both physiologically hyperaroused and lesser aroused ID groups. The current study addressed these aims.

1. Method

1.1. Research design

This study employed a cross-sectional experimental design. Both female and male study participants who met criteria for insomnia disorder or had no sleep complaints (ie, normal sleepers) were enrolled. All participants signed an informed consent to undergo study procedures and were compensated at a rate of $300 each if they completed all study requirements. The study was reviewed and approved by the Institutional Review Board of National Jewish Health, Denver, CO where the study was conducted.

1.2. Participants

Participants for the current project were recruited via posted announcements, our outpatient sleep clinics, and through various local listservs and web announcements. Given the research plan, we recruited and enrolled a sample of persons with insomnia disorder (ID) as well as a control group comprised of non-complaining normal sleepers (NS). Prior to their acceptance into the study, all participants underwent a thorough screening that included, structured psychiatric [24] and sleep interviews [25], a medical exam, and one night of screening polysomnography to rule-out occult primary sleep disorders.

For the purposes of the current project we attempted to recruit a sample of hyperaroused persons with ID and a normally alert group of NS. Classification into the insomnia disorder (ID) group was based on DSM-5 and ICSD-3 criteria (ie, reporting sleep difficulties at least 3 times per week for a minimum of 3 months despite having adequate sleep opportunity, having (daytime functional impairment (not due to a coexisting mental health or medical condition), and having an Insomnia Severity Index (ISI) [26] score > 14. To ensure the enrollment of enough hyperaroused ID participants, we also required all of those in the insomnia cohort to report an inability to nap in the daytime, have a Hyperarousal Scale [27] (HS) score $\geq$ 29, and have an Epworth Sleepiness Scale (ESS) score $\leq$ 3 [28,29]. Classification into the normal sleeper group included reporting a general satisfaction with sleep and no sleep/wake complaints, denying a practice of routine daytime napping and having an ESS score $\leq$ 10, an ISI score $\leq$ 7, and a HS score $\leq$ 25. Excluded from the project were those with: (a) a sleep-disruptive medical condition (eg, rheumatoid arthritis); (b) a current major psychiatric (Axis I) condition on the basis of a Structured Clinical Interview for Psychiatric Disorders (SCID) [24]; (c) a score of <27 on a screening Mini Mental Status Exam [30] (d) sedative or hypnotic dependence and unwillingness/inability to abstain from these medications while in the study; (e) use of anxiolytics, antidepressants, or any other psychotropic medication; or (f) an apnea/hypopnea index (AHI) > 15 or a periodic limb movement-related arousal index (PLMAI) > 15 during on a screening home-based polysomnogram. Additionally, self-described NS who met criteria for any sleep disorder and those insomnia sufferers who met criteria for a comorbid sleep disorder in addition to insomnia were also excluded.

A sample of 35 individuals with insomnia disorder and 54 normal sleepers voluntarily enrolled and completed all study procedures. As described below, the ID and NS groups were each subdivided into "alert" and "sleepy" subgroups based on their Multiple Sleep Latency Test performances for subsequent study comparisons. Demographic and psychometric characteristics of the samples are provided in Table 1. As shown, the ID and NS groups were generally comparable in their demographic features with the exception of the ID group being significantly older than the NS group. They also differed on the various psychometric measures as preordained by the study selection criteria.

1.3. Polysomnography

Immediately prior to daytime testing, all participants underwent two consecutive nights of polysomnography (PSG) conducted

Table 1
Demographic and psychometric comparisons of the participant subgroups.

variable	Participant group (A)				Analyses of variance results F & P values for variables with continuous distributions		
	Insomnia disorder		Normal sleeper				
	Alertness level(B)[a]		Alertness level(B)				
	Alert	Sleepy	Alert	Sleepy	A	B	A x B
Age in Years Mean (SD)	42.6 (14.6)	35.7 (12.2)	29.9 (9.0)	32.8 (11.5)	**F = 7.89** **P = 0.005**	F = 0.50 P = 0.48	F = 3.14 P = 0.08
Insomnia Severity Index score Mean (SD)	17.7 (3.2)	16.3 (1.0)	1.8 (1.6)	2.0 (1.7)	**F = 880.91** **P < 0.0001**	F = 1.65 P = 0.20	F = 3.40 P = 0.07
Epworth Sleepiness Scale score- Mean (SD)	2.0 (1.1)	2.3 (0.9)	4.2 (2.3)	5.1 (2.3)	**F = 31.32** **P < 0.0001**	F = 1.76 P = 0.19	F = 0.54 P = 0.47
Hyperarousal Scale Score Mean (SD)	37.6 (9.3)	40.9 (8.0)	21.4 (3.7)	21.5 (4.0)	**F = 146.02** **P < 0.0001**	F = 1.32 P = 0.25	F − 1.19 P = 0.28
MSLT Mean Sleep Latency (min)	14.14 (2.91)	3.96 (0.49)	12.50 (0.60)	4.73 (0.31)	F = 0.53 P = 0.47	**F = 212.44** **P < 0.0001**	F = 3.900 P = 0.051
					Analyses of categorical variables- Fisher exact test P values		
Number of Females/Males	18/7	7/3	15/9	23/7	P = 0.72		
Race	Asian − 1 African American − 2 White − 21 Mixed − 1	Asian − 0 African American − 0 White − 10 Mixed − 0	Asian − 1 African American − 1 White − 20 Mixed − 2	Asian − 0 African American − 1 White − 27 Mixed − 2	P = 0.96		
Education Level	2 High School 3 Associates Degree 18 Bachelor Degree 2 Master Degree 0 Doctors Degree	2 High School 3 Associates Degree 18 Bachelor Degree 2 Master Degree 0 Doctors Degree	2 High School 3 Associates Degree 18 Bachelor Degree 2 Master Degree 0 Doctors Degree	2 High School 3 Associates Degree 18 Bachelor Degree 2 Master Degree 0 Doctors Degree	P = 0.37		

Note.
[a] Alertness level based on mean MSLT sleep latencies with "Alert" indicating a mean MSLT latency >8 min and "Sleepy" indicating a mean MSLT latency ≤8 min; Statistical results that are significant are highlighted with **bold** type.

in their homes. All PSGs were conducted using Alice-PDX® ambulatory recording devices equipped with expansion yokes. The first night focused on gathering sleep staging data and screening out participants exceeding the above-mentioned AHI and PLMAI cut-offs for study inclusion. This montage included electroencephalogram (EEG) channels (FPZ, C_4-M_1, O_1-M_2), bilateral electrooculogram (EOG), chin electromyogram (EMG), two channels of anterior tibialis EMG (right and left leg), a nasal-oral thermistor, two respiratory effort belts across the chest and abdomen, and a pulse oximeter. The second night focused on gathering sleep-staging data only; therefore, the montage only contained the aforementioned EEG, EOG, and chin EMG channels. All PSGs were scored using the American Academy of Sleep Medicine scoring criteria [31] for assignment of sleep stages, identification of respiratory events (eg, apneas, hypopneas), and identification of periodic limb movements and periodic limb movement-related arousals. In addition to the screening data, mean values of time in bed (TIB) total sleep time (TST), sleep onset latency (SOL), wake time after sleep onset (WASO), sleep efficiency (SE), and time spent in N1, N2, N3, and REM sleep were derived from the two PSGs. These variables were collected to compare the study groups and for use in exploratory analyses not related to this study.

1.4. Multiple Sleep Latency Test (MSLT)

All participants underwent a four-trial MSLT [32] immediately following their two nights of PSG monitoring. We chose to conduct a four-trial MSLT rather than the conventional five-trial protocol so as to limit subject burden and time requirements for participants to complete our daytime testing. The first nap commenced two to 3 h after participants woke up from their second night of PSG monitoring, with each subsequent nap occurring at 2 h intervals. For each nap, participants were placed in a private, darkened room in the sleep laboratory and instructed to attempt to fall asleep. Sleep onset latency for each nap was defined as the time between the beginning of the nap trial and either (1) three consecutive 30 s epochs of N1 sleep, or (2) the first 30 s epoch of any other stage of sleep. Since extended daytime sleeping has been shown to lengthen subsequent MSLT nap latencies [33] we used a procedure employed in our previous research [15] and stopped each nap trial 5 min after the sleep onset criterion was met to minimize carry-over effects from one nap to the next. If no sleep occurred, the trial was terminated at 20 min and a sleep latency of 20 min was assigned.

1.5. Neurocognitive testing

All study participants completed four trials of a series of six computer-administered tasks selected from the Cambridge Neuropsychological Test Automated Battery (CANTAB) [34]. Participants completed testing in a quiet, private room. They were seated in front of a touch screen computer tablet equipped with the testing software and had comfortable access to a press pad accessory used for reaction time tasks. The study coordinator (CJB) was also present in the room and provided verbal instructions for each task. The computer recorded all test responses and the CANTAB software calculated multiple response latency and accuracy measures for each of the tests. The tasks alternated between simple tasks (eg, Simple Reaction Time, Choice Reaction Time, Big/Little Circle) and more complex tasks (eg, Rapid Visual Information Processing, Attention Switching Task, Spatial Working Memory). They are presented below in the order the tests appeared for participants.

1.5.1. Simple reaction time (SRT)

This task measured simple reaction time using a press pad device. The participant was instructed to press a button on the press pad whenever the stimulus (ie, a white square) appeared on the screen. The stimulus appeared at a variable interval between the

trial response and the onset of the next stimulus. Participants completed a 24 trial practice phase followed by two 50 trial assessment phases. Average response latency was calculated across both assessment phases (ie, average time to press the button from the time the stimulus appears). Administration time for this test was about 5 min.

1.5.2. Rapid Visual Information Processing (RVP)

The RVP measured visual sustained attention and captured responses using a press pad device. A white box appeared in the center of the computer screen with digits 2 to 9 appearing in a pseudo-random order at a rate of 100 digits per minute. First, participants underwent a 2-min training phase wherein they looked for the target sequence 3-5-7 and pressed a button when they saw the last number of that target sequence. After the training phase, participants underwent a 4-min assessment phase wherein they looked for the target sequences 2-4-6, 3-5-7, and 4-6-8, and again, pressed a button whenever they saw the last number of any of the three target sequences. For scoring purposes, the CANTAB test calculated the number of responses recorded as having occurred within 1800 ms of the final digit presentation for each of the target sequences. Administration time for this test was about 8 min.

1.5.3. Choice reaction time (CRT)

The CRT was a two-choice reaction time test similar to the SRT, but introduced stimulus and response uncertainty by having two possible stimuli and two possible responses. An arrow shaped stimulus was displayed on either the left or right side of the screen. Using a press pad, participants pressed the left hand button if the stimulus appeared on the left side of the screen and the right hand button if it appeared on the right side. Participants began with a practice phase of 24 trials, followed by two assessment phases, each containing 50 trials. Administration time for this test was about 3 min.

1.5.4. Attention switching task (AST)

The AST was a test of executive functioning that provided a measure of cued attentional set-shifting using response time captured on a press pad device. On each trial, an arrow appeared on either the left or right hand side of the screen. A cue command of “direction” or “side” was presented at the top of the screen indicating whether the participant should make a response about the direction the arrow was pointing or the side of the screen on which the arrow appeared. For some trials, side and arrow direction were congruent (eg, a left-facing arrow appearing on the left side of the screen), and for others, side and arrow direction were incongruent (for example, a left-facing arrow appearing on the right side of the screen). This test provided a practice block before each assessment to teach the participant which cue they should follow. The practice block provided auditory feedback as to whether they pressed the correct button based on the cue. First, participants were instructed to press the appropriate press pad button (left or right) according to the *direction* the arrow was pointing; this meant they had to ignore the side of the screen on which it appeared. Next, participants pressed the button according to the *side* of the screen the arrow appeared, which meant ignoring the direction the arrow was pointing. Finally, participants were prompted before each cue to focus on either the *direction or side*, causing their attentional set to shift from cue to cue. Administration time for this test was about 8 min.

1.5.5. Big/little circle (BLC)

The BLC was a simple, visual discrimination test of attention. The test was designed to train a participant to follow a simple rule (eg, “touch the little circle”) and then a reverse rule (eg, “touch the big circle”). The participant was presented with a screen containing one big circle and one little circle per trial; after each trial, the circles randomly switched sides (eg, the big circle appears on the left during trial 1, the right during trial 2, the right during trial 3, etc.). Participants were first instructed to touch the little circle (20 trials) and then instructed to touch the big circle (20 trials). Administration time for this test was about 2 min.

1.5.6. Spatial working memory (SWM)

The SWM measured a participant's ability to retain spatial information and to manipulate remembered items in working memory. The test began with a number of colored boxes on the screen, beginning with 3 boxes and increasing to 10 boxes. The number of boxes on the screen determined how many tokens must be located. Once a token was found, participants placed it in a “home” area to indicate how many they found and how many more they needed to find. The computer hid only one token at a time, so participants only focused on locating one token at a time. Once a token was found in a box, the computer never hid another token in that box again. Participants decided the order in which the boxes were searched, and they needed to create their own heuristic strategy to determine, through process of elimination, where all of the tokens were located. The color and position of boxes were changed from trial to trial to discourage the use of stereotyped search strategies. Participants began with 3 training trials, each with 3 boxes, followed by 8 assessed trials increasing in difficulty using two sets of the following: 4 boxes, 6 boxes, 8 boxes, and 10 boxes. Administration time for this test was about 7 min.

1.6. Procedure

All participants underwent a home-based PSG test to determine if they had any respiratory-related or periodic limb movement events exceeding our inclusion criteria. Those who continued to meet inclusion criteria completed a second, consecutive home-based PSG. The following morning, they came to the institution's sleep laboratory to complete daytime performance tasks and the four-trial MSLT under the supervision of trained laboratory technologists and the study's project coordinator (CJB). The two PSG nights and subsequent day of laboratory testing were conducted on either Tuesday through Thursday or Wednesday through Friday. When participants arrived for the daytime laboratory testing, they were attached to a full montage of PSG electrodes. Participants then underwent a 30-min neurocognitive test battery with the study coordinator (CJB). Afterwards, the laboratory technologists checked and readjusted electrodes (if necessary) to ensure an acceptable transmission signal and then provided the participant instructions to complete the first MSLT trial. This sequence of neurocognitive tests followed by a MSLT trial was repeated until four MSLT trials were complete, with each MSLT trial beginning 2 h after the last trial began. Participants were monitored between trials to prevent unscheduled sleep episodes. After the last trial, the laboratory technologist removed all of the electrodes and the participant was allowed to leave the laboratory. Fig. 1 shows the sequence of procedures each participant underwent during the day of laboratory testing.

2. Results

2.1. Preliminary analyses

All study analyses were conducted using the Statistical Analysis System (SAS) version 9.3. Prior to conducting our main study analyses, we first conducted a preliminary analysis to test the

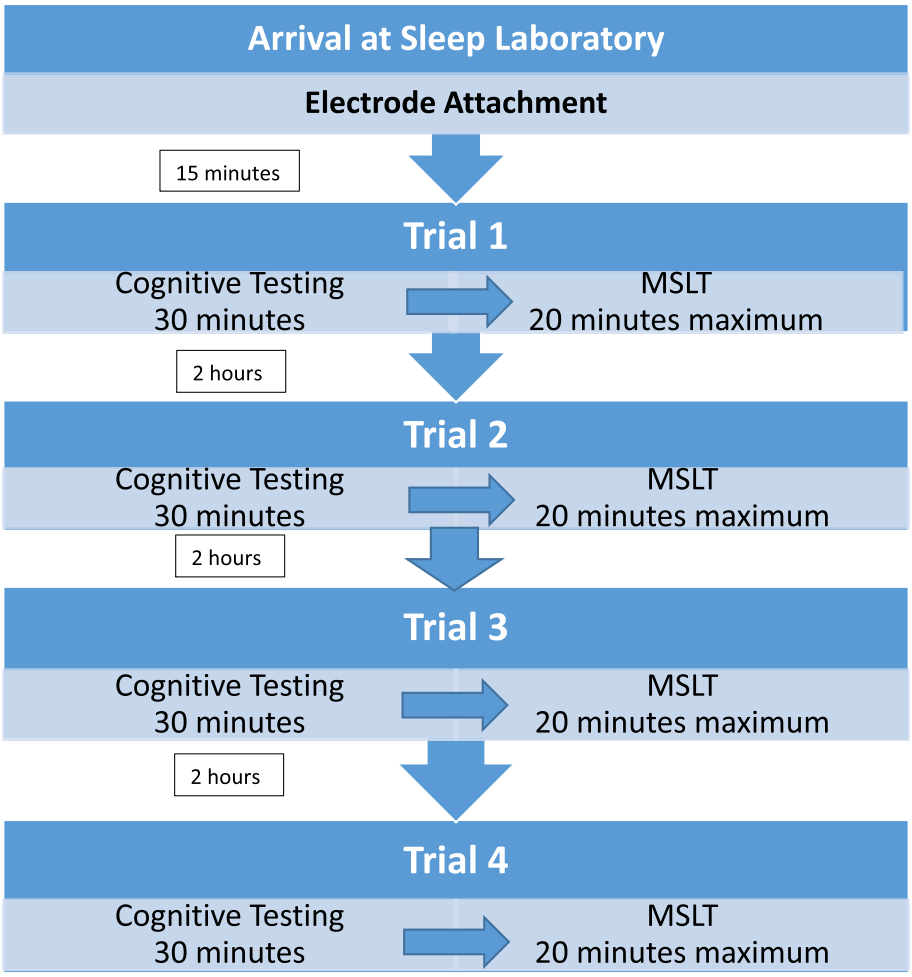

Fig. 1. The Figure shows the numbers of participants falling in each MSLT mean sleep latency subgroup. Insomnia = participants meeting criteria for insomnia disorder; Normal = participants classified as normal sleepers. The numbers included at the upper end of each bar is the number of participants falling in each subgroup. For example, there were 4 participants with insomnia and 12 participants in the normal sleeper group who had mean MSLT latencies falling in the 0–4 min range, etc.

effectiveness of our selection criteria for enrolling a sample of physiologically hyperaroused insomnia sufferers and normally alert NS controls. To do so, we computed mean MSLT nap latencies for each participant and then constructed a frequency distribution of those nap latencies for the insomnia and normal control groups. The frequency distribution of these latencies for each group is shown in Fig. 2. These data clearly show a wide distribution of latencies across the pathologically sleepy and normally alert ranges for each of the study groups. Given these findings, we concluded that our selection criteria in general and use of the hyperarousal scale [27] in particular did not result in the enrollment of an ID cohort that uniformly appeared physiologically hyperaroused. Our selection criteria also did not lead to the enrollment of a uniformly alert NS group, at least as measured by MSLT results. In fact, a sizable proportion of the normal sleeper group appeared excessively sleepy in the daytime. Given these findings, we resorted to the strategy used in our prior study [15] of this nature and used mean MSLT latencies to subdivide our sample into alert and sleepy subgroups. Specifically, we classified all participants who had mean MSLT latencies >8 min as "alert" whereas those whose mean MSLT latencies were ≤8 min were classified as sleepy. We chose this particular MSLT threshold since it is the one suggested in the Third Edition of the International Classification of Sleep Disorders [35] to separate those with and without pathological daytime sleepiness. As a result of this procedure, 25 of our insomnia group and 24 of our normal group were classified as "alert," whereas the remaining 10 in the insomnia group and 30 in the normal group fell in the "sleepy" category. MSLT mean sleep latencies of the alert and sleepy subgroups of persons with ID and those comprising the normal sleeper group have been included in Table 1.

2.2. Polysomnographic findings

A multivariate 2 (insomnia vs. normal sleeper) x 2 (alert vs. sleepy) x 9 (sleep measures) multivariate analysis of variance was conducted to compare the four subgroups on mean values of the various sleep measures derived from polysomnography. Due to the noted age differences between the insomnia and normal sleeper groups, age was used as a covariate in this analysis. Results of this analysis showed significant main effects for participant group ($F[1, 84] = 9.93$, $p = 0.0023$) and alertness level ($F[1,84] = 5.09$, $p = 0.0267$ as well as a significant group x alertness level interaction ($F[1,84] = 4.08$, $p = 0.0466$). Given these findings we conducted follow-up univariate analyses of variance to identify subgroup differences for each of the sleep measures. The age-adjusted mean and standard error values of the various sleep measures for the participant subgroups are shown in Table 2 along with results of the univariate tests conducted. Results of these

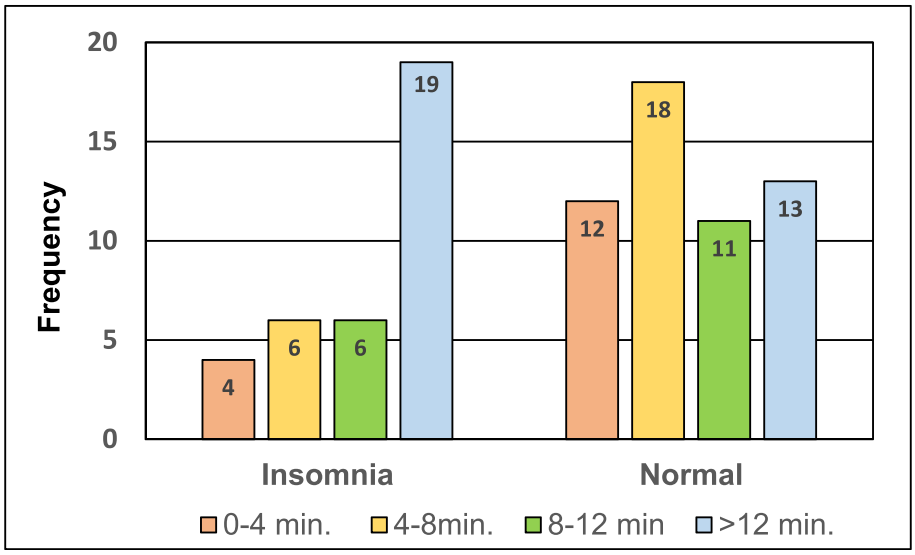

Fig. 2. Distribution of mean MSLT latencies across groups.

Table 2
Age adjusted mean and standard error values of measures derived from two PSG nights for the participant subgroups.

variable	Participant Group (A)				Analysis of Variance Results F (DF = 1, 84) & P values[a]		
	Insomnia Disorder		Normal Sleeper				
	Alertness Level (B)		Alertness level (B)				
	Alert n = 25	Sleepy n = 10	Alert n = 24	Sleepy n = 30	A	B	A x B
Time in Bed	446.7 (10.3)[a]	386.4 (15.4)[b]	450.1 (10.2)[a]	438.7 (8.9)[a]	**F = 5.62** **P = 0.020**	**F = 10.04** **P = 0.002**	**F = 4.54** **P = 0.036**
Total Sleep Time	360.5 (14.0)	315.7 (21.0)	381.7 (13.9)	388.9 (12.2)	**F = 8.63** **P = 0.004**	F 1.49 P = 0.226	F = 2.76 P = 0.101
Onset Latency	33.6 (4.9)	23.9 (7.3)	16.5 (4.9)	13.6 (4.3)	**F = 5.94** **P = 0.017**	F = 1.37 P = 0.245	F = 0.0.39 P = 0.536
Wake after Onset	52.2 (8.3)	46.8 (12.5)	52.2 (8.3)	36.8 (7.2)	F = 0.28 P = 0.600	F = 1.28 P = 0.262	F = 0.29 P = 0.595
Sleep Efficiency	80.1 (2.3)	81.8 (3.5)	84.7 (2.3)	88.9 (2.04)	**F = 4.39** **P = 0.039**	F = 1.08 P = 0.300	F = 0.16 P = 0.690.
N1 Time	34.0 (3.1)	25.2 (4.6)	36.8 (3.0)	30.2 (2.7)	F = 1.28 P = 0.262	**F = 5.24** **P = 0.025**	F = 0.10 P = 0.749
N2 Time	182.4 (9.9)	160.0 (14.8)	209.3 (9.8)	218.8 (8.6)	**F = 14.20** **P = 0.0003**	F = 0.35 P = 0.554	F = 2.08 P = 0.153
N3 Time	69.4 (5.1)	65.4 (7.6)	66.4 (5.1)	68.2 (4.4)	F = 0.00 P = 0.951	F = 0.04 P = 0.893	F = 0.26 P = 0.614
REM Time	66.9 (5.8)	64.7 (8.6)	72.7 (5.7)	79.5 (5.0)	F = 2.42 P = 0.123	F = 0.13 P = 0.723	F = 0.48 P = 0.491

Note: Participants classified as "Alert" had a mean MSLT latency of >8 min whereas those classified as "Sleepy" had a mean MSLT latency of ≤8 min. All values listed in the table are minutes except for sleep efficiency which is a percentage. Values shown are means and standard error terms in parentheses. Values of time in bed that share the same superscript letter were not found to be significantly different from each other based on *a posteriori* comparisons conducted.

[a] Significant statistical results are shown in **bold** type.

analyses showed those with ID had less total sleep time, longer sleep onset latencies, lower sleep efficiencies and less time in stage N2 sleep than did the normal sleepers. Those classified as "alert" had significantly more stage N1 sleep than did the participants classified as "sleepy." Finally, *a posteriori* comparisons conducted to examine subgroup differences connoted by the significant group x alertness level interaction found for time in bed showed that the sleepy insomnia group spent significantly less time in bed than did the other three subgroups.

2.3. Performance test findings

Prior to conducting our planned group comparisons with the performance data, we examined the distributions of each measure obtained from the various performance tests. Those measures with distributions that departed markedly from normal distributions were subjected to common data transformation operations (logarithmic, exponential, etc.) to provide more normal distributions required for parametric analyses. However, we noted that many of the measures of error and correct response rates were highly skewed with most participants obtaining identical scores on them. Since these measures could not be normalized and did not provide sufficient variance to discriminate among our participant subgroups, they were dropped from consideration in our final analyses. Those measures retained for our analyses are listed in Table 3. Additionally, we have provided a table showing the subgroup raw score means and standard deviations of all measures acquired including those dropped from our analyses as supplementary

Table 3
Summary of performance measures retained for analyses.

Simple tasks	Measures retained for analyses	Abbreviations used in tables
Simple Reaction Time (SRT)	Mean response latency across trials	SRT_Latency
	Mean SD response latency across trials	SRT Latency SD
	# correct responses across trials	SRT_Correct
	# commission errors across trials	SRT_CME
Choice Reaction Time (CRT)	Mean response latency across trials	CRT_Latency
	Mean SD response latency across trials	CRT_Latency SD
	# correct responses across trials	CRT_Correct
	# incorrect responses across trials	CRT_Incorrect
Big Circle Little Circle (BLC)	Mean response latency across trials	BLC_Latency
Complex Tasks		
Rapid Visual Information Processing (RVP)	Mean response latency across trials	RVP_Latency
	Mean SD response latency across trials	RVP_Latency SD
	# of "hits" across trials	RVP_Hits
	# of "misses" across trials	RVP_Miss
	# of "false alarms" across trials	RVP_Fa
Attention Switching Test (AST)	Mean response latency across trials	AST_Latency
	Mean SD response latency across trials	AST_Latency SD
	Mean # correct responses across trials	AST_Correct
	Mean # incorrect responses across trials	AST_Incorrect
	Mean consistency and congruency cost	AST_Cost
Spatial Working Memory (SWM)	Total # of errors across trials	SWM_Total Errors
	Total Between Errors	SWM Between Errors
	Total Within Errors	SWM Within Errors
	Total Double Errors	SWM Double Errors
	Mean latency to 1st response across	SWM MEANFRTOTAL
	Mean SD of latency to 1st response	SMW SDFRTOTAL
	Mean latency to last response	SWM MEANLRTOTAL
	Mean SD of latency to last response	SWM SDLRTOTAL

Note: Commission errors are responses that are too early. "Hits" refer to the number of occasions upon which the target sequence is correctly responded to within a response window of 1800 ms "Misses" refer to the number of occasions the subject fails to respond to a target sequence within the response window. "False alarms" refer to the number of times a subject responds outside the response window of a target sequence. SWM Total errors is the number of times a box is selected that is certain not to contain a blue token and therefore should not have been visited by the subject; SWM between errors are defined as times the subject revisits a box in which a token has previously been found; SWM Between errors Has possible values for n are 4, 6 and 8 in the clinical mode, specified using the Box option. This measure calculates the results for those trials containing the number of boxes specified by n only; SWM Within errors are defined as the number of errors made within a search, ie, the number of times a subject revisits a box already found to be empty during the same search; SWM Double errors These are occasions where the subject has committed an error that can be categorized as both a within and a between error. This is calculated for all trials of four or more tokens only.

material to this report. As expected, non-parametric Wilcoxon Tests showed no significant differences among the subgroups on any of the measures dropped from our main study analyses.

The remaining measures were subjected to multivariate analyses of variance. We conducted one 2 (insomnia vs. normal sleeper) x 2 (alert vs. sleepy) x 9 (measures) multivariate analysis of variance using the group of measures derived from the simple performance tests, and a second 2 (insomnia vs. normal sleeper) x 2 (alert vs. sleepy) by 18 (measures) such analysis with the group of measures derived from the more complex performance tests. To protect against Type 1 error, we used a $p = 0.025$ (ie $0.05 \div 2$) to assign statistical significance to the main and interaction effects tested in these two omnibus analyses. Additionally, we relied on the Greenhouse-Geisser adjusted p values for tests of repeated measures main and interaction effects. Subsequently, we conducted 2 (insomnia vs. normal sleeper) x 2 (alert vs. sleepy) univariate analyses of variance with the various performance measures to follow-up any significant main or interaction effects shown in the multivariate analyses.

Results of the multivariate analysis of the simple performance task measures showed a significant main effect for alertness level ($F\ [1, 84] = 8.52$, $p = 0.0045$) as well as a significant alertness level × measure interaction ($F\ [1, 84] = 7.08$, $p = 0.0074$). Table 4 shows the statistical model's age-adjusted means and standard error terms for the nine simple performance test measures included in our multivariate analysis as well as results of our follow-up univariate tests for the significant main effect of participant alertness level. These data show that the participants classified as sleepy, by virtue of their MSLT performances, had significantly longer average response latencies on the choice reaction time, greater response latency variability (suggestive of attentional lapses) on both the simple reaction time and choice reaction time tasks and fewer correct responses and more incorrect responses on the choice reaction time task than did those classified as alert. Thus, performance on the simple performance tasks was dictated by level of daytime alertness and not by the presence vs. absence of an insomnia disorder.

In contrast to these findings, the multivariate analysis of the complex reaction time test measures showed a significant overall effect ($F\ [1,84] = 6.62$, $p = 0.012$) for participant type (ID vs. normal sleeper) and a significant participant type × measure interaction ($F\ [17, 1428] = 6.62$, $p = 0.012$). Table 5 shows the age-adjusted means, standard error terms and results of univariate tests of participant group (Insomnia vs. Normal Sleeper) main effects for measures obtained from the complex tests. As shown by the results in the table, those with ID had longer mean and more variable response latencies as well as fewer correct responses on the Attention Switching Test (AST) than did the normal sleepers. Also the ID group has a greater error proneness as reflected by their performances on the AST and Spatial Working Memory test. Thus, performance on the more complex tasks administered was dictated by presence vs. absence of an insomnia disorder and not by participants' levels of daytime alertness.

3. Discussion

The current study was conducted to examine the effects of daytime alertness and ID on laboratory-based simple and complex

Table 4
Age-adjusted means, standard error terms and results of univariate tests of main effects of participants' alertness levels for their simple test performances.

Performance measure	Alert group			Sleepy group			F (1, 84) & P values For Univariate Main Effects of Alertness Level
	Insomnia Disorder (A)	Normal Sleeper (B)	Subgroups A + B	Insomnia Disorder (C)	Normal Sleeper (D)	Subgroups C + D	
SRT_CT	99.72 (0.10)	99.62 (0.10)	99.67 (0.07)	99.40 (0.15)	99.61 (0.09)	99.50 (0.09)	F = 2.44 P = 0.12
SRT CME	0.28 (0.10)	0.38 (0.10)	0.33 (0.07)	0.60 (0.15)	0.39 (0.09)	0.50 (0.09)	F = 1.52 P = 0.22
SRT Latency	279.38 (9.66)	264.27 (9.58)	271.83 (6.55)	281.99 (14.47)	274.73 (8.40)	278.11 (8.36)	F = 0.70 P = 0.41
SRT Latency SD	61.04 (4.36)	62.01 (4.33)	61.52 (2.96)	78.55 (6.53)	64.99 (3.79)	71.77 (3.77)	**F = 4.53** **P = 0.04**
CRT Latency	331.20 (8.83)	301.02 ((8.76)	316.11 (5.99)	340.67 (13.23)	332.37 (7.68)	336.52 (7.64)	**F = 4.40** **P = 0.04**
CRT Latency SD	63.08 (4.24)	50.36 (4.21)	57.02 (2.88)	74.03 (6.35)	61.68 (3.69)	67.86 (3.67)	**F = 5.39** **P = 0.03**
CRT _CT	49.89 (0.05)	49.83 (0.08)	49.86 (0.04)	49.62 (0.08)	49.76 (0.05)	49.69 (0.05)	**F = 7.25** **P = 0.009**
CRT_ICT	0.11 (0.05)	0.17 (0.05)	0.14 (0.04)	0.37 (0.08)	0.23 (0.05)	0.31 (0.05)	**F = 6.46** **P = 0.01**
BLC Latency	520.97 (12.99)	492.93 (12.89)	506.95 (8.81)	545.68 (19.46)	520.13 (11.30)	532.91 (11.24)	F = 3.38 P = 0.07

Note: SRT = Simple Reaction Time Test; CRT = Choice Reaction Time Test; BLC = Big/Little Circle Test; CME = Commission Errors; CT connotes correct responses; ICT connotes incorrect responses. Latency indicates mean latency per trial whereas as Latency SD indicates the average within trial standard deviation of response latencies. All values shown are means (and SEs) averaged across the four testing trials. F values shown are for the main effect of alertness level obtained from univariate AONVAs. Bolded F and P values connote a significant test result.

measures of cognitive performance and to further explore the impact of physiological hyperarousal on these measures. Specifically, we tested the main and interacting effects of daytime alertness level and ID on the range of performance measure considered herein. Overall, our findings showed that daytime alertness/sleepiness, not the presence vs. absence of ID, affected performance on simple reaction time tasks. In this regard, the group of persons with ID and normal sleepers who appeared excessively sleepy on the MSLT performed more poorly on these simple tasks than did the group of persons with ID or normal sleepers who had normal, more alert MSLT results. In contrast, it was the presence vs. absence of ID that affected performances on more complex and mentally demanding cognitive tests. In responding to such tasks, the ID group as a whole had slower and more variable response latencies, produced fewer correct responses and had more errors than did the normal sleepers as evidenced by $^{1}/_{3}$ of the performance measures obtained from these tests. These deficits were specifically noted on attention switching tests and some measures of spatial working memory. Collectively, these findings replicate our prior studies {Edinger, 2008; Edinger, 2013 #80} and those of others [11–14] in documenting deficits of persons with ID on laboratory measures of cognitive performance. Moreover, these findings demonstrate that complex and more demanding tests are required to document the subtle cognitive impairment associated with ID.

In contrast to our previous findings [15], we did not find that our alert ID participants had the worst test performances on any of the measures used herein compared to our other participant groups including those normal sleepers showing normal MSLT sleep latencies. Given our prior findings and those of others [11], we had suspected that persons with ID and normal MSLT latencies would comprise a physiologically hyperaroused ID subgroup whose arousal level would compromise their cognitive test performances. As such, we expected this subgroup to perform significantly worse than would the other subgroups particularly on the complex tests used in this study. However, our study analyses did not suggest this to be the case. Reasons for differences between our previous study and the current one are unclear but it should be noted that the much larger sample included in our previous study may have provided more power for detecting the specific deficits manifest by hyperaroused persons with ID. We also should note that the MSLT is not a direct measure of physiological hyperarousal and, hence, may represent an unreliable method for detecting this phenomenon. If so, the ID subgroup labeled as "alert" in this study may not actually have had the underlying physiological hyperarousal presumed. If so, then future studies investigating this characteristic in those with ID may benefit by more direct measures of arousal such as cortisol assays or heartrate variability [36,37].

Perhaps among the more surprising findings from this study is the sizable subset of our study participants who appeared excessively sleepy on the MSLT. The MSLT results of the sleepy ID group may in part be due to the fact that this group had the lowest average amount of total sleep time on their nocturnal PSGs. Their ability to fall asleep so quickly on the MSLT despite their relative inability to sleep at home may represent a paradoxical response to sleeping in a novel laboratory environment away from the conditioned cues for poor sleep that are present in the home setting. In contrast, the sleepy normal group did not appear to evidence any relative sleep deficits on their PSGs when compared to the other three subgroups. In fact, they evidenced the longest average sleep time, least time awake per night and highest sleep efficiencies of all the subgroups. Moreover, they all produced normal scores on the Epworth Sleepiness Scale (ESS) and they did not report a practice of routine daytime napping. Yet along with the sleepy ID group, which did evidence marked sleep disturbance and short sleep on their PSGs, this sleepy group of non-complaining normal controls, showed deficits on simple performance tasks. The significance of MSLT findings in this group remains unclear. It may be that they have the easiest time sleeping when they desire to do so but do not have intrusive sleeping that interferes with their daytime activities. In contrast, they may be chronically sleep restricted people, hard driving and perhaps fairly caffeinated during the day, so they do not report proneness to sleep on the ESS but are able to sleep readily during the MSLT. In addition, this group may be prone to underestimate their daytime sleepiness and cognitive deficits, and they may actually require more sleep than they typically obtain. Unfortunately, the data obtained herein do not help determine if any of these speculations are correct so further research of these sleepy groups is necessary.

Table 5
Age-Adjusted Means, Standard Error Terms and Results of Univariate Tests of Participant Group (Insomnia vs. Normal Sleeper) Main Effects for Measures from the Complex Tests.

Performance measure	Insomnia disorder group			Normal sleeper group			F (1, 84) & P values For Univariate Main Effects of Participant Type
	Alert Insomnia Group (A)	Sleepy Insomnia Group (B)	Subgroups A + B	Alert Normal Group (C)	Sleepy Normal Group (D)	Subgroups C + D	
AST_CT	154.77 (0.70)	154.57 (1.05)	154.67 (0.63)	157.30 (0.70)	156.28 0.61	156.79 (0.47)	**F = 7.48** **P = 0.008**
AST_ICT	4.94 (0.69)	5.29 (1.04)	5.12 (0.62)	2.55 (0.69)	3.54 (0.60)	3.05 (0.46)	**F = 6.13** **P = 0.02**
AST_COST	56.00 (5.45)	57.07 (8.16)	56.54 (4.92)	43.84 (5.41)	45.60 (4.74)	44.73 (3.64)	F = 3.57 P = 0.06
AST_Latency	533.26 (15.87)	531.44 (23.77)	532.35 (14.32)	462.05 (15.75)	510.75 (13.81)	488.90 (10.60)	**F = 5.69** **P = 0.02**
AST_Latency SD	227.69 (10.56)	215.60 (15.81)	221.64 (9.53)	178.76 (10.48)	202.36 (9.19)	190.56 (7.06)	**F = 6.58** **P = 0.01**
RVP_Miss	4.98 (0.56)	5.61 (0.84)	5.30 (0.51)	4.41 (0.56)	5.68 (0.49)	5.05 (0.38)	F = 0.15 P = 0.70
RVP_Hit	22.00 (0.56)	21.39 (0.84)	21.69 (0.51)	22.58 (0.56)	21.32 (0.50)	21.95 (0.38)	F = 0.16 P = 0.69
RVP_Fa	0.95 (0.26)	0.53 (0.39)	0.74 (0.23)	1.15 (0.26)	1.14 (0.23)	1.14 (0.17)	F = 1.84 P = 0.18
RVP_Latency	378.24 (11.74)	408.16 (17.58)	393.20 (10.60)	371.27 (11.65)	406.12 (10.21)	388.70 (7.84)	F = 0.11 P = 0.74
RVP_Latency SD	113.17 (11.62)	146.68 (17.41)	129.92 (10.49)	112.72 (11.53)	132.76 (10.11)	122.74 (7.76)	F = 0.12 P = 0.73
SWM_Total Errors	21.67 (2.85)	34.35 (4.26)	28.01 (2.53)	21.23 (2.82)	21.50 (2.48)	20.85 (1.87)	**F = 4.14** **P = 0.04**
SWM Between Errors	21,29 (2.80)	33.84 (4.19)	27.57 (2.53)	20.59 (2.78)	21.10 (2.44)	20.84 (1.87)	**F = 4.37** **P = 0.04**
SWM Within Errors	1.08 (0.36)	1.67 (0.54)	1.37 (0.33)	2.40 (0.36)	1.45 (0.32)	1.93 (0.24)	F = 0.57 P = 0.45
SWM Double Errors	0.69 (0.29)	1.16 (0.43)	0.92 (0.26)	1.77 (0.28)	1.04 (0.25)	1.41 (0.19)	F = 1.06 P = 0.31
SWM MEANFRTOTAL	1245.91 (107.14)	1449.36 (160.45)	1347.63 (96.72)	1468.69 (106.31)	1513.07 (93.20)	1490.88 (71.57)	F = 1.06 P = 0.31
SWM SDFRTOTAL	419.58 (89.43)	494.87 (133.93)	457.23 (80.73)	593.96 (88.73)	561.18 (77.80)	505.07 (59.74)	F = 0.60 P = 0.44
SWM MEANLRTOTAL	28537.63 (1324.05)	32182.23 (1982.85)	30359.93 (1195.24)	29023.75 (1313.73)	29071.11 (1151.81)	29047.43 (884.43)	F = 1.04 P = 0.31
SWM SDLRTOTAL	17894 (1013.72)	21348 (1518.10)	19639.16 (915.09)	18515.29 (1005.81)	18140.49 (881.85)	18327.84 (677.13)	F = 1.54 P = 0.22

Note: AST = Attention Switching Test; RVP = Rapid Visual Information Processing; SWM = Spatial Working Memory.
See Table 3 for definitions of specific measures listed.

The current findings add to our previous work and have a number of important implications in understanding ID and planning for future ID research. First, this study along with previous findings [10,11,15] indicate that there are measureable daytime performance deficits among persons with ID but those deficits are revealed only with some of the more demanding and complex types of tests used herein. Tests typically used in neuropsychological assessment of persons with suspected brain impairment or damage are not optimal for identifying such deficits. Secondly, not all reaction time tasks are equally sensitive to the daytime deficits seen in ID patients. As noted by our findings, only a subset of the complex test measures obtained showed differences between our ID and normal subgroups. Thirdly, it appears that different sorts of reaction time tasks may be needed to identify the deficits shown by sleepy and ID groups. More simple and boring tasks may be needed for the sleepy group, whereas more complex tasks involving a heavy cognitive load may be needed for the ID group. Finally, considering this latter implication, researchers may need to be selective in choosing tests for ID patients enrolled in clinical trials if daytime performance measures are included as outcomes in such trials.

Admittedly this study had a number of limitations that merit consideration. The study sample was at best moderate in size and included a relatively small number of insomnia sufferers. In addition, the sample was largely comprised of Caucasians who were young or middle aged adults, so the findings may not generalize to more ethnically diverse samples of older and younger age groups. We also acknowledge that we used a limited range of reaction time tasks to assess daytime cognitive performance and only a subset of these showed group differences. We chose the tests used on rational grounds with an attempt to limit subject burden during the study procedures. Nonetheless, it is possible that a longer and more diverse set of tasks may have revealed more relative deficits for our ID subgroups than shown herein. We also should note that cognitive testing in the laboratory is a contrived situation that may not fully reveal the cognitive deficits persons with ID may show in their typical day-to-day settings. Perhaps cognitive deficits noted in such settings would be different or perhaps more pronounced. If so, efforts to obtain cognitive assessments in such settings perhaps through wearable devices or other methods of momentary event monitoring may be useful. Despite these limitations, our results serve to corroborate our previous results [10,15] and suggest relative deficits in sleepy individuals and among persons who meet criteria for ID. Additional studies with a larger range of daytime tests as well as clinical trials that target the deficits noted would appear useful.

Funding

This study was funded by the investigator initiated grants program of Merck Sharp & Dohme, Corporation, Grant # 2786.

Financial Disclosure Statement

JDE has received previous funding from Merck and donated sleep recording equipment from Philips-Respironics. The other authors have no disclosures relevant to this study.

Nonfinancial disclosure

None.

Acknowledgements

The authors would like to thank Philips Respironics, Inc, for donating the Alice PDX polysomnographic recorders and software used in the project. The views expressed herein are exclusively those of the authors and do not reflect the views of Merck Sharp & Dohme, Corporation or Philips Respironics, Inc.

Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2021.08.004

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2021.08.004.

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