The Neural Underpinnings of Emotional Conflict Control in Pilots

Hao Jiang; Kaijun Xu; Xi Chen; Quanchuan Wang; Yong Yang; Chao Fu; Xiangmei Guo; Xipeng Chen; Jiazhong Yang

BACKGROUND: Piloting an aircraft is a complex cognitive task. Human error represents a major contributing factor in aviation accidents. Emotion plays an important role in aviation safety. We performed a functional magnetic resonance imaging (fMRI) study to explore whether pilots and nonpilots may differ in the neural mechanisms responsible for the processing of conflict emotional information.

METHODS: A total of 27 civil aviation pilots and 24 nonpilot controls performed the emotional Stroop task, in which participants were required to identify the facial expressions of the stimuli while ignoring the congruent or incongruent emotional words superimposed on the faces. Neural responses to the stimuli were compared between pilots and controls. Also, a psychophysiological interaction (PPI) analysis was performed to explore whether there were differences in effective connectivity between pilots and nonpilots.

RESULTS: Behavioral data showed that pilots (21.23 ms) and nonpilots (26.78 ms) had equivalent congruency effects. Nevertheless, their neural activation patterns differed. Compared with pilots, nonpilots exhibited neural activity in the right supramarginal gyrus when processing incongruent stimuli, and more regions were activated in the process of conflict monitoring. The PPI analysis showed greater activity between the right supramarginal gyrus and the right lingual gyrus when nonpilots confronted incongruent vs. congruent stimuli. However, this effective connectivity was not found in pilots.

CONCLUSION: These results suggest different mechanisms underlying emotional conflict control between pilots and the general population.

KEYWORDS: emotional conflict control, fMRI, pilot, supramarginal gyrus, lingual gyrus.

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Flying a plane is a demanding cognitive task in which pilots deal with a rapidly changing environment and engage in complex interactions with the flight deck. Pilots need to pay attention to a huge amount of information within the cockpit as well as in the surrounding environment.[28] The task requirements impose a large cognitive demand on pilots. On other occasions, pilots' cognitive demands may be very low, which could make them inattentive. As a result, it has been found that human error is a major contributing factor (about 70–80%) in aviation accidents and mishaps.[30]

In such high-risk tasks, emotion plays a critical role. When pilots experience an emergency, they need to stay calm and focus on the task, and not get overwhelmed by negative emotions, such as anxiety, fear, impulsivity, or depression. For example, on May 14, 2018, on China Sichuan Airline flight 3U8633, a windshield suddenly broke during flight. The flight crew was faced with an extremely low temperature of −50°C and low pressure and hypoxia at an altitude of 9000 m. They calmly handled the emergency and the plane landed successfully without any passengers being injured. On the other hand, negative emotions can disrupt attentional control and lead to performance impairment.[1,35] Furthermore, neural mechanisms underlying emotional processing in pilots have also been

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explored. For instance, Causse and colleagues[4,5] conducted a series of experiments using functional magnetic resonance imaging (fMRI). They found that pilots' decision-making processes were underpinned by the contribution of the brain circuitry of emotion and reward.

In view of the significant effect of emotion on flight safety, pilots should have a high degree of emotional stability, or they should have the ability to regulate their emotions. Emotional stability is a personality characteristic. Emotionally stable people have a high threshold of emotional response, and they can recover quickly.[22] Emotion regulation, on the other hand, is a goal-directed process whose function is to influence the emotion experienced.[16] How can pilots be emotionally stable or have a strong ability to regulate emotions? First, candidates must follow a complex selection process that includes the assessment of psychopathology, and individuals with undesirable personality characteristics are screened out for pilot training.[6] For example, neuroticism, which is the opposite of emotional stability (from the Big Five personality model or the Eysenck Personality Questionnaire), is an undesirable characteristic that hinders career success.[8] Second, with the accumulation of flight training and experience, pilots gradually develop better emotional awareness and improve their ability to regulate emotion[26] and thereby acquire higher emotional stability.

One way of studying the processing of emotional stimuli is the use of a variant of the Stroop paradigm.[23] In the classic Stroop task, a colored word is presented, and participants are required to respond to one of two properties of the word—the meaning or the color. Better performance is usually found when these two properties are congruent (e.g., a green-colored word "GREEN") than when they are incongruent (e.g., a red-colored word "GREEN"). In the emotional variant of the Stroop task, the stimuli contain emotional information that may trigger response conflicts, which are referred to as emotional conflicts. For example, a face with a fearful expression is presented with the word "happy" or "fear" across the face, and participants are asked to identify the emotional expression of the face. The emotional expression of the face and the emotional word can thus be incongruent, triggering response conflicts. Not surprisingly, people are slower at responding to incongruent vs. congruent stimuli, showing the congruency effect. Furthermore, the processing of emotional conflict usually involves two processes: conflict monitoring and conflict resolution.[3] Conflict monitoring refers to a function that detects or monitors for conflicts in information processing, while conflict resolution is a cognitive control process used to overcome conflicts. Such a dissociation can be confirmed by the result that response times are faster for incongruent stimuli if they are preceded by another incongruent stimulus, relative to if they are preceded by a congruent stimulus.[10] This finding demonstrates the phenomenon of conflict adaptation. That is, incongruent stimuli recruit more control to overcome the conflict, leading to higher levels of control in subsequent trials. Consequently, incongruent trials result in high or low conflict resolution if they are preceded by another incongruent or congruent trial, respectively. This so-called conflict adaptation effect is considered as evidence for implicit emotion regulation.[17] As a fascinating tool for exploring attentional control and bias, the Stroop task and the emotional Stroop task have also been adopted in many neuroimaging studies. For instance, some researchers have found that two dissociable neural systems are responsible for emotional and nonemotional information processing.[7,11,13] A ventral subregion and a dorsal subregion of the anterior cingulate cortex (ACC) were found to engage in emotional and nonemotional tasks, respectively.[36] For emotional tasks, the rostral anterior cingulate cortex is activated in conflict monitoring, and conflict resolution is achieved by inhibition of amygdalar activity.[11,13] Participants in these studies were healthy individuals or individuals with a mental disorder. Given that emotion may be crucial for aviation safety, it is surprising that neuroimaging studies on emotional conflict in pilots are scarce, especially those that compare pilots with the general population.

Given the importance and scarcity of research on pilots' emotional conflict control, we decided to carry out a preliminary study to address this issue. The main purpose of the current study was to explore whether the neural mechanisms underlying emotional conflict control differ between pilots and nonpilots. Considering the importance of emotion, as well as the personality traits of pilots in aircraft piloting, we expected that neural mechanisms would differ in pilots vs. nonpilots. To investigate this hypothesis, we designed an fMRI study involving the emotional Stroop task. The neural activity of pilots and nonpilots was compared when performing the main task.

METHODS

Subjects

The study protocol was approved in advance by the Ethics Committee of the University of Electronic Science and Technology of China. Each subject provided written informed consent before participating. A total of 27 Chinese civil aviation pilots and 24 nonpilot controls participated in this study. Of the pilots, 14 were general aviation pilots, and the remaining 13 commercial pilots were first officers from various airlines. All pilots had passed the assessment of psychopathology before they became flight candidates. All participants were male and had normal or corrected-to-normal vision. Considering the potential influence of anxiety and depression on control of emotional conflict, the self-rating anxiety scale (SAS) and the self-rating depression scale (SDS) were used to measure the level of anxiety and depression for each participant.

Equipment and Materials

Each participant performed an emotion classification task while lying in a 3T MRI scanner (GE Discovery MR 750) at the Center for Information in Medicine (CIM) of the University of Electronic Science and Technology of China. Stimuli were presented with E-Prime 2.0 software and were projected onto a screen that could be viewed by the participants via a mirror mounted on the head coil. Functional images were acquired using a standard EPI pulse sequence. The scan parameters were as follows: TR = 2000 ms, TE = 30 ms, FA = 90°, matrix size = 64 × 64, field of view = 24 cm × 24 cm, 35 slices, and slice thickness = 4 mm (no gap). A total of 255 volumes were acquired. Structural images were acquired with a T1-weighted SPGR sequence: TR = 5.976 ms, TE = 1.976 ms, FA = 9°, field of view = 25.6 cm × 25.6 cm, 154 slices, and slice thickness = 1 mm (no gap).

In each trial, a male or female face with a happy or sad expression was presented on a black background. These photographic stimuli were acquired from the Chinese Affective Face Picture System (CAFPS). One of two red Chinese words, meaning either "happiness" or "sadness", was superimposed in the center of a face, creating an emotionally congruent or incongruent stimulus. A total of 120 black-and-white faces were used, half male and half female. Of these stimuli, 24 were used for practice, and the remaining 96 were used for experimental trials.

Procedure

In the emotion classification task, participants were instructed to identify the facial expression of the figure and were required to respond as fast and accurately as possible while ignoring the task-irrelevant red Chinese words superimposed on the face. For half of the participants, a happy face was indicated by pressing a button with the thumb of their left hand, while a sad face was indicated by pressing a button with their right hand. The response settings were reversed for the other half of the participants. The task consisted of 96 experimental trials. Each trial started with a face stimulus, presented for 1000 ms. After a varying interstimulus interval (ISI) of 3000–5000 ms (average ISI = 4000 ms), the next trial began. During the ISI, the screen was black. Stimuli were presented in pseudorandom order. Random ordering was not used because pseudorandom ordering can create exactly equal numbers of congruent and incongruent trials, which would be beneficial for analysis. In addition, each face stimulus was displayed only once during the study, thus avoiding repetition priming[25] and partial repetition effects.[20] All 96 trials were divided into 2 equal segments (i.e., each segment consisted of 48 trials), with an instruction of "please have a rest" lasting 4000 ms in between, followed by a central fixation mark of 4000 ms, and then the second segment started.

Statistical Analysis

The neuroimaging data were preprocessed using SPM12 software. The first five scans of the functional data were discarded to allow for equilibration effects. Then, the remaining 250 volumes were slice-time corrected, followed by head motion correction. The structural images were coregistered to the functional images, and functional images were spatially transformed to the MNI template (resampled size: 3 mm^3). Finally, images were smoothed using a Gaussian kernel with 8 mm of full width at half maximum.

After preprocessing, two separate general linear models (GLM 1 and GLM 2) with different stimulus events (convolved with a canonical hemodynamic response function) were carried out for each participant. In GLM 1, regressors were created for congruent and incongruent trial types, and linear contrasts between events of interest (incongruent trials > congruent trials) were calculated to acquire brain activation maps. The purpose of GLM 2 was to dissociate between conflict monitoring and resolution, so regressors were created for congruent-congruent (cC), incongruent-congruent (iC), congruent-incongruent (cI), and incongruent-incongruent (iI) trial types. Our focus was on the latter two trial types, because emotional conflict is low in the iI type and is high in the cI type. Consequently, the contrast (high conflict resolution > low conflict resolution) represents conflict resolution, while the reverse contrast (low conflict resolution > high conflict resolution) represents conflict monitoring (or generation). A high-pass filter (cutoff period = 128 s) was used to reduce the effects of low-frequency changes. The six head motion parameters generated in the realignment process were included as nuisance regressors to account for biases in head-related activation. To compare the differences in activation maps between pilots and controls, individual contrast maps were entered into a two-sample *t*-test. Given our focus on emotional processing and regulation, we produced several regions of interest based on some recent research on the neural network of emotion processing.[12,21] These regions of interest included the lateral and medial prefrontal cortex, insula, amygdala, superior temporal gyrus, supplementary motor area, anterior cingulate cortex, and parietal cortex. All these regions were defined by the anatomical automatic labeling (AAL) brain atlas.[34] As this was a preliminary study with an exploratory nature, the analyses were performed with thresholds of voxel-wise $P < 0.001$ (uncorrected for multiple comparisons) and a cluster size > 20 voxels. In order to examine whether activations in these regions differed between pilots and controls, the activation value for each voxel in activated clusters was extracted using RESTPlus software and averaged across the whole cluster. Then, mean activations were compared between pilots and controls using a two-sample *t*-test.

Finally, psychophysiological interaction (PPI) analyses were carried out to search for regions that have effective connectivity with the source regions. The analyses examined whether the correlated activity of these regions with the source regions was modulated by psychological variables.[14] In our study, the source region was the region exhibiting group differences identified in the analyses above. For each participant, the deconvolved activity time courses of the source region were extracted. To this end, a 6-mm radius sphere was created, with the peak-activated voxel of the source region serving as the center of the sphere. Then, the first eigenvariate of the time courses of the voxels within the sphere was deconvolved to calculate the neural activity. The neural activity was multiplied with the vector of the psychological variable (incongruent > congruent) to obtain the PPI term. Another general linear model was constructed, with three regressors: the PPI term, the physiological variable, and the psychological variable. Of interest was the psychophysiological interaction; thus, the physiological and the psychological variable were nuisance regressors. Individual PPI results

Table I. Response Times (ms) and Standard Deviations in the Task.

	PILOTS	CONTROLS
Incongruent trials	674.62 ± 76.44	683.43 ± 70.07
Congruent trials	653.39 ± 73.59	656.65 ± 64.29
cI *	679.37 ± 71.58	680.82 ± 75.99
iI †	669.86 ± 84.83	686.03 ± 68.48
Congruency effect	21.23 ± 30.32	26.78 ± 27.91
Conflict adaptation effect	9.51 ± 35.59	−5.21 ± 35.93

* cI = incongruent trials preceded by congruent trials; †iI = incongruent trials preceded by incongruent trials.

were entered into a two-sample *t*-test, contrasting effective connectivity patterns between pilots and controls (voxel-wise $P < 0.001$, cluster size > 20 voxels).

RESULTS

Before analyses, data from two pilots (one general aviation pilot and one commercial pilot) and three controls were discarded due to high proportions of error and/or no-response trials. The remaining data from 25 pilots and 21 controls were used for further analyses. The mean age of the pilots (25.76 ± 3.11) differed significantly from that of the controls (28.81 ± 3.92), $t(44) = 2.941$, $P < 0.01$. Thus, age was employed as a covariate in the imaging analyses below. The scores of SAS (pilots: 35.01 ± 6.25; controls: 38.00 ± 4.56) and SDS (pilots: 34.71 ± 6.13; controls: 38.22 ± 9.96) did not differ between pilots and controls.

Behavioral Data

Trials in which participants pressed the wrong button were removed. From the remaining trials, response times (RTs) falling outside 3 SD were also discarded. On average, 85.4 trials were included in the subsequent analysis for each participant. The averaged RTs and the SDs for congruent and incongruent trials, as well as for incongruent trials that were preceded by another congruent or incongruent trial are shown separately in **Table I**.

Two analyses of variance (ANOVAs) were conducted. First, the averaged RTs were submitted to a 2 (group: pilots vs. controls) × 2 (congruency: congruent vs. incongruent) ANOVA. The results showed that the main effect of group was insignificant [$F(1,44) = 0.085$, $P = 0.772$, $\eta^2_P = 0.002$]. A significant main effect of congruency was found [$F(1,44) = 30.741$, $P < 0.001$, $\eta^2_P = 0.411$]. Incongruent trials were responded to 24 ms slower than congruent trials. In addition, group did not interact significantly with congruency [$F(1,44) = 0.410$, $P = 0.525$, $\eta^2_P = 0.009$]. The congruency effect for the pilots was not different from that for the controls.

Second, we focused on incongruent trials. The incongruent trials were divided into those following incongruent trials (iI), and those following congruent trials (cI). The averaged RTs were submitted to a 2 (group: pilots vs. controls) × 2 (trial sequence: cI vs. iI) ANOVA. Two main effects and their interaction effect were all insignificant, $P > 0.171$. The conflict adaptation effect was calculated by subtracting RTs in iI trials from those in cI trials. The conflict adaptation effects were not significantly reliable for both pilots (9.51 ms) and nonpilots (−5.21 ms).

Neuroimaging Data

From the behavioral data analyses above, it seems that pilots and controls did not differ in the processing of conflict emotional information. To investigate whether regions underpinning conflict control differed between these two groups, two general linear models (GLM) were created and analyzed. In GLM 1, incongruent trials were contrasted with congruent trials. Results showed that, compared with pilots, the controls showed increased activation in the right supramarginal gyrus when facial expression was incongruent with the superimposed words (voxel-wise $P < 0.001$, cluster size > 20 voxels) (**Fig. 1A**; **Table II**). Mean activation across each voxel in this cluster was calculated for pilots and controls. A two-sample *t*-test was carried out to compare the difference between them. The results revealed that the activation of controls was significantly stronger than that of pilots [$t(44) = 3.473$, $P < 0.005$] (**Fig. 1B**). By contrast, decreased activity in the right supramarginal gyrus was associated with incongruent vs. congruent stimuli for pilots.

In GLM 2, emotional conflict monitoring and resolution were dissociated. This was achieved by contrasting low conflict resolution (incongruent trials following another congruent trial, cI) with high conflict resolution (incongruent trials following another incongruent trial, iI). Conflict monitoring was indexed by the contrast cI > iI, whereas conflict resolution was represented by the contrast iI > cI. First, separate one-sample *t*-tests were run for pilots and controls, respectively. For conflict

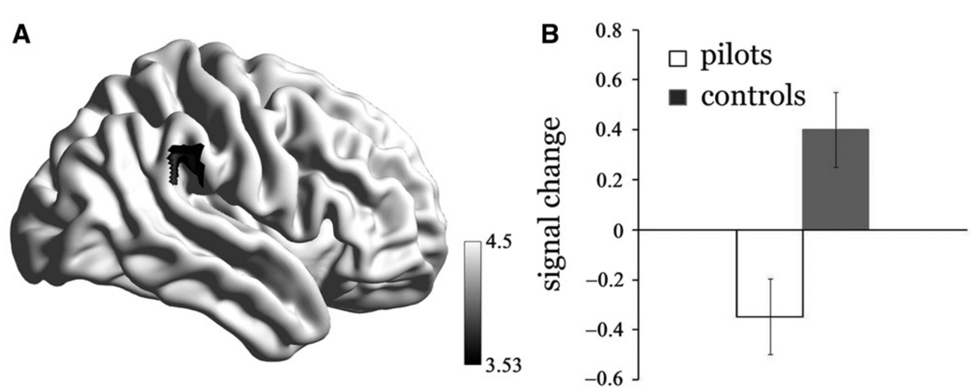

Fig. 1. A) The brain region (right supramarginal gyrus, peak voxel MNI: 63/−36/27) with significant difference between pilots and controls when contrasting incongruent vs. congruent stimuli ($P < 0.001$, uncorrected with cluster size > 20 voxels). B) Averaged signal changes (beta ± SEM) in the region for pilots and controls.

Table II. The Brain Region Exhibiting Significant Difference Between Pilots and Controls in the Contrast (Incongruent Trials > Congruent Trials) ($P < 0.001$, Uncorrected With Cluster Size > 20 Voxels).

			CENTER (MNI)			
BRAIN REGIONS (AAL) *	BA†	CLUSTER SIZE (VOXELS)	X	Y	Z	PEAK *t*-VALUE
SupraMarginal_R	40	31	63	−36	27	3.871

* AAL = Anatomical Automatic Labeling; †BA = Brodmann Area.

monitoring, activation was observed in the right superior parietal gyrus for pilots. In addition, the right middle frontal gyrus and the right supplementary motor area were also activated for controls (**Fig. 2**; **Table III**). For conflict resolution, no region was found to be activated within the predefined ROIs for both groups. Then, a whole-brain analysis was conducted. Results showed that conflict resolution activated a cluster of 12 voxels in the left postcentral gyrus (MNI −42/−24/51) for pilots, and a cluster of 40 voxels also in the left postcentral gyrus (MNI −48/−21/54) for controls. Second, two-sample *t*-tests were run to compare pilots with controls. These analyses revealed no difference between these two groups, both for conflict monitoring and resolution.

Effective Connectivity Analyses

The right supramarginal gyrus was found to have stronger activation in controls than in pilots when responding to incongruent vs. congruent stimuli; thus, this region was treated as the source region to search for other regions that covaried with it by means of PPI analyses. Compared with pilots, controls showed an enhanced effective connection between the source region (right supramarginal gyrus) and the right lingual gyrus (voxelwise $P < 0.001$, cluster size > 20 voxels) (**Fig. 3**; **Table IV**). Though uncorrected for multiple comparison, this result provides a preliminary finding for future investigation.

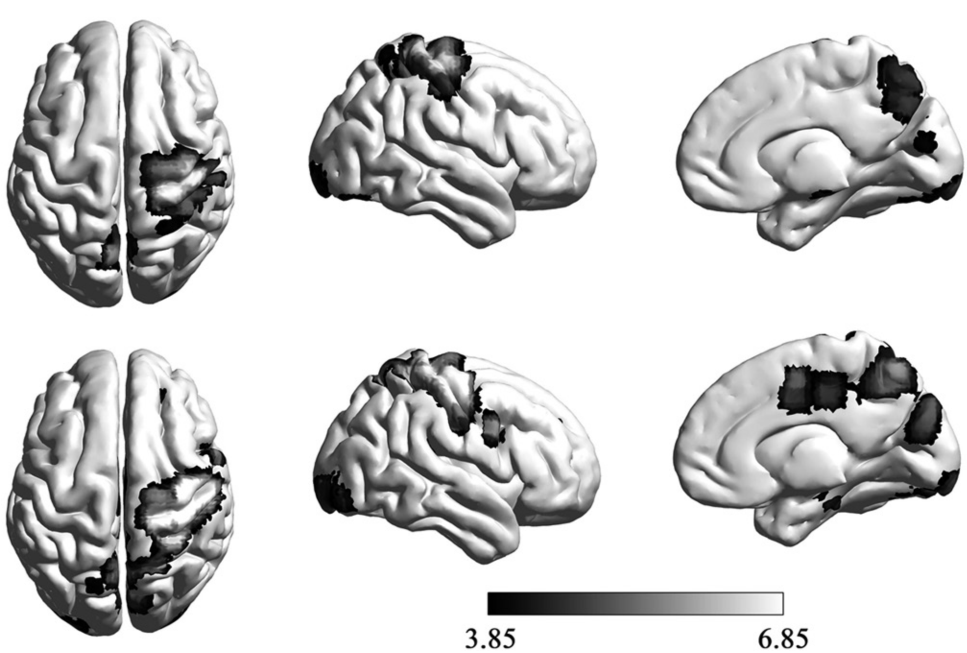

Fig. 2. The brain regions activated in the process of conflict monitoring for pilots (the first row) and nonpilots (the second row) ($P < 0.001$, uncorrected with cluster size > 20 voxels).

DISCUSSION

The focus of the current research is on emotional control, which is very important to aviation safety. Although applicants are required to take psychological tests and individuals with undesired personality traits will be screened out for further flight training, it remains unknown and needs to be investigated whether pilots and nonpilots would differ behaviorally when processing emotional information. In our study we also intended to explore whether the neural underpinnings of emotional conflict control would differ between pilots and the general population. To this end, pilots and nonpilots performed an emotional Stroop task, in which participants were required to identify the emotion of congruent or incongruent faces. Neuroimaging data were recorded and compared between these two groups to find brain regions responsible for any group difference in emotional conflict control. Behavioral data analyses showed robust congruency effects in both pilots and nonpilots, and the sizes of the effects were equivalent for both groups. Nonetheless, neuroimaging data analyses revealed different neural mechanisms between them.

At this point, one may notice a discrepancy between behavioral and neuroimaging results. One possible reason for the discrepancy lies in the relatively small number of participants used in our study. It is also plausible that neurological, psychological, and behavioral outcomes may not always match each other. For instance, Egner et al.[11] found different neural systems responsible for emotional vs. nonemotional conflict, albeit emotional and nonemotional stimuli produced identical behavioral effects. Likewise, in our study, different neural mechanisms for pilots and nonpilots also achieved similar behavioral results. Since behavioral results did not differ between pilots and nonpilots, we will discuss the neuroimaging results below.

The analyses of neuroimaging data were divided into two parts. First, we searched for the different brain regions between pilots and nonpilots responsible for emotional conflict control. In this exploratory study, regions activated for incongruent trials were contrasted with those for congruent trials, and the only cluster that showed a difference between pilots and nonpilots was the right supramarginal gyrus. The supramarginal gyrus was found to activate in response to emotional stimuli, such as

Table III. The Brain Regions Activated in the Process of Conflict Monitoring for Pilots and Controls ($P < 0.001$, Uncorrected With Cluster Size > 20 Voxels).

	BRAIN REGIONS (AAL) *	CLUSTER SIZE (VOXELS)	CENTER (MNI) X	Y	Z	PEAK *t*-VALUE
Pilots	Parietal_sup_R	89	42	−39	57	5.164
Controls	SupraMarginal_R	24	48	−21	33	5.012
	Frontal_mid_R	38	27	39	30	4.258
	Supp_motor_area_R	95	6	−3	51	5.196
	Parietal_sup_R	195	33	−39	63	6.826

* AAL = Anatomical Automatic Labeling.

emotional words.[7] More recent studies discovered that the right supramarginal gyrus plays an important role in empathy and overcoming emotional egocentricity. Specifically, the right supramarginal gyrus is responsible for decoupling our own emotional state from that of others.[19,32] The present finding of more activation in the right supramarginal gyrus when processing incongruent stimuli in controls may indicate that emotional conflict has a greater impact on nonpilots than on pilots. This implies that pilots have a relatively high threshold of response for irrelevant emotional information and are thus more emotionally stable. In addition, our study showed that controls had greater activation only in the right supramarginal gyrus, and not on the left side. This lateralized activation may be due to the fact that only men were recruited as participants for our study. Previous research has shown sex differences in neural activation during processing of emotional words, and the right supramarginal gyrus only showed activation in male participants, especially during processing of negatively valenced words.[18]

Additionally, emotional conflict control involves two processes: conflict monitoring and resolution. Though we found a cluster displaying a difference between pilots and nonpilots when responding to incongruent vs. congruent stimuli, it was not clear whether it was related to conflict monitoring or resolution. To dissociate between conflict monitoring and resolution, incongruent trials were divided into two types: incongruent trials that were preceded by a congruent trial (cI), and incongruent trials that were preceded by an incongruent trial (iI). Emotional conflict is low in the iI type and is high in the cI type, so the contrast (high conflict resolution > low conflict resolution) represents conflict resolution, while the reverse contrast represents conflict monitoring (or generation). We found some regions responsible for conflict monitoring for both pilots and nonpilots. However, no region was observed within the predefined regions of interest for conflict resolution, for both groups. In addition, no difference was found between pilots and nonpilots in the regions responsible for emotional conflict monitoring. This may be due to the small sample size in the present study. Nonetheless, some implications can also be obtained. First, nonpilots activated more brain regions than pilots when monitoring emotional conflict, implying that nonpilots are more sensitive to emotional conflict information. Second, the right supramarginal gyrus was activated in conflict monitoring for nonpilots but not pilots. This confirms our result in the last step and suggests that the right supramarginal gyrus was responsible for conflict monitoring. Third, both groups activated only the postcentral gyrus when resolving conflict. This seems to indicate that participants did not make as much effort in conflict resolution as conflict monitoring, and thus the conflict adaptation effect did not show up behaviorally. Therefore, the neural activity in conflict resolution could explain the lack of conflict adaptation effect in behavioral data. Note that it is not unusual that conflict adaptation effects did not occur in previous studies.[24,33] The null effect of conflict adaptation could be attributed to subjective conflict experience[9] or response fluency.[37]

In the second part of our neuroimaging data analyses, psychophysiological interaction (PPI) analyses were performed to search for brain regions whose activities covaried with the right supramarginal gyrus. We searched the whole brain and adopted a liberal P threshold. The only cluster that showed a PPI difference between pilots and nonpilots was the right lingual gyrus. The results indicate that the activity of the right lingual gyrus covaries more with the right supramarginal gyrus in emotion-incongruent than in emotion-congruent trials among nonpilots. The lingual gyrus, like the supramarginal gyrus, plays an important role in the processing of emotion.[15,29] Compared with positively valenced emotion, the lingual gyrus was found to be more involved in recognition of negative images, such as disgusted, fearful, or sad faces.[2]

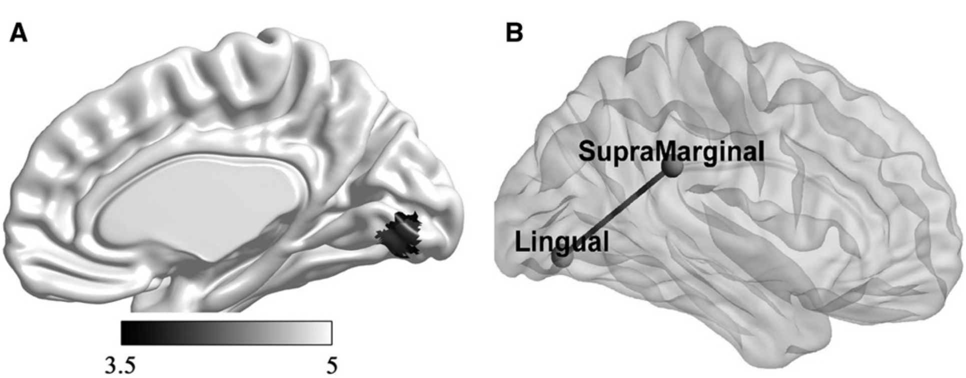

Fig. 3. A) The brain region (right lingual gyrus, peak voxel MNI: 12/−75/−3) with significant difference in psychophysiological interaction with the right supramarginal gyrus between pilots and controls ($P < 0.001$, uncorrected with cluster size > 20 voxels). B) The effective connectivity between the right lingual gyrus and the right supramarginal gyrus.

Table IV. The Brain Region Exhibiting Significant Differences Between Pilots and Controls in the Psychophysiological Interaction Analysis ($P < 0.001$, Uncorrected With Cluster Size > 20 Voxels).

			CENTER (MNI)			
BRAIN REGIONS (AAL) *	**BA†**	**CLUSTER SIZE (VOXELS)**	**X**	**Y**	**Z**	**PEAK *t*-VALUE**
Lingual_R	18	26	12	−75	−3	4.049

* AAL: Anatomical Automatic Labeling; †BA: Brodmann Area.

Additionally, the right lingual gyrus is responsible for the processing of information on facial stimuli, including non-emotional (e.g., the gender of the face) and emotional (e.g., the facial expression) properties, with the latter producing greater activation than the former.[27] Furthermore, the right lingual gyrus exhibits greater activation when the emotional information is expressed via verbal (e.g., an emotional word) than nonverbal (e.g., a face picture) means. This raises the intriguing question of how the right lingual gyrus would respond if both verbal and nonverbal emotional information was presented simultaneously, particularly if these two kinds of information were in conflict, such as in the emotional Stroop task adopted in our research. We consider two possibilities. First, according to Narumoto et al.,[27] incongruent words are more salient than facial expressions and thus may induce more activation in the right lingual gyrus. This processing of incongruent words interferes with participants' task of identifying the facial expression in the picture and therefore needs to be inhibited or suppressed. Second, the activation of the lingual gyrus may also indicate a conflict resolution process or an emotion-regulatory process. A recent study[31] found that the right lingual gyrus was activated when negative emotion was suppressed by participants. In addition, the right lingual gyrus is very helpful in other emotion regulation methods, such as cognitive reappraisal.[15] Which one of the two possibilities is true remains unclear and needs more investigation. On the contrary, the pilots in our study did not show any connectivity between the right lingual gyrus and the right supramarginal gyrus. This may again imply that the incongruent emotional words did not have much impact on pilots. Consequently, pilots were more immune to the conflict between incongruent words and faces. The absence of neural activity interaction between the right supramarginal gyrus and the right lingual gyrus in pilots compared with nonpilots may serve as another indicator of emotional stability in pilots. This helps to keep pilots emotionally stable when encountering a stimulus such as "WARNING" presented on their flight display or an auditory warning signal. Pilots' emotional stability may result from a combination of personal traits and accumulative training and experience, which in turn is beneficial to aviation safety.

Our study has some limitations. First, we only used two emotions, happiness and sadness. Different kinds of emotions may impact people in different ways and may have different neural mechanisms.[2] Therefore, other kinds of emotions need to be examined. Second, the result of the PPI analysis did not survive corrections for multiple comparisons. Third, we did not find the conflict adaptation effect in the behavioral data (at least in terms of $cI - iI$), and the dissociation of neural activities for conflict monitoring and resolution was not robust enough. The latter two limitations may be due to the sample size not being large enough. These limitations are motivators for further research.

Despite its limitations, this study is still the first step to exploring the differences between pilots and nonpilots in neural mechanisms underlying emotional conflict control. In this way, the current study adds to a continually growing body of research in which neurophysiological methods are applied to explore how a pilot's brain works while flying an aircraft. The current study is also helpful for practical application, such as pilot selection and training. Our results indicate that it is necessary to screen out applicants with undesirable traits such as neuroticism. Otherwise, it would be a very difficult or even an impossible task to train an individual with undesirable traits to remain emotionally stable in stressful situations.

In conclusion, compared with pilots, nonpilots exhibited greater neural activity in the right supramarginal gyrus during processing of emotionally incongruent stimuli, and the activity in this region covaried with that in the right lingual gyrus. These results indicate that the mechanisms underlying emotional conflict control are different for pilots and nonpilots, and pilots may possess higher emotional stability than the general population.

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