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Comparison of Cortical Activation during Subtraction in Mental Calculation and with a Calculator

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Abstract

Several studies have shown that various types of cognitive processing exist and exert different effects on brain activity. However, when a subject performs the same task, whether the task involves processing or not, such as in mental calculation or with a calculator, the different influences on the brain remain unclear. The purpose of this study was to examine whether the influence of cortical activation when performing mental calculation and using a calculator have different effects on the brain. Fifteen healthy, right-handed participants (mean age, 26.3 ± 8.5 years; 12 men, 27.7 ± 9.0 years; 3 women, 20.6 ± 1.1 years) were recruited as subjects. We measured oxygenated hemoglobin (oxy-Hb) levels while subjects performed subtraction tasks by mental calculation or using a calculator (3 min each). Measurements were made at the frontal lobe and temporal lobe. In both lobes, oxy-Hb level was significantly increased during mental calculation. Locations showing significantly increased oxy-Hb in mental calculation were the prefrontal cortex in the frontal lobe and supramarginal gyrus in the temporal lobe. These results suggest that the brain responds differently to tasks in mental calculation and using a calculator. We hypothesized that using the electronic calculator needs fewer neural networks than performing mental calculation. In recent years, thanks to the development of machines, many tasks have been automated, making our lives easier and more convenient. Our results may provide one example that the developments of modern technology influence brain function.

Keywords: Near-infrared spectroscopy; Oxygenated hemoglobin concentration; Mental calculation

Abbreviations: fNIRS: Functional Near-Infrared Spectroscopy; fMRI: Functional Near-Infrared Spectroscopy; Oxy-Hb: Oxygenated Hemoglobin Concentration; PFC: Prefrontal Cortex; BA: Brodmann Area

Introduction

Several studies have used cognitive processes to study cerebral functions. Recently, much interest has been shown in the effects of cognitive processing on brain activity using functional magnetic resonance imaging (fMRI) or functional near-infrared spectroscopy (fNIRS). Some studies have reported that cognitive processing can increase cortical activation during tasks [1,2]. Various types of cognitive processing exist, and these are expected to exert different effects on brain activity. For example, mathematical thinking, as a cognitive process, activates local and spatially distributed cortical networks to an extent depending on task specificity and complexity [3-5]. Exact calculations are correlated with language function, activating language-specific regions such as the perisylvian regions of the left hemisphere. Such activation is visible when mathematical facts learned by rote are retrieved from the verbal memory [6,7]. Mathematical calculations produce mainly intraparietal sulcus activation when nonverbal strategies are employed or approximate calculations are performed [8-11]. Additional regions relevant to mathematical calculation are the dorsolateral and inferior frontal gyri, together with the anterior cingulate region and bilateral parietal cortexes [12,13]. In general, different processes are necessary during mental calculations, such as recognition of the numbers in their Arabic form, comprehension of the verbal representation of numbers, assignment of magnitudes to numerical quantities, attention, memory, and other more specialized processes [14-17]. In this way, mental calculation needs complicated neural networks for exact and approximate calculation._In recent years, thanks to the development of machines, many activities are being automated, making our lives easier and more convenient. However, downsides exist to such an easy, convenient lifestyle. Living in a society in which results are given without engaging in a process may delay development of inhibitory functions in the brains of children [18,19]. One example of convenience is the use of electronic calculators. We hypothesized that using an electronic calculator would require fewer neural networks than performing mental calculation. The purpose of this study was to examine whether the influence of cortical activation when performing mental calculation and using a calculator would have different effects on the brain.

Methods

Subjects

Fifteen healthy, right-handed participants (mean age, 26.3 ± 8.5

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years; 12 men, 27.7 ± 9.0 years; 3 women, 20.6 ± 1.1 years) were recruited as volunteer subjects. No subjects had a history of neurological, major medical, or physical disorders, and none were taking medication at the time of the study. Prior to participating in the experiment, all subjects provided written informed consent. This study was approved by the ethics committee of the School of Medicine at Shinshu University, Japan.

Study protocol

We measured oxygenated hemoglobin (oxy-Hb) levels while subjects performed subtraction tasks either by mental calculation and using a calculator (3 min each). The subject sat in a chair at a table and performed subtraction problems written on a paper on the table after receiving a signal to start. We used calculations requiring subtraction of a two-digit number from a three-digit number, with each place requiring borrowing, such as "subtract 28 from 112". The reason we used subtraction with borrowing was to take difficulty into consideration, as addition was considered too easy and multiplication or division too complex for subjects to calculate mentally. Subtraction is not overly easy or difficult for mental calculation, and so was selected. The locations at which measurements of oxy-Hb were performed were the frontal and temporal lobes (Figures 1 and 2). Oxy-Hb was measured at 45 locations in the frontal lobe and 44 locations in the temporal lobe over the two hemispheres during mental calculation and calculator and compared across tasks performed by mental calculation and using the calculator. When subjects calculated a problem using a calculator, they used their fingers to enter numbers on the keypad. This influences the primary motor cortex of the brain and causes significant increases in cerebral blood flow. Therefore, in the case of mental calculation, the subjects were also asked to tap the keys of the calculator with the display covered.

fNIRS data acquisition

We performed fNIRS throughout the tasks by mental calculation and with a calculator using a multi-channel near-infrared spectroscope (OMM-3006; Shimadzu, Kyoto, Japan). Subjects wore a head cap covering the entire head. The locations of the channels are shown in Figures 1 and 2. The sampling rate for each channel was approximately 8 Hz. We focused on oxy-Hb concentration, which is reported to be sensitive to neuro-hemodynamic relations [20,21]. Changes in oxy-Hb concentration were detected using three wavelengths (780, 805, and 830 nm) of near-infrared light with a pulse width of 5 ms. Mean total irradiation power was <1 mW. Changes in oxy-Hb concentration from control baseline were estimated using a modification of the Lambert-Beer law [22]. The depth of light penetration from the surface of the brain in adult humans has been reported to range from 0.5 to 2 cm [23].

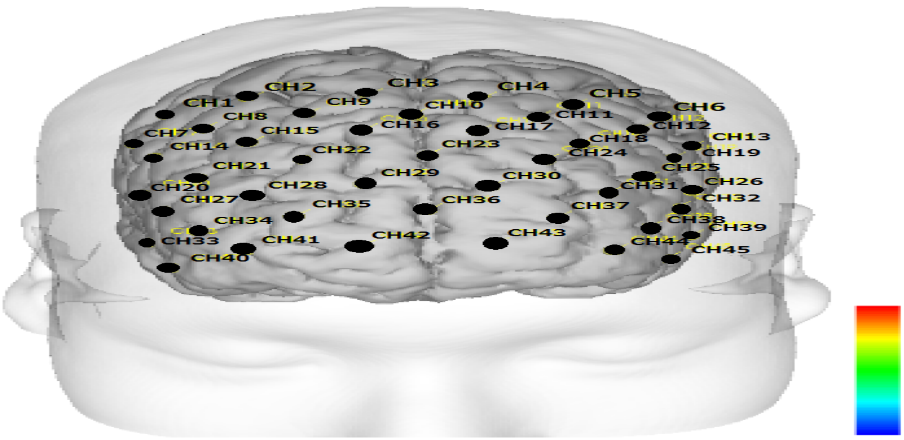

Figure 1: Location of near-infrared spectroscopy probes on the scalp over the frontal lobe. Near-infrared spectroscopy data were obtained using a 45-channel spectrometer. Subjects wore a head cap such that channels 1-45.

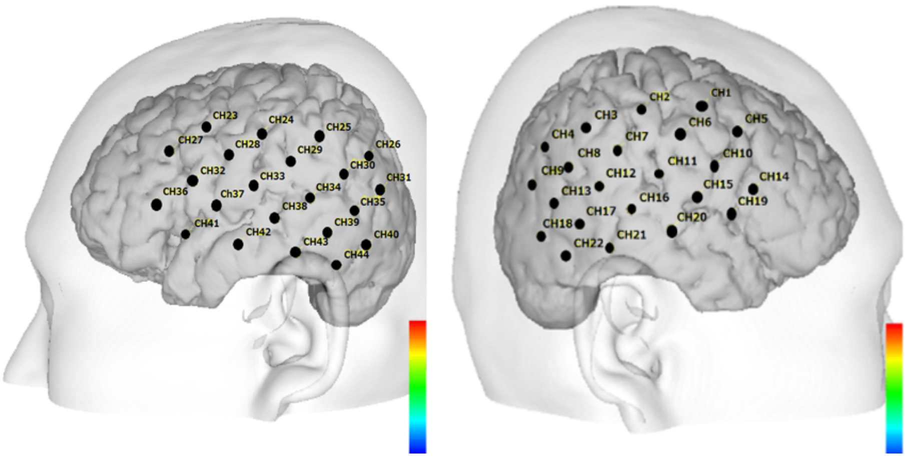

Figure 2: Location of near-infrared spectroscopy probes on the scalp over the temporal lobe. Near-infrared spectroscopy data were obtained using a 44-channel spectrometer. Subjects wore a head cap such that channels 1-22 were placed over the right hemisphere and channels 23-44 were placed over the left hemisphere.

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fNIRS data analysis

Analyses of fNIRS data were performed using least-squares estimation with a general linear model [24,25]. The temporal course of oxy-Hb in mental calculation and use of the electronic calculator were correlated with the design matrix using a boxcar function with two possible values: 1 and -1. The model equation, including the observed data, design matrix and error term, was convoluted with a Gaussian kernel [26]. The design matrix employed a 6-s delayed-boxcar function convolved with a Gaussian kernel of dispersion of 6-s full-width at half-maximum, which modeled the temporal correlation in the fNIRS time series. Task periods were contrasted against sedentary periods for mental calculation and use of the electronic calculator using a two-tailed t test.

Statistical analysis

Oxy-Hb levels were compared across mental calculation and use of the calculator using a paired-t test. The level of significance was set at $p<0.05$. Statistical analyses were performed using the SPSS version 4.0.1 statistical package (SPSS, Chicago, IL).

Results

Oxy-Hb measured by fNIRS

In each of the 15 subjects, oxy-Hb was compared across the mental calculation and electronic calculator using a paired t-test. For mean oxy-Hb of the whole range of measurements (frontal and temporal lobes) compared across mental calculation and calculator, oxy-Hb was significantly increased in mental calculation (0.009 ± 0.004 mmol/L·cm) than in calculator (0.005 ± 0.006 mmol/L·cm; Figure 3). In the frontal lobe, oxy-Hb was significantly increased with mental calculation (0.011 ± 0.004 mmol/L·cm) compared to with the calculator (0.005 ± 0.003 mmol/L·cm; $p<0.001$; Figure 4). In the temporal lobe, oxy-Hb was again significantly increased with mental calculation (0.008 ± 0.005 mmol/L·cm) compared to with the calculator (0.004 ± 0.008 mmol/L·cm; $p<0.001$; Figure 5). To examine the location of changes in oxy-Hb, we analyzed each channel individually for oxy-Hb. In the frontal lobe, oxy-Hb was significantly increased in mental calculation compared to use

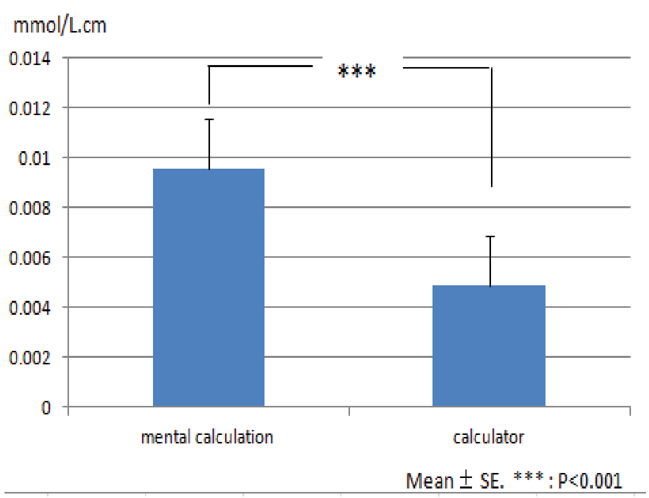

Figure 3: Mean oxy-Hb of the whole range of measurement (frontal lobe and temporal lobe) compared across mental calculation and calculator use. Level of oxy-Hb was significantly increased with mental calculation.

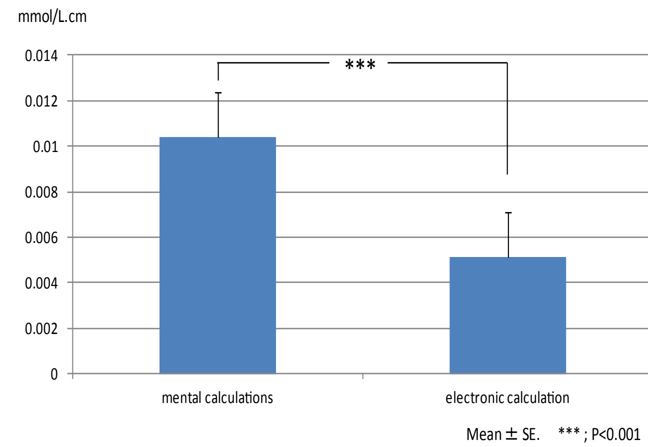

Figure 4: Mean oxy-Hb in frontal lobe measured by fNIRS when subjects performed subtraction by mental calculation and with a calculator. Oxy-Hb was significantly increased with mental calculation compared with use of the calculator.

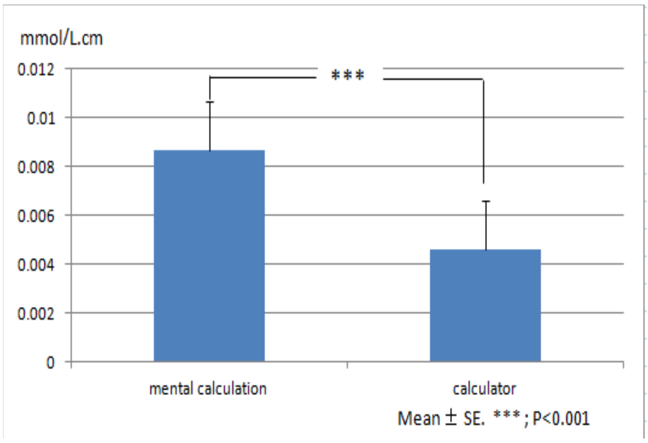

Figure 5: Mean oxy-Hb at temporal lobe measured by fNIRS when subjects performed subtraction by mental calculation and with a calculator. Oxy-Hb was significantly increased with mental calculation compared with use of a calculator.

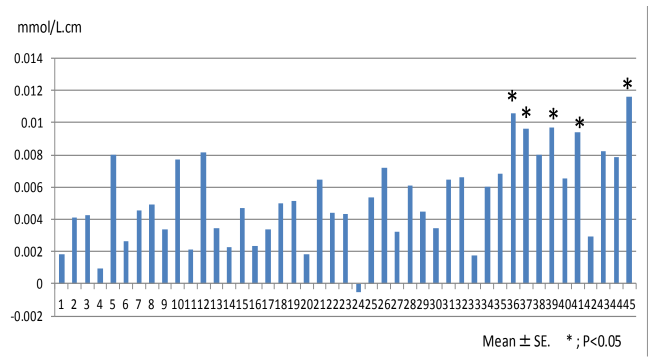

Figure 6: Differences in change in oxy-Hb with mental calculation and calculator use in the frontal lobe. Oxy-Hb level was significantly increased with mental calculation compared with calculator use at 36ch, 37ch, 39ch, 41ch, and 45ch.

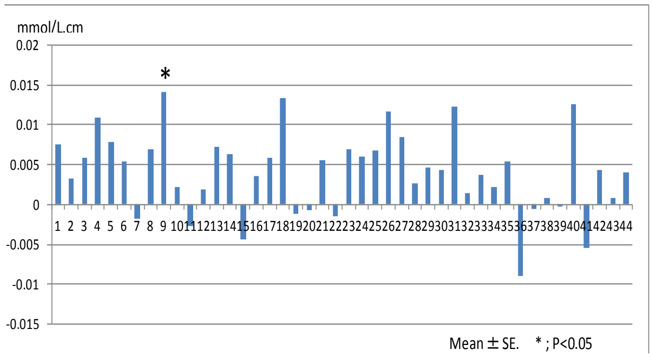

Figure 7: Difference in change in oxy-Hb level with mental calculation and calculator use in the temporal lobe. Oxy-Hb level was significantly increased with mental.

of the calculator in 36ch ($p<0.05$), 37ch ($p<0.05$), 39ch ($p<0.05$), 41ch ($p<0.05$), and 45ch ($p<0.05$) (Figure 6). In the temporal lobe, oxy-Hb was significantly increased in mental calculation compared to use of the calculator in 9ch ($p<0.05$) (Figure 7).

Discussion

This study examine differences in mean oxy-Hb in the frontal lobe, temporal lobe and both lobes between subjects performing subtraction tasks by mental calculation or using a calculator. To examine the locations of changes in oxy-Hb, individual analysis of channels showed oxy-Hb at 36ch, 37ch, 39ch, 41ch, and 45ch in the frontal lobe and at 9ch in the temporal lobe were significantly increased in mental calculation compared to use of the calculator. Locations of 36ch, 37ch, and 41ch are at the frontal pole, approximately over Brodmann area (BA)10, while 36ch, 37ch, 41ch, 39ch, and 45ch are located over the prefrontal cortex (PFC) containing Brodmann areas (BA) 9, 10, 11, 12, 46, and 47. Recent research has suggested that the frontal pole is involved in strategic processes in memory recall and various executive functions [24]. This brain region has been implicated in planning complex cognitive behaviors, personality expression, decision-making, and moderating social behavior [25]. In the temporal lobe, 9ch was located at the supramarginal gyrus, part of BA 40 in the inferior parietal lobe, which is involved in reading both in terms of meaning and phonology [26].

Mental calculation has already been reported to increase oxy-Hb of the brain in the prefrontal cortex, supporting our investigate findings [27,28].

In recent years, thanks to the continued development of machines, many tasks are becoming automated, making our lives easier and more convenient. We tend to demand instant and immediate effects and results. We overlook the process, and forget the difficulties involved in solving problems. There is little room for inventive ideas or creativity. The machine does everything for you.

There is yet another downside. With economic development in America, the number of people in local communities with whom we interact has been suggested to have been decreased [29]. It is hypothesized that we do not fully use our brain when we participate in fewer interactions in communities. For example, significantly more brain blood flow has been reported in players participating in a traditional 4-player mahjong game compared to a player participating in a video mahjong game [30]. In the same way, living in a society in which results are given without an intermediate process may delay the development of inhibitory functions in the brains of children [18]. Another example of the convenience of our modern world is the use of electronic calculators. We hypothesized that using an electronic calculator would involve fewer neural networks than performing mental calculation. We examined whether the cortical activation performing mental calculation and using a calculator would have different effects on the brain. Our results showed significantly higher mean oxy-Hb levels in the frontal lobe, temporal lobe and both lobes of subjects when performing mental calculation for subtraction than when using the calculator.

With the development of modern technology, use of the calculator has taken the place of mental calculation. This is just one example of changes in our lifestyle. Further studies from different perspectives are needed to clarify how lifestyle changes are affecting brain function.

Conclusion

The purpose of this study was to examine whether cortical activation differs between performing mental calculation and using a calculator. Our fNIRS study demonstrated that oxy-Hb in the prefrontal cortex, covering BAs 9, 10, 11, 12, 46, and 47, and the supramarginal gyrus part of BA 40 were significantly increased when performing subtraction tasks by mental calculation compared to when using a calculator. These results suggest that using an electronic calculator involves fewer neural networks than performing mental calculations and our results may provide one example in which the development of modern technology results in a change to the processes influencing our brain.

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