Association of the five-factor personality model with prefrontal activation during frontal lobe task performance using two-channel near-infrared spectroscopy

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Aim: The aim of this study was to investigate the biological background of the five-factor model using near-infrared spectroscopy and cognitive tasks.

Methods: Twenty right-handed healthy volunteers participated in this study. Their personality traits were assessed using the NEO Five-Factor Inventory, and changes in oxyhemoglobin concentration ([oxy-Hb]) were measured during cognitive tasks using a wireless near-infrared spectroscopy.

Results: The average [oxy-Hb] in the right prefrontal area had a significant positive correlation with the agreeableness score during the Stroop test at incongruent stimulus block. For the verbal fluency task, there were no significant correlations of bilateral [oxy-Hb] changes with any items.

Conclusion: Higher agreeableness scores may involve less suppression to the default mode network related to resting state brain function. Keeping selective attention during the Stroop test may require more power of concentration than retrieving words during the verbal fluency task.

Key words: near-infrared spectroscopy, oxyhemoglobin, personality assessment, prefrontal cortex, Stroop test.

I N RECENT YEARS, the five-factor model (FFM) of personality has been increasingly recognized among personality psychologists as a comprehensive model of normal personality traits.[1,2] The FFM can be embodied in the NEO Five-Factor Inventory (NEO-FFI) or NEO Personality Inventory-Revised (NEO-PI-R).[3] These inventories were developed by Costa and McCrae from a research viewpoint of life-span development of personality and lead to a conceptual model shaped by factor analytic study. The five factors are neuroticism, extraversion, openness, agreeableness, and conscientiousness,[2,4] which are found across all cultures.[5] According to Costa and McCrae, neuroticism represents the tendency of the individual whose thought and behavior are easily disturbed by unpleasant experiences or disturbing emotions. Extraversion means the trait of preferring lively social interactions and activity. Openness refers to receptiveness to new ideas, approaches, and experiences. Agreeableness is seen in selfless concern for others and in trusting and generous sentiments. Low agreeableness (or antagonism) expresses tough-mindedness and hardheadedness. Although agreeable people are preferred to antagonistic people, antagonism also has its virtues. Conscientiousness is a dimension of individual differences in organization and achievement. Highly conscientious people have a sense of responsibility and are self-disciplined, but also ambitious and hardworking. Low conscientious people are relatively lazy, easy-going and less exacting with themselves or others.[6]

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Today, the NEO-PI-R has been translated into the languages of many countries and applied to various areas, for example, counseling, psychiatric assessment, behavioral therapy, health psychology, vocational counseling, industrial psychology, and educational psychology.[7] As noted above, the FFM is well accepted. There are some brain-imaging studies that reveal correlations between FFM and brain volume or function.[8–16]

For brain functional imaging, functional magnetic resonance imaging (fMRI), single photon emission computed tomography (SPECT) and positron emission tomography (PET) have been used most commonly. However, these methods have the disadvantages of requiring large equipment and of measuring under unusual conditions; for example, a very noisy environment and /or narrow gantry for subjects.

Near-infrared spectroscopy (NIRS) has been increasingly used in investigating psychiatric disorders and conducting psychological experiments. Compared with other neuroimaging methods, such as fMRI, SPECT and PET, NIRS measurement is quite simple and enables measurements under natural conditions, which are advantageous in actual usage. NIRS is non-invasive for continuous and repetitive measurements, albeit with the limitation of low spatial resolution and the inability to examine deep brain structures. In this study, we used a 2-channel wireless NIRS system. Though it has only two channels, there are some advantages, for instance, invalid NIRS data caused by a low signal/noise ratio common to multi-channel systems on haired scalps[17] is not a problem for the 2-channel system on the forehead.

However, recently, there has been only one NIRS study associated with the FFM. Sato *et al.* examined correlations between FFM and cerebral cortex reactivity during a verbal fluency task (VFT).[18] VFT is commonly used to evaluate cognitive function, and Stroop test is also commonly used in combination with VFT. There has been an FFM study about behavior performance during Stroop test;[19] on the other hand, to our best knowledge, there are no FFM studies associated with prefrontal reaction during Stroop test. We employed the Stroop test beside VFT because it is also generally regarded as a representative task to elicit prefrontal cortex reaction.[20] Thus, we aimed to investigate the biological background of the FFM comprehensively; that is, to examine the correlation between personality factors based on the FFM

and brain function measured by the 2-channel wireless NIRS system during VFT and Stroop test.

METHODS

Subjects

Twenty healthy volunteers (11 men and nine women) participated in this study. All participants were employed by our university or a national hospital, and had either university or junior college education. They were right-handed and none reported psychiatric or neurological abnormalities. In addition, especially to exclude psychiatric disorders, expert psychiatrists interviewed them and did not point out their pathological findings. The average age was 33.75 (ranging from 26 to 51 years old; SD = 6.24). All participants provided written informed consent. The study was approved by the Ethics Committee of Yokohama City University.

Personality questionnaires

The Japanese version of the NEO-FFI[7] was used to obtain self-report ratings of the 'Big Five' personality traits (neuroticism, extraversion, openness, agreeableness, and conscientiousness).

This instrument consists of 60 items to which participants respond on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Scores were standardized by converting raw scores to T-scores, using raw score means and SD of men and women in a sampled general population.[7] The average T-score in the general population is 50, with SD = 10. This reference average and standard deviation were used to correct raw scores for men and women separately, because it is well known that women generally have higher raw scores of neuroticism and agreeableness than men.

Tasks and procedure

Stroop test

The Japanese 'Hiragana' letter version of the Stroop test[21,22] was used. Hiragana are Japanese syllabary characters. The computerized Stroop test stimuli consisted of the Japanese words for RED, BLUE, YELLOW and GREEN. Each word was written in one of these four colors and was presented in the center of a black screen.

This paradigm involved three conditions: resting visual fixation, congruent color–word stimulus blocks, and incongruent color–word stimulus blocks. In the congruent color–word stimulus block, the subjects were asked to silently name the color of a word that was printed in the same color as fast and accurately as possible by touch-typing the corresponding key on the keyboard; the subjects were asked to touch-type the '4' key on the 10-key keypad using the right index finger when they wanted to give 'red' as the answer. When they wanted to give 'blue', 'yellow' and 'green' as the answer, they touch-typed the '5' key using the right middle finger, the '6' key using the right medicinal finger, and the '+' key using the right little finger, respectively. After the subjects typed the key, the screen showed the next word. In the incongruent color–word stimulus block, the subjects were asked to silently name the color of a word that was printed in a color different from its semantic meaning as fast and accurately as possible by touch-typing the corresponding key on the keyboard. In this condition, the corresponding keys were the same as in the congruent condition. After the subjects typed the key, the screen showed the next word. The paradigm began with an initial resting block of 10 s, followed by two congruent and incongruent stimulus blocks, interleaved sequentially by four 30-s blocks of resting visual-fixation; the task condition order was 'resting visual-fixation', 'congruent color–word stimulus', 'resting visual-fixation', 'incongruent color–word stimulus', 'resting visual-fixation', 'congruent color–word stimulus', 'resting visual-fixation', 'incongruent color–word stimulus', and 'resting visual-fixation'. Each stimulus block consisted of 25 words that appeared one by one on the screen in random order. After each response, reaction time and answer were recorded. Before NIRS measuring, subjects were sufficiently trained to perform this task. Reaction times were adopted as the behavioral performance data, and they were averaged according to the task condition (congruent and incongruent).

VFT (phonemic version)

In the VFT, the subjects were instructed to generate loudly as many words whose initial syllable was /a/, /ka/, or /sa/, as they could. The initial syllables changed in turn every 20 s during the 60-s task, to reduce the time during which the subjects were silent. The number of words generated during the VFT was determined as a measure of task performance. The

subjects were instructed to pronounce the syllables /a/, /i/, /u/, /e/, and /o/ repeatedly during the 30-s pre-task periods. All instructions were given visually by using a PC screen from the pre-task period to the task period. The number of generated words represented the behavioral performance of this task.

NIRS measurements

NIRS measurements were carried out with a two-channel wireless system (Pocket NIRS-NIY, DynaSence, Hamamatsu, Japan). The Pocket NIRS-NIY utilizes near-infrared light emitted at three different wavelengths (735, 810, and 850 nm) to detect primal changes in [oxy-Hb] and [deoxy-Hb] of capillary blood in brain cortical regions. Two pairs of emission (light source: LED-diode) and detection (light detector: photo-diode) probes were attached to the foreheads of the subjects bilaterally. The midpoint between one detection probe and the corresponding emission probe was located at Fp1, while the other pair of probes was located at Fp2, according to the international 10/20 electrode placement system for electroencephalography. The distance between the detection probe and the corresponding emission probe was 3 cm. These probe settings enabled us to detect hemodynamic changes in two separate cortical areas. The anatomical location of these areas likely corresponded to part of the bilateral prefrontal cortex (BA 10).[23] The two sets of probes do not interfere with each other for simultaneous recording of [oxy-Hb] or [deoxy-Hb] changes. Recordings were acquired at a sampling rate of 10 Hz. Because the individual optical path length is unknown, the hemoglobin concentration value is not an absolute but a relative value; this value is expressed as a change from baseline concentration (arbitrary units).

The baseline was determined as the mean level over a 10-s period just before the task period. Simultaneous NIRS and fMRI studies have correlated cerebral blood flow more strongly to [oxy-Hb] than to [deoxy-Hb].[24] Therefore, [oxy-Hb] changes were adopted as a measure of cerebral activation in this analysis. Obtained [oxy-Hb] data were averaged for each participant during the baseline period and each task period. The [oxy-Hb] changes (task minus baseline) were used for the statistical analysis. No baseline corrections or smoothing methods were employed to avoid overcorrections. For the Stroop test, data were averaged according to the task condi-

tion (congruent and incongruent) because each task condition was carried out twice.

Statistical analysis

The [oxy-Hb] changes were analyzed using a two-way repeated measured ANOVA with two within-subject factors: 'hemisphere' and 'task (or condition)'. To investigate the relationship of [oxy-Hb] changes during the tasks and the personality of subjects, partial correlation analysis was used. Age and the corresponding behavioral performance data were used as control variables. Namely, the number of generated words was used for the VFT and the reaction times were used for the Stroop test. The level of significance was set at $P < 0.05$. In addition, the Bonferroni correction was applied for multiple comparisons. After Bonferroni correction, $r > 0.7024$ or $r < -0.7024$ were considered to be statistically significant.

RESULTS

The two-way ANOVA revealed a significant main effect of 'task (or condition)' (F [2, 38] = 28.122, $P < 0.00001$) (Fig. 1). However, there was no significant main effect of 'hemisphere' (F [1, 19] = 0.037, $P = 0.8492$) and 'task' by 'hemisphere' interaction (F [2, 38] = 0.234, $P = 0.7923$). Subsequent analyses revealed that VFT had significantly increased reaction compared to both congruent and incongruent conditions on the Stroop test. The correlations between [oxy-Hb] changes during the tasks and the personality factors of the subjects are shown in Table 1. For the Stroop test, the average of [oxy-Hb] in the right prefrontal area showed a significant positive correlation with the agreeableness score during the incongruent stimulus block. The scatter plot of them is shown in Figure 2. No other items of the FFM were significantly correlated with the [oxy-Hb] changes in the right prefrontal area. No items were correlated in the left prefrontal area. For the VFT, there were no significant correlations between bilateral [oxy-Hb] changes and any of the FFM items.

DISCUSSION

In this study, we examined correlations between personality and brain function. To assess personality, we used the NEO-FFI. To evaluate brain function, we adopted the prefrontal cerebral blood reaction to cog-
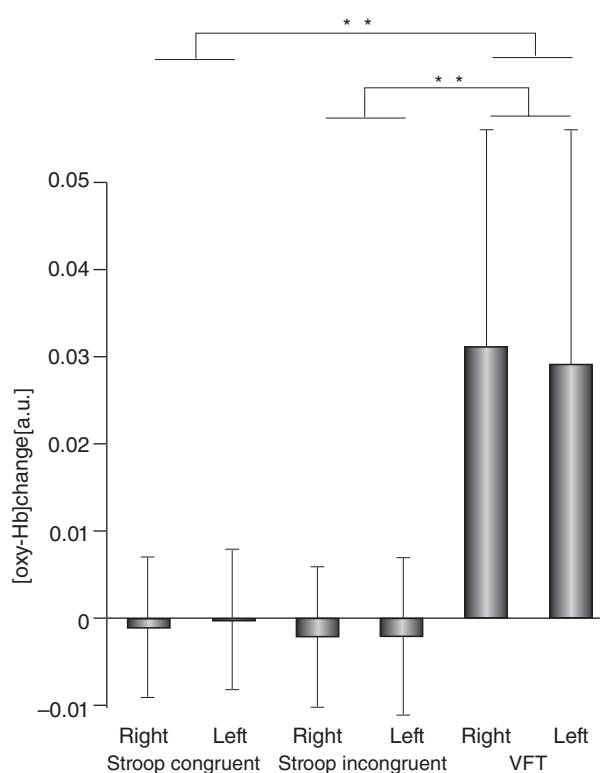
Figure 1. Mean oxyhemoglobin concentration ([oxy-Hb]) changes during the congruent condition of the Stroop test, the incongruent condition, and the verbal fluency task (VFT). Error bars represent the standard deviations. **$P < 0.01$.

nitive tasks (Stroop test and VFT). This reaction was represented by [oxy-Hb] changes measured by a two-channel wireless NIRS system with a block design. According to our findings, [oxy-Hb] changes were different between the VFT and the Stroop test in healthy subjects. The most remarkable findings were significant positive correlations between agreeableness scores in the NEO-FFI and [oxy-Hb] changes during the Stroop test in the incongruent stimulus blocks.

The VFT has been used for an assessment of the subject's ability to retrieve series of nouns based on a common criterion, and VFT is the most frequently applied paradigm within the field of NIRS. In healthy subjects, two-channel NIRS has detected increased [oxy-Hb] in bilateral prefrontal cortices during VFT.[25] As for correlations between FFM and prefrontal reaction measured by NIRS during VFT, Sato *et al.*[18] reported correlations between several personality traits in FFM with [oxy-Hb], [deoxy-Hb], and [total-

Table 1. Partial correlation coefficients

	Neuroticism	Extraversion	Openness	Agreeableness	Conscientiousness
Stroop test					
Congruent condition					
Right	−0.2703	−0.1147	0.0887	0.6679	−0.0435
Left	−0.2922	−0.0070	−0.0830	0.1055	0.2195
Incongruent condition					
Right	−0.2612	0.0253	−0.0805	0.7429*	0.3304
Left	0.1005	−0.0973	−0.2721	−0.2043	0.2044
VFT					
Right	0.2525	−0.2855	0.0261	−0.1730	0.2228
Left	−0.0042	0.0211	0.0052	0.0750	0.3610

*$P < 0.05$.

Hb] changes in relative dorsal or lateral channels, which seemed to distribute mainly around F3 and F4 in accordance with the international 10/20 electrode placement system for electroencephalography. However, our results did not. The possible reason for this difference may be due to differences in measuring points. Our measuring points were placed on Fp1 and Fp2. Because our probes were fixed by double-stick tape, it was difficult to place measurement points close to the hairline. Hence, we could not measure the measurement points that correlated with the FFM according to Sato *et al.*[18]
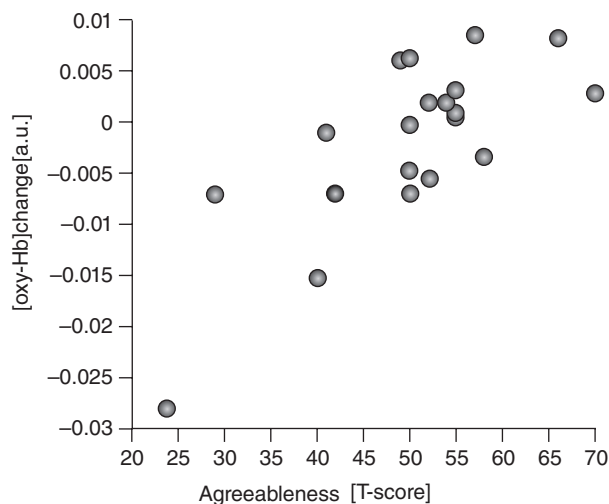
Figure 2. Correlation between the agreeableness and mean oxyhemoglobin concentration ([oxy-Hb]) change in right prefrontal area during the incongruent condition of the Stroop test.

To our best knowledge, there have been no studies examining the relation between [oxy-Hb] changes during the Stroop test and the FFM. The Stroop test is a test for executive function, inhibitory control and attention; it is also one of the most frequently used tests for an assessment of the subject's selective attention. Specifically, the Stroop test is able to assess the ways in which habitual behavior and cognition could be suppressed under cognitively conflicted conditions. Our results showed that a significant positive correlation between agreeableness and [oxy-Hb] changes in the incongruent stimulus blocks. Therefore, our results suggest that agreeableness is related to prefrontal reactivity, especially on the cognitive conflicted condition. Because subjects with high agreeableness might be described as trusting and avoiding conflict,[6] they are assumed to have more difficulty in suppressing their habitual behavior and cognition and to spend a lot of energy selecting answers.

Recently, the notion of the default mode network (DMN) has been presented. This network consists of the posterior cingulate cortex and precuneus, the inferior parietal cortices, and dorsal and ventral areas of the medial frontal cortex.[26–29] The DMN function has been largely linked to self-relevant, internally directed information processing.[30] The DMN is also suppressed during demanding cognitive tasks directed towards external stimuli.[31] However, deactivations within parts of the DMN may depend on task characteristics.[32] As for the Stroop test, Harrison *et al.*[33] have reported healthy subjects' deactivations during the Stroop test as 'task-induced deactivations (TID) of the DMN'. They demonstrated that healthy

subjects showed decreasing [oxy-Hb] during the Stroop test compared with during rest, regardless of whether the block was congruent or incongruent. However, they showed stronger deactivation during the incongruent condition than during the congruent condition.

It is well known that tasks that activate cognitive function are capable of deactivating the DMN. Heavy stimulation to cognition may cause stronger TID than light stimulation, consistent with the observation that stronger TID were observed during the incongruent condition than during the congruent condition in the Stroop test.

Our target area in this study includes a part of the DMN region, the medial frontal cortex. Therefore, we think our result of [oxy-Hb] changes during Stroop test might reflect TID of DMN, basically. However, in this study, the more agreeable persons did not show deactivation. Sampaio *et al.*[34] reported that agreeableness was positively correlated with activity in the medial prefrontal cortex using resting state fMRI. Therefore, compared with less agreeable persons, more agreeable persons may be less likely to suppress the DMN after the beginning of the Stroop test due to higher activity at resting state.

The VFT is also one of the cognitive tasks. Then, why was deactivation of the DMN not seen in the VFT during the present study? Possible explanations are as follows: (i) during the VFT, medial frontal deactivation was masked by broad activation[17,35] due to the low spatial resolution of NIRS; and (ii) the VFT may impose a lower cognitive function load than the Stroop test. Paying selective attention during the Stroop test (especially during the incongruent condition) may need more power of concentration than retrieving words during VFT.

Our results showed the biggest correlation coefficient in the incongruent condition of the Stroop test and the smallest ones in the VFT. Therefore, the correlation between agreeableness and prefrontal blood flow may be more clearly observed on more difficult tasks.

In our result, only the right prefrontal cortex showed a significant correlation with agreeableness. Using resting state functional MRI, Ryan *et al.*[36] demonstrated that higher agreeableness scores were related to stronger covariation between the right BA10 region and posterior cingulate cortex (pCC) activity. The pCC is now considered to be a hub of default activity.[37] Therefore, the right BA 10 activity of a more agreeable person may be more strongly influenced by default activity. As a result, it may be less likely to be suppressed by cognitive tasks. This is one possible reason why the right prefrontal cortex definitely showed a significant correlation with agreeableness.

In conclusion, our finding shows a correlation between personality and prefrontal function. That is, higher agreeableness scores may represent the weakening of suppression to the DMN. Of interest, Costa and McCrae suggest that high agreeableness is positively related to dependent personality disorder.[38] For better understanding of personality and brain function, further studies using FFM and NIRS in patients with personality disorder will extend our knowledge.

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