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Original article

# Prefrontal cerebral blood volume patterns while playing video games—A near-infrared spectroscopy study

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**Abstract**

Video game playing is an attractive form of entertainment among school-age children. Although this activity reportedly has many adverse effects on child development, these effects remain controversial. To investigate the effect of video game playing on regional cerebral blood volume, we measured cerebral hemoglobin concentrations using near-infrared spectroscopy in 12 normal volunteers consisting of six children and six adults. A Hitachi Optical Topography system was used to measure hemoglobin changes. For all subjects, the video game Donkey Kong® was played on a Game Boy® device. After spectroscopic probes were positioned on the scalp near the target brain regions, the participants were asked to play the game for nine periods of 15 s each, with 15-s rest intervals between these task periods. Significant increases in bilateral prefrontal total-hemoglobin concentrations were observed in four of the adults during video game playing. On the other hand, significant decreases in bilateral prefrontal total-hemoglobin concentrations were seen in two of the children. A significant positive correlation between mean oxy-hemoglobin changes in the prefrontal region and those in the bilateral motor cortex area was seen in adults. Playing video games gave rise to dynamic changes in cerebral blood volume in both age groups, while the difference in the prefrontal oxygenation patterns suggested an age-dependent utilization of different neural circuits during video game tasks.


*Keywords:* Video game; Oxygenation; Cerebral blood volume; Child development; Optical imaging; Near-infrared spectroscopy; Prefrontal

## 1. Introduction

The wide popularity of video games among children has had a strong effect on how they interact with each other. Many parents have found it difficult to distract their children away from video games, and these games have been associated with many adverse effects, such as photosensitive epilepsy, enuresis, encopresis, visual injuries, obesity, tendonitis, hand-arm vibration syndrome, and enhancement of allergic responses [1–5]. Additionally, many studies have investigated the influences of video games on aggressive behavior in children [6,7]. On the other hand, a familiarity with a wide range of video games can help reciprocal conversation ability in children, which may enhance sociability. In particular, 'electronic friendship' is often required among boys [8]. Despite the great popularity of video games, there have been only a few studies examining the biological effects of video games on brain activity. One study examining visual attention showed that playing action video games enhanced the capacity of visual attention and spatial distribution in habitual video game players [9]. Using positron emission tomography (PET), Haier et al. [10] observed regional glucose metabolic changes in subjects who had just learned a complete visuospatial/motor task. In this study, practice in playing video games led to a decrease in overall brain glucose metabolism, suggesting that subjects used fewer brain circuits and/or fewer neurons per circuit after practicing the task. Another PET study showed a significant reduction in the binding of

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11C-labeled raclopride to dopamine D2 receptor during the playing of video games, suggesting the increased release and binding of dopamine to its receptors during the task [11]. Both studies showed a positive correlation between better performance in a game task and decreased glucose metabolism or increased dopamine release. The conventional cerebral functional imaging has an advantage in its ability to assess the spatial resolution of cognitive and deep brain activities; however, it requires a high degree of patient restraint during measurements in pediatric research settings.

The use of near-infrared spectroscopy (NIRS), on the other hand, has the advantages of reduced need for patient restraint, little need for sedation, and continuous real-time measurement [12–16]. NIRS can detect concentration changes in oxy- and deoxy-hemoglobin (Hb) as well as total-Hb in response to neural activation. In this study, we monitored brain oxygenation using NIRS to investigate the effects of playing video games on regional cerebral blood volume (CBV) in children and adults.

## 2. Methods

### 2.1. Subjects and procedure

Twelve volunteers, consisting of six children (three males and three females; age range 7–10 years, mean age 8 years) and six adults (three males and three females; range 26–44 years, mean 34 years), all right-handed, participated in the study. Two of the children (cases 5 and 6) were habitual video game players who had played video games for at least 2 h every day. None of the adults was habitual video game players. Informed consent was obtained from each adult, and parental consent was obtained from the parents of each child. NIRS can detect concentration changes in oxy- and deoxy-Hb in brain tissue using 780- and 830-nm wavelengths of near-infrared light. The strength of the reflected light is inversely related to the concentration of the Hb. The regional CBV, presumed to be the total-Hb, was estimated from the concentration of oxy- and deoxy-Hb. A Hitachi Optical Topography system (ETG-100; Hitachi Medical Corp., Tokyo, Japan) was used to measure changes in the concentration of each Hb using a method previously described [15]. Fig. 1 shows the positions of the eight optical fibers placed on the head of a subject and the 12 measurement positions. To better understand the location of each channel on the brain's cortical region, the position of each probe in case 1 as a representative case was transferred to a three-dimensional brain image. The position on the subject's head contacting the four transmitting and four detecting probes and three base points (nasion, left and right ear) were measured using a three-dimensional magnetic position digitizer. Using these position data the probe positions were transferred to a three-dimensional image and mapped on the cortical surface along the perpendicular line to the plane decided from the source vector line and detection vector line.

Once the probes were in position on the target brain regions (the prefrontal and bilateral fronto-parietal regions), the participant was asked to repeat, for a total of nine times, a sequence of a popular action game called Donkey Kong® after a 10-s pre-scan period. The sequence consisted of a 15-s period in which the subject played the game (task) on a Game Boy® hand-held device (Nintendo Corp., Kyoto, Japan) followed by a 15-s relaxation period. The details of the video game are as follows: a character 'Donkey Kong' riding on a wagon jumps from rail to rail to not fall from the rails. The movement of the character is prevalently horizontal and controlled by a left-hand switch, while the jumping is controlled by a right-hand switch. To control the game, the player needs to exercise prompt judgment to control the character's movement and appropriate finger movements. To become oriented to the game, the subject was allowed to practice it for one minute before starting the task. After the prefrontal activity was measured, the bilateral fronto-parietal regions were examined.

### 2.2. Data analysis

The signal from each of the 12 measurement positions was captured every 1 s for time-course data analysis. From the nine task trials, the average total-, oxy-, and deoxy-Hb concentrations from each probe position were obtained for each time point. A total of 30 Hb concentration data were collected from each 30-s sequence. The average total-, oxy-, and deoxy-Hb concentrations at each position at each time point were statistically compared with the baseline level (paired *t*-test). We selected a time of 1 s before the start of stimulation as a baseline. A *P*-value of less than 0.05 was considered statistically significant. We chose positions F8 and F10 for the time-course data analysis because these positions were at the center of the prefrontal region and because their signals were hardly contaminated by the patients' movement artifacts.

We also analyzed the correlation between the mean change in total- and oxy-Hb in the total prefrontal regions (12 positions) and those in the total bilateral fronto-parietal regions (24 positions; motor cortex area) to investigate the hemodynamic changes of CBV between those regions during video game playing. The changes in total-Hb (or oxy-Hb) at each position were obtained as follows. During (or after) the task, the Hb concentration at each position was captured every 0.5 s and these values were totalled as the sums of the Hb concentration for each point. The changes in total-Hb (or oxy-Hb) at each position were calculated by subtracting the sum of total-Hb (or oxy-Hb) concentrations during the task from the sum of those concentrations after the task. Each change in total-Hb (or oxy-Hb) in the total prefrontal regions or in the total bilateral fronto-parietal regions was averaged as the mean

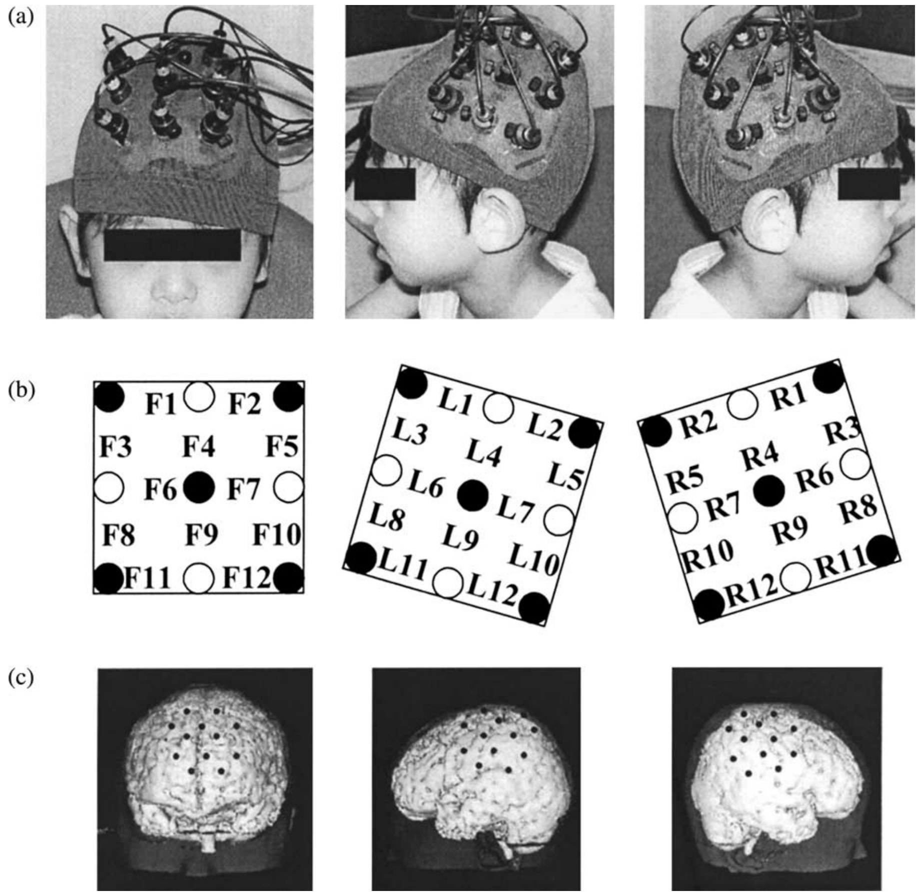


Fig. 1. Locations of NIRS probes on the scalp and schematic diagram of the probes. (a) A conventional head splint equipped with NIRS probes was attached to the bilateral sides and the forehead. A swimming cap was used to keep the probes in place. (b) The head splint is 10×10 mm in size, producing 12 channels via five transmitting probes (●) and four detecting probes (○). Each channel is numerically labeled. (c) Possible probe positions on the brain's cortical region, which were applied in this study. Each brain image was constructed using 100 horizontal brain MRI slices from the same participant as in Fig. 1A. Each probe position was transferred to three-dimensional cortical surface images.

prefrontal total-Hb (or oxy-Hb) change or the mean fronto-parietal total-Hb (or oxy-Hb) change, respectively. Pearson's correlation was used to analyze the correlation.

## 3. Results

Fig. 2 shows the grand average of each Hb concentration change at the 12 prefrontal measurement points in a child (case 1) and in an adult (case 8). In the child, total-Hb and oxy-Hb concentrations were decreased at all measurement points during video game play, but in the adults, these concentrations were increased at all measurement points. Fig. 3 shows the statistical analysis of the grand averages of total-Hb concentration changes as a function of time in a child (case 2) and in an adult (case 9). In the child, the total-Hb concentrations gradually decreased, reaching minimum plateaus approximately 12 s after the beginning of the task before returning to the baseline. In the adult, the total-Hb concentrations immediately increased, peaking 14 s after the beginning of the task before returning to the baseline.

Table 1 shows the following data for each subject: the number of trails, the time to peak or bottom (*t* max and *t* min), the mean (SD) concentration changes during the task, and the levels of significance for these changes. The F8 (right prefrontal) and F10 (left prefrontal) positions were chosen for statistical data analysis. Two children (cases 1 and 2) showed significant decreases in bilateral prefrontal total-Hb concentrations. One child (case 5) showed a significantly decreased total-Hb concentration at F10, and a significantly increased total-Hb at F8. A unilateral significant increase in total-Hb concentration was seen in one child (case 6). On the other hand, four adults (cases 7–10) showed significant increases in bilateral prefrontal total-Hb concentrations, while one adult (case 11) showed both significantly decreased and significantly increased total-Hb concentrations. The patterns of oxy-Hb concentration change were similar to those of the total-Hb concentration change both in children and adults. However, the patterns of deoxy-Hb concentration change varied widely among subjects. Three children showed a significant increase, and one child a significant decrease, in deoxy-Hb

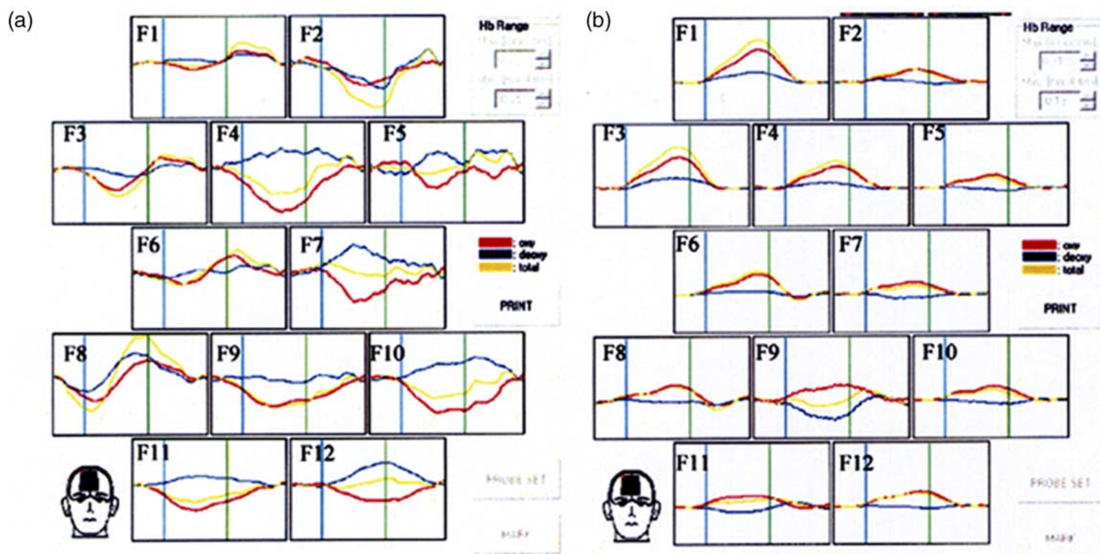


Fig. 2. Changes in Hb concentrations during and after the video game task performed by a child (a) and an adult (b). A head splint that produced 12 channels (F1–F12) was mounted on the prefrontal region (see face illustration). The location of F1 corresponds to the top right of the splint. The blue and green vertical lines indicate the starting and ending times of the video game task, respectively. The concentrations of Hb are colored red (total-Hb), yellow (oxy-Hb), and blue (deoxy-Hb).

concentration in the unilateral prefrontal region. Among the adults, three showed a significant increase, and three a significant decrease, in either the unilateral or bilateral prefrontal region.

Fig. 4 shows the correlations between mean prefrontal total-Hb (or oxy-Hb) change and mean fronto-parietal (motor cortex area) total-Hb (or oxy-Hb) change. Five of the six children showed decreased mean prefrontal total- and oxy-Hb changes (Fig. 4a and c); on the other hand, all subjects except one adult case showed increased mean prefrontal total- and oxy-Hb changes (Fig. 4b and d). A significant positive correlation between mean prefrontal oxy-Hb changes and mean fronto-parietal oxy-Hb changes was seen in the adults (Fig. 4d, $P=0.024$), whereas the correlation for total-Hb changes did not reach the level of statistical significance (Fig. 4b, $P=0.050$). There was no correlation between mean prefrontal total-Hb (or oxy-Hb) changes and mean fronto-parietal total-Hb (or oxy-Hb) changes in the children (Fig. 4a ($P=0.019$) and 4c ($P=0.685$), respectively).

## 4. Discussion

Much interest has been focused on the effects of video game playing on brain development and the development of cognitive ability in children. Though little scientific proof has been shown [9–11], many parents have expressed

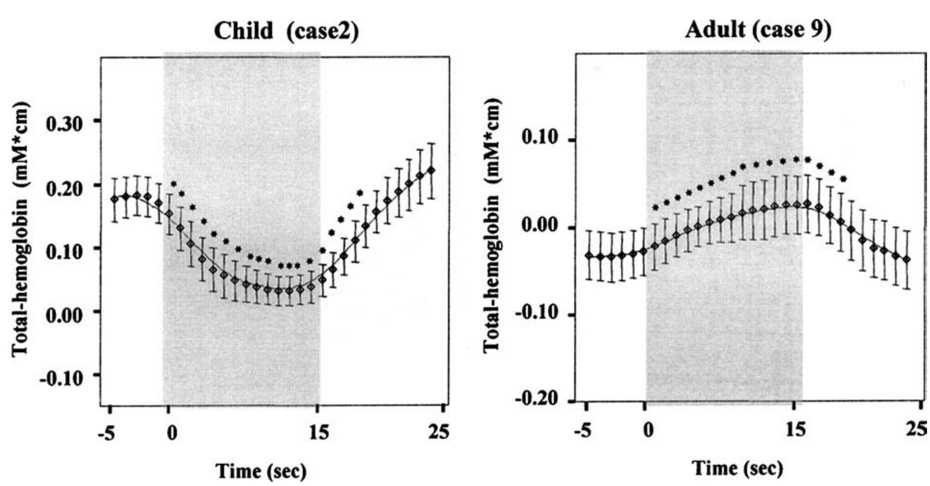


Fig. 3. Grand averages of changes in the total-Hb concentration in the F10 position as a function of time in a child (case 2) and an adult (case 9). The meshes indicate the 15-s periods of the video game task. Changes in total-Hb concentration are given in mM cm. The data were obtained every 1 s. The vertical bars indicate standard error. *Significance of mean concentration changes from 1 s before the start of the task.

Table 1
Changes in total-, oxy-, and deoxy-Hb concentration during video game playing in children and adults

| | No. | *n* | Left prefrontal (F10 position) *T* min/max (s) | Left prefrontal Mean (SD) mM cm | Left prefrontal *P* | Right prefrontal (F8 position) *t* min/max (s) | Right prefrontal Mean (SD) mM cm | Right prefrontal *P* |
|---|---|---|---|---|---|---|---|---|
| *Total-Hb* | | | | | | | | |
| Child | 1 | 9 | 10 | −0.088 (0.026) | 0.036 | 11 | −0.110 (0.009) | 0.039 |
| | 2 | 9 | 12 | −0.139 (0.028) | <0.001 | 10 | −0.053 (0.031) | 0.036 |
| | 3 | 9 | 14 | 0.063 (0.031) | 0.179 | 6 | −0.039 (0.017) | 0.097 |
| | 4 | 3 | 1 | 0.054 (0.082) | 0.257 | 15 | 0.148 (0.101) | 0.137 |
| | 5 | 9 | 13 | −0.148 (0.041) | 0.027 | 15 | 0.203 (0.072) | 0.008 |
| | 6 | 9 | 5 | 0.038 (0.035) | 0.083 | 15 | 0.224 (0.056) | 0.001 |
| Adult | 7 | 9 | 7 | 0.066 (0.018) | 0.001 | 7 | 0.039 (0.008) | 0.028 |
| | 8 | 9 | 4 | 0.062 (0.004) | 0.014 | 13 | 0.022 (0.002) | 0.001 |
| | 9 | 9 | 14 | 0.057 (0.020) | 0.013 | 15 | 0.047 (0.018) | 0.008 |
| | 10 | 9 | 8 | 0.085 (0.051) | 0.011 | 6 | 0.116 (0.044) | <0.001 |
| | 11 | 9 | 15 | −0.145 (0.023) | <0.001 | 14 | 0.093 (0.007) | 0.001 |
| | 12 | 9 | 10 | −0.027 (0.013) | 0.069 | 13 | −0.025 (0.021) | 0.186 |
| *Oxy-Hb* | | | | | | | | |
| Child | 1 | 9 | 10 | −0.136 (0.009) | 0.029 | 11 | −0.317 (0.026) | 0.001 |
| | 2 | 9 | 8 | −0.101 (0.002) | 0.019 | 9 | −0.290 (0.032) | 0.012 |
| | 3 | 9 | 14 | 0.027 (0.054) | 0.357 | 15 | 0.052 (0.038) | 0.244 |
| | 4 | 3 | 3 | 0.064 (0.094) | 0.272 | 13 | 0.213 (0.080) | 0.113 |
| | 5 | 9 | 11 | −0.170 (0.004) | 0.009 | 13 | 0.219 (0.008) | 0.002 |
| | 6 | 9 | 4 | 0.069 (0.008) | 0.038 | 15 | 0.196 (0.048) | 0.001 |
| Adult | 7 | 9 | 7 | 0.021 (0.011) | 0.099 | 6 | 0.020 (0.008) | 0.040 |
| | 8 | 9 | 10 | 0.025 (0.009) | 0.048 | 11 | 0.059 (0.013) | 0.000 |
| | 9 | 9 | 7 | 0.029 (0.006) | 0.031 | 13 | 0.027 (0.008) | 0.044 |
| | 10 | 9 | 4 | 0.018 (0.002) | 0.012 | 13 | 0.073 (0.018) | 0.006 |
| | 11 | 9 | 5 | 0.125 (0.067) | 0.010 | 6 | 0.093 (0.050) | 0.011 |
| | 12 | 9 | 9 | −0.016 (0.004) | 0.203 | 12 | −0.025 (0.015) | 0.211 |
| *Deoxy-Hb* | | | | | | | | |
| Child | 1 | 9 | 10 | 0.054 (0.043) | 0.109 | 12 | 0.156 (0.026) | 0.002 |
| | 2 | 9 | 15 | −0.085 (0.026) | 0.089 | 10 | 0.116 (0.028) | 0.027 |
| | 3 | 9 | 10 | 0.048 (0.013) | 0.085 | 15 | −0.056 (0.022) | 0.110 |
| | 4 | 3 | 4 | −0.068 (0.068) | 0.215 | 15 | −0.088 (0.018) | 0.148 |
| | 5 | 9 | 5 | −0.039 (0.051) | 0.135 | 3 | −0.072 (0.007) | 0.013 |
| | 6 | 9 | 1 | 0.008 (0.001) | 0.004 | 15 | 0.031 (0.019) | 0.101 |
| Adult | 7 | 9 | 15 | 0.047 (0.005) | 0.005 | 10 | 0.021 (0.012) | 0.077 |
| | 8 | 9 | 15 | −0.023 (0.005) | 0.002 | 4 | −0.017 (0.006) | 0.004 |
| | 9 | 9 | 15 | 0.024 (0.001) | 0.155 | 15 | 0.016 (0.007) | 0.163 |
| | 10 | 9 | 6 | −0.057 (0.003) | 0.026 | 3 | 0.026 (0.004) | 0.001 |
| | 11 | 9 | 14 | −0.122 (0.033) | 0.001 | 11 | 0.013 (0.008) | 0.129 |
| | 12 | 9 | 2 | 0.006 (0.001) | 0.032 | 2 | 0.007 (0.003) | 0.019 |

Number of trails (*n*), time to bottom or peak (*t* min pr *t* max), mean changes in each Hb (in mM cm), and level of significance for each subject.

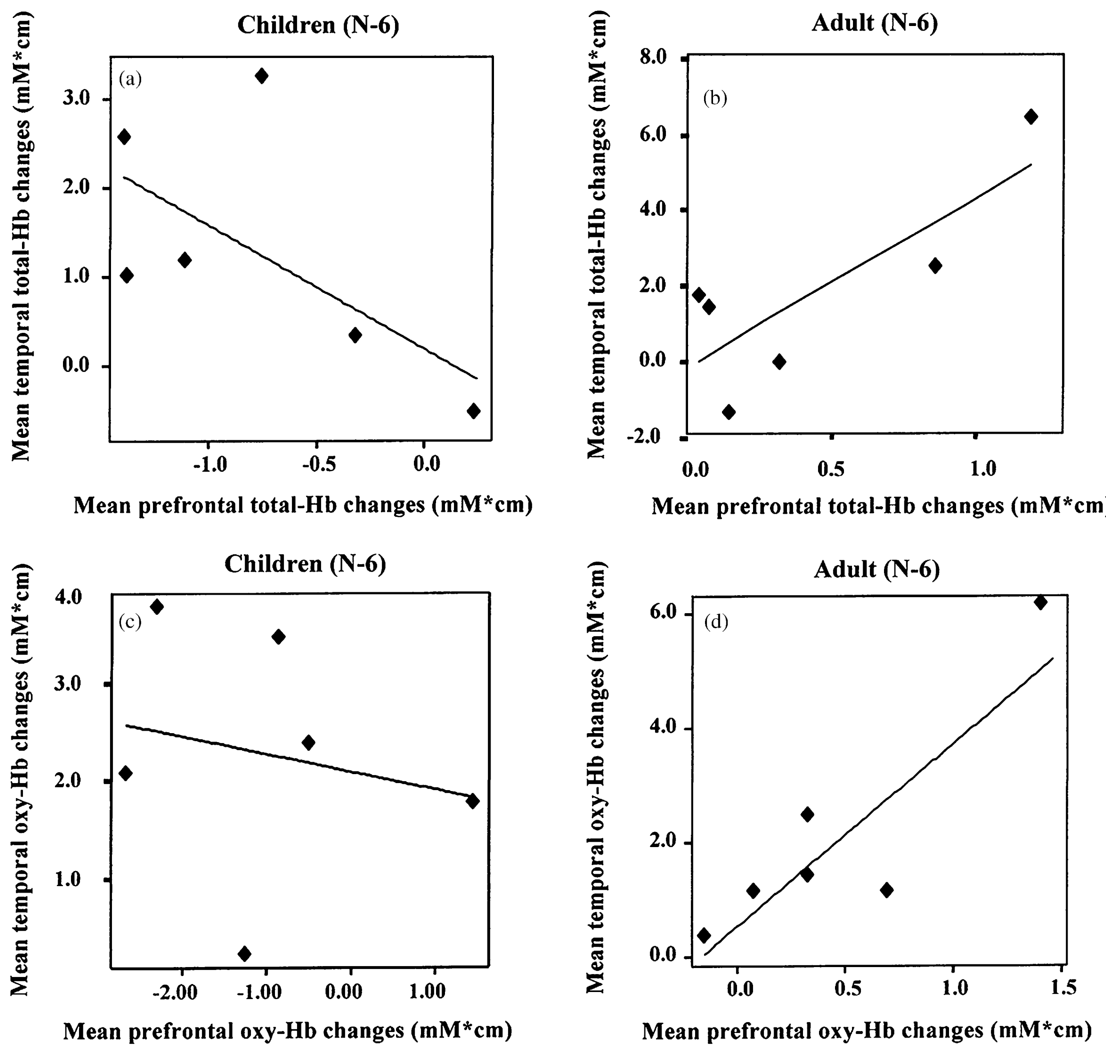


Fig. 4. Correlations between mean prefrontal total-Hb (or oxy-Hb) change and mean fronto-parietal total-Hb (or oxy-Hb) change in the children and the adults (a, total-Hb correlation in children; b, total-Hb correlation in adults; c, oxy-Hb correlation in children; d, oxy-Hb correlation in adults). A significant positive correlation in the oxy-Hb change was seen in the adults (Fig. 4d, $P=0.024$), whereas the correlation in total-Hb changes did not reach the level of statistical significance (Fig. 4b, $P=0.050$). There was no correlation in the total-, oxy-Hb changes in children (Fig. 4a, $P=0.019$. Fig. 4c, $P=0.685$, respectively).

concerns about the amount of time their children spend on video games and about the relationship between this activity and adverse child behavior. To our knowledge, this is the first report to assess changes in cerebral blood flow during video game playing.

The present NIRS study showed various changes in total-, oxy-, and deoxy-Hb concentrations during video game playing in children and adults. Significantly increased prefrontal total-Hb concentrations were observed in five adults and two children during video game playing in either the unilateral or bilateral prefrontal region. On the other hand, significantly decreased prefrontal total-Hb concentrations were seen in three children and one adult. One adult and two children showed no significant changes in prefrontal total-Hb concentrations during the task. There are two possible explanations for this finding. First, an individual's game performance, level of interest in the game, and attention devoted to the task might all contribute to the various changes in total-Hb concentrations. These factors, which might influence prefrontal oxygenation, were not numerically measured in this study. In one study using NIRS, an extended attention trail-making task increased oxy- and total-Hb concentrations in the bilateral frontal regions, suggesting a compensatory increase in cerebral perfusion [17]. Other imaging studies using PET showed a positive correlation between better performance in the game task and a decreased glucose metabolism or an increased dopamine release [10,11]. In the present study, the duration of the video game task and the relaxation period were relatively short (15 s each) compared to other NIRS studies, whose subjects mainly were sedated neonates. We used such short periods in order to prevent contamination by the artifacts of a subject's movement and to maintain interest and attention. However, detailed quantitative analyses of a subject's game performance and levels of interest and attention would yield a better understanding of the various changes in each Hb concentration.

A second possible explanation is that an age-dependent utilization of different neural circuits during the video game task might affect the prefrontal CBV patterns. Indeed, five of six adults showed significantly increased prefrontal total-Hb concentrations, and three of six children presented significantly decreased total-Hb concentrations during the game task. Further, a significant positive correlation between mean oxy-Hb changes in the prefrontal region and those in the bilateral motor cortex area was seen in adults but not in children. Cerebral oxygenation may be regulated by various physiologic parameters, including CBV, cerebral blood flow, the cerebrovascular regulatory mechanism, and systemic arterial pressure. Segal et al. [18] reported that playing video games significantly increased systolic and diastolic blood pressure, heart rate, and oxygen consumption in adolescents aged 16–25 years. Thus, in our study, these physiologic responses might have contributed to the increases in simultaneous prefrontal and fronto-parietal mean oxy-Hb changes in the adults. The reason for the decreased total-Hb concentrations in the three children and for the absence of a correlation between the mean prefrontal total-, oxy-Hb changes and fronto-parietal total-, oxy-Hb changes are complicated. The mean fronto-parietal total- and oxy-Hb changes were elevated in all but one of the children. The children might have been extremely absorbed in playing the video game while using the prefrontal cognitive processes to a much smaller degree than adults. In this sense, in children neuronal signals would pass through the motor cortex after integrating perceptual stimulation at the visual association area, projecting the signals to peripheral motor neurons without passing through pre-frontal neurons. Alternatively, the decreased CBV in the measurement positions in children may indicate that CBV is being supplied to an activation area that is deeper in the brain, i.e. further from the scalp, than is the case in adults. Hoshi et al. [17] reported the region-dependant temporal variation of brain activity in the prefrontal area during mental tasks, suggesting compensatory cerebral oxygenation patterns among each brain regions.

This study has a few limitations. First, we investigated only short-term effects of video game playing on brain oxygenation levels. Brain oxygenation patterns should be compared between subjects who do not normally play video games and habitual video game players in order to determine the long-term effects of this activity on child brain development. Second, because NIRS is not capable of a high degree of spatial analysis, we could not investigate the deeper cortical brain areas, such as the supplementary motor area, the inferior frontal lobe area, the inner part of the visual association area, and the basal ganglia region, any of which might be associated with neural activation during video game playing.

In conclusion, various changes in prefrontal total-, oxy-, and deoxy-Hb concentrations during video game playing were shown in both children and adults. These changes might be regulated by a subject's game performance, levels of attention and interest, physiologic responses, or age-dependent utilization of different neural circuits. Further investigation is needed for a better understanding of these changes in prefrontal Hb concentrations. NIRS is expected to enable the study of the biological effects of video game playing on developmental brain activity.

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