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Longitudinal course of insomnia: Age-related differences in subjective sleepiness and vigilance performance in a population-based sample

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ABSTRACT

Objective: The present study utilized a population-based sample investigating the following aims: (1) compare the longitudinal course of insomnia in middle-aged and older adults and (2) examine age-related differences on subjective complaint and objective performance in middle-aged and older adults based on the course of insomnia.

Methods: 1657 middle-aged adults (48.16% male, mean age = 55.35 ± 4.03 years) and 405 older adults (48.40% male, mean age = 70.13 ± 3.88 years) from the Korean Genome and Epidemiology Study (KoGES) were classified into 4 groups — no insomnia (NI), single episode insomnia (SEI), remitted persistent insomnia (PI-R), and ongoing persistent insomnia (PI-O) based on their course of insomnia over 5 time points spaced two years apart. Their performance on the psychomotor vigilance task (PVT) and subjective daytime sleepiness were compared across different insomnia groups, and the results were compared between middle-aged adults and older adults.

Results: Analysis of covariance indicated that subjective daytime sleepiness was significantly different across the insomnia groups in middle-aged adults based on insomnia group ($P = <.0001$), but, did not affect objective vigilance performance. In contrast, older adults displayed significantly different PVT response time, but not daytime sleepiness, based on insomnia group ($P = 0.03$).

Conclusion: Insomnia impacts psychomotor performance and subjective sleepiness differently, based on age group. There may be underlying processes associated with the aging that amplifies the impact of insomnia on vigilance performance, yet lessens perceived sleepiness in older adults.

Introduction

Insomnia is a prevalent sleep disorder worldwide and also one of the most common health problems affecting the general population [1]. As a condition characterized by difficulty initiating sleep, difficulty maintaining sleep, early morning awakenings, and non-restorative sleep, insomnia leads to aversive daytime consequences and social impairment in various settings [2]. Both the International Classification of Sleep Disorders (ICSD-2) [3] and the Diagnostic and Statistical Manual of Mental Disorders-4th edition (DSM-IV) [4] identify impaired daytime functioning as a crucial part of diagnosing insomnia, and thus, determining the dimensions and the degree of how insomnia affects waking performance poses a critical public health concern [5].

Previous findings from insomnia research have found that the effects of insomnia, such as increased fatigue, depression, anxiety, and vigilance, may differ across different age groups [6]. The aging process is an important consideration for insomnia research because despite unchanging sleep need in older adults, aging results in significant changes in sleep architecture, and older adults may find it more challenging to obtain sleep need [7,8]. Previous epidemiologic data revealed that insomnia is present in 12–25% of older adults (age ≥ 65 years) [9], and this number poses an important public health issue because of the detrimental consequences (i.e., injury from falls, motor vehicle accidents) of insomnia on daily functioning commonly associated with vigilance and attention [10,11].

Most studies that have explored age-related differences in response to sleep disturbance have focused on acute sleep deprivation in a laboratory settings, with the main findings indicating that older people are more resilient to sleep loss [7,12]. For example, a study by Adam et al. [12] revealed that older men (mean age = 66.4 years) were better able to maintain stable performance on a psychomotor vigilance task

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(PVT) during a 40-hour sleep restricted schedule compared to younger men (mean age = 25.2). Similarly, Duffy et al. [7] demonstrated that older adults (mean age = 68.1) display faster response time and fewer attentional failures in PVT and lower levels of daytime sleepiness as compared with younger adults (mean age = 21.9) under a sleep-restricted schedule. The authors concluded that the aging process is associated with the ability to sustain vigilance and alertness, which result from reduced sleep need and homeostasis [7,13].

However, insomnia is distinctly different from sleep deprivation in that the core of an insomnia diagnosis consists of inadequate sleep quality despite adequate opportunity and circumstances for sleep. While it is certainly true that the daytime consequences of insomnia may be explained by partial chronic sleep deprivation, the daytime symptoms that accompany insomnia are not only ascertained by lack of sleep. Thus, it is possible that the effects of insomnia on a psychomotor vigilance task in older adults may be different when compared to the effects of sleep deprivation.

While there is ample anecdotal evidence for daytime impairment in insomnia patients, studies investigating performance impairments with insomnia patients have been equivocal [14]. Several laboratory-based studies conducted with insomnia patients have reported that documenting daytime deficits of insomnia patients is rather elusive and difficult [15]. On the other hand, several studies [14,16,17] have shown that individuals with insomnia display relative psychomotor performance deficits as compared with normal sleepers. Additionally, there is a lack of evidence that supports age-related psychomotor deficits from insomnia. Only one study done by Raymann et al. [17] explored PVT in the context of both insomnia and aging, where they conducted a 7-minute PVT protocol on 8 sex-matched young adults (mean age = 27.0), older adults (mean age = 65.8), and individuals with insomnia (mean age = 59.1). In this study, older adults had significantly slower response time only if they had insomnia. While this study was limited by their small sample size, the authors concluded that slow response speeds during PVT in older adults may be due to age-related sleep disturbance commonly found in older adults, and not merely aging itself. While sleep deprivation had no effect on older adults, findings from this study raise a possibility that insomnia may result in significant psychomotor deficits in older adults.

Previous studies that have used both subjective and objective test measurements have shown a discrepancy between subjective complaint and objective performance in individuals with insomnia [18,19]. However, these findings were primarily based on samples of adults aged ≤65, and thus there is a lack of information on whether older adults with insomnia also experience a discrepancy between subjective and objective symptomatology. One common characteristic of insomnia in older adults is a discrepancy between subjective reports of sleep and objective measures (i.e. PSG) [20]. Thus, we predicted that older adults displaying insomnia symptoms would also show different functional outcomes depending on the observed domain of impairment (subjective vs. objective).

Additionally, evidence from various community-based studies [5,21–23,25] suggests that insomnia is a chronic condition with high rates of persistence and remission, and longitudinal observations may produce findings that better represent the natural course of insomnia in the general population. Consistent with previous findings that persistent insomnia is associated with more adverse functioning outcomes [24,25], it is possible that having persistent insomnia, defined by two or more episodes of insomnia, could result in greater subjective and objective impairment compared to good sleepers or single episode insomnia.

In the current study, we utilized a representative population sample from the Korean Genome and Epidemiology Study (KoGES) and investigated age-related differences based on subjective sleepiness and psychomotor vigilance in middle-aged adults and older adults. The current study extends from previous studies by studying a population-based sample and utilizing longitudinal data for determining longitudinal course of insomnia.

The current study had two aims: (1) to compare the longitudinal course of insomnia and the characteristics of ongoing persistent insomnia in middle-aged and older adults and (2) to examine age-related differences on subjective complaints and objective performance in middle-aged and older adults based on the longitudinal course of insomnia. Thus, we tracked the course of insomnia over 10 years (5 assessments) and investigated its relationship with outcome measures in middle-aged and older adults. To the best of our knowledge, no studies have compared subjective sleepiness and psychomotor vigilance in the context of aging based on the longitudinal course of insomnia in a population-based sample.

Methods

Participants and procedure

Subjects for the present study were selected from the participants of KoGES, which is a prospective cohort study that started in 2001. Study designs and procedures have been previously reported [26]. 5020 Korean male and female adults aged 40–60 years were recruited at baseline to participate in the biennial health examinations that include a range of demographic, medical, and sleep-related factors. All health examinations were administered at Korea University Ansan Hospital after participants signed an informed consent form that was approved by the Human Subjects Review Committee at Korea University Ansan Hospital.

In 2003, a questionnaire targeting the presence and duration of insomnia symptoms was introduced into the KoGES battery and administered during every on-site visit thereafter. PVT was included in 2010 and was administered on 3052 individuals from March 2011 to November 2012. We selected a subset of participants (n = 2216) who completed the baseline insomnia questionnaire and all of the follow-up examinations up to the 6th evaluation. A total of 154 participants were excluded from the study due to being a shift worker (n = 79), having a history of dementia (n = 2), cerebrovascular disease (n = 33), traumatic head injury (TBI; n = 1), and incomplete data (n = 39). Thus, analyses were conducted on 2062 participants who met all of the above criteria. (see Fig. 1).

Definitions of insomnia

We assessed the presence of insomnia according to the four symptomatic domains of insomnia that are indicated in the DSM-IV: difficulty in initiating sleep, difficulty in maintaining sleep, early morning awakening, and non-restorative sleep. Each domain was assessed using a 4-point Likert scale representing the frequency of the symptoms (i.e. never, once or twice a week, three or four times a week, and more than 5 times a week). Insomnia was defined by a presence of at least one of the symptoms occurring at least 3 times a week. This questionnaire was administered during all of the follow-up visits by trained interviewers.

For the purpose of this study, we further classified individuals into four groups based on the frequency of insomnia episodes during baseline and follow-up time points: (1) “no insomnia” (NI; no insomnia during baseline or any of the follow-up time points), (2) “single episode insomnia” (SEI, insomnia at one time point), (3) “persistent insomnia-in remission” (PI-R; insomnia at two or more points but not at the time of testing), and (4) “persistent insomnia-ongoing” (PI-O; insomnia at 2 ≤ time points, including the time of testing).

Perceived daytime sleepiness

The Epworth Sleepiness Scale (ESS) was used to detect the level of subjective sleepiness and was administered during the morning

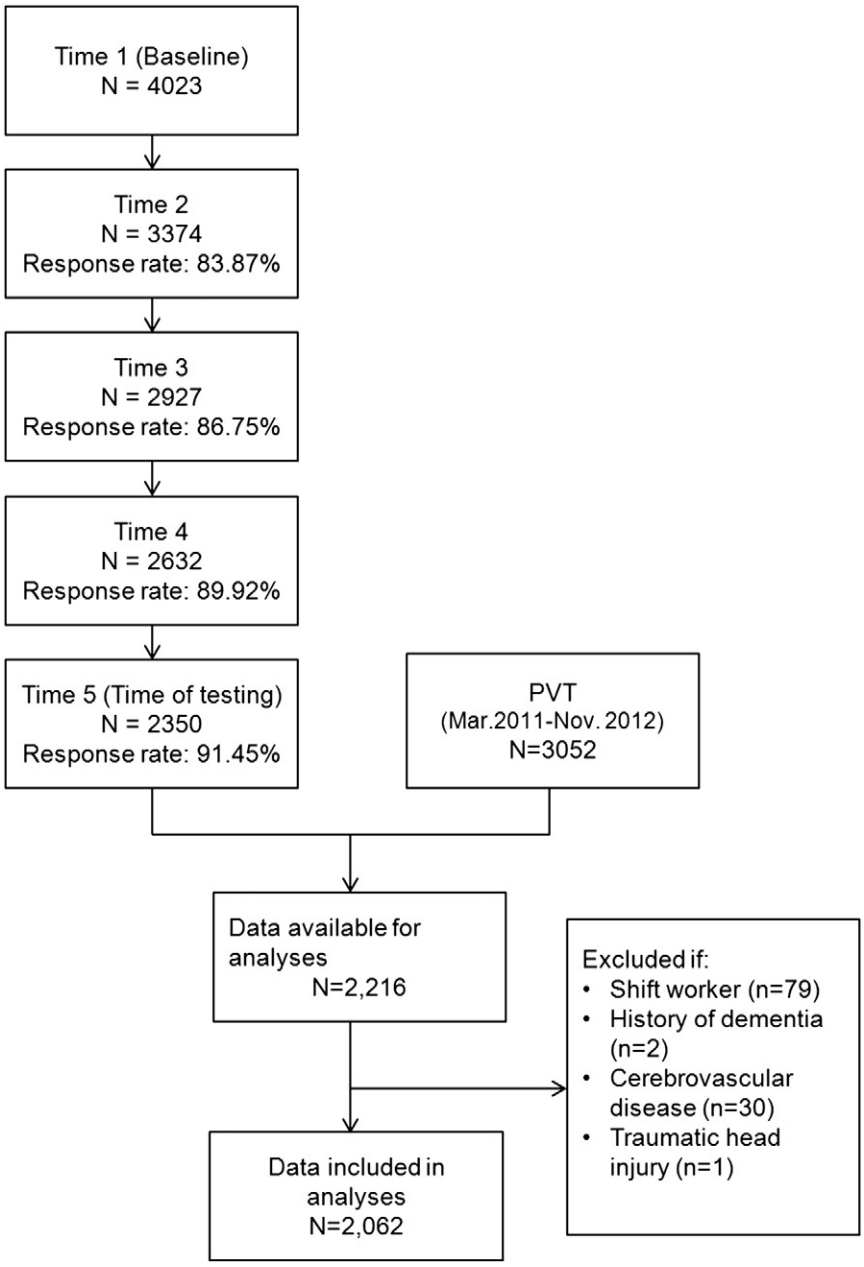

Fig. 1. Participants' flowchart.

(8:00 A.M.–12:00 P.M.) of the comprehensive examination [27]. The questionnaire asks 8 questions on the participant's likelihood of falling asleep in different situations (e.g., watching a movie, driving a vehicle), and participants make their answer choice based on a 4-point Likert scale. The total score is derived from the participant's response to the questions and higher score indicates higher level of daytime sleepiness. The ESS has been widely used in various sleep research settings [27] and has been validated in Korean language [28].

Objective psychomotor vigilance task (PVT) performance

Psychomotor vigilance and sustained attention were measured with a standardized 10-minute PVT protocol [29] from 8:00 A.M.–1:00 P.M. of the examination date. Subjects were instructed to press a response button as soon as a visual stimulus (red dot) appeared on the screen. Their response time (RT) was represented in milliseconds (ms), and RT ≥ 500 ms was counted as lapses (errors of omission). We also obtained 1/RT (reciprocal response time) by dividing each RT by 1000 and then reciprocally transforming these values. An average of these transformed values was presented as a single outcome "mean 1/RT", and same procedures were followed to obtain "fastest 10% 1/RT" (mean 1/RT of the fastest 10% performances) and "slowest 10% 1/RT" (mean 1/RT of the slowest 10% performances). Reciprocally transformed RT values well reflect decreasing speed of the responses and intermediate response variables without overlapping with long lapses, and are thus used as sensitive measures of sleep loss [29]. We also used Tukey transformed values $(\sqrt{x}+\sqrt{x+1})$ of the lapses for analyses.

Other measurements

Information on medical history and information on physiological measurements were obtained during the health examinations and

a questionnaire-based interview. Hypertension was defined when participants were taking antihypertensive medication or were presented with systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg. Diabetes mellitus was defined as taking insulin or hypoglycemic medications or fasting glucose ≥125 mg/dL. Information on sleep medications was taken from a self-reported list of medications or the response, "three or more times a week" to the question, "During the past month, how often have you taken medicine to help you sleep?".

Statistical analysis

Between-group comparisons (NI, SEI, PI-R, and PI-O) of various demographic values, ESS scores, and PVT scores were presented as mean and standard deviation or as frequency count and percentages. Continuous variables were contrasted with analysis of variance (ANOVA) or the Kruskal–Wallis test, and categorical variables were contrasted using the chi-square test. ANOVA was used to see univariate group differences in ESS and PVT performances, and analysis of covariance (ANCOVA) was applied for multivariate comparisons adjusting for sex, education level, BMI, current smoking, heavy drinking, and sleep medicine. Linear trends were tested using the generalized mixed model, and post-hoc group comparisons were made with the Tukey test. All statistical tests were conducted using the SAS software (SAS Institute, Cary, North Carolina). P-values less than 0.05 were considered to be significant for all analyses.

Results

General characteristics

General characteristics of the study sample (n = 2062, 994 male) are presented in Table 1 and compared across the different insomnia groups by middle-aged (age range = 49–64, mean age = 55.35 ± 4.03) and older (age range = 65–79, mean age = 70.13 ± 3.88) adults. Female gender, education level, sleep duration, and use of sleep medication were significantly associated with insomnia in middle-aged adults, (P's < 0.050) but only female gender and use of sleep medication were associated with insomnia in older adults (P < .001). Sleep duration was also significantly different across the insomnia groups, with NI having the longest average hours of sleep and PI having the shortest hours of sleep during the past month (P < .0001). Additionally, older adults were presented with more episodes of insomnia (1.90 ± 1.08) as compared with middle-aged adults (1.69 ± 0.94), although their difference was marginally significant (P = 0.07).

Age-related differences based on the longitudinal course of insomnia

As shown in Table 1, there was a higher proportion of middle-aged adults in the PI (33.19%) groups compared to the SEI group (21.12%), and the similar trend was observed in older adults (23.46% SEI vs. 38.51% PI groups). Among individuals with PI, there was a higher proportion of ongoing PI (PI-O) as compared with PI in remission (PI-R) for both age groups (56.18% vs. 43.82% in middle-aged adults and 55.13% vs. 44.87% in older adults). The PI-O group had a high percentage of females and used sleep medication more frequently.

To compare insomnia characteristics within the PI-O group, separate analyses were conducted (Table 2). Middle-aged individuals who had PI-O presented lower education level, higher prevalence of hypertension, diabetes, and use of sleep medication as compared with older individuals with PI-O (P's < 0.05) (data not shown). Older adults had a higher proportion of difficulty initiating sleep (61.63% vs. 44.04%, P = 0.004) and difficulty maintaining sleep (48.84% vs. 35.60%, P = 0.03), but had a lower proportion of nonrestorative sleep (58.14% vs. 70.87%, P = 0.03). Additionally, the total number of insomnia symptoms and episodes across five time points did not differ between age groups (P's > 0.05).

Comparison of subjective sleepiness in the insomnia groups

Associations between insomnia and ESS are presented in Table 3 based on different age groups. In middle-aged adults, scores were significantly different across the insomnia groups, with PI-O showing the highest score (5.91 ± 3.71), followed by PI-R (5.86 ± 3.37), SEI (5.26 ± 3.27), and NI (4.74 ± 2.75) (P < .0001). Multivariate analyses adjusting for covariates also revealed a significant independent association between ESS and insomnia groups (P < .0001), and post-hoc multiple comparisons showed significant between-group differences between NI, SEI, and PI groups (P's < 0.05), but difference between PI-R and PI-O groups were not statistically significant (P < 0.94). ESS scores in older adults were not significantly different either by the presence of insomnia or different insomnia groups (P = 0.85).

Comparison of PVT performances in the insomnia groups

Table 4 shows the results from PVT performances by the insomnia groups. In middle-aged adults, mean 1/RT and slowest 10% were different across the groups (P's < 0.05) but adding covariates to the model attenuated statistical significance. However, mean 1/RT in older adults were significantly different across the insomnia groups, (3.59 ± 0.40 in NI, 3.84 ± 0.45 in SEI, 3.41 ± 0.57 in PI-R, and 3.34 ± 0.59 in PI-O; P = 0.03), and significant group differences were found between NI and SEI, as well as PI-O (P's < 0.05). The fastest 10% was also different across the groups in older adults (P = 0.03), and the NI group showed significantly high performance in comparison to both SEI (P = 0.01) and PI-O (P = 0.02).

Discussion

This study assessed the impact of insomnia on psychomotor performance and daytime sleepiness in the context of aging, utilizing a community-dwelling sample representing the Korean population. When comparing middle-aged and older adults with insomnia, older adults with ongoing persistent insomnia were more likely to be females, have lower education levels, have higher prevalence of physical illness, and have lower physical quality of life than middle-aged adults with persistent insomnia. Additionally, there was a phenomenological difference of insomnia symptoms in older adults with ongoing persistent insomnia, with older adults having more difficulty initiating sleep, maintaining sleep and early morning awakenings compared to middle-aged adults.

Table 1
General characteristics of the study sample (n = 2062)

	Middle-aged adults (age range = 49–64) (n = 1657, 80.36%)				Older adults (age range = 65–79) (n = 405, 19.64%)			
	NI	SEI	PI-R	PI-O	NI	SEI	PI-R	PI-O
	(n = 757)	(n = 350)	(n = 241)	(n = 309)	(n = 154)	(n = 95)	(n = 70)	(n = 86)
Age (mean SD)	55.21 ± 3.97	55.20 ± 3.88	55.86 ± 4.23	55.47 ± 4.17	69.76 ± 3.84	70.14 ± 4.05	70.25 ± 3.90	70.65 ± 3.81
Sex (male n, %)[a,b]	406 (53.63%)	165 (47.14%)	109 (45.23%)	118 (38.19%)	89 (57.79%)	54 (56.84%)	24 (34.29%)	29 (33.72%)
BMI (mean SD)	24.84 ± 2.96	24.59 ± 2.82	24.47 ± 2.61	24.61 ± 2.87	24.62 ± 2.82	25.10 ± 3.43	24.85 ± 3.20	24.16 ± 2.89
Education level[a]								
Elementary or less	43 (5.69%)	24 (6.86%)	30 (12.45%)	25 (8.09%)	34 (22.52%)	26 (27.66%)	23 (32.86%)	25 (29.07%)
Middle and high school	493 (65.21%)	231 (66.00%)	173 (71.78%)	234 (75.73%)	81 (52.60%)	51 (54.26%)	35 (50.00%)	52 (60.47%)
College or above	220 (29.10%)	95 (27.14%)	38 (15.77%)	50 (16.18%)	39 (25.32%)	17 (18.09%)	12 (17.14%)	9 (10.47%)
Sleep medication (n, %)[a,b]	0 (0.00%)	3 (0.86%)	5 (2.07%)	10 (3.24%)	1 (0.65%)	2 (2.11%)	3 (4.29%)	10 (11.63%)
Hypertension	277 (36.59%)	119 (34.00%)	78 (32.37%)	126 (40.78%)	96 (62.34%)	58 (61.05%)	47 (67.14%)	60 (69.77%)
Diabetes (n, %)	167 (22.06%)	89 (25.43%)	48 (19.92%)	77 (24.92%)	65 (42.21%)	35 (36.84%)	26 (37.14%)	37 (43.02%)
Sleep duration in hours (Mean SD)[a,b]	6.32 ± 1.03	6.12 ± 1.07	5.97 ± 1.22	5.34 ± 1.30	6.29 ± 1.13	6.08 ± 1.18	6.00 ± 1.31	5.11 ± 1.49

NI = no insomnia, SEI = single episode insomnia, PI-R = persistent insomnia-in remission, and PI-O = persistent insomnia-ongoing.
[a] Significant group difference in middle-aged adults (P < 0.01).
[b] Significant group difference in older adults (P < 0.01).

Table 2
Insomnia subtypes in the ongoing persistent insomnia group at endpoint (n = 395)

Insomnia characteristics	Middle-aged adults (age 49–64; n = 309)	Older adults (age 65–79; n = 86)	P-value
Insomnia subtype, n (%)			
Difficulty initiating sleep (DIS)	136 (44.01%)	53 (61.63%)	0.004
Difficulty maintaining sleep (DMS)	110 (35.60%)	42 (48.84%)	0.03
Early morning awakening (EMA)	73 (23.62%)	28 (32.56%)	0.09
Non-restorative sleep (NRS)	219 (70.87%)	50 (58.14%)	0.03
Total number of insomnia symptoms, n (%)			0.12
1	168 (54.37%)	39 (45.35%)	
2	75 (24.27%)	18 (20.93%)	
3	44 (14.24%)	17 (20.93%)	
4	22 (7.12%)	11 (12.79%)	
Total episode of insomnia, n (%)	3.60 ± 1.10	3.73 ± 1.07	0.33

Psychomotor performance was not significantly different between individuals who had single episodes or persistent episodes of insomnia over the 10 year period. This suggests that even a single episode of insomnia may have a significant impact on psychomotor performance. The most prominent difference was found between those in the persistent insomnia and no insomnia group. Nonetheless, our analysis with ESS in middle-aged adults indicated that having PI resulted in a significantly elevated level of sleepiness than having SEI or no insomnia. Current status of insomnia in the persistent insomnia groups had significant difference in levels of excessive daytime sleepiness, suggesting the possibility that the course of insomnia—aside from the presence of the condition currently—may affect perceived sleepiness in middle-aged adults.

Differences between age groups were observed based on multiple longitudinal observations of insomnia symptoms over 10 years, with middle-aged and older adults exhibiting differences in subjective and objective outcomes affected by insomnia symptoms. More specifically, our results indicate that middle-aged adults are more likely to have subjective daytime complaints reflected by higher excessive daytime sleepiness scores based on varying degrees of insomnia persistence compared to older adults. However, insomnia did not affect their performance on a psychomotor vigilance task, regardless of insomnia persistence. In contrast, older adults showed the opposite results. Older adults displayed significantly slower response speed during a psychomotor vigilance task based on whether they had ongoing persistent, remitted persistent, single, or no insomnia symptoms, and those in the ongoing persistent insomnia subgroup showed the slowest response speed. This suggests that insomnia has the strongest detrimental effect in psychomotor vigilance in older adults who have persistent insomnia with current insomnia status. However, subgroups did not differ on subjective daytime complaints in older adults.

Previous studies designed to investigate the effect of insomnia on psychomotor performance have produced conflicting results, mostly resulting from limited sample sizes and laboratory settings, and a lack of an attempt to document age-related discrepancy in psychomotor deficits that result from insomnia. This study extends previous studies by observing both subjective complaints and objective performance utilizing a large sample size in a population-based sample, with both middle-aged and older age groups. Our results are consistent with past studies that have simultaneously investigated objective and subjective consequences of insomnia and demonstrated that there is a discrepancy between subjective complaints and objective performance in young or middle-aged individuals with insomnia (age ≤ 65) [18,19]. While these studies have consistently demonstrated that objective performance was unaffected by the presence of insomnia, our study provides novel finding on the older adult population who exhibited impaired vigilance performance in the absence of increased level of subjective sleepiness.

These results on psychomotor performance and insomnia in older adults were similar to the previous observations of Raymann et al.'s study [16] which also showed that insomnia resulted in poorer PVT performance in older adults. Under constant routine conditions of keeping participants in a fixed body position, elderly insomniacs displayed a slower response speed and earlier drop in vigilance with increasing time. However, in that study, older adults without sleep complaints had only a marginally less fast response time than did younger adults without sleep problems. While other previous findings have indicated age-related psychomotor impairment in older adults [11,30], our study also confirmed that older adults have relatively slower PVT performance as compared with that of younger adults, regardless of the presence of insomnia symptoms. Further studies may be required to clarify the relationship and interaction between insomnia symptoms and the aging process, but our results suggest that psychomotor performance decreases with age, and insomnia may exacerbate this detrimental effect.

Psychomotor deficits related to insomnia and old age point to underlying brain processes, which may relate to the functioning of the prefrontal cortex. Previously, insomnia in older adults has been linked with performance deficits related to the prefrontal cortex, and namely, impairment in attention and psychomotor vigilance [9,31]. The prefrontal cortex has been highlighted as a brain region especially vulnerable to both sleep deprivation and aging [32,33]. Moreover, an fMRI study [34] has revealed prefrontal hypoactivation in elderly insomnia patients, providing further evidence for decreased functioning of prefrontal cortex in insomnia. Poorer PVT performance found in our older adults with insomnia may also reflect interference in the prefrontal region during a daytime performance, because PVT involves components of executive functioning that has been related to this particular cortical system [35].

The cognitive reserve theory provides a possible explanation as to why objective performance is affected by insomnia in older adults but not in middle-aged adults in our study. Cognitive reserve refers to the phenomenon in which the ability to compensate for disease-induced neural dysfunction is determined by one's premorbid cognitive abilities [36]. Older adults generally require additional brain activity to perform cognitive tasks at the same level as middle-aged adults,

Table 3
Level of daytime sleepiness by insomnia groups

		NI	SEI	PI-R	PI-O	P-value[a]
Middle-aged adults (age < 65)	n	757	350	241	309	
	ESS	4.74 ± 2.75	5.26 ± 3.27[b]	5.86 ± 3.37[c]	5.91 ± 3.71[c,d]	<.0001
Older adults (age ≥ 65)	n	154	95	70	86	
	ESS	4.19 ± 3.16	4.52 ± 3.63	4.53 ± 3.04	4.90 ± 4.15	0.85

NI = no insomnia, SEI = single episode insomnia, PI-R = persistent insomnia-in remission, PI-O = persistent insomnia-ongoing, and ESS = Epworth Sleepiness Scale.
[a] P-value adjusted for sex, education level, BMI, sleep medication, hypertension, and diabetes.
[b] Significant difference (P < .05) from no insomnia group.
[c] Significant difference (P < 0.01) from no insomnia group.
[d] Significant difference (P < 0.05) from SEI group.

Table 4
Psychomotor vigilance task (PVT) performance by insomnia groups

	Outcome variable	NI	SEI	PI-R	PI-O	P-value[a]
Middle-aged adults (age < 65)	n	757	350	241	309	
	Mean 1/RT	3.87 ± 0.40	3.84 ± 0.45	3.82 ± 0.39	3.80 ± 0.38	0.77
	Lapses	2.47 ± 1.45	2.67 ± 1.84	2.60 ± 1.54	2.58 ± 1.44	0.47
	Fastest 10%	4.86 ± 0.45	4.86 ± 0.49	4.82 ± 0.44	4.82 ± 0.45	0.97
	Slowest 10%	2.53 ± 0.42	2.48 ± 0.48	2.48 ± 0.45	2.45 ± 0.44	0.55
	RRT slope	−0.03 ± 0.04	−0.03 ± 0.05	−0.03 ± 0.04	−0.03 ± 0.04	0.15
Older adults (age ≥ 65)	n	154	95	70	86	
	Mean 1/RT	3.59 ± 0.47	3.42 ± 0.53[b]	3.41 ± 0.57	3.34 ± 0.59[b]	0.04
	Lapses	3.61 ± 2.07	4.18 ± 3.04	4.40 ± 2.96	4.58 ± 3.15	0.36
	Fastest 10%	4.64 ± 0.50	4.44 ± 0.55[b]	4.48 ± 0.63	4.38 ± 0.61[b]	0.03
	Slowest 10%	2.16 ± 0.52	2.07 ± 0.59	2.02 ± 0.57	1.99 ± 0.57	0.58
	RRT slope	−0.03 ± 0.05	−0.02 ± 0.06	−0.04 ± 0.05	−0.02 ± 0.06	0.31

NI = no insomnia, SEI = single episode insomnia, PI-R = persistent insomnia-in remission, and PI-O = persistent insomnia-ongoing.
[a] P-value after adjusting for age, sex, education, BMI, moderate-heavy drinking, sleep medication, hypertension, and diabetes.
[b] Significant difference (P < 0.05) from no insomnia group.

and are less able to maintain functioning during clinical conditions such as insomnia [6,37]. Previous research focusing on sleep disorders and cognitive reserve [38,39] has also demonstrated a negative correlation between premorbid cognitive abilities and the degree of impairment resulting from sleep disturbance. Additionally, our sample of middle-aged adults had higher education level than older adults and displayed faster reaction time, which provides support that middle-aged adults may have had higher cognitive reserve to cognitively compensate on a psychomotor vigilance task.

Because PVT is a well-known measure of vigilance and sustained attention, as well as psychomotor performance [29], one might assume that decreased performance in older adults may parallel with perceived lack of vigilance, and consequently, increased level of sleepiness. However, our results indicate that subjective sleepiness is not affected by insomnia in older adults, a finding consistent with previous studies [11]. Evidence suggests that it is rare for older adults to complain from increased daytime sleepiness in the presence of both sleep deprivation [7] and insomnia [11], which may be due to the fact that the aging process is associated with changes in adenosine signal transmission that results in declined sense of sleep need and reduced vulnerability to sleep loss [40].

Age-related changes in the SWS stage as well as decreased sleep duration could also contribute to the ability to tolerate sleep-deprived condition in older adults [7,41]. Previous studies with PSG demonstrated a strong relationship between SWS and arousal during sleep, which results in reduced sleep efficiency and continuity [41]. Declined sleep duration and continuity in older adults slow the rate at which sleep needs build up during prolonged wakefulness, thus enable them to tolerate sleep loss [7,13].

This study represents one of the largest longitudinal data on insomnia and its association with daytime sleepiness and vigilance performance. Nonetheless, there are some methodological limitations that must be considered. Our criteria for determining insomnia followed the symptomatology described in the DSM-IV, but due to a lack of information on interference of daily functioning and the duration of insomnia symptoms, exact disorder definitions could not be ascertained in our insomnia categorization. However, many previous epidemiology studies have used similar methods where they determined insomnia by the frequency of symptoms, and the prevalence of insomnia in our data is comparable with those previous reports from Korea [42].

Another limitation is that participants' responses to the insomnia questionnaire may not be representative of their sleep patterns over the entire 10-year interval because the reference point for insomnia symptoms was the previous month and it is difficult to determine whether any change had occurred in their sleep patterns between biennial examinations. However, considering that most insomnia symptoms persist over one year, our study is based on the assumption that our 2-year interval for each time point accurately reflects the natural history of insomnia. This is evident when comparing the longitudinal course of insomnia from our sample to Western samples [5,25].

It is also worth noting that a major limitation to this study is that we were not able to evaluate the presence of obstructive sleep apnea, narcolepsy, or other common sleep disorders.

In conclusion, our results suggest that the consequences of insomnia vary by age group, and that there may be a mechanism associated with the aging process that could amplify the impact of insomnia on vigilance performance yet lessen perceived sleepiness in older adults. Further research with advanced brain imaging techniques may facilitate our understanding of the role of aging in insomnia and daytime functioning and the underlying mechanisms of age-related and insomnia-related changes in cognitive performance.

Conflict of interest statement

Hyun Kim, Sooyeon Suh, Eo Rin Cho, Hae-Chung Yang, Chang-Ho Yun, SeungKu Lee, and Chol Shin have no conflicts of interest to disclose.

Dr. Thomas is the co-inventor and patent holder of the ECG-derived sleep spectrogram (for phenotyping sleep quality and central/complex sleep apnea; licensed by Beth Israel Deaconess Medical Center to MyCardio, LLC). He is also the co-inventor and patent holder of the Positive Airway Pressure Gas Modulator (for treatment of central and complex sleep apnea) and a consultant in software development for DeVilbiss.

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