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Regular Article

Information processing during sleep and stress-related sleep vulnerability

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Aims: Previous studies showed enhanced attention and decreased inhibitory processes during early non-rapid eye movement sleep in primary insomnia patients, as measured by event-related potentials. The current study aims to examine information processing during sleep in non-insomniac individuals with high vulnerability (HV) to stress-related sleep disturbances.

Methods: Twenty-seven non-insomniac individuals were recruited, 14 with low vulnerability and 13 with HV. After passing a screening interview and polysomnographic recording, subjects came to the sleep laboratory for 2 nights (a baseline night and a stress-inducing night) for event-related potentials recordings.

Results: The HV group demonstrated shorter P2 latency during the first 5 min of stage 2 sleep and higher P900 amplitudes under the stress condition during slow-wave sleep, which indicates an increased level of inhibitory processes. In addition, they had shorter N1 latencies during slow-wave sleep that could indicate an elevated level of attention processing during deep sleep.

Conclusions: Unlike patients with chronic insomnia, individuals with high sleep vulnerability to stress show a compensatory process that may prevent external stimulation from interfering with their sleep. This may be one of the factors preventing their acute sleep disturbances from becoming chronic problems.

Key words: event-related potential, information processing, insomnia, stress-related sleep vulnerability.

HYPERAROUSAL HAS BEEN well recognized to be a major causative factor in chronic insomnia patients. Research has shown that individuals with insomnia appear to be hyperaroused physiologically and cognitively. For instance, insomnia patients showed a higher level of autonomic nervous system activities, as indicated by higher body temperature,[1] heart rate,[2] and metabolic rate,[3,4] and reported more ruminative thoughts as well as cognitive activities prior to sleep.[5,6]

Perlis *et al*. proposed a hyperarousal hypothesis for insomnia from a neurocognitive perspective.[7] The hypothesis suggests that sleep difficulties in patients with primary insomnia are associated with elevated information processing around sleep onset. This increased information processing is associated with higher levels of cortical and cognitive arousal, which may result from a conditioned association between bedroom cues and hyperarousal. The hypothesis is primarily supported by the demonstration of elevated beta- and gamma-band electroencephalography (EEG) power prior to and during sleep in insomnia patients.[8–11] More recently, Yang and Lo utilized event-related potential (ERP) to show that, compared with control subjects, insomnia patients have elevated N1, attenuated P2 and N350, as well as a slower P900 in the early part of non-rapid eye movement (NREM) sleep.[12] Similarly, Bastien *et al*. reported an elevated N1 in the evening and the following morning, and a lower N350 at sleep onset in insomnia patients.[13] As the N1 is an attention-related

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component, and P2, N350, and P900 are inhibition-related components, these results suggest that patients with insomnia are inclined to have increased arousal and decreased inhibition around bedtime and after EEG-defined sleep onset.

Although cortical hyperarousal has been consistently supported as a characteristic of patients with chronic insomnia, little is known about whether cortical hyperarousal is a predisposing trait associated with the vulnerability to sleep disturbances or is resulted from chronic experiences of sleep disturbances.[14,15] Using the Ford Insomnia Response to Stress Test (FIRST) to measure the degree of stress-related sleep vulnerability,[16] Fernández-Mendoza *et al*. reported that psychological traits of cognitive-emotional hyperarousal are associated with vulnerability to stress-related sleep disturbances.[14] Yang *et al*. also showed an association between sleep vulnerability and subjective rating of pre-sleep arousal.[15] These studies suggest that cognitive-emotional hyperarousal can be associated with stress-related sleep reactions and can be a predisposing trait that exists before sleep disturbances become chronic. However, the measurements for hyperarousal used in previous studies have all been subjective in nature; therefore, the association between cortical arousal and vulnerability to stress-related sleep disturbances remains to be investigated.

The present study compares information processing during sleep, as measured by ERP, between individuals with high or low vulnerability to stress-related sleep disturbances in order to understand the role of cortical hyperarousal in the development of insomnia. Three possible predictions can be made. First, if the high vulnerable (HV) individuals show a higher level of arousal than the low vulnerable (LV) individuals, this would suggest that cortical hyperarousal is a predisposing trait for insomnia that occurs not only in chronic insomnia patients but also in vulnerable individuals. Specifically, the HV group would show higher N1, lower P2, N350, and P900 than the LV group. Second, if HV individuals have similar information processing patterns to LV individuals, this implies that cortical hyperarousal is not a predisposed factor but associated with the onset of chronic of insomnia. Third, it is also possible that the HV group might show a reduced level of information processing during sleep than the LV group. This might imply that the HV individuals employ a protective compensatory process that prevents stress-related sleep disturbances from becoming a chronic problem. Specifically, the HV group would show a higher level of inhibition, which would be indicated by higher P2, N350, and P900.

METHODS

Subjects

Potential subjects were recruited through Internet advertisements. They were required to complete the FIRST to evaluate their degree of sleep vulnerability. The FIRST is a 9-item questionnaire that was designed to quantify the degree of vulnerability as an individual trait to stress-related sleep disturbance, and was shown to have good test–retest reliability and internal consistency.[16] For each item, subjects were asked to rate the likelihood of experiencing sleep disturbances in response to a common stressful situation in daily life (e.g., having an important meeting the next day) on a 4-point Likert-scale ranging from 1 (not likely) to 4 (very likely). The total score ranges from 9 to 36 and the median score was 20 in the original study.[16] In our previous study, subjects who scored higher than 23 were within the top one-third of the whole sample and those who scored lower than 18 were within the bottom one-third.[17] We therefore used 18 and 23 as cut-off points in the current study to categorize the subjects into LV and HV groups, respectively. Subjects whose FIRST score was between 19 and 22 were excluded.

Other inclusion criteria were: (i) age from 18 to 45 years; (ii) no subjective sleep-related complaints, no sleep-related disorders and no history of current medical, or psychiatric disorders associated with sleep disturbances; (iii) not a habitual smoker or alcohol user; (iv) currently not using medications that could affect sleep; and (v) not a shift worker or on an irregular sleep–wake schedule. The screening procedures included a clinical interview, a semi-structured diagnostic interview with the Mini International Neuropsychiatric Interview, and a package of screening questionnaires (Beck Depression Inventory [BDI], Beck Anxiety Inventory [BAI], and Insomnia Severity Index [ISI]), which were all conducted by a graduate student who had completed a training program in behavioral sleep medicine and was under the supervision of a licensed clinical psychologist certified in behavioral sleep medicine. A total of 27 subjects were finally included (the HV group: $n = 13$, six men, mean age = 23.8 ± 3.59 years; and the LV group: $n = 14$, six men, mean age = 24.6 ± 3.59

years). Except for two graduate students, the rest of the subjects were all college students. An informed consent form was obtained before the start of the formal experimental procedure.

Procedure

After passing the screening, subjects were scheduled to sleep in the sleep laboratory for three nights of PSG recording, and were instructed to limit caffeine intake to 1 cup per day before noon. The first night served as a screening/adaptation night, to rule out possible sleep disorders (sleep-related breathing disorders, periodic limb movement disorder) and to habituate the subjects for sleeping in the lab. Subjects arrived in the lab approximately 2 h before their usual bedtime. After explaining the procedures as well as hooking up and calibrating for PSG recording, they were put to bed around their usual bedtime. The PSG montage included four EEG channels (C3/A2, C4/A1, O1/A2, and O2/A1), left and right electrooculograms (EOG), a submental electromyogram (EMG), an electrocardiogram (ECG), nasal/oral airflow, chest and abdominal respiratory efforts, and oxygen saturation.

The second and third nights served as the baseline and the stress conditions. The sequences of the two conditions were counterbalanced across subjects. During the baseline night, subjects arrived in the lab 1.5 h before their usual bedtime. Before going to bed, subjects were required to fill the Pre-Sleep Arousal Scale (PSAS) to evaluate their subjective arousal level. They went to sleep at their regular bedtimes. ERP recording was conducted throughout the night. They awoke at their usual wake-up time in the morning.

The procedures for the stress condition were similar to the baseline condition, except that in order to induce stress, after the completion of electrode application, subjects were told that they would have to give a speech right after waking up in the morning. Specific instruction for the speech is as follows: 'The length of the speech should be around 10 min; the experimenter will remind you of the time limit at the 9th min. There will be two evaluators listening to your speech and will give a rating on the spot. Your speech will also be recorded by a video camera. The rating will be based on five criteria: organization of the content, fluency of the speech, compliance with the time limit, stage presence, and personal charisma. You have to perform as well as you can; an additional monetary reward will be provided according to your performance.' The following morning subjects gave a speech right after waking up. A debriefing session was conducted to inform the purpose of stress induction after completion of the study, and a post-experiment consent form was obtained.

The recording montage for the experimental nights included five EEG channels (C3/A2A2, C4/A1A2, Fz/A1A2, Cz/A1A2 and Pz/A1A2), vertical and horizontal EOG, and submental EMG for both sleep and ERP recording. The procedure of ERP induction was adopted from the oddball paradigm used by Yang and Lo.[12] Auditory pure tones, either 1000 or 1500 Hz for 45 ms, were presented every 1.5 s via a plug-type earphone to both ears. A higher-pitch tone was designed to be the standard tone for half the subjects and to be the rare tone for the rest. The ratio of rare-to-standard tones was 20:80. Subjects were instructed to count the number of target tones while they were still awake but not to resist falling asleep.

The experimental procedure was approved by an ethics review board of the department. The subjects were treated in compliance with the ethical standards of the Taiwan Psychological Association.

Data analysis

Sleep stages were scored in 30-s intervals according to the *American Academy of Sleep Medicine Manual for the Scoring of Sleep and Associated Events*.[18] ERP analysis was conducted with the BrainVision Program (Brand Products GmbH, Munich, Germany). The recorded EEG was initially filtered with a 30-Hz low-pass filter. It was then segmented with periods of 1350 ms, from 150 ms prior to the onset of tones to 1200 ms after the onset of tones. Baseline corrections were then conducted with an EEG average of 150 ms prior to stimulus onset as the baseline. Segments containing EOG signals over 75 μV above or below the baseline were excluded from analysis. The remaining segments were averaged for the target tone during different sleep stages. N1, P2, N350, and P900 were calculated as negative or positive peaks during the ranges of 76–150, 150–260, 250–475, and 600–1000 ms, respectively. These time windows were slightly adjusted for some subjects according to a visual inspection of their average waveforms.

The ERP we focused on were known to have a distribution primarily in the central and frontal regions in a previous study.[19] Statistics were analyzed for data at Fz and Cz only to avoid complexity. To examine information processing during sleep onset

period and NREM sleep, data from the first 5 min of continuous-stage N2 sleep and the first half of sleep (divided into stages N2 and slow-wave sleep [SWS]) were analyzed, respectively. Mixed-design 2×2 ANOVA were conducted to compare the amplitude and latency of ERP components as well as the subjective arousal ratings between the HV and LV groups and baseline and stress conditions.

RESULTS

Basic characteristics of the subjects

The mean FIRST scores of the HV and LV participants were 25.92 (± 1.66) and 16.00 (± 1.14), respectively. There were no significant differences between their scores on the ISI ($M_{HV} = 4.69 \pm 2.39$, $M_{LV} = 3.92 \pm 2.71$, $t = -0.76$, $P = 0.455$), the BAI ($M_{HV} = 4.85 \pm 4.67$, $M_{LV} = 2.85 \pm 2.41$, $t = -1.37$, $P = 0.187$), or the BDI ($M_{HV} = 6.85 \pm 5.93$, $M_{LV} = 4.46 \pm 2.90$, $t = -1.30$, $P = 0.205$). The scores were all within normal range. No significant group differences were found for any sleep parameters obtained during the screening/adaptation night (Table 1).

ERP findings

First 5 min of continuous stage 2 sleep

The 2 (group: HV vs LV) by 2 (condition: baseline vs stress) ANOVA results for amplitudes and latencies of N1, N350, P900, as well as the amplitudes of P2 showed no significant main or interaction effect (Table 2 and Fig. 1a). However, a significant group effect was observed for the P2 latencies: the HV group had shorter P2 latency than the LV group.

Continuous stage 2 sleep

The ANOVA on the amplitudes of N1, P2, and N350, and the latency of P2 showed no significant main or interaction effects (Table 3 and Fig. 1b). On Fz, N1 latency, ($F(1,25) = 5.93$, $P = 0.022$, $\eta_p 2 = 0.192$) and P900 latency ($F(1,25) = 4.92$, $P = 0.036$, $\eta_p 2 = 0.164$) showed significant group-condition interaction effects, and N350 latency resulted in a marginally significant interaction effect ($F(1,25) = 4.26$, $P = 0.050$, $\eta_p 2 = 0.146$); however, no significant difference was found in post-hoc comparisons. A significant condition main effect was found for the P900 amplitude on Cz. Both HV and LV participants had greater P900 amplitudes in the stress condition than in the baseline condition ($F(1,25) = 6.14$, $P = 0.020$, $\eta_p 2 = 0.197$), but no significant difference was found in post-hoc tests.

SWS

The ANOVA on the amplitudes N1, P2, and N350, as well as the latency of N350, showed no significant main or interaction effects (Table 4 and Fig. 1c). The ANOVA indicated a significant group main effect for N1 latency on Cz ($F(1,25) = 4.79$, $P = 0.038$, $\eta_p 2 = 0.142$); the HV group had a faster N1 latency than the LV group. P2 latency had a significant group-condition interaction effect on Fz ($F(1,25) = 5.05$, $P = 0.034$, $\eta_p 2 = 0.129$); however, post-hoc tests showed no significant group differences under either

Table 1. Sleep parameters for the screening/adaptation night

Sleep parameters	LV	HV	*t*-value	*P*-value
TST (min)	398.21 ± 46.30	372.65 ± 50.03	1.38	0.180
SOL (min)	11.41 ± 11.91	13.14 ± 19.39	−0.28	0.780
SE (%)	90.98 ± 6.83	86.72 ± 9.87	1.31	0.201
WASO (%)	6.75 ± 5.88	10.54 ± 10.04	−1.21	0.239
Sleep stages (%)				
S 1	8.13 ± 4.80	9.50 ± 4.47	−0.77	0.451
S 2	56.71 ± 9.90	53.84 ± 9.26	0.78	0.445
SWS	10.39 ± 5.65	7.75 ± 7.11	1.08	0.293
REM	18.01 ± 4.54	18.36 ± 4.55	−0.20	0.844

Data are presented as mean ± SD.
HV, subjects with higher vulnerability; LV, subjects with lower vulnerability; REM, rapid eye movement sleep; SE, sleep efficiency; SOL, sleep-onset latency; SWS, slow-wave sleep; TST, total sleep time; WASO, wake after sleep onset.

Table 2. ERP amplitudes and latencies for the first 5 min of continuous stage 2 sleep

		Baseline		Stress		*F*-value		
		LV	HV	LV	HV	Condition	Group	Interaction
				(a) Amplitudes				
N1	Fz	−3.94 ± 4.87	−4.09 ± 5.08	−4.09 ± 4.43	−0.90 ± 4.33	1.55	1.31	1.86
	Cz	−4.01 ± 4.38	−4.18 ± 4.19	−3.98 ± 5.41	−1.92 ± 3.34	1.35	0.46	1.28
P2	Fz	10.26 ± 6.16	10.03 ± 6.92	8.03 ± 4.77	10.22 ± 6.01	0.52	0.29	0.73
	Cz	13.02 ± 8.01	15.25 ± 8.96	11.29 ± 5.90	12.60 ± 6.81	1.53	0.57	0.04
N350	Fz	−7.33 ± 8.20	−6.17 ± 7.07	−8.37 ± 5.14	−7.69 ± 5.43	0.48	0.28	0.02
	Cz	−10.70 ± 10.81	−8.46 ± 9.20	−12.40 ± 8.31	−9.20 ± 6.47	0.56	0.82	0.09
P900	Fz	8.81 ± 5.35	7.21 ± 4.35	7.93 ± 4.12	6.67 ± 4.74	0.50	0.92	0.03
	Cz	8.73 ± 5.57	8.05 ± 4.99	8.50 ± 4.77	5.86 ± 3.39	1.08	1.38	0.71
				(b) Latencies				
N1	Fz	140.14 ± 26.18	136.15 ± 19.26	133.86 ± 24.46	132.46 ± 27.05	1.60	0.10	0.11
	Cz	137.00 ± 23.17	132.00 ± 23.79	135.14 ± 24.39	128.31 ± 23.97	0.45	0.52	0.05
P2	Fz	251.43 ± 29.05	243.08 ± 32.17	246.29 ± 30.13	219.38 ± 24.89	2.67	**6.41***	1.10
	Cz	252.71 ± 25.85	240.77 ± 29.39	245.14 ± 29.14	226.46 ± 16.35	2.39	**4.82***	0.23
N350	Fz	372.57 ± 37.71	370.15 ± 39.74	369.00 ± 26.92	360.15 ± 37.46	0.65	0.29	0.15
	Cz	367.14 ± 35.05	371.38 ± 39.69	366.43 ± 29.36	352.00 ± 30.74	2.36	0.20	2.04
P900	Fz	831.43 ± 64.45	833.23 ± 93.49	791.85 ± 87.54	833.54 ± 99.02	0.93	0.68	0.96
	Cz	825.86 ± 73.29	835.69 ± 79.97	791.00 ± 73.44	838.46 ± 101.4	0.54	1.55	0.74

*$P < 0.05$.
Data are presented as mean ± SD of ERP amplitudes (μV) and latencies (ms).
ERP, event-related potential; HV, subjects with higher vulnerability; LV, subjects with lower vulnerability.

condition. The P900 amplitude had a significant group-condition interaction effect on Fz ($F(1,25) = 6.73$, $P = 0.016$, $\eta_p2 = 0.212$). Post-hoc tests showed there was no significant group differences under the baseline condition, but HV participants had a higher P900 than LV participants under the stress condition ($F(1,25) = -2.22$, $P = 0.036$). P900 latency was significantly affected by condition (Fz: $F(1,25) = 9.69$, $P = 0.005$, $\eta_p2 = 0.279$; Cz: $F(1,25) = 11.33$, $P = 0.002$, $\eta_p2 = 0.312$), which indicated that P900 was slower under the stress condition than under the baseline condition.

Subjective arousal before sleep

ANOVA results showed significant condition effects, including higher physical arousal ($F(1,25) = 6.18$, $P = 0.02$), higher cognitive arousal ($F(1,25) = 11.39$, $P = 0.002$), and higher total PSAS scores ($F(1,25) = 8.57$, $P = 0.007$) under the stress condition than under the baseline condition (Table 5). In addition, a significant group-condition interaction effect was revealed for cognitive arousal ($F(1,25) = 9.15$, $P = 0.006$) and total PSAS scores ($F(1,25) = 7.68$, $P = 0.01$). Post-hoc comparisons showed that the HV group had a higher cognitive arousal score ($t = -2.35$, $P = 0.030$) and total score ($t = -2.37$, $P = 0.028$) than the LV group under the stress condition, but not under the baseline condition.

DISCUSSION

The results of the present study show that the HV group did not demonstrate a typical ERP pattern for insomnia patients. The amplitudes of N1, P2, and N350 did not differ between LV and HV individuals. In contrast to typical insomnia patients, who show elevated information processing and decreased inhibitory processes, the HV group showed some signs of an enhanced inhibitory process. They also had higher P900 amplitudes (which were reported as being related to an inhibitory process and found to be associated with the depth of sleep in previous study[20]) during SWS under the stress condition. This may reflect a compensatory process invoked by HV individuals to keep external stimulation from

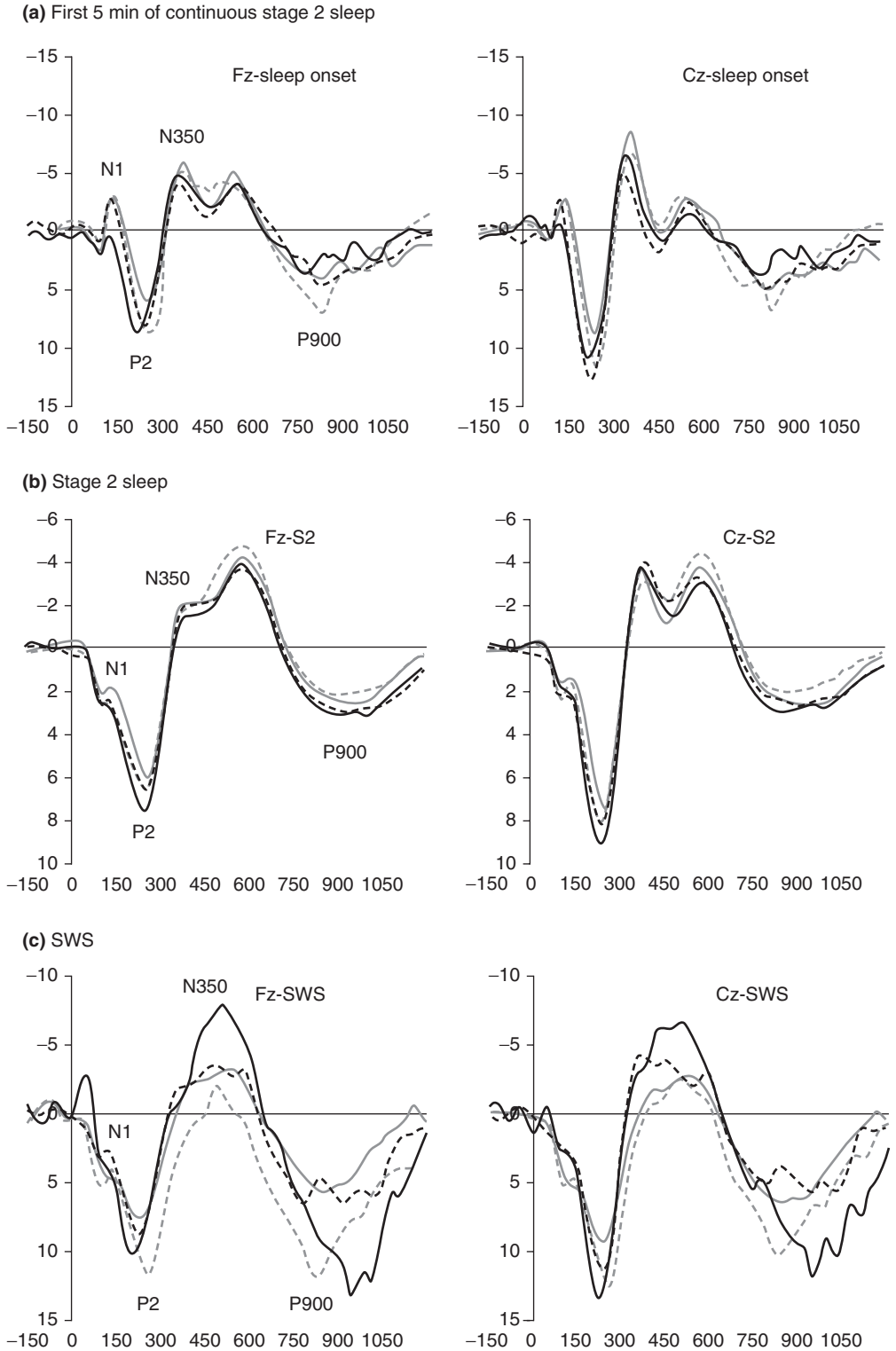

Figure 1. Grand averages of the event-related potential (ERP) on Fz and Cz during: (a) the first 5 min of continuous stage 2 sleep, (b) overall stage 2 sleep, and (c) overall slow-wave sleep (SWS). - - -, low vulnerable (LV) baseline; ——, LV stress; - - -, high vulnerable (HV) baseline; ——, HV stress.

Table 3. ERP amplitudes and latencies for stage 2 sleep

		Baseline		Stress		*F*-value		
		LV	HV	LV	HV	Condition	Group	Interaction
				(a) Amplitudes				
N1	Fz	1.23 ± 1.33	1.48 ± 1.42	1.07 ± 1.61	1.35 ± 1.33	0.25	0.31	<0.01
	Cz	0.87 ± 1.32	1.22 ± 1.03	0.50 ± 1.50	0.84 ± 1.30	2.04	0.63	<0.01
P2	Fz	6.60 ± 2.85	6.81 ± 4.45	6.40 ± 3.55	7.93 ± 3.64	0.93	0.44	1.96
	Cz	7.96 ± 4.17	8.38 ± 5.60	7.97 ± 4.52	9.46 ± 4.70	1.27	0.29	1.23
N350	Fz	−3.48 ± 2.58	−1.82 ± 2.54	−3.32 ± 2.82	−2.79 ± 3.38	0.59	1.30	1.12
	Cz	−5.03 ± 4.30	−3.97 ± 3.26	−5.14 ± 5.26	−4.73 ± 5.03	0.56	0.20	0.32
P900	Fz	2.61 ± 1.64	3.22 ± 2.81	3.15 ± 1.71	3.66 ± 2.03	1.92	0.59	0.02
	Cz	2.61 ± 1.75	2.99 ± 2.45	3.43 ± 1.94	3.55 ± 1.68	6.14*	0.12	0.20
				(b) Latencies				
N1	Fz	135.57 ± 26.40	133.08 ± 38.11	142.14 ± 28.35	120.92 ± 35.50	0.53	1.01	5.93*
	Cz	136.71 ± 26.14	129.23 ± 35.03	138.00 ± 31.40	121.23 ± 33.75	0.65	1.12	1.24
P2	Fz	261.86 ± 20.34	250.46 ± 35.83	253.00 ± 23.70	242.77 ± 31.24	1.75	1.48	0.01
	Cz	260.14 ± 18.93	244.00 ± 30.69	253.00 ± 17.68	349.54 ± 34.38	1.30	4.13	0.07
N350	Fz	412.43 ± 41.16	397.54 ± 32.12	393.00 ± 35.26	410.31 ± 43.98	0.18	0.01	4.26
	Cz	404.86 ± 39.74	393.08 ± 34.46	393.14 ± 38.20	398.31 ± 36.61	0.28	0.06	1.93
P900	Fz	876.86 ± 56.69	896.31 ± 74.85	918.14 ± 70.19	859.85 ± 77.99	0.02	0.89	4.92*
	Cz	872.14 ± 53.03	874.62 ± 65.04	907.43 ± 82.51	853.54 ± 80.46	0.19	1.35	3.02

*$P < 0.05$.

Data are presented as mean ± SD of ERP amplitudes (μV) and latencies (ms).

ERP, event-related potential; HV, subjects with higher vulnerability; LV, subjects with lower vulnerability.

interfering with their sleep during stress conditions. On the other hand, during the first 5 min of stage 2 sleep, the HV group showed faster P2 than the LV group. This finding may indicate that HV individuals are prone to react more quickly to inhibit external stimulation while trying to fall asleep. The HV group also showed faster orientation as indicated by an earlier N1 during SWS. However, no amplitude differences in N1 and the subsequent P2 were found between the two groups. Overall, these results could be interpreted to mean that HV individuals have faster attention orientation during sleep while having a faster inhibitory process to protect them from being aroused.

Unlike the cortical arousal measured by the ERP, the results from subjective rating scales showed that the HV group scored higher on subjective pre-sleep arousal under the stress condition than the LV group. This finding is consistent with previous studies showing higher subjective arousability and pre-sleep arousal levels in participants with higher FIRST scores.[14,15] Bonnet and Arand also reported that a subgroup of normal young adults whose sleep was consistently more vulnerable to various types of situational stress showed higher autonomic nervous system (ANS) activations.[4] These findings suggest that the HV may be an individual trait associated with a general tendency toward hyperarousal related to ANS activation. The neurocognitive aspect of hyperarousal and/or cortical hyperarousal, however, may develop after the sleep disturbance continues for a longer period of time. As Perlis *et al.* proposed in their model, increased information processing around bedtime can partially be learned through classical conditioning associating higher neurocognitive activities with bedtime cues.[7] A recent study comparing psychological and behavioral variables between chronic insomnia patients and individuals with high vulnerability to stress-related transient insomnia also showed that dysfunctional cognition and cognitive arousal, but not somatic arousal, are predictors for insomnia severity in chronic insomnia patients.[15] Considered together, our findings suggest that different aspects of hyperarousal may play distinct roles in the developing course of chronic insomnia. These results imply that different aspects of hyperarousal

Table 4. ERP amplitudes and latencies for SWS

		Baseline		Stress		*F*-value		
		LV	HV	LV	HV	Condition	Group	Interaction
				(a) Amplitudes				
N1	Fz	2.78 ± 5.84	1.97 ± 4.48	3.01 ± 5.91	2.98 ± 5.11	0.20	0.07	0.08
	Cz	2.34 ± 6.75	1.75 ± 4.86	3.67 ± 5.00	3.04 ± 4.26	0.78	0.19	<0.01
P2	Fz	12.89 ± 8.81	10.44 ± 6.67	9.63 ± 5.07	13.96 ± 7.11	0.01	0.20	3.86
	Cz	14.05 ± 6.86	12.75 ± 9.83	11.78 ± 5.68	17.13 ± 9.81	0.01	0.20	3.86
N350	Fz	−1.47 ± 8.02	−4.29 ± 7.70	−2.78 ± 7.13	−2.84 ± 10.37	<0.01	0.30	0.54
	Cz	−2.72 ± 7.08	−6.96 ± 9.58	−3.09 ± 8.94	−5.28 ± 9.96	0.15	1.16	0.36
P900	Fz	14.85 ± 12.68	9.00 ± 8.22	8.11 ± 5.82	14.38 ± 8.65	0.08	0.01	6.73*
	Cz	12.20 ± 10.81	7.59 ± 4.61	8.99 ± 4.02	11.67 ± 8.63	0.05	0.21	3.20
				(b) Latencies				
N1	Fz	145.00 ± 22.92	138.77 ± 25.50	146.71 ± 30.36	117.54 ± 37.09	1.83	4.13	2.53
	Cz	143.29 ± 26.85	136.46 ± 22.32	146.29 ± 24.02	117.69 ± 28.90	1.94	4.79*	3.69
P2	Fz	245.14 ± 32.95	221.08 ± 29.88	227.14 ± 32.71	234.62 ± 30.20	0.10	0.70	5.05*
	Cz	245.43 ± 30.43	230.92 ± 25.04	229.00 ± 32.99	227.69 ± 21.34	2.82	0.76	1.27
N350	Fz	387.43 ± 44.07	390.92 ± 46.35	410.00 ± 45.18	409.23 ± 58.50	2.88	0.01	0.03
	Cz	383.57 ± 41.76	382.15 ± 40.26	397.71 ± 53.04	400.62 ± 55.55	1.89	<0.01	0.03
P900	Fz	786.71 ± 108.3	817.23 ± 111.5	848.57 ± 67.13	899.69 ± 63.39	9.69**	2.47	0.20
	Cz	802.57 ± 104.3	812.15 ± 119.1	858.57 ± 69.91	904.62 ± 45.99	11.33**	1.10	0.68

*$P < 0.05$; **$P < 0.01$.
Data are presented as mean ± SD of ERP amplitudes (μV) and latencies (ms).
ERP, event-related potential; HV, subjects with higher vulnerability; LV, subjects with lower vulnerability; SWS, slow-wave sleep.

should be separately considered in the understanding of hyperarousal in insomnia etiology.

Although the findings of the present study have significant theoretical and clinical implications, they should be interpreted with caution in light of the potential limitations. First, the level of stress experienced during the daytime was not well controlled in the study, although the subjects all reported no unusual events during the day. This possible confounding variable might have contributed partially to the findings. In future studies, the stress experienced should be assessed before experimental manipula-

Table 5. Scores of the PSAS

	Baseline		Stress		*F*-value		
	LV	HV	LV	HV	Condition	Group	Interaction
Physical	9.00 ± 1.88	9.31 ± 1.88	9.43 ± 1.70	10.62 ± 2.63	6.18*	1.12	1.58
Cognitive	11.07 ± 2.97	11.23 ± 2.98	11.29 ± 2.97	15.15 ± 5.21	11.39**	2.55	9.15**
Total	20.07 ± 4.10	20.54 ± 3.78	20.21 ± 4.84	25.77 ± 7.06	8.57**	3.03	7.68*

*$P < 0.05$; **$P < 0.01$.
Data are presented as mean ± SD of PSAS scores.
HV, subjects with higher vulnerability; LV, subjects with lower vulnerability; PSAS, Pre-sleep Arousal Scale.

tion and can be controlled statistically. Second, individual differences in reaction to the speech task could be another confounding variable. As our data did show an increase in pre-sleep arousal during the stress condition in both groups, this factor might have only a minimal effect on our results. However, this should be taken into consideration in future studies. Finally, the sample size of the present study is small, and most of the participants were college students. This may limit the generalizability of our results to other populations. Future studies should be conducted on participants from different age groups to examine the generalizability of our results as well as to explore possible age effects.

In summary, our results suggest that the CNS hyperarousal during sleep as measured by non-REM ERP is most likely not a predisposing trait of chronic insomnia, but might rather be developed during the course of transition from transient sleep disturbance to chronic insomnia. Non-insomniac individuals with high sleep vulnerability even showed a compensatory process that may prevent external stimulation from interfering with their sleep. Future studies can further investigate whether CNS hyperarousal is reversible with cognitive-behavioral therapy or medication, as well as possible factors that may facilitate the development of CNS hyperarousal in the vulnerable individuals. With a better understanding of the mechanisms, intervention can be developed to prevent transient sleep disturbance in vulnerable individuals from becoming a chronic problem.

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