The role of nicotine on respiratory sensory gating measured by respiratory-related evoked potentials

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Pyt Davenport. The role of nicotine on respiratory sensory gating measured by respiratory-related evoked potentials. J Appl Physiol 108: 662–669, 2010. First published January 7, 2010; doi:10.1152/japplphysiol.00798.2009.—Respiratory perception can be altered by changes in emotional or psychological states. This may be due to affective (i.e., anxiety) modulation of respiratory sensory gating. Nicotine withdrawal induces elevated anxiety and decreases somatosensory gating. Respiratory sensory gating is evidenced by decreased amplitude of the respiratory-related evoked potentials (RREP) N1 peak for the second occlusion (S2) when two 150-ms occlusions are presented with a 500-ms interval during an inspiration. The N1 peak amplitude ratio of the S2 and first occlusion (S1) (S2/S1) is <0.5 and due to central neural sensory gating. We hypothesized that withdrawal from nicotine is anxiogenic and reduces respiratory gating in smokers. The RREP was recorded in smokers with 12-h withdrawal from nicotine and nonsmokers using a paired occlusion protocol. In smokers, the RREP was measured after nicotine withdrawal, then with either nicotine or placebo gum, followed by the second RREP trial. Nonsmokers received only placebo gum. After nicotine withdrawal, the smokers had a higher state anxiety compared with nonsmokers. There was a significant interaction between groups (nonsmokers vs. smokers with nicotine vs. smokers with placebo gum) and test (pre- vs. posttreatment) in RREP N1 peak amplitude S2/S1. The S2/S1 in the smokers were larger than in nonsmokers before treatment. After gum treatment, the smoker-with-placebo group had a significantly larger S2/S1 than the other two groups. The S2/S1 was significantly decreased after the administration of nicotine gum in smokers due to significantly decreased S2 amplitudes. The RREP N1 and P1 peaks were unaffected. These results demonstrated that respiratory sensory gating was decreased in smokers after nicotine withdrawal. Nicotine increased respiratory sensory gating in smokers with a S2/S1 similar to that of the nonsmokers. Nicotine did not change respiratory sensory information arrival, but secondary information processing in respiratory sensation.

load perception; anxiety; affective state; mechanosensation; respiratory-related evoked potential

Respiratory perception can be altered by changes in emotional or psychological states (10, 53). This may be due to affective modulation of respiratory sensory gating (15, 16). It has been reported that individuals with altered affective states due to migraine, schizophrenia, posttraumatic stress disorders, and panic disorders suffered from disrupted sensory gating (6, 7, 12, 39, 41). Migraine patients demonstrated a significantly reduced P50 gating response to auditory stimuli compared with healthy subjects (7). Individuals with schizophrenia demonstrated higher auditory P50 and N100 gating ratio compared with control groups (48). Ludewig et al. (39) reported that individuals with panic disorders have decreased auditory prepulse inhibition (PPI) compared with healthy controls (39). These studies suggest that affective state can modulate cognitive functions and sensory gating.

It has been reported that withdrawal from addictive substances results in changes in affective state and subsequent cognitive gating (11, 24, 25, 45). Smoking abstinence or nicotine withdrawal effects on gating were found to be closely related to changes in affective state (13, 14, 19, 25, 47, 49). It has also been reported that patients with psychiatric disorders tend to smoke more cigarettes than smokers without psychiatric diseases (22, 42). This is thought to be due to a linkage between disrupted cognitive neural mechanisms and therapeutic usage of nicotine to restore normal sensory gating (2, 4, 5).

In smokers after cessation for 6–15 h, acute smoking or administration of nicotine increases auditory evoked potential (AEP) P100 peak amplitudes (24). Nicotine was suggested as a possible agent to restore sensory gating functions (2, 3, 5, 24, 40, 50). Adler et al. (2) found that administration of nicotine increased auditory sensory gating to near-normal levels in patients with schizophrenia. In animal studies using a paired stimuli paradigm, it was found that bupropion HCl decreased auditory gating by decreasing the first stimulus (S1) AEP peak amplitude (50). They also found that administration of nicotine reduced the second stimulus (S2) AEP peak amplitudes and, therefore, restored auditory gating in mice (50).

Perceputal gating has been demonstrated in auditory, visual, and respiratory somatosensory evoked potentials (EP) studies (8, 15, 26–29). Respiratory mechanosensory gating has been investigated in this laboratory using the respiratory-related EPs (RREP) measured with a paired respiratory obstruction paradigm (15). The application of the paired stimuli of 150-ms duration with 500-ms interstimulus interval resulted in a reduced response in the S2-elicted RREP. The RREP N1 peak was identified as a measure of gating, and the peak amplitudes of S2 were decreased to one-half of S1. This resulted in the N1 peak amplitude ratio of S2 to S1 (S2/S1) ≤ 0.5 (15).

While it was known that smoking abstinence and nicotine modulate sensory gating in other sensory modalities, it was unknown if smoking abstinence modulates respiratory sensory gating. Smoking introduces its constituents, including nicotine, via the airways. Smoking has a close relationship with respiratory sensations; hence it was reasoned that smoking or nicotine may have an effect on cortical activation in response to respiratory occlusion or resistive loads. We reasoned that smoking abstinence would decrease respiratory sensory gating. The subsequent administration of nicotine would increase respiratory sensory gating, thus providing evidence for modulation of respiratory mechanosensation.

The purpose of this study was to investigate the effect of nicotine abstinence on respiratory cortical responses to paired obstruction paradigm in college-aged smokers. It was hypothe-
esized that, after 12 h of abstinence, the anxiety level, measured by the State Trait Anxiety Inventory (STAI) and the RREP N1 peak S2/S1 of smokers would be greater than that of nonsmokers. It was further hypothesized that, in abstaining smokers, the N1 peak S2/S1 would be decreased (increased gating) after the administration of nicotine gum. We focused this project on college-aged young adults between 18 and 25 yr in a large university with over 45,000 students. This group was chosen because these individuals are a group of smokers that are generally healthy and do not possess complicated health issues. We also matched nonsmokers to smokers based on age and sex.

MATERIALS AND METHODS

This study was reviewed and approved by the Institutional Review Board at the University of Florida. All subjects were interviewed with a phone screening questionnaire to ensure eligibility to participate. The inclusion criteria for smokers were self-reported smoking intensity of no more than 1 pack per day; free of self-reported cardiovascular, respiratory, and neurological disease; and a systolic blood pressure <140 mmHg. The inclusion criteria for nonsmokers were self-reported no history of smoking for at least 3 yr; no use of nicotine replacement products for at least 3 yr; free of self-reported cardiovascular, respiratory, and neurological disease; and a systolic blood pressure <140 mmHg. A pregnancy test was administered to all women, and any woman who tested positive was excluded.

Subjects. Sixteen healthy, nonsmoking adults (7 women and 9 men) and 17 healthy smoking adults (7 women and 10 men) participated in the study. The mean ages for the nonsmokers and smokers were 22 ± 1.99 and 21.8 ± 1.65 yr, respectively. The average number of cigarettes smoked in the smokers was 14 ± 5.6 per day. The subjects were instructed to refrain from caffeine and any excessive exercise for 12 h before the experiment. The subjects were also required to provide a saliva sample to measure nicotine metabolite for determining the eligibility of the participants’ data for analysis. The nature of the experiment was explained to the subject on arrival to the laboratory, and the subject provided written consent to participate in the study.

Pulmonary function test. All subjects were pre-screened with the pulmonary function test. The forced vital capacity (FVC) was measured for each subject at least three times. The subject was instructed to respire normally for a few breaths and provide a forced expiration after a deep inspiration. The instruction was based on the American Thoracic Society Standard for spirometry testing (1). At least 1 min of rest was given to the subject between tests. The forced expiratory volume in 1 s (FEV1) and the FVC were recorded (Jaeger Toennies), and the ratio of FEV1 to FVC (FEV1/FVC) was calculated. The averaged percent predicted values of FVC for the smokers and nonsmokers were 112 ± 12 and 112 ± 15.7%, respectively. The averaged percent predicted values of FEV1 for the smokers and nonsmokers were 108 ± 11.3 and 107 ± 13.8% predicted, respectively. All subjects had a FEV1/FVC > 70%. The resistance was measured with impulse oscillometry (Jaeger Toennies). The resistance was within predicted normal values for all subjects.

Apparatus. A scalp electrode cap based on the International 10–20 system was positioned onto the subject’s head. The EEG activity was referenced to the joined ear lobes. Conducting paste was applied through the center of the electrode to establish electrode contact with the scalp. The impedance level of each electrode was checked to ensure that it was <5 kΩ. The recording sites were F3, Fz, C3, Cz, C4, and Pz. Electrodes were placed over the lateral edge of the left eye for recording vertical electrooculogram activity. The EEG activity was band-pass filtered at 0.3 Hz to 1 kHz, amplified at 50 k, digitized at 2.5 kHz, and led into an online signal averaging computer system (model 1401, Cambridge Electronics Design or SynAmps 2, Neuroscan). The EEG activity was monitored by the experimenter.

The subjects were instructed to sit in a chair with their neck, back, arms, and legs supported. They respired through a mouthpiece with a non-rebreathing valve. The non-rebreathing valve was connected to a pneumotachograph (2600 series, Hans Rudolph) and an occlusion valve, which was screened from the subject. The occlusion valve was connected to a double trigger system (15). The trigger control device provided an electrical output used to initiate data sample collection by the computer. The mouthpiece was suspended to minimize facial muscle activity. Mouth pressure (Pm) was recorded from the center of the non-rebreathing valve by a differential pressure transducer (model MP-45, Validyne Engineering). Airflow was recorded by a differential pressure transducer connected to the pneumotachograph. The Pm and airflow were led into the online computer system and digitized at 2.5 kHz (model 1401, Cambridge Electronics Design or SynAmps 2, Neuroscan). The Pm and airflow were also led to an oscilloscope and observed by the experimenter. The subject was monitored by a video camera. During the trial, the subject watched a videotaped movie and ignored the stimuli.

Protocol. Two visits (at least 48 h apart) to the laboratory were required for the smokers to complete the study. There was a 12-h withdrawal period required before each smoker’s visit. On arrival to the laboratory, the subject’s height, weight, and blood pressure were measured. The pregnancy test was administered (if required). The pulmonary function test and the STAI questionnaires were then given. The first RREP trial was presented with ~100 paired occlusions collected (15).

There was a 30-min rest period between the RREP trials during which the subject was given nicotine (4 mg) or placebo gum. The subject was instructed to chew and keep the gum in the mouth throughout the 30-min intertrial period. The plasma nicotine level peaks ~30 min after placing the gum in the mouth and provides a 60-min plateau of nicotine (9). The subject was then asked to complete another STAI questionnaire. Then the second RREP trial was performed. After the second RREP trial, the smokers were scheduled for the return visit at least 48 h later (Fig. 1). If the subject was given nicotine gum in the first visit, he or she would be given placebo gum for the second visit, and vice versa (Fig. 1). The sequence of the gum

Fig. 1. The schematic presentation of the experimental protocol. The smokers (S) were given nicotine or placebo gum based on randomization for the first day. STAI, State Trait Anxiety Inventory; PRREP, paired respiratory-related evoked potential.
administration was randomized. Nonsmokers had only one laboratory visit and received placebo gum only.

In the paired RREP trial, the first occlusion was delivered at the onset of inspiration for a duration of 150 ms, followed by an inter-stimulus interval of 500 ms, and then a second 150-ms occlusion. The paired occlusions were applied every two to six breaths for a total of 100 paired occlusions for each RREP trial.

Data analysis: the RREP peak analysis. An 1,100-ms epoch of EEG activity, airflow, and Pm was sampled when the initial inspiratory obstruction was triggered. The data were stored on a disk for computer analysis (Signal 2, Cambridge Electronics Design or SCAN, Neuroscan). During offline data analysis, each paired occlusion data frame was reviewed, and the inclusion criteria for the epochs were as follows: 1) the prestimulus EEG activity baseline was stable (baseline was determined as no change of EEG activity exceeding 20 µV from baseline during the previous 50 ms before the beginning of Pm change); 2) there was no vertical electrooculogram eye-blink activity; 3) there was no change in EEG activity exceeding 50 mV (identified by baseline-to-peak measure on the ordinate); and 4) there was no change in EEG activity during the previous 50 ms before the beginning of Pm change for both obstruction periods. Responses to occlusions that were confounded by artifacts were excluded from analysis. A minimum of 64 paired occlusion epochs were averaged to obtain the RREP in each trial. The peak latencies were measured from the time of the onset of the Pm stimulus to the averaged EP peak. The definition of the component peaks was based on previous reports for peak localization (20, 54). The amplitudes were measured from baseline to peak for each averaged EP component. The F3, F4, Cz, C3, and C4 electrodes were chosen for analysis, because these electrodes were the primary recording sites for the RREP peaks. The N1 was the negative peak occurring in the frontal F3 and F4 electrodes 25–45 ms after the stimulus. The P1 was the positive peak occurring in the central C3 and C4 electrodes 45–70 ms after the stimulus. The N1 was the negative peak occurring in the parietal Cz electrode 85–125 ms after the stimulus.

The S2/S1 between smokers and nonsmokers were compared for each peak amplitude separately for the paired RREPs. The statistical analysis was performed using a 3 × 2 mixed model repeated-measure ANOVA with Bonferroni or Holm-Sidak post hoc analysis for groups [smokers with nicotine (S-N), smokers with placebo (S-P), and nonsmokers] and posttreatment measures). The significance level was set at 0.001. Table 1 shows the averaged N1 peak latencies pre- and posttreatment for all three groups. For the nonsmokers and S-P group, there was no significant difference in latencies between S1 and S2, or between pre- and posttreatment for N1, P1, and N1 peaks. For the S-N group, there was also no stimulus timing effect or treatment effect on Ni, P1, and N1 peak latencies (Table 2).

Peak amplitude S2/S1. There were no significant differences in S2/S1 for the Ni (Fig. 3) and the P1 (Fig. 4) peaks between nonsmokers and smokers at baseline or after treatment. For the Ni peak amplitude S2/S1 (Fig. 5), there was a significant interaction between group and test [F(2,47) = 10.30; P < 0.001]. Post hoc analysis showed that the S-N group had a significantly higher Ni peak S2/S1 compared with the nonsmokers group at baseline (Fig. 5). There was no significant difference in S2/S1 between the S-N group and the S-P group.
NICOTINE AND RREP MEASURES OF RESPIRATORY SENSORY GATING

Table 1. Averaged Nf, P1, and N1 latencies for smokers and nonsmokers before and after treatment

<table>
<thead>
<tr>
<th>Peak Latency, ms</th>
<th>Pretreatment</th>
<th>S1</th>
<th>S2</th>
<th>Posttreatment</th>
<th>S1</th>
<th>S2</th>
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<tbody>
<tr>
<td>N1</td>
<td></td>
<td></td>
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<tr>
<td>Nonsmokers</td>
<td>35.72 ± 8.09</td>
<td>36.75 ± 7.75</td>
<td>36.96 ± 8.12</td>
<td>35.80 ± 8.09</td>
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<tr>
<td>S-N</td>
<td>39.14 ± 6.37</td>
<td>37.70 ± 6.95</td>
<td>38.29 ± 5.44</td>
<td>37.65 ± 6.33</td>
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<tr>
<td>S-P</td>
<td>37.25 ± 4.8</td>
<td>36.63 ± 48.31</td>
<td>37.12 ± 5.41</td>
<td>36.17 ± 5.16</td>
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<tr>
<td>P1</td>
<td></td>
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<tr>
<td>Nonsmokers</td>
<td>50.68 ± 10.07</td>
<td>52.06 ± 8.02</td>
<td>52.55 ± 10.73</td>
<td>52.18 ± 10.92</td>
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<tr>
<td>S-N</td>
<td>54.29 ± 0.99</td>
<td>54.57 ± 0.78</td>
<td>53.92 ± 6.59</td>
<td>53.92 ± 6.59</td>
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<tr>
<td>S-P</td>
<td>52.39 ± 8.7</td>
<td>51.98 ± 7.98</td>
<td>53.52 ± 7.8</td>
<td>51.83 ± 8.19</td>
<td></td>
<td></td>
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<tr>
<td>N1</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Nonsmokers</td>
<td>98.86 ± 20.98</td>
<td>94.86 ± 21.4</td>
<td>98.4 ± 20.63</td>
<td>92.08 ± 20.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-N</td>
<td>100.38 ± 19.96</td>
<td>96.39 ± 18.12</td>
<td>98.67 ± 18.67</td>
<td>95.45 ± 15.55</td>
<td></td>
<td></td>
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<tr>
<td>S-P</td>
<td>97.96 ± 16.43</td>
<td>90.92 ± 17.94</td>
<td>95.92 ± 16.77</td>
<td>89.5 ± 19.64</td>
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</tbody>
</table>

Values are means ± SD. S1, first stimulus; S2, second stimulus; S-N, smokers with nicotine treatment; S-P, smokers with placebo treatment.

or between the nonsmokers group and the S-P group at baseline (Fig. 5). However, after treatment, the N1 peak S2/S1 of the S-P group was significantly higher than that of the S-N group and also the nonsmokers (S2/S1 = 0.84, 0.43, and 0.42, respectively). The N1 S2/S1 of the S-N group was not different between nonsmokers and smokers after treatment (S2/S1 ratios = 0.41 and 0.45, respectively). By within-group comparisons, the S-N group had a significant decrease in the S2/S1 after nicotine treatment, whereas the S-P group had a significant increase in the S2/S1 compared with baseline.

Within the S-N group, there was a significant effect of treatment on N1 peak amplitudes \([F(1,16) = 4.968, P < 0.05]\). Post hoc analysis indicated that the N1 S1 amplitude was not significantly different between baseline and postnicotine treatment (−4.23 ± 1.78 and −4.0 ± 2.4 μV, respectively) (Fig. 6). However, the N1 S2 amplitude was significantly reduced after nicotine treatment compared with baseline (−2.74 ± 1.41 and −1.57 ± 0.97 μV, respectively; \(P = 0.008\)) (Fig. 6). There was also a significant effect of stimulus timing on N1 peak amplitudes \([F(1,16) = 29.87, P < 0.001]\). Post hoc analysis revealed that the S2 N1 peak amplitudes were significantly smaller than S1 both pre- and postnicotine treatment. Within the S-P group, there was a significant interaction between treatment and stimulus timing for N1 peak amplitudes \([F(1,16) = 7.47, P < 0.05]\). Post hoc analysis showed that the N1 S2 amplitudes were significantly smaller than S1 at baseline. The N1 S2 amplitudes were not significantly different from S1 after placebo treatment.

**STAI scores.** There was no significant interaction between treatment group and test for the state or trait anxiety scores. There was a trend that the S-P and S-N groups had a higher mean score in their state anxiety level at baseline compared with the nonsmokers group (S-P = 32.93 ± 11.81, S-N = 32.47 ± 12.5, and nonsmokers = 25.75 ± 4.09); however, there was no significant difference between groups. There was also no difference in anxiety level between pre- and posttreatment measures for each group.

**Baseline N1 gating ratio and STAI at first visit.** The baseline N1 gating ratios were compared between the nonsmokers and

![Fig. 3. The averaged N1 peak amplitude second stimulus (S2)-to-first stimulus (S1) ratios (S2/S1) (means ± SE) for F3 and F4 channels for the nonsmokers (NS), smokers with placebo treatment (S-P), and smokers with nicotine treatment (S-N) groups. Solid line, NS group; dash line, S-P group; dotted line, S-N group. There was no significant difference in S2/S1 between pre- and posttreatment in either group for both channels.](http://jap.physiology.org/)
smokers at their first visit to the laboratory after 12 h of withdrawal (Fig. 7). There was a significant difference between the nonsmokers and smokers \( F(1,31) = 6.32, P = 0.017 \). The smokers had a higher S2/S1 compared with nonsmokers at their first visit (0.595 ± 0.245 and 0.372 ± 0.226, respectively). The one-way ANOVA analysis revealed a significant difference \( F(1,30) = 5.196, P = 0.05 \) in state anxiety level between the smokers and nonsmokers at baseline on their first day of visit (Fig. 8). After 12 h of nicotine withdrawal, the smokers had a higher state anxiety total score compared with nonsmokers (32.94 ± 11.93 and 15.75 ± 4.09, respectively; \( P = 0.05 \)).

**DISCUSSION**

The averaged \( N_1 \) S2/S1 of \(<0.5 \) in nonsmokers supports the central neural gating hypothesis in respiratory mechanosensation (15, 21). This study further demonstrated that respiratory sensory gating represented by the \( N_1 \) peak S2/S1 may be modulated in smokers after 12 h of withdrawal from nicotine. This study also showed that the \( N_1 \) peak S2/S1 was restored to normal in smokers after the administration of nicotine. These results suggest that cognitive perception of respiratory sensation can be modulated by nicotine abstinence and nicotine replacement.

Although there were no previous studies examining the effects of nicotine withdrawal on respiratory sensation, modulated cognitive performance, such as attention and memory with nicotine abstinence, has been documented (23, 43). Domier et al. (23) found that overnight abstinence (13 h or more) from smoking lengthened smokers’ reaction time in cognitive behavioral tests. In another study, Pineda et al. (43) found that, after 12 h of nicotine withdrawal, smokers exhibited delayed P300 peak latencies compared with nonsmokers. They also found that P300 amplitudes were larger in nonabstinent smokers compared with abstinent smokers. In rodents, the effect of nicotine withdrawal was tested with PPI startle response, auditory sensory gating, social interaction test, and...
difference (experiment. Open bars, data for NS; hatched bars, data for S. *Significant ison between NS and S at baseline measurement on the first day of the experiment. Reduced PPI startle response was increased in a stressful environment in rats. Semenova et al. (49) found that nicotine withdrawal of 24 h resulted in sensorimotor gating deficits, represented by a decreased PPI startle response in mice. This suggests that a neurophysiological change occurred due to nicotine withdrawal over time.

It was reported in previous studies that anxiety was a commonly reported affective symptom after nicotine withdrawal (19, 30). Other studies have mentioned that the amount of nicotine intake varied in each smoker, depending on their smoking pattern (38, 43). The initial inclusion criterion in this study for smoking intensity was between 0.5 and 1 pack per day. However, many smokers who met this criterion were often unable to make their appointments due to high failure rate in smoking abstinence. This may explain why the state anxiety total scores of the smokers group had a higher standard deviation compared with that of the nonsmokers.

The result of the present study demonstrated that acute nicotine restores respiratory sensory gating in smokers by reducing the N1 peak S2/S1 to equal that of nonsmokers. There were no studies directly examining effects of nicotine on auditory or somatosensory N100 peak amplitudes in normal controls; however, previous studies have reported that smoking/nicotine is effective in restoring sensory gating and PPI (2, 34, 36, 37). Adler et al. (2) found that auditory P50 gating was improved in individuals with schizophrenia after smoking, but not in smokers free of disease. Kumari et al. (36) found that cigarette smoking improved PPI and decreased startle amplitude after overnight abstinence in healthy male smokers. Another study found that, in nonsmokers, administration of nicotine improves PPI (37). These results lend support to the present study, suggesting that nicotine may be effective in modulating secondary respiratory information processing in smokers.

The fact that the respiratory P1 peak gating S2/S1 was unchanged after nicotine administration in the present study suggests that the nicotine may not modulate respiratory sensory information arrival in the cortex, but only information processing after the arrival. This is consistent with Pineda et al. (43), where they found that the P300 cognitive peak was larger in nonabstinent smokers than abstinent smokers and suggested that nicotine may create a psychological state that promotes efficient cognitive information processing. In another study, Kisley et al. (34) examined the effect of consciousness on auditory sensory gating and found that the P300 peak was not state dependent; however, the N100 peak suppression by paired click was diminished during sleep compared with wakefulness. Therefore, the respiratory N1, but not P1 peak, sensory neural gating may be affective state dependent and more sensitive to nicotine administration.

The difference of the state anxiety level between smokers and nonsmokers at baseline measurement could be due to various reasons. In the present study, there was no data supporting that nicotine withdrawal induced smokers’ anxiety. There was also no within-group difference found in the smokers before and after the administration of nicotine gum. Therefore, it was difficult to determine whether the elevated anxiety level was due to nicotine withdrawal. One limitation of this study is that there is no other anxiety measure on smoking habits, withdrawal symptoms, and urges to smoke, except the STAI scores. In addition, the initial inclusion criterion in this study for smoking intensity was between 0.5 and 1 pack per day. However, many smokers who met this criterion were often unable to make their appointments due to high failure rate in smoking abstinence. Most smokers who were able to make their appointments indicated their smoking frequencies varied on a daily basis. The reason for no significant difference on STAI scores between the S-P group and the S-N group may be due to the fact that the smokers who made their appointments to the laboratory experienced less intense withdrawal symptoms. Future studies are needed to systematically explore emotional effects on respiratory sensory gating.

In somatosensory information processing, incoming stimuli reach the thalamus, which projects to the amygdala and the sensory cortex (31, 33, 46). The sensory cortex has projections to the hippocampus and amygdala to generate emotional responses and subsequent behaviors (31, 52). It is known that the amygdala also has projections to the thalamus and sensory cortex (31, 35). The fact that the amygdala and the hippocampus are closely related to emotion, learning, and memory suggests that the limbic system can mediate the information processing in the somatosensory cortex.

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Fig. 7. The group-averaged N1 peak amplitude S2/S1 (mean + SD) comparison between NS and S at baseline measurement on the first day of the experiment. Open bars, data for NS; hatched bars, data for S. *Significant difference (P < 0.05) between the S group and NS group in N1 gating ratio.

Fig. 8. Group-averaged state anxiety level total score in NS and S at baseline measure on the first visit. *Significant difference (P < 0.05) between NS and S in their state anxiety level after 12 h of withdrawal from nicotine.
sponses to the second stimulus decrease after nicotine administration, suggesting that the brain underwent a state change that promotes a learning process to suppress perception of redundant stimuli. This is supported by the results from previous studies that demonstrated that cognitive performance regarding working memory and selective attention were effectively improved by acute nicotine in abstinent smokers (18, 23, 43).

Summary. In summary, respiratory sensory gating is decreased in smokers after 12-h withdrawal from nicotine, represented by increased RREP N1 peak S2/S1. Smokers showed a higher state anxiety level after the withdrawal compared with nonsmokers. Respiratory sensory gating is increased after nicotine treatment in smokers. This is evidenced by decreased S2/S1 of the RREP N1 peak, resulting from decreased S2 amplitude. The unaffected RREP P1 peak ratio suggests that nicotine does not change respiratory sensory information arrival in the cortex and only affects secondary respiratory information processing.

DISCLOSURES

No conflicts of interest are declared by the author(s).

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