Frontal activation patterns during Tetris game play and differences between high and low performers: a preliminary functional near-infrared spectroscopy study

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Abstract

Background: Tetris has recently expanded its place of activity not only to the original entertainment but also to clinical applications such as prevention of trauma flashback. However, to our knowledge, no studies focused on the cortical activation patterns themselves when playing Tetris in a natural form. This study aimed to investigate the activation patterns in the frontal cortex during naturally-performed Tetris for 90 seconds in 24 healthy subjects using functional near-infrared spectroscopy robust to artifacts by motion and electric devices. We also calculated the correlations of behavioral data with cortical activations, and compared the differences in activations between the high and low performers of Tetris.

Results: The results demonstrated that significant activations in the frontal cortex during Tetris play had two factors, each showing a similar activation pattern. One of the factors was distributed over the lateral prefrontal cortex bilaterally, and the other was localized to the right prefrontal cortex. Moreover, in the high performers, the activations of the areas centered on the right dorsolateral prefrontal cortex (DLPFC) were estimated to increase and correlations of the activations between those areas and the other areas decrease compared with the low performers.

Conclusions: It is suggested that high Tetris performers might reduce functional connectivity between activations of the areas centered on the right DLPFC and the other areas, and increase the local activations compared with low performers. It would be necessary to consider whether its visuospatial cognitive loads stimulate the appropriate areas of the subject's brain to effectively utilize Tetris play for clinical interventions.

1. Background

Tetris is a worldwide falling block puzzle computer game that has attracted many people over three decades. Studies using Tetris have been conducted across various disciplines mainly in the field of behavioral and cognitive sciences (Haier et al. 1992a, b, 2009; De Lisi and Wolford 2002; Holmes et al. 2009, 2010; Rietschel et al. 2012; Belchior et al. 2013; Nouchi et al. 2013; Price et al. 2013; Yoshida et al. 2014; Harmat et al. 2015; Lindstedt and Gray 2015; Skorka-Brown et al. 2015; James et al. 2016; Sibert et al. 2016; Bikic et al. 2017; Iyadurai et al. 2017; Lau-Zhu et al. 2017; de Sampaio Barros et al. 2018; Meneghetti et al. 2018; Gold and Ciorciari 2019; Milani et al. 2019). Because visuospatial cognitive loads of Tetris are thought to compete with build-up of intrusive traumatic memories in the brain, recent studies have attempted to use Tetris for clinical application, in particular for prevention of traumatic flashbacks (Holmes et al. 2009, 2010; James et al. 2016; Iyadurai et al. 2017). Other studies looking at clinical applications of Tetris have demonstrated that this game may reduce drug cravings through competing visuospatial loads (Skorka-Brown et al. 2015). Overall, Tetris is expected to be used for cognitive training due to the cognitive effects associated with the game (e.g. improvement of attention, mental rotation and visuospatial working memory) (De Lisi and Wolford 2002; Belchior et al. 2013; Nouchi et al. 2013; Bikic et al. 2017; Milani et al. 2019). Important features of Tetris that make it suitable for clinical application include the fact that people of different cultures and with different cognitive levels are able to play Tetris

with minimal instructions, having a high level of motivation and compliance because it is a worldwide entertainment game which can be conducted on various computer platforms non-verbally (it was certified in Guinness World Records as “most ported videogame” [1]) (Ackerman 2016).

There are few studies investigating brain activity related to Tetris play (Haier et al. 1992a, b, 2009; Rietschel et al. 2012; Price et al. 2013; Yoshida et al. 2014; Harmat et al. 2015; de Sampaio Barros et al. 2018). Moreover, to our knowledge, canonical referential data of functional neuroimaging in healthy subjects during playing Tetris in a natural form has not been published yet. This would confirm Tetris’s neurocognitive clinical application based on evidence. Therefore, also as a potential preliminary step towards clinical application of Tetris, this study aimed to detect frontal activation patterns during playing Tetris using functional near-infrared spectroscopy (fNIRS), which has proven to be a reliable tool to explore cortical activation during the naturally performed Tetris game (Yoshida et al. 2014; Harmat et al. 2015; de Sampaio Barros et al. 2018).

fNIRS is a non-invasive neuroimaging technique, which requires little restriction compared with other neuroimaging methods such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG). It shows low sensitivity to artifact by motion and electric devices. In addition, considering its high portability and low cost, the use of fNIRS is expected to spread worldwide (for a review see Pinti et al. 2018). In fNIRS, near-infrared light penetrates into tissues and is differentially absorbed by hemoglobin depending upon the oxygenation state and its optical path length in the tissues (modified Beer–Lambert Law). This relationship enables fNIRS to detect relative changes in concentration of oxygenated hemoglobin ([oxy-Hb]) and deoxygenated hemoglobin ([deoxy-Hb]) by emitting near-infrared light at several different wavelengths into the cortex and detecting its remnants (Jöbsis 1977; Hoshi 2003; Ferrari et al. 2004). Areas with high neural activity show increased oxygen consumption followed by supply oxygenated hemoglobin (neurovascular coupling) (Fox and Raichle 1986; Hoshi et al. 2001). This means that neural activity is measured indirectly by using relative changes in regional cerebral blood volumes (rCBV).

To our knowledge, there are three English articles using fNIRS during Tetris play (Yoshida et al. 2014; Harmat et al. 2015; de Sampaio Barros et al. 2018). However, these studies used Tetris to induce subjective flow experience without an interest of the underlying neural activation patterns of playing Tetris per se. Additionally, the extension of the cortex analyzed in those studies was much smaller than that of our study. The results of these previous studies suggest that the bilateral ventrolateral prefrontal cortex, the right dorsolateral prefrontal cortex (DLPFC) and the right inferior parietal lobe are significantly activated by Tetris play itself (de Sampaio Barros et al. 2018; Yoshida et al. 2014).

Using functional neuroimaging techniques, except for fNIRS, Tetris was first studied by Haier et al. (1992a), using PET in eight male healthy high performers trained intensively in Tetris. These subjects showed decreased metabolism over all brain areas induced by Tetris training. This led authors to conclude that activity of brain cortical areas was reduced by learning. They also reported that cortical metabolism after Tetris training could increase in areas needed for high Tetris performance, including the

right precuneus and left cingulate (Haier et al. 1992b). Using fMRI Haier et al. (2009) demonstrated significant BOLD-signal increases in precentral gyrus, superior parietal lobule, inferior parietal lobule and occipital gyrus (after a 3-month training) during playing Tetris in 15 healthy females. In addition, cortical thickness increased in left superior frontal gyrus and anterior superior temporal gyrus after training Tetris. Another fMRI study showed significant BOLD-signal increases in the right occipital cortex and the left DLPFC during Tetris play (Price et al. 2013). However, in these functional neuroimaging studies, Tetris was performed under restricted experimental conditions. Thus, it is difficult to consider that cortical activation patterns were investigated during naturally-performed Tetris. Only an electroencephalography (EEG) study investigated neural activation and network activity during naturally-performed Tetris. In the study, the activations were measured on Fz, F3, F4, C3, C4, T3, T4, P3, P4, O1, and O2 of the international 10/20 system for EEG, and the network activities were investigated between Fz and the other measurement points. Its findings showed increasing activations across the cortical areas and elevated network activities between the motor planning area in the frontal cortex (Fz) and the other cortical areas (the sensory and executive brain regions) as difficulty of Tetris increases (Rietschel et al. 2012).

Based on the findings of previous Tetris studies, we hypothesized that significant activation would be found in the lateral prefrontal cortex. Furthermore, as an exploratory investigation we attempted to identify frontal areas required to play Tetris successfully taking into account the relation between activation and performance.

2. Materials And Methods

2.1. Subjects

Twenty-four right-handed healthy Japanese subjects participated in this study (13 men, 11 women; mean age ± standard deviation (SD) 27.3 ± 6.8 years). None of them had history of psychiatric or neurological disorders.

Written informed consent was obtained from all the subjects before the experiments. The procedures and methods in this study were consistent with the policies described in the Declaration of Helsinki. This research was approved by the Ethics Committee of Osaka University Graduate School of Medicine.

2.2. fNIRS Measurement

Relative changes in [oxy-Hb] and [deoxy-Hb] were measured by using fNIRS (ETG-4000; Hitachi Medical Corporation, Tokyo, Japan) during playing Tetris. In this study we used the ETG-4000’s probe mounted with fifty-two measurement points (channels). Seventeen laser diodes (emitters) and sixteen photodiodes (detectors) were arranged reciprocally at 3 cm intervals on a piece of thermoplastic shell (3 × 11) covering most of the frontal and part of the temporal surface areas (Fig. 1). Detection depth at the channels was 2–3 cm under the scalp. The lowest center photodiode was located on Fpz using the international 10/10 system for EEG. The channels set at the most lateral posterior edges corresponded to the T3-Cz-T4 row of the international 10/20 system or a little anterior to this row. Because the cortical region/channel

association of this setting had been determined by the virtual registration method of fNIRS with automated Talairach atlas labels for functional brain mapping [2], which enables probabilistic registration for standalone fNIRS channel positions onto the Talairach stereotactic coordinates without the subject's MRI, we referred to studies using this method and a study on anatomical correlation of EEG sensors in order to interpret our data (Tsuzuki et al. 2007; Koessler et al. 2009; Tsuzuki and Dan 2014; Yokoyama et al. 2015; Tomita et al. 2017).

2.3. Tasks

In the present study Tetris was employed as the activation task. Tetris was performed using Nintendo Game boy pocket (Nintendo, Kyoto, Japan) which is a handheld game console. In this Tetris, on the monochrome liquid crystal display the player moves and rotates blocks that fall one by one. There are seven kinds of blocks consisting of four square blocks called Tetrimino. Tetrimino is moved by the cruciform button under the left thumb and rotated by the two round buttons under the right thumb aiming to arrange Tetrimino without gaps at the bottom. The lines vanish at the moment when they are made, and numbers of the vanished lines are recorded as LINE, which represents the behavioral data collected in this study. In addition, the upcoming Tetrimino is shown in the Preview box of the right side on the display.

In the baseline task, consisting of a resting state before and after Tetris execution, subjects were instructed to gaze at the display and tap their right and left thumbs reciprocally on the buttons of the console at a uniform pace.

2.4. Experimental Procedure

Before the experiment, the subjects played Tetris for several minutes to confirm they knew how to play the game. Tetris used in this study can produce the game version from Level 0 to Level 9 in order from the one with the lowest falling speed of Tetrimino (blocks), and at first, we intended to have the subjects play Level 0 Tetris. However, if the subjects answered “Yes” to the question of whether you are good at Tetris and the fact was confirmed during the above pre-experimental play, we applied Level 1 Tetris to the subjects because we predicted that Level 0 would be too easy to induce the cortical activations characteristic of Tetris for them (Haier et al. 1992a; de Sampaio Barros et al. 2018). Accordingly, the subjects were given tasks closer to the individual optimal levels of difficulty, which had been shown to induce more right prefrontal activation than the easy or hard level during Tetris play (de Sampaio Barros et al. 2018). In fact, 9 subjects played Tetris at Level 1 and 15 subjects played at Level 0, and as expected, LINE of those who played at Level 1 was in the top nine.

During the experiment, the subjects sat on a chair in a silent room. The subjects executed the first baseline task (30 sec), Tetris game (90 sec), and the second baseline task (60 sec). Instructions were given orally. We previously succeeded in detecting activation patterns during cognitive and motor tasks by using this procedure with the ETG-4000 (Nakahachi et al.2008, 2010, 2015, 2016).

2.5. Data Analysis

2.5.1. Preparation

Relative changes in [oxy-Hb] and [deoxy-Hb] are defined as the product of the concentration of hemoglobin and optical path length, and are expressed in the unit of mM•mm. Changes in [oxy-Hb] was analyzed at temporal resolution of 100 msec using this fNIRS (ETG-4000) because [oxy-Hb] is considered to be most sensitive to changes in rCBV, and it strongly correlates with the BOLD signal of fMRI, while the direction of [deoxy-Hb] changes is influenced by changes in blood oxygenation and volume of the vein (Hoshi et al. 2001, 2003; Scarapicchia et al. 2017). The analysis software of ETG-4000 was set at the "integral mode". In that configuration, mean changes in [oxy-Hb] for the baseline states 10 sec before the start of the activation task and after 50 sec from the finish of the activation task, were corrected to 0 mM•mm by using linear fitting. The activation task period was set at 90 sec, and the recovery period from the finish of the activation task period up to baseline stabilization was set at 50 sec. The moving average method for 5 sec was applied to smooth out short-term motion artifacts.

2.5.2. Detection of Activation Patterns

For statistical analyses, firstly, the authors determined frontal activation patterns during Tetris play. Mean changes in [oxy-Hb] during Tetris play were calculated for each subject in each channel, followed by a two-tailed single-sample t-test, which is equal to a paired t-test against zero (mean changes in [oxy-Hb] during baseline periods) to detect significant activations. The two-tailed single-sample t-test was conducted on all fifty-two channels; the significant α levels of 0.05 were corrected by the false discovery rate (FDR) (Benjamini and Hochberg 1995) to control multiple comparisons, which could be applied to fNIRS (Singh and Dan 2006). Next, we expected that components of the Tetris-induced activations could be classified by the functions, and this might give suggestion of the cortical areas to successfully perform Tetris, so that the following analysis was carried out. In order to extract channel groups showing similar patterns of changes in [oxy-Hb] from the significantly activated channels by the above single-sample t-test, factor analysis using major factor method with direct oblimin rotation was performed for mean changes in [oxy-Hb] during Tetris play of each subject in those channels. In each channel, the extracted factor, which indicated the absolute value of factor loading over 0.4 and higher than the other factors, was selected as the represented factor of the channel. Also, mean changes in [oxy-Hb] of each subject during Tetris play were averaged among the channels belonging to each extracted factor, and compared using paired Student's t-test.

2.5.3. Detection of Activations for High Performance

Pearson's correlation coefficients between LINE and the mean values of [oxy-Hb] changes in all subjects were calculated for each channel. Next, the twenty-four subjects were trisected into high, middle and low performer groups of 8 members based on their LINE values. One-way ANOVA using Tukey correction for multiple comparisons was performed with mean changes in [oxy-Hb] during Tetris play for each subject in each channel. In addition, to investigate differences in LINE in detail, independent Student's t-test was carried out to compare mean changes in [oxy-Hb] during Tetris play between the high and the low performer groups (8 members respectively) in each channel. Moreover, based on the findings of Rietschel

et al. (2012), that the cortical network activity, i.e. functional connectivity measured by EEG increases as the difficulty of Tetris increases, we predicted that functional connectivity would be reduced in the high performer group compared with the low performer group, particularly in cortical areas required for playing Tetris successfully. Thus, the following analyses were carried out. After mean changes in [oxy-Hb] during Tetris play were determined for each subject, Pearson's correlation coefficients were calculated between each channel and the other 51 channels, and paired Student's t-test was performed on the 52 mean values of the Pearson's correlation coefficients over 51 channels, between both the low and high performer groups. Furthermore, for each channel, the 51 Pearson's correlation coefficients were compared using paired Student's t-test between the two groups.

In the above analyses, when controlling multiple comparisons, the significant α levels of 0.05 were corrected by FDR.

2.5.4. Estimation of Activations for High Performance

If the correction for multiple comparison using FDR in the previous section is too strict to detect significant channels, in order to estimate the frontal areas for successfully performing Tetris, we subsequently decided outlier channels on the basis of the statistic values larger than the mean + 2 SD.

3. Results

3.1. Activation Patterns

The grand average waveforms of changes in [oxy-Hb] across all the subjects were obtained for each channel (Fig. 1). Fourteen channels (26.9%) demonstrated significant increases in [oxy-Hb] on a single-sample t-test with FDR correction ($p = 0.0004$ to 0.0120), and the largest t value was shown in channel 24 ($t = 4.137$) (Fig. 1, Appendix Table 1). Factor analysis using major factor method with direct oblimin rotation was performed on mean changes in [oxy-Hb] during Tetris play of these significantly activated 14 channels, and two factors were extracted. While the channels with large factor loading of factor 1 were distributed on both sides of the prefrontal cortex, the channels with large factor loading of factor 2 were confined to the right side of the prefrontal cortex (Fig. 1). Additionally, there were no significant differences ($t = 0.003$, $p = 0.998$) among averages of mean changes in [oxy-Hb] during Tetris play in those channels belonging to each of the factor 1 and factor 2 (the average ± SD: 0.181 ± 0.229, 0.181 ± 0.247, respectively).

3.2. Differences in Activations between High and Low Performers

3.2.1. Correlation between Activations and LINE

Pearson's correlation analyses between LINE and mean changes in [oxy-Hb] during Tetris play for each channel were carried out, and no significant channels were found after FDR correction.

3.2.2. Comparison of Activations between Groups due to the Difference in LINE

Based on LINE values (the mean ± SD: 8 ± 4), 24 subjects were divided into three groups of 8 subjects each, named high (13 ± 1), middle (7 ± 2) and low (3 ± 2) performer. One-way ANOVA for each channel found no significant channels after FDR correction. Independent Student’s t-test of mean changes in [oxy-Hb] during Tetris play for each channel between the high and low performer groups also showed no significant channels after FDR correction.

3.2.3. Comparison between High and Low Performers on Correlation Coefficients of Activations among Channels

The averages of the mean values of Pearson’s correlation coefficients between each channel and the other 51 channels were 0.385 ± 0.161 for the high performer group and 0.554 ± 0.108 for the low performer group. Comparing with a paired Student’s t-test, it was found that the correlation between channels was significantly larger in the low performer group relative to in the high performer group ($t = 5.722$, $p < 0.001$). For each channel, Paired Student’s t-test for these Pearson’s correlation coefficients between the two groups showed significant differences in twenty-nine channels after FDR correction (p = 1.981E-18 to 0.021) (Fig. 2).

3.3. Estimation of Differences in Activations between High and Low Performers

On the similar items described in Sect. 3.2., the frontal areas for successfully performing Tetris were estimated using the channels indicating the statistical values larger than the mean + 2 SD as outlier channels. Pearson’s correlation analyses between LINE and Activation during Tetris play showed no outlier channels. For reference, the channel with the largest correlation coefficient was channel 24 ($r = 0.294$, $p = 0.163$), and the channels belonging to factor 2 in the above factor analysis showed $r > 0.20$ while those belonging to factor 1 showed $| r | < 0.135$ (Fig. 3, Appendix Table 2). One-way ANOVA among the three groups found channel 24 as the only outlier channel ($F >$ the mean + 2 SD = 2.221) (Fig. 3, Appendix Table 2). Multiple comparisons performed on channel 24 by Tukey's method revealed that the activation of the high performer group was significantly larger than that of the low performer group ($p = 0.0499$). Independent Student’s t-test between the high and low performer groups detected channels 12, 23, 24, 33 as outlier channels ($t > 2.313$) (Fig. 3, Appendix Table 2). In comparison between the high and low performer groups on the correlation coefficients of activations among channels, Paired Student’s t-test for each channel showed channel 12 and 24 as outlier channels ($t > 12.023$) (Fig. 3, Appendix Table 2).

4. Discussion

4.1. Summary of Results

In this study, we used fNIRS to determine frontal activation patterns in healthy subjects while playing Tetris. We found bilateral significant activations in 14 (26.9%) of the 52 channels investigated in both hemispheres (Fig. 1, Appendix Table 1). Consistent with our hypothesis and with findings from previous fNIRS studies during Tetris play, significant activations in this study were detected in the lateral prefrontal cortex. (Yoshida et al. 2014; de Sampaio Barros et al. 2018). Furthermore, factor analysis to extract channel groups showing similar activation patterns allowed us to extract two factors from these significantly activated 14 channels. Those channels with a large factor loading for the factor 2 were confined to the right-sided lateral prefrontal cortex (Fig. 1). Subsequently, exploratory analyses were carried out assuming the frontal cortical areas necessary for successfully performing Tetris, and channels with such a possibility appeared to overlap with those showing a large factor loading of factor 2 derived from the aforementioned factor analysis.

4.2. Identification of the Right DLPFC

Among the frontal cortical areas necessary for successfully performing Tetris assumed in this study, the channel 24 was the only channel coincidently estimated by all the exploratory analyses, and the other estimated channels were radially distributed rearward around channel 24 (Fig. 3, Appendix Table 2). The cortical region/channel association of the channel 24 showed 100% agreement with Brodmann area (BA) 46 in the right dorsolateral prefrontal cortex by the virtual registration methods of fNIRS with automated Talairach atlas labels [2] (the channels showing 100% agreement are rare except for BA 10). By using fNIRS, de Sampaio Barros et al. (2018) reported that in subjects showing a large flow-state during Tetris play, activation of the right DLPFC and the right inferior parietal lobe were high when the measurement focused on the two areas involved in the frontoparietal attentional network. This supports our finding that the subjects in the high performer group, many of who are thought to achieve a large flow-state during Tetris play, exhibited an increase in activation of the right DLPFC while playing the game. Based on these arguments, we consider that at least the right DLPFC (BA 46) might be a crucial frontal cortex area for successfully performing Tetris.

4.3. Function of the Right DLPFC during Tetris play

In previous studies, attention, mental rotation, working memory, planning and decision making during speeded manipulations for visuospatial tasks were mentioned as the main cognitive functions required for smooth performance of Tetris game (De Lisi and Wolford 2002; Haier et al. 2009; Holmes et al. 2009; Miller et al. 2011; Belchior et al. 2013; Nouchi et al. 2013; Harmat et al. 2015; Lindstedt and Gray 2015; Skorka-Brown et al. 2015; Sibert et al. 2016; Bikic et al. 2017; Lau-Zhu et al. 2017; de Sampaio Barros et al. 2018; Meneghetti et al. 2018; Gold and Ciorciari 2019; Milani et al. 2019). There are studies suggesting that goal-directed smooth manipulations or executive control of these cognitive functions on visuospatial activity are closely related to the activation of the area centered on the right DLPFC (Smith and Jonides 1999; Semrud-Clikeman et al. 2012; Srovnalova et al. 2012; Funahashi and Andreau 2013; Giglia et al. 2014; Heinze et al. 2014; Wu et al. 2014; Colombo et al. 2016; Tomasino and Gremese 2016; Carter et al.

2017; Suzuki et al. 2018). These studies support the fact that the right DLPFC was estimated as the most important in the frontal cortex for successfully performing Tetris in our study.

4.4. Functional Connectivity

It is noteworthy that in this study by using a method to infer the frontal cortex areas necessary for successfully performing Tetris based on the EEG evidence that cortical network activity increases as the difficulty level of Tetris increases (Rietschel et al. 2012), we quantitatively compared functional connectivity between the high performer group and the low performer group. An interesting finding obtained was that functional connectivity declines in the high performer group, mainly in the channels involved in successful performance of Tetris. This phenomenon is likely related to the neural efficiency hypothesis, indicating that high performers exclude inefficient cortical functional connectivity, using the brain more efficiently than low performers (Haier et al. 1992a, b; Rypma et al. 2006; Neubauer and Fink 2009; Lipp et al. 2012; Rietschel et al. 2012).

4.5. Clinical Implication

As mentioned above (in the Introduction), so far clinical applications of Tetris have been carried out based exclusively on the psychological assumption that playing Tetris could stimulate the processing pathway of visuospatial cognitive loads (Holmes et al. 2009, 2010; Skorka-Brown et al. 2015; James et al. 2016; Iyadurai et al. 2017). In the present study, it is suggested that the aforementioned psychological assumptions are actually likely to be correct by the method of functional neuroimaging. Especially in the high performers, our findings may represent neurobiological evidence to boost the use of Tetris for clinical applications, including preventive interventions against traumatic flashbacks and drug cravings.

4.6. Limitations

This study has several limitations. First, 24 subjects were used to analyze the activation patterns of the frontal cortex during Tetris play. However, in the exploratory analyses to detect the frontal cortical areas for successfully playing Tetris, statistical power was not high since the subjects were divided into three equal parts based on their behavioral data. Thus, the small number of subjects may have been the cause of extinguishing statistical significances in these exploratory analyses, so that distinctive activations for high performers could only be estimated without correction for multiple comparison. Nevertheless, because the results of the exploratory analyses represent an important part of the main findings, we consider this study as preliminary. Thus, further studies using large sample size are needed to confirm the present findings. Second, [oxy-Hb] changes are expressed as relative values compared with baseline state, and it is assumed that optical path length would be constant across subjects and measurement points. Therefore, evaluations using this type of fNIRS (continuous wave-based) device that cannot measure the absolute values should be regarded as estimates (Pinti et al. 2018). Third, we investigated only the frontal lobe in the present study. The previous studies using Tetris have also suggested the involvement of the parietal and occipital lobes (Haier et al., 1992a, b; Haier et al., 2009; de Sampaio Barros et al., 2018; Gold and Ciorciari 2019). In the studies to compare high performers with low performers of cognitive tasks as this study, differences in activations across the brain lobe level may be

found due to differences in strategies. Therefore, it would be worth investigating across wide brain areas. Fourth, recent evidence indicates that signals of fNIRS may involve components from blood flow of the scalp (Takahashi et al. 2011; Kirilina et al. 2012). However, because strong correlations between fNIRS and fMRI signals have been reported (for a review see Scarapicchia et al. 2017), the activation seen in this study is thought to include considerable signals from neurons. Future development of techniques on fNIRS that can separate systemic signals from brain activity components is awaited.

5. Conclusion

The activations of the frontal cortex during naturally-performed Tetris were distributed over the lateral prefrontal cortex in both hemispheres. The activations included two factors, which were the activations estimated to associate with the Tetris performance only in the right hemisphere and performance-independent activations in both hemispheres. Furthermore, our findings suggest that high Tetris performers while producing increased activations of the areas centered on the right DLPFC (BA 46) may disengage those from unnecessary functional connections with other cortical areas to use the brain more efficiently, compared with low performers. Thus, since the cortical activation patterns during Tetris play seem to be considerably different depending on the subject’s performance, in order to effectively utilize Tetris play for clinical interventions, it would be necessary to consider whether its visuospatial cognitive loads stimulate the appropriate areas of the subject’s brain (e.g. competing with visuospatial trauma memory). This might help explore better interventions and avoid wasting time applying ineffective interventions. Future studies may confirm and extend the findings of this study by using larger samples or by exploring brain activity during Tetris play in wider brain areas.

Declarations

Footnotes

[1] The web site where Tetris is certified as a “most ported videogame” by Guinness World Records.

http://www.guinnessworldrecords.com/world-records/most-ported-computer-game/

[2] The web site that we referred to identify the cortical region/channel association in this study.

http://www.jichi.ac.jp/brainlab/virtual_registration/Result3x11_E.html

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Osaka University Graduate School of Medicine. Written informed consent was obtained from all the subjects. The procedures and methods in this study were consistent with the policies described in the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

Funding

Not applicable.

Authors' contributions

TN, RI and MI conceived and designed the experiments. TN and RI performed the experiments. TN analyzed the data. TN, RI, IS and KK contributed materials and analysis tools. TN, RI and LC wrote the paper. TN, RI, LC, HT and YN critically revised the paper. Final version of the manuscript was read and approved by all authors

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Not applicable.

Abbreviations

BA: Brodmann area; [deoxy-Hb]: concentration of deoxygenated hemoglobin; FDR: false discovery rate; LINE: the number of lines vanished by laying blocks horizontally without gaps during Tetris play; [oxy-Hb]: concentration of oxygenated hemoglobin.

References

1. Ackerman D (2016) The Tetris Effect: The Game that Hypnotized the World. PublicAffairs, New York
2. Belchior P, Marsiske M, Sisco SM, Yam A, Bavelier D, Ball K et al (2013) Video game training to improve selective visual attention in older adults. Comput Human Behav 29:1318-1324.
3. Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. J R Sta Soc [Ser B] 57:289-300.
4. Bikic A, Christensen TØ, Leckman JF, Bilenberg N, Dalsgaard S (2017) A double-blind randomized pilot trial comparing computerized cognitive exercises to Tetris in adolescents with attention-deficit/hyperactivity disorder. Nord J Psychiatry 71:455-464.

5. Carter AR, McAvoy MP, Siegel JS, Hong X, Astafiev SV, Rengachary J et al (2017) Differential white matter involvement associated with distinct visuospatial deficits after right hemisphere stroke. Cortex 88:81-97.
6. Colombo B, Balzarotti S, Mazzucchelli N (2016) The influence of the dorsolateral prefrontal cortex on attentional behavior and decision making. A t-DCS study on emotionally vs. functionally designed objects. Brain Cogn 104:7-14.
7. De Lisi R, Wolford JL (2002) Improving children's mental rotation accuracy with computer game playing. J Genet Psycho 163:272-282.
8. de Sampaio Barros MF, Araújo-Moreira FM, Trevelin LC, Radel R (2018) Flow experience and the mobilization of attentional resources. Cogn Affect Behav Neurosci 18:810-823.
9. Ferrari M, Mottola L, Quaresima V (2004) Principles, techniques, and limitations of near infrared spectroscopy. Can J Appl Physiol 29:463-487.
10. Fox PT, Raichle ME (1986) Focal physiological uncoupling of cerebral blood flow and oxidative metabolism during somatosensory stimulation in human subjects. Proc Natl Acad Sci USA 83:1140-1144.
11. Funahashi S, Andreau JM (2013) Prefrontal cortex and neural mechanisms of executive function. J Physiol Paris 107:471-482.
12. Giglia G, Brighina F, Rizzo S, Puma A, Indovino S, Maccora S et al (2014) Anodal transcranial direct current stimulation of the right dorsolateral prefrontal cortex enhances memory-guided responses in a visuospatial working memory task. Funct Neurol 29:189-193.
13. Gold J, Ciorciari J (2019) A Transcranial Stimulation Intervention to Support Flow State Induction. Front Hum Neurosci, 13:274.
14. Haier RJ, Karama S, Leyba L, Jung RE (2009) MRI assessment of cortical thickness and functional activity changes in adolescent girls following three months of practice on a visual-spatial task. BMC Res Notes 2:174.
15. Haier RJ, Siegel BV Jr, MacLachlan A, Soderling E, Lottenberg S, Buchsbaum MS (1992a) Regional glucose metabolic changes after learning a complex visuospatial/motor task: a positron emission tomographic study. Brain Res 570:134-143.
16. Haier RJ, Siegel, BV, Tang C, Abel L, Buchsbaum MS (1992b) Intelligence and Changes in Regional Cerebral Glucose Metabolic Rate Following Learning. Intelligence 16:415-426.
17. Harmat L, de Manzano Ö, Theorell T, Högman L, Fischer H, Ullén F (2015) Physiological correlates of the flow experience during computer game playing. Int J Psychophysiol 97:1-7.
18. Heinze K, Ruh N, Nitschke K, Reis J, Fritsch B, Unterrainer J et al (2014) Transcranial direct current stimulation over left and right DLPFC: Lateralized effects on planning performance and related eye movements. Biol Psychol 102:130-140.
19. Hoshi Y (2003) Functional near-infrared optical imaging: utility and limitation in human brain mapping. Psychophysiology 40:511-520.

20. Hoshi Y, Kobayashi N, Tamura M (2001) Interpretation of near-infrared spectroscopy signals: a study with a newly developed perfused rat brain model. J Appl Physiol 90:1657-1662.
21. Holmes EA, James EL, Coode-Bate T, Deeprose C (2009) Can playing the computer game "Tetris" reduce the build-up of flashbacks for trauma? A proposal from cognitive science. PLoS One 4:e4153.
22. Holmes EA, James EL, Kilford EJ, Deeprose C (2010) Key steps in developing a cognitive vaccine against traumatic flashbacks: visuospatial Tetris versus verbal Pub Quiz. PLoS One 5:e13706.
23. Iyadurai L, Blackwell SE, Meiser-Stedman R, Watson PC, Bonsall MB, Geddes JR et al (2018) Preventing intrusive memories after trauma via a brief intervention involving Tetris computer game play in the emergency department: a proof-of-concept randomized controlled trial. Mol Psychiatry 23:674-682.
24. James EL, Lau-Zhu A, Tickle H, Horsch A, Holmes EA (2016) Playing the computer game Tetris prior to viewing traumatic film material and subsequent intrusive memories: Examining proactive interference. J Behav Ther Exp Psychiatry 53:25-33.
25. Jöbsis FF (1977) Noninvasive infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science 198:1264-1267.
26. Kirilina E, Jelzow A, Heine A, Niessing M, Wabnitz H, Brühl R et al (2012) The physiological origin of task-evoked systemic artefacts in functional near infrared spectroscopy. Neuroimage 61:70-81.
27. Koessler L, Maillard L, Benhadid A, Vignal JP, Felblinger J, Vespignani H et al (2009) Automated cortical projection of EEG sensors: anatomical correlation via the international 10-10 system. Neuroimage 46:64-72.
28. Lau-Zhu A, Holmes EA, Butterfield S, Holmes J (2017) Selective Association Between Tetris Game Play and Visuospatial Working Memory: A Preliminary Investigation. Appl Cogn Psychol 31:438-445.
29. Lindstedt JK, Gray WD (2015) Meta-T: Tetris® as an experimental paradigm for cognitive skills research. Behav Res Methods 47:945-965.
30. Lipp I, Benedek M, Fink A, Koschutnig K, Reishofer G, Bergner S et al (2012) Investigating neural efficiency in the visuo-spatial domain: an FMRI study. PLoS One 7:e51316.
31. Meneghetti C, Carbone E, Di Maggio A, Toffalini E, Borella E (2018) Mental rotation training in older adults: The role of practice and strategy. Psychol Aging 33:814-831.
32. Milani L, Grumi S, Di Blasio P (2019) Positive Effects of Videogame Use on Visuospatial Competencies: The Impact of Visualization Style in Preadolescents and Adolescents. Front Psychol 10:1226.
33. Miller MW, Rietschel JC, McDonald CG, Hatfield BD (2011) A novel approach to the physiological measurement of mental workload. Int J Psychophysiol 80 75-78.
34. Nakahachi T, Ishii R, Canuet L, Iwase M (2015) Implied functional crossed cerebello-cerebral diaschisis and interhemispheric compensation during hand grasping more than 20 years after unilateral cerebellar injury in early childhood. Cerebellum Ataxias 2:15. doi: 10.1186/s40673-015-0032-0

35. Nakahachi T, Ishii R, Canuet L, Takahashi H, Ishitobi M, Kamio Y et al (2016) Cortical activation patterns in healthy subjects during the traditional Japanese word generation task Shiritori determined by multichannel near-infrared spectroscopy. Neuropsychiatr Electrophysiol 2:2. doi: 10.1186/s40810-016-0016-1
36. Nakahachi T, Ishii R, Iwase M, Canuet L, Takahashi H, Kurimoto R et al (2008) Frontal activity during the digit symbol substitution test determined by multichannel near-infrared spectroscopy. Neuropsychobiology 57:151-158.
37. Nakahachi T, Ishii R, Iwase M, Canuet L, Takahashi H, Kurimoto R et al (2010) Frontal cortex activation associated with speeded processing of visuospatial working memory revealed by multichannel near-infrared spectroscopy during Advanced Trail Making Test performance. Behav Brain Res 215:21-27.
38. Neubauer AC, Fink A (2009) Intelligence and neural efficiency. Neurosci Biobehav Rev 33:1004-1023.
39. Nouchi R, Taki Y, Takeuchi H, Hashizume H, Nozawa T, Kambara T et al (2013) Brain training game boosts executive functions, working memory and processing speed in the young adults: a randomized controlled trial. PLoS One 8:e55518.
40. Pinti P, Tachtsidis I, Hamilton A, Hirsch J, Aichelburg C, Gilbert S, Burgess PW (2018) The present and future use of functional near-infrared spectroscopy (fNIRS) for cognitive neuroscience. Ann N Y Acad Sci doi: 10.1111/nyas.13948
41. Price RB, Paul B, Schneider W, Siegle GJ (2013) Neural Correlates of Three Neurocognitive Intervention Strategies: A Preliminary Step Towards Personalized Treatment for Psychological Disorders. Cognit Ther Res 37:657-672.
42. Rietschel JC, Miller MW, Gentili RJ, Goodman RN, McDonald CG, Hatfield BD (2012) Cerebral-cortical networking and activation increase as a function of cognitive-motor task difficulty. Biol Psychol 90:127-133.
43. Rypma B, Berger JS, Prabhakaran V, Bly BM, Kimberg DY, Biswal BB, D'Esposito M (2006) Neural correlates of cognitive efficiency. Neuroimage 33:969-979.
44. Scarapicchia V, Brown C, Mayo C, Gawryluk JR (2017) Functional Magnetic Resonance Imaging and Functional Near-Infrared Spectroscopy: Insights from Combined Recording Studies. Front Hum Neurosci 11:419.
45. Semrud-Clikeman M, Fine JG, Bledsoe J, Zhu DC (2012) Gender differences in brain activation on a mental rotation task. Int J Neurosci 122:590-597.
46. Sibert C, Gray WD, Lindstedt JK (2017) Interrogating Feature Learning Models to Discover Insights Into the Development of Human Expertise in a Real-Time, Dynamic Decision-Making Task. Top Cogn Sci 9:374-394.
47. Singh AK, Dan I (2006) Exploring the false discovery rate in multichannel NIRS. Neuroimage 33:542-549.
48. Skorka-Brown J, Andrade J, Whalley B, May J (2015) Playing Tetris decreases drug and other cravings in real world settings. Addict Behav 51:165-170.

49. Smith EE, Jonides J (1999) Storage and executive processes in the frontal lobes. Science 283:1657-1661.
50. Srovnalova H, Marecek R, Kubikova R, Rektorova I (2012) The role of the right dorsolateral prefrontal cortex in the Tower of London task performance: repetitive transcranial magnetic stimulation study in patients with Parkinson's disease. Exp Brain Res 223:251-257.
51. Suzuki K, Kita Y, Oi Y, Okumura Y, Okuzumi H, Inagaki M (2018) Right prefrontal cortex specialization for visuospatial working memory and developmental alterations in prefrontal cortex recruitment in school-age children. Clin Neurophysiol 129:759-765.
52. Takahashi T, Takikawa Y, Kawagoe R, Shibuya S, Iwano T, Kitazawa S (2011) Influence of skin blood flow on near-infrared spectroscopy signals measured on the forehead during a verbal fluency task. Neuroimage 57:991-1002.
53. Tomasino B, Gremese M (2016) Effects of Stimulus Type and Strategy on Mental Rotation Network: An Activation Likelihood Estimation Meta-Analysis. Front Hum Neurosci 9:693.
54. Tomita N, Imai S, Kanayama Y, Kawashima I, Kumano H (2017). Use of Multichannel Near Infrared Spectroscopy to Study Relationships Between Brain Regions and Neurocognitive Tasks of Selective/Divided Attention and 2-Back Working Memory. Percept Mot Skills 124:703-720.
55. Tsuzuki D, Dan, I. (2014) Spatial registration for functional near-infrared spectroscopy: from channel position on the scalp to cortical location in individual and group analyses. Neuroimage 85:92-103.
56. Tsuzuki D, Jurcak V, Singh AK, Okamoto M, Watanabe E, Dan I (2007) Virtual spatial registration of stand-alone fNIRS data to MNI space. Neuroimage 34:1506-1518.
57. Wu YJ, Tseng P, Chang CF, Pai MC, Hsu KS, Lin CC, Juan CH. (2014) Modulating the interference effect on spatial working memory by applying transcranial direct current stimulation over the right dorsolateral prefrontal cortex. Brain Cogn 91:87-94.
58. Yokoyama C Kaiya H, Kumano H, Kinou M, Umekage T, Yasuda S et al (2015) Dysfunction of ventrolateral prefrontal cortex underlying social anxiety disorder: A multi-channel NIRS study. Neuroimage Clin 8:455-461.
59. Yoshida K, Sawamura D, Inagaki Y, Ogawa K, Ikoma K, Sakai S (2014) Brain activity during the flow experience: a functional near-infrared spectroscopy study. Neurosci Lett 573:30-34.

Figures

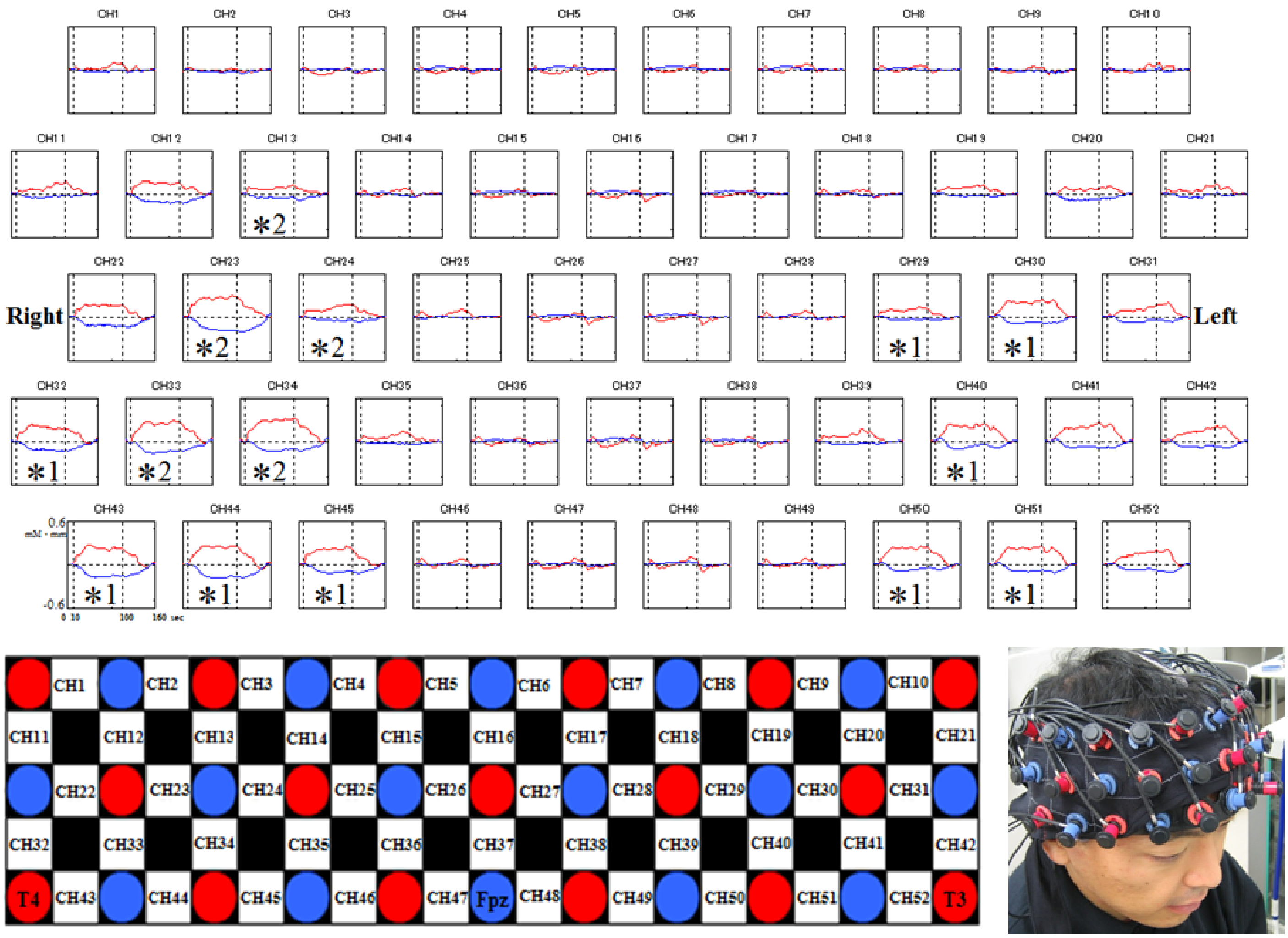

Figure 1

Grand average waveforms of changes in [oxy-Hb] (red) and [deoxy-Hb] (blue) during Tetris play for all channels, and arrangement of measurement points (channels) and optical diodes. In the upper diagram, the x-axis denotes time from 0 to 160 sec and the y-axis denotes activation between -0.6 and 0.6 mM•mm. The task period is shown by two vertical dashed lines at 10 and 100 sec. Picture on the bottom right shows the actual attached probe (written informed consent was obtained from the individual for the publication of this image). Schematic diagram on the bottom left presents the channels 1–52 as white squares among emitters (laser diodes, red circles) and detectors (photodiodes, blue circles) with the locations of Fpz, and T3, T4 (approximate) using the international 10/10 system for EEG. *1,*2, channel with significant activation and the number indicates the factor derived by a factor analysis (major factor method); CH, channel

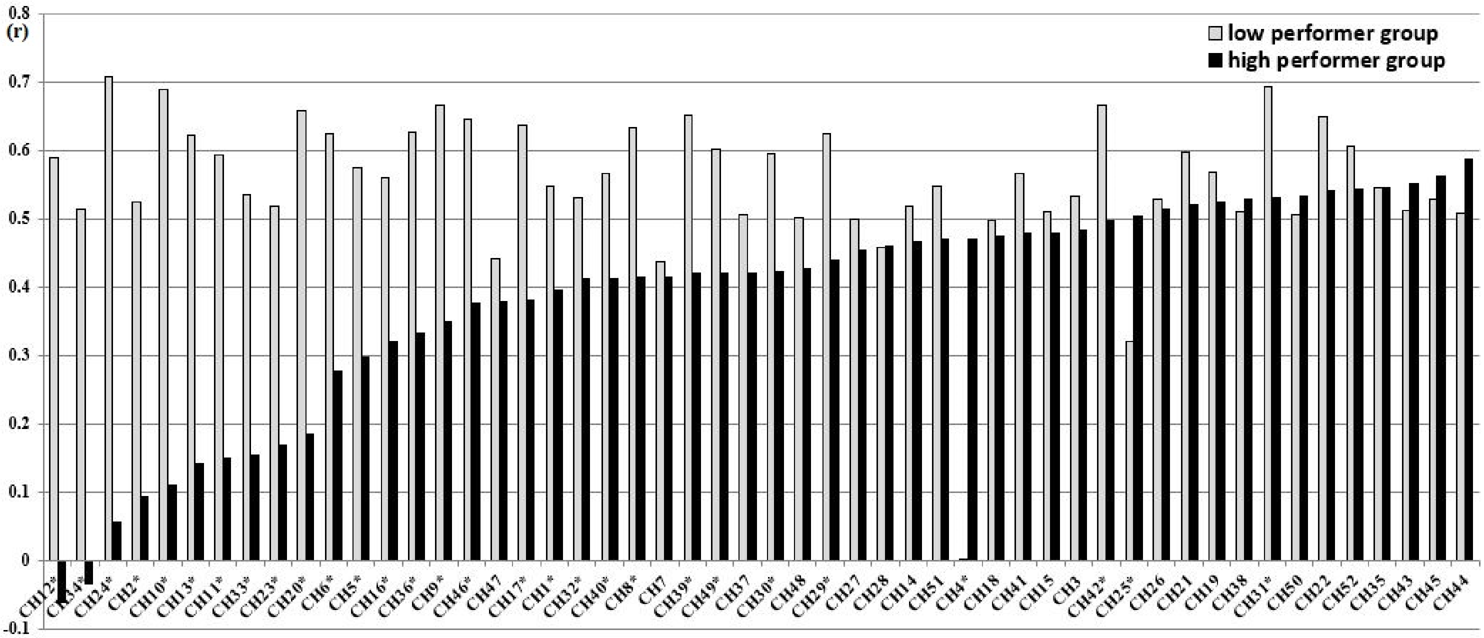

Figure 2

Averages of Pearson's correlation coefficients (r) between each channel and the other 51 channels for mean changes in [oxy-Hb] during Tetris play of each subject in the high and low performer groups. Bar graphs are arranged in ascending order for r of the high performer group. *, Twenty-nine significant channels after paired Student's t-test on the Pearson's correlation coefficients of mean changes in [oxy-Hb] among each channel and the other 51 channels between the two groups; CH, channel

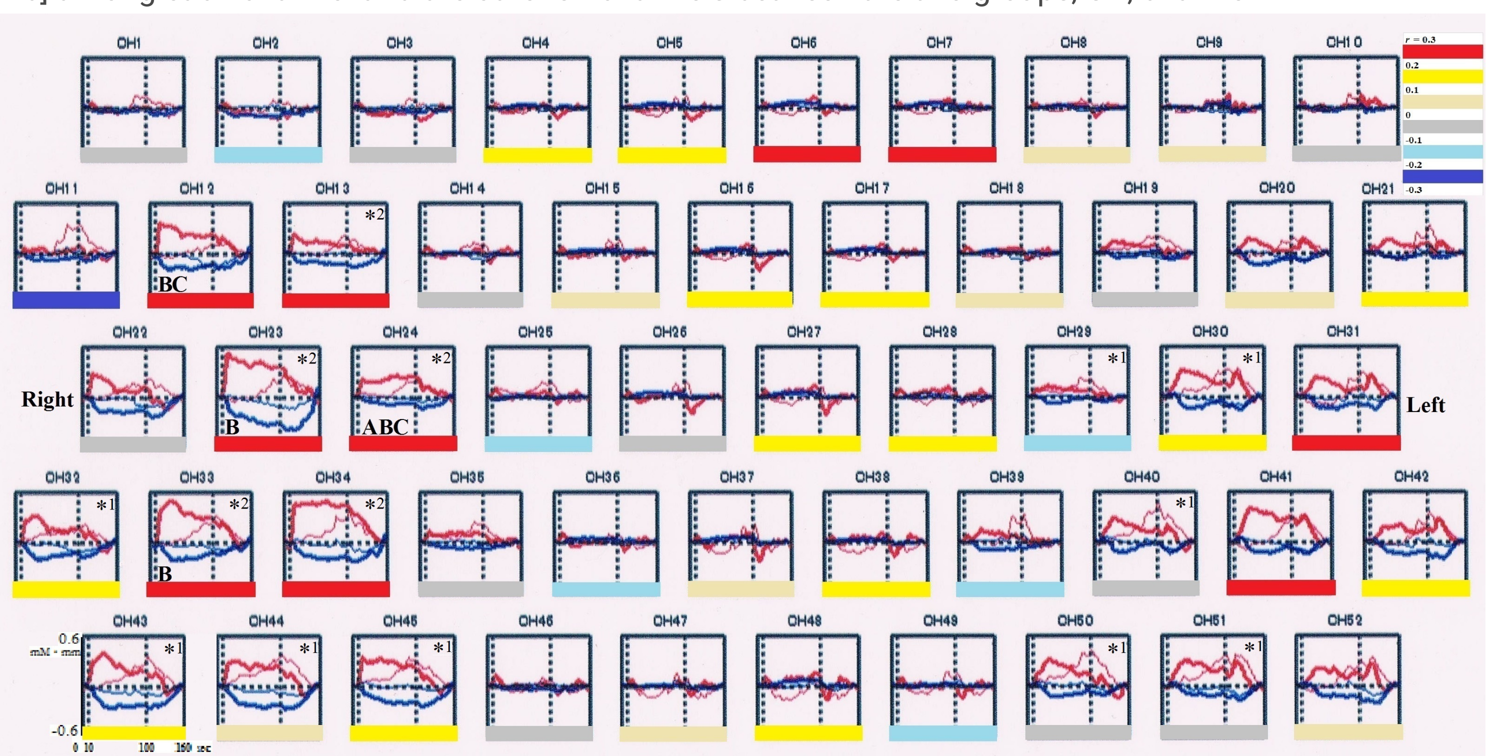

Figure 3

The high (thick line) and low (thin line) performer groups' grand average waveforms of changes in [oxy-Hb] (red) and [deoxy-Hb] (blue) during Tetris play for all channels. For each channel, the x-axis denotes time from 0 to 160 sec and the y-axis denotes activation between -0.6 and 0.6 mM•mm. The task period is shown by two vertical dashed lines at 10 and 100 sec. In each channel, A, one channel that shows the F value > the mean + 2 SD derived by one-way ANOVA on the high, low and middle performer groups' mean changes in [oxy-Hb] during Tetris play; B, four channels that show the t values > the mean + 2 SD derived by independent Student's t-tests on the high and the low performer groups' mean changes in [oxy-Hb] during Tetris play; C, two channels that show the paired Student's t values > the mean + 2 SD, of when the Pearson's correlation coefficients between each channel and the other 51 channels for mean changes in [oxy-Hb] during Tetris play of each subject in the low performer group are compared with those in the high performer group. In each channel, Pearson's correlation coefficient (r) between the 24 participants' mean changes in [oxy-Hb] and LINE values during Tetris play is color coded. *1,*2, same as in Figure1; CH, channel

Supplementary Files

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- ESM1AppendixTable1.pdf