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ORIGINAL PAPER

The effects of negative air ions on cognitive function: an event-related potential (ERP) study

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Abstract

This study investigated the effects of negative air ions (NAIs) on cognitive function in young male adults, specifically examined whether NAIs could influence the behavioral and neuroelectrical indices of inhibition. Thirty-nine young adults participated in the NAI and the control sessions in a counterbalanced order. A computerized Stroop color-word test was administrated, and N2 of the event-related potential was recorded and then analyzed. The results revealed that participants in the NAI session demonstrated shorter reaction times and higher accuracy for both Stroop congruent and incongruent trials. Larger N2 amplitudes were also observed in the NAI session than in the control session, whereas no alterations in the latencies were found. These findings suggest that NAIs resulted in a general improvement in both basic information processing and inhibition. This facilitation may be related to an enhanced neuronal processing or alertness status reflected by larger amplitudes of the N2 component.

Keywords Negative air ion · Inhibition · Event-related potential · N2 · Stroop color-word test

Introduction

Since the discovery of negative air ions (NAIs) in the nineteenth century, the possible effects of NAIs on human performance and behavior have attracted a great deal of interest (Jiang et al. 2018). NAIs, which are the negatively ionized air molecules or atoms, can be generated naturally by cosmic radiation, by radioactive decay in the air, or by the frictional forces in thunderstorms and lightning (Krueger 1985). NAIs can also be generated artificially by commercially available air ionizers via high-voltage currents or minerals.

Most of the empirical research addressing the potential influence of NAIs on humans has focused on the physiological and psychological domains, with the reported effects of NAIs including serotonin modulation (Tikhonov et al. 2004) and the reduction of the negative impacts of stress (Malik et al. 2010; Nakane et al. 2002). The alleviation of depression and enhancements in the positive emotional processing of individuals with seasonal depression have also been documented (Bowers et al. 2018; Goel et al. 2005; Harmer et al. 2012). Notably, although some findings have suggested positive effects of NAIs on mood, the evidence regarding these effects remains equivocal (Perez et al. 2013).

In addition to the above findings relating to the effects of NAIs on psychophysiological functions, few research examining the effects of NAIs on human cognitive function has

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linked NAIs to superior perceptuomotor and arithmetic speed (Andrade et al. 1992), memory (Andrade et al. 1992), and selective and sustained attention (Arora and Batra 2014). Other studies exploring the influence of NAIs on information processing have revealed that NAIs could positively enhance the right ear advantage among learning-impaired adults (Morton and Kershner 1984) and children (Morton and Kershner 1990), indicating the potential impacts of NAIs on learning. Meanwhile, healthy young adults tested in a test room with a higher concentration of total air ions (i.e., NAIs + positive air ions) demonstrated superior performance in terms of verbal factor, reasoning, and perceptual speed than their counterparts tested in a test room with a lower concentration of total air ions (Wallner et al. 2015). Collectively, these studies provided some preliminary evidence for the beneficial effects of NAIs on some aspects of cognitive function; nevertheless, whether these positive effects would extend to other aspects of top-down cognitive control, such as inhibition, remained unclear.

Inhibition broadly refers to the ability to focus selectively on relevant information and resolve conflicting responses while disregarding irrelevant information (Miyake et al. 2000). Inhibition has been associated with academic performance (Hillman et al. 2012), while dysfunctional inhibition has been linked to attention-deficit/hyperactivity disorder (ADHD) (Hart et al. 2013). Studies using the Stroop color-word test (Stroop 1935) have indicated poor Stroop test performance in ADHD individuals (Lansbergen et al. 2007; Yurtbasi et al. 2018) and older adults (West and Alain 2000; Zurrón et al. 2014), reflecting relatively poor inhibition. These findings suggested a close correlation between Stroop test performance and inhibition.

Notably, the performance of inhibition might be influenced by various stages of information processing, including the early stage involving conflict detection and resolution (Larson et al. 2014). Using neuroelectrical techniques, such as event-related potential (ERP) recordings, might further elucidate the impacts of NAIs on various stages of information processing. ERP refers to the patterns of neuroelectrical activities time-locked to or induced by certain events. Given the high degree of temporal resolution (i.e., in ms), ERP is a highly effective means for the differentiation of implicit and distinct cognitive stages of information processing characterized by specific ERP components (Kotchoubey 2006). The N2 of ERP component, which is a frontocentral negativity appearing around 200 to 400 ms after the onset of a stimulus (Folstein and Van Petten 2008), has been associated with the conflict detection and resolution and detection of visual novelty or variations from an attended to visual template (Folstein and Van Petten 2008). However, the question of whether NAIs might affect this stage of information processing remains a matter of speculation. Therefore, analyzing N2 might provide valuable insights regarding the effects of NAIs on information processing since the results of such an analysis could offer indices of inhibition.

To further explore the effects of NAIs, the current study was designed to evaluate the effects of NAIs on inhibition by using two distinct approaches. First, as the impacts of NAIs on cognitive function have rarely been examined, we aimed to extend the existing knowledge of such effects on inhibition by utilizing a standard neurocognitive test, the Stroop color-word test. In light of the potential relationships between NAIs, stress, and inhibition (Malik et al. 2010; Nakane et al. 2002; Roos et al. 2017; Sänger et al. 2014), we hypothesized that NAIs would have positive impacts on Stroop test performance; that is, participants inhaling NAIs would exhibit superior behavioral performance during the Stroop color-word test. Also, given that no previous research has utilized a neuroelectrical approach to explore the influence of NAIs on inhibition, the second purpose of this study was to examine the linkage between NAIs and N2 alterations. We hypothesized that if inhibition was influenced by NAIs, an alternation of N2 would be observed.

Materials and methods

Participants

A total of 40 non-smoking healthy young male adults aged 20–25 years were recruited in Taoyuan County, Taiwan. The eligible participants met the following criteria: (1) no history of neurological or psychological disorders, (2) not currently using any medications affecting the central nervous system, (3) right-handedness, (4) normal or corrected-to-normal vision based on the minimal 20/20 standard, and (5) free from color blindness. Furthermore, to exclude the potential influence of the working memory capacity (Kane and Engle 2003), the digit span forward and backward tests of the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) (Wechsler 1997) were administrated. Of the original 40 participants, one voluntarily withdrew from the experiment, and therefore, data was only analyzed for the final group of 39 participants. The written informed consent form approved by the Institutional Review Board of Fu Jen Catholic University was obtained from participants before the initiation of the experiment. Table 1 presents the participants' characteristics.

Test room and the NAI apparatus

Both the control and NAI sessions were conducted in the same room, where the Stroop color-word test and electroencephalography (EEG) were conducted. An indoor NAI generator (Model Haotion Care, type C, Taiwan), which emits 2500 ions/cm^3, was present in both experimental sessions; however, it was only turned on during the NAI session. To obtain the

Table 1 Participant characteristics (mean ± SD)

Variable	Gender	
	Male ($n = 28$)	Female ($n = 11$)
Age (years)	22.20 ± 1.31	22.36 ± 1.12
Height (cm)	175.10 ± 6.48	161.45 ± 4.15
Weight (kg)	67.54 ± 7.67	54.54 ± 5.82
BMI (kg/m^2)	21.99 ± 1.77	20.89 ± 1.62
Education (years)	14.19 ± 1.12	13.81 ± 0.98
Digit span (points)	21.90 ± 3.45	23.27 ± 3.98

maximum effect, the airflow of NAIs was directed toward the participant's breathing space by adjusting the soft tube connecting to the NAI generator. NAI concentration was assessed with a negative ion tester (COM-3010PRO, COMSYSTEM INC., Japan) located approximately 15 cm in front of the participants' noses during the experimental sessions. The averaged ambient levels of NAIs during the control and the NAI sessions were 26.13 ± 23.41 (ions/cm^3) and 1489.30 ± 148.92 (ions/cm^3), respectively.

Stroop color-word test

A computerized Stroop color-word test (Stroop 1935), adapted from previous research (Song et al. 2017), was administrated to assess multiple aspects of cognitive function. The Stroop color-word test consisted of two types of trials (i.e., the congruent and the incongruent trials). The stimuli in the congruent trials were one of the three colored Chinese words (i.e., 紅 (RED), 藍 (BLUE), and 綠 (GREEN)), with the semantic meaning of the word corresponding to the color of the pixels in which the word was presented (e.g., the word "紅 (RED)" was presented in red pixels). The stimuli in the incongruent trials also consisted of the same Chinese words. However, the semantic meaning of the word was non-corresponding to the color of the pixels in which the word was presented (e.g., the word "紅 (RED)" was presented in blue pixels). The stimuli were presented on the black background of a 15-in. LCD screen using the Neuroscan STIM 2.0 software (Neurosoft Labs Inc., Sterling, VA, USA).

Four blocks of 108 trials were randomized such that the order for the trials in each block was unique. The occurrence of the types of trials (i.e., congruent and incongruent trials) and the colors (i.e., red, green, and blue) occurred with equal probability. The presentation time for each stimulus was 500 ms. Participants were instructed to respond using a response pad as fast and accurately as possible. Only correct responses made between 200 ms and 1000 ms after the initial appearances of the stimuli were accepted for further analysis of the reaction times (RTs). Those responses made outside the acceptable response window and any pressing of a wrong button for a given stimulus were both considered incorrect responses. For the behavioral indices, the averaged correct response RTs and the response accuracy in each type of trials were calculated.

ERP recording and analysis

The continuous EEG activity of each participant during the Stroop color-word test was recorded using a Neuroscan Quick-Cap, with 32 Ag/AgCl electrodes arranged following the international 10–20 system (NeuroScan Inc., El Paso, TX, USA). All the electrodes were filled with conductive gel and were re-referred to the averaged right and left mastoid, with the AFz electrode site serving as the ground. The impedance was maintained below 10 KΩ throughout the experimental sessions. The EEG data were digitalized at the A/D sampling rate of 1000 Hz and amplified 500 times with the NeuroScan SynAmps EEG amplifier (NeuroScan Inc., El Paso, TX, USA). Additionally, a 60-Hz notch filter was applied to eliminate potential artifacts. The electrooculographic (EOG) activity of both eyes was recorded through the additional electrodes attached above and below the left orbit and outer canthus of each eye.

Based on previous research (Li et al. 2018), the offline stimulus-lock EEG data were epoched from 200 pre-stimulus onsets to the 1000-ms post-stimulus onset. The baseline was then corrected using a 100-ms pre-stimulus time interval and filtered using a zero-shift low-pass filter at 30 Hz (12 dB/oct). Subsequently, epoch segments were discarded if the response made was incorrect or if the identified artifact exceeded a ± 100-μV threshold. Finally, artifact-free epoch segments were averaged for each type of Stroop congruency.

After visually inspecting the grand-average waveforms, N2 was identified by the largest negative ongoing amplitude evoked in the frontal cortex within a fixed period of 200–350 ms after the stimulus onset. In this study, N2 was qualified as the peak amplitude and its latency within the 200–350 ms time window, and then the amplitudes and latencies from the three midline frontocentral electrodes (Fz, FCz, and Cz) on correct trials were clustered into the anterior N2 indices.

Experimental procedure

The experiment was conducted in a dimly illuminated, electrically shielded, and sound-attenuated room designed for EEG recording in the summer of 2018. A within-subject design was applied, with each participant visiting the laboratory on two non-consecutive occasions to complete the two experimental sessions (i.e., the control session and NAI session). Participants were instructed to refrain from engaging in vigorous exercise and caffeinated beverages for 6 h before visiting the laboratory. The two experimental sessions were presented in a counterbalanced order.

Upon their first visits, the experimental procedure and the Stroop color-word test were introduced to the participants. After being fitted with the Neuroscan Quick-Cap, participants performed a practice block of the Stroop color-word test till achieving an 80% accuracy rate. Participants then conducted the four blocks of the experimental Stroop color-word test, while his or her continuous EEG activities were simultaneously recorded. A short rest interval of 5 min was included between the blocks. The procedure for the second visit was identical to that for the first visit. Each of the experimental sessions lasted approximately 60 min.

In order to minimize the confounding influence of the environment, an ambient temperature of 24 °C ± 2 °C and relative humidity of 50% ± 5% were maintained throughout the experimental sessions. Each participant received 30 US dollars in remuneration for participating in the entire experiment.

Statistical analysis

Statistical analyses were performed using the SPSS 20.0 software. The protocol employed a repeated measure design with the session and the Stroop color-word test congruency as within-subject factors. For the behavioral measure, a 2 (session, control vs. NAI) × 2 (Stroop congruency, congruent vs. incongruent) repeated measures analysis of variance (ANOVA) was conducted separately for the RTs and the accuracy to test the effects of NAIs on the Stroop test performance.

For the ERP N2 indices, a 2 (session) × 2 (Stroop congruency) repeated measures ANOVA was computed separately for the amplitudes and latencies of N2. Greenhouse-Geisser epsilon corrections were performed when necessary to meet the sphericity assumption. The post hoc Student-Newman-Keuls method and multiple *t* test comparisons were performed with familywise alpha levels set at .05 prior to Bonferroni correction.

Results

Participant characteristics

The characteristics of the final 39 participants are shown in Table 1. Compared with the female participants, the male participants were taller and weigh more (p's < 0.001). No other significant differences were observed in terms of the age, body weight index (BMI), educational levels, or digit span test performance (p's > 0.05).

Behavioral measures

Table 2 shows the mean RTs and accuracy of the Stroop color-word test for two experimental sessions.

Table 2 Summary of statistical analyses of behavioral indices (mean ± SE)

Measures	Session	
	Control	NAI
Reaction time (ms)		
Congruent	569.97 ± 14.72	534.32 ± 11.65
Incongruent	620.82 ± 19.53	572.41 ± 15.13
Accuracy (%)		
Congruent	0.93 ± 0.01	0.94 ± 0.01
Incongruent	0.88 ± 0.02	0.91 ± 0.01

Reaction time

A two-way ANOVA revealed a main effect of the Stroop congruency (F (1, 38) = 78.81, $p < 0.001$, $\eta_p^2 = 0.67$), with a shorter mean RT in the congruent trials than the incongruent trials. A significant session effect was observed (F (1, 38) = 19.05, $p < 0.001$, $\eta_p^2 = 0.33$), with a shorter mean RT during the NAI session than during the control session. Furthermore, there was a significant interaction effect between Stroop congruency and session (F (1, 38) = 8.15, $p < 0.05$, $\eta_p^2 = 0.17$). Follow-up analyses revealed that the mean RT of the congruent trials during the NAI session was significantly shorter than the mean RT of the congruent trials during the control session ($p < 0.001$). Moreover, the mean RT of the incongruent trials during the NAI session was significantly shorter than the mean RT of the incongruent trials during the control session. Additionally, the mean RTs in the congruent trials during both sessions were significantly shorter than the mean RTs in the incongruent trials during both sessions ($p < 0.001$) (Fig. 1a).

Accuracy

The two-way ANOVA indicated a main effect of the Stroop congruency (F (1, 38) = 34.80, $p < 0.001$, $\eta_p^2 = 0.47$), with higher accuracy in the congruent trials compared with the incongruent trials. A significant session effect was also been observed (F (1, 38) = 4.99, $p < 0.05$, $\eta_p^2 = 0.11$), with higher accuracy during the NAI session than during the control session (Fig. 1b).

ERP N2 measures

Table 3 presents the grand average N2 amplitude and the latency for each Stroop congruency for the two experimental sessions. Regarding the amplitude, the analyses revealed a significant main effect of the session (F (1, 38) = 8.37, $p < 0.05$, $\eta_p^2 = 0.18$), with significantly larger (that is, more

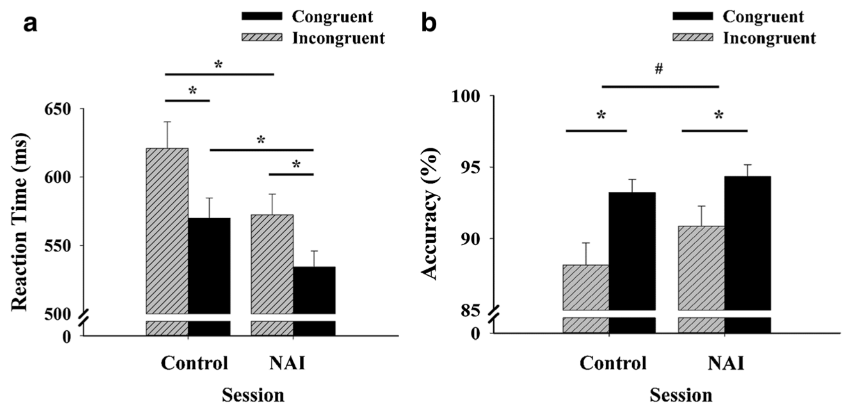

Fig. 1 **a** Comparison of the mean RTs according to the Stroop congruency and the experimental sessions. **b** The comparison of the mean response accuracy according to the Stroop congruency and the experimental sessions. The data are presented as the mean ± SE. *$p < 0.001$; #$p < 0.05$

negative) N2 amplitudes occurring during the NAI session than during the control session. No further effects or interaction was observed (Fig. 2). Regarding the latency, no significant differences were obtained ($p > 0.05$).

Discussion

The present study is among the first to investigate the effects of NAIs on cognitive function using both behavioral and neuroelectrical approaches. The primary findings were that the participants demonstrated shorter RTs and higher accuracy levels for both congruent and incongruent trials of the Stroop color-word test during the NAI session. With respect to neuroelectrical indices, the elevated NAI levels influenced N2 by yielding more negative anterior N2 amplitudes regardless of the Stroop congruency.

Our findings of longer RTs for the incongruent trials than for the congruent trials reflect the typical Stroop effect (Chang et al. 2017; Stroop 1935). Given that processing the semantic meaning of the words (i.e., the task-irrelevant attribute) is more automated than processing the color of the pixels (i.e., the task-relevant attribute), the semantic meaning processing interferes with the color naming processing in the incongruent trials, resulting in prolonged RTs compared with the RTs in the congruent trials (Stroop 1935).

Table 3 Summary of statistical analyses of N2 (mean ± SE)

Measures	Session	
	Control	NAI
Amplitude (μV)		
Congruent	− 5.34 ± 0.73	− 7.10 ± 0.76
Incongruent	− 5.36 ± 0.78	− 6.86 ± 0.70
Latency (ms)		
Congruent	286.70 ± 5.72	279.98 ± 4.65
Incongruent	283.68 ± 5.65	279.89 ± 4.78

A novel aspect of our results was the finding of a significant improvement in the Stroop behavioral performance in young male adults. Specifically, our findings indicated that the NAIs resulted in significantly shorter RTs and higher accuracy, suggesting the acceptance of our hypothesis. These findings are in line with prior research reporting positive effects of NAIs on various aspects of cognitive function, such as memory (Andrade et al. 1992) and perceptuomotor speed (Andrade et al. 1992), as well as selective and sustained attention (Arora and Batra 2014). Although shorter RTs might be achieved by sacrificing accuracy (that is, through a speed-accuracy trade-off) (Rinkenauer et al. 2004), the increased accuracy in both Stroop congruency seen in this study renders this speed-accuracy trade-off less tenable as an explanation for the apparent RT-related effects of the NAIs. Collectively, the current results support the conclusion that NAIs have beneficial effects on some cognitive processes and extend the existing knowledge regarding the influence of NAIs to inhibition.

Notably, the current findings might also suggest general benefits of NAIs on cognitive function in young male adults. Specifically, the shorter RTs in the incongruent trials, in which the participants were required to engage in top-down cognitive processing (i.e., inhibition) in order to focus on the relevant attribute while suppressing the more automatic processing (Alvarez and Emory 2006; Demakis 2004), suggest that an enhancement of inhibition was induced by the NAIs. Meanwhile, the shorter RTs observed in the congruent trials indicated the beneficial effects of NAIs on more basic information processing (Stroop 1935). Accordingly, the current findings of improved performance on the Stroop color-word test in the NAI session might be due to more effective suppression of the irrelevant information, or general facilitation in the basic information processing in association with inhibition.

With respect to neuroelectrical activities, the current study has pioneered an approach to examining the influence of NAIs on the ERP components. Our findings that larger N2 amplitudes were induced by NAIs regardless of the Stroop

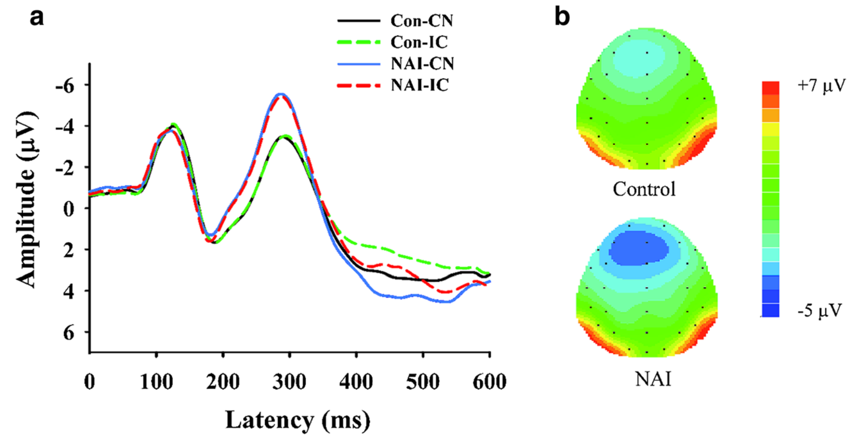

Fig. 2 **a** The averaged stimulus-locked grand-average waveform of N2 from 3 electrode sites (Fz, FCz, and Cz) across the Stroop congruency as a function of the experimental sessions. **b** Topographic scalp plots for N2 (200–350 ms) collapsed across the Stroop congruency for NAI session and control session. Con-CN congruent trials in the control session, Con-IC incongruent trials in the control session, NAI-CN congruent trials in the NAI session, NAI-IC incongruent trials in the NAI session

congruency, which were in alignment with the behavioral findings of improved performance, are of particular interest. Given that N2 has been associated with cognitive control, the detection of novelty in attended to stimuli (Folstein and Van Petten 2008), and the general alerting system (Suwazono et al. 2000), the enhanced N2 amplitudes in the NAI session might imply more efficient cognitive control processing or novelty detection, or enhanced general alertness. Our findings corroborate several studies in which positive associations between cognitive control and N2 amplitudes have been reported. For instance, healthy children demonstrated larger N2 amplitudes than children with ADHD did, reflecting more substantial activation of the inhibitory processes (Dimoska et al. 2003). Meanwhile, larger N2 amplitudes in younger adults than in older adults (Karayanidis et al. 2011; Lucci et al. 2013), as well as in healthy individuals than in individuals with major depression (Holmes and Pizzagalli 2008), have also been reported, suggesting the possible correlations between N2 amplitudes and cognitive performance. Collectively, the evidence in the current study suggests that NAIs might enhance the neuronal processing or alertness status, regardless of the Stroop congruency.

Notably, our results revealed no differentiated N2 between congruent and incongruent trials. The non-significant difference in N2 amplitudes between the congruent and incongruent trials might suggest the insensitivity of the anterior N2 component to the conflict between responses (Ramos-Goicoa et al. 2016; West et al. 2005; Zurrón et al. 2013). Meanwhile, given that N2 latency has been associated with the time required to evaluate stimuli (Folstein and Van Petten 2008), the non-significant difference in the N2 latencies across the Stroop congruency, as well as the experimental sessions, might indicate that the neural networks underlying the evaluation speed for the color-word stimuli were not influenced by the conflict or the NAIs.

Although the design of this study does not allow for a definite conclusion regarding the mechanisms involved in changes such as enhanced Stroop test performance, the effects of NAIs on arousal alertness and stress reduction might provide some potential explanations. For instance, after comparing several aspects of cognitive tasks performed under different NAI levels, Baron (1987) reported curvilinear correlations between relatively complex cognitive tasks and the NAI levels. However, the correlations between simple cognitive tasks and the NAI levels were somewhat linear. Based on the inverted-U hypothesis of the arousal-performance relationship (Yerkes and Dodson 1908), Baron (1987) further argued that those correlations might have been induced by the altering of arousal levels. Given the general enhancement of both basic information processing and inhibition induced by NAIs, the NAI concentration employed in the current study (~ 1500 ions/cm^3), which was between the moderate and high NAI concentrations used by Baron (1987), might have just adjusted the arousal of the participants to the level that benefits both types of cognitive function. Additionally, individuals' cognitive performance might be affected by the stress levels they perceived (Shields et al. 2016); that is, improved cognitive performance might be the result of a decrease in the perceived stress level that is induced by the Stroop color-word test (Skoluda et al. 2015). Several studies have revealed the effects of NAIs on decreasing perceived stress levels. For instance, Takahashi et al. (2008) and Grafetstatter et al. (2017) reported significantly lower subjective stress perceptions after transient and 7-day NAI exposures, respectively. Findings from Nakane et al. (2002) further suggested that the presence of NAIs not only lowered stress perceptions and salivary chromogranin A-like immunoreactivity, which reflects the activity of the sympathetic-adrenomedullary system (Kanno et al. 1999), but also significantly improved computer typing task performance. Additionally, using the paper version of the Stroop color-word test as an acute psychological stressor, Nakane (2003) noted that NAIs significantly improved task performance along with lowering subjective stress perceptions. Accordingly, the present findings of beneficial effects of NAIs on cognitive function might be attributable to the adjusted arousal levels and stress perceptions.

Although the current study extends current knowledge by examining the influence of NAIs on inhibition using both behavioral and neuroelectrical approaches, certain limitations of the study should be noted. First, the present study was not carried out using a double-blind approach, which might have introduced some potential bias. We recognize the importance of minimizing this potential bias in future research by directing a similar amount of fresh air flow toward participants. Second, given different concentrations of NAIs might impact differentially on the cognitive function (Baron 1987), the single concentration of NAIs utilized in the current study cannot clarify whether the concentration was the optimal dose for inhibition. Third, the influence of NAIs on different stages of information processing during inhibition needs further study. Examining other ERP components, such as the P300 component, might provide further information regarding the influence of NAIs on the later stage of information processing involving in the attentional resource allocation and stimulus evaluation (Polich 2007). Forth, given that only the inhibition and general information processing were examined in the current study, we were not able to draw the conclusion of the benefits of NAIs to other aspects of cognitive function. Finally, only young male adults were recruited in this study also limits the generalizability of the current findings to female or other ages of populations. Despite the aforementioned limitations and the preliminary nature of the current study, the findings of this study highlight a potentially easy and economical method of cognitive enhancement that deserves further attention.

Conclusion

This study is one of the first research to examine the influence of NAIs on the temporal dynamics of inhibition using the ERP components. Our results indicated that NAIs enhanced young adults' cognitive function as reflected by shorter RTs and higher accuracy, regardless of the Stroop congruency. Such effects in behavior performance corresponded with the neuroelectrical activity of N2. Accordingly, NAIs might influence the early stage of information processing during inhibition. Together, this study provides some preliminary evidence of NAIs as a feasible alternative approach for generating benefits on cognitive function involved both basic information processing and inhibition from behavioral and neuroelectrical perspectives. Further research utilizing the double-blind approach and addressing the influence of concentration of NAIs on different stages of inhibition and other aspects of cognitive function, as well as other populations, is warranted to extend our understanding of NAIs and cognitive function relationship.

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Author contributions YKC and YMC designed the study and oversaw the data collection. CHC and YKC analyzed the data and wrote up the initial manuscript. SRC, CHW, and YCC assisted with the analysis of the data and organized the manuscript. All authors played a part in the preparation of the manuscript at each stage of its development. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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