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Brain Activities of Idea Generation Types Using Sketch

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Designers’ problem-solving activities and the thinking process has attracted attention and the tool development and education for it are carried out in various places. Their effectiveness, however, is evaluated only by subjective way (e.g. interview and questionnaire), and to develop the objective evaluation method is required. This study focuses on the idea generation using sketches and aims to clarify the relationship between the idea generation and brain activities. This study defined the three types of idea generation using sketch and compared the brain activities (the concentration change in the oxygenated hemoglobin of the prefrontal cortex) of the participants conducting them using a NIRS (Near Infrared Spectroscopy) apparatus. The grand-average of the NIRS signal of them were calculated and suggests the more the task becomes creative, the more the prefrontal cortex activates. This indicates the possibilities to differentiate the sketch idea generation types on the basis of the creativity.

Keywords: sketch; idea generation; NIRS

1 Introduction

Design is said to be an activity to solve the inverse problem and difficult to be solved. Designers generate/choose the design attributes (causal factors) that satisfy a set of design requirements (result) from multiple alternatives. Designers’ problem-solving activities and the thinking process for deriving the design solution (hereinafter called design thinking) has been studied from 1950s. Most researchers have pointed out that designer heuristically repeats the three-stage process: analysis, synthesis and evaluation (Cross, 1984; March, 1984; Mesarović, 1964, Page, 1953). Recently, the word “design thinking” attracts attention among various fields due to the activities of “d.school” established by IDEO and Stanford University, and the tool development and the education regarding design thinking are carried out in various places (Plattner, Meinel, & Leifer, 2011). Their effectiveness, however, is evaluated only by subjective way (e.g. interview and questionnaire) and difficult to be confirmed. This causes the need to develop the way to analyze and evaluate it objectively.

Due to the development of the brain activity measurement devices, the research measuring the brain activities of the participants doing design tasks has become popular. Alexiou, Zamenopoulous, and Gilbert (2011) compared the brain activities between the ill- and well-structured design problems of furniture layout, using a function Magnetic Resonance Imaging (fMRI) apparatus and suggested that the former problem whose evaluation criteria is not well specified activates more brain regions than the latter one. Particularly, the former task activated the two types of the brain regions: one includes the areas involved in visual imagery, semantic processing, and multi-sensory integration, such as the temporal, occipital, and parietal regions; the other is the prefrontal cortex (PFC) for constructing executive schemes of action. Kowatari et al. (2009) measured the brain activities of the undergraduate/graduate students designing the shape of a pen using a Magnetic Resonance Imaging (MRI) device and concluded the design task facilitated and suppressed the right and left PFCs, respectively. Folley and Park (2005) utilized a Near Infrared Spectroscopy (NIRS) apparatus and compared the brain activities between schizophrenic patients and healthy participants during the task to generate new uses of the objects shown in the computer screen. As a result, compared to the healthy participants, the patients generated more uses, and the more brain regions in both the right and left PFCs were activated. Gibson, Folley, and Park (2009) also compared the brain activities between the creative individuals (musicians) and healthy participants. The result reveals that the musicians also derived more uses and activated more brain regions in the PFCs, same as the patients. Nagamori, Nakajima, Yokoi, and Yamanaka (2009) measured the brain activities of the undergraduate/graduate students when they work on the following two creative tasks using NIRS apparatus. Task 1 is to select and arrange one or three colors which are fit to the given concept (adjective phrase, such as “cool” and “cute”). Task 2 is to make a “cute chair” using single- or multi-color blocks. The results of the two tasks show some task conditions (e.g., selecting one color in Task 1 and using multi-color blocks in Task 2) activate the PFC more than the others. In other words, the more creativity the task requires, the more brain regions in the PFC activate. Kato, Otagiri, Nagamori, and Izu (2016) compared the brain activities of the participants conducting the Finke’s pattern generation (form assemble) task (Finke, Ward, & Smith, 1996) employing the hand drawing and computer operation. The result shows the latter one activates the right PFC more, and the activation seems to be occurred by the ways of idea transformations (not occurred by the assembling methods: hand drawing and computer operation).

These studies confirmed the design tasks activate the brain regions in the PFC, suggesting the possibilities to evaluate how the person is creative state during the design task by measuring them. This study focuses on the brain activities regarding the design using sketches which is a common tool in the product design activities, and aims to clarify the relationship between the design activity and brain activities. This paper is organized as follows. Section 2 illustrates the types of the idea generations by sketching. Section 3 presents the method to measure the brain activities. Section 4 describes the result and discussion of the brain activity measurement experiment, while Section 5 provides conclusions and future tasks.

2 Idea generation types using sketches

This study focuses on the classification of the sketch (drawing) generation proposed by Goel (1995). This classification includes two types of drawing generations as follows. One is “new generation (NG)” that generates a drawing (idea) using the long-term memory (LTM) of the person. LTM stores the information regarding what the parson has encountered and is used to make logical deductions, to understand ideas, as well as to memorize fact. The other is “transformation” which translates a drawing from the previously generated drawings. The transformation is further classified into two types: “lateral transformation (LT)” that modifies a drawing into another related, but distinctly different drawing; "vertical transformation (VT)" which reiterates and reinforces an existing drawing through explication and detailing. Note that Goel defines one more type of transformation: "reinterpretation" that generates the drawing having different meaning (object) from the previous drawings. However, this study eliminated it because the change of meaning (design object) seldom happens in product design. The three types of the drawing generations are illustrated using some sketch examples in order from the sketch generated earlier Figure 1(a)-(f). These sketches were drawn for the idea generation of USB flash memory during the experiment described in Section 4. Sketch (a) was drawn firstly (i.e. drawn without referring any sketch) and is categorized as NG. Sketch (b) was drawn secondly but drawn without referring Sketch (a) and is also categorized as NG. Sketch (c) was generated based on the function and shape of the sketches (a) and (b) (slider mechanism and hole) and is categorized as LT. Sketch (d) is categorized as NG for the same reason of sketch (b). Sketch (e) is categorized as VT because it illustrates the detail (parts action) of Sketch (d). Note that the categorization requires the opinion (concept) of the person who draws the sketch. The aforementioned categorization was done using the interview of them.

This study compared the aforementioned idea generation types by using the brain activities measured when the participants conduct the idea generation. The following section illustrates the method to measure the brain activities.

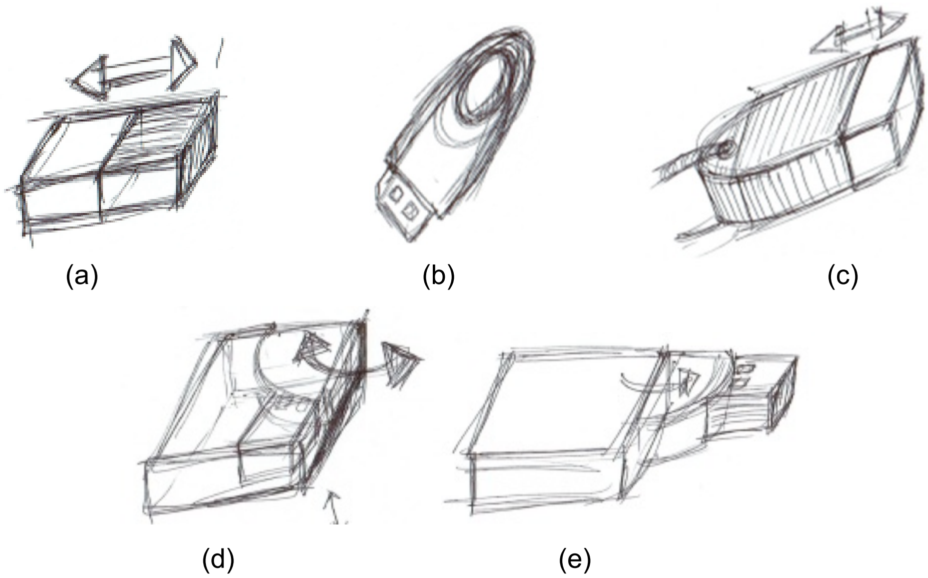


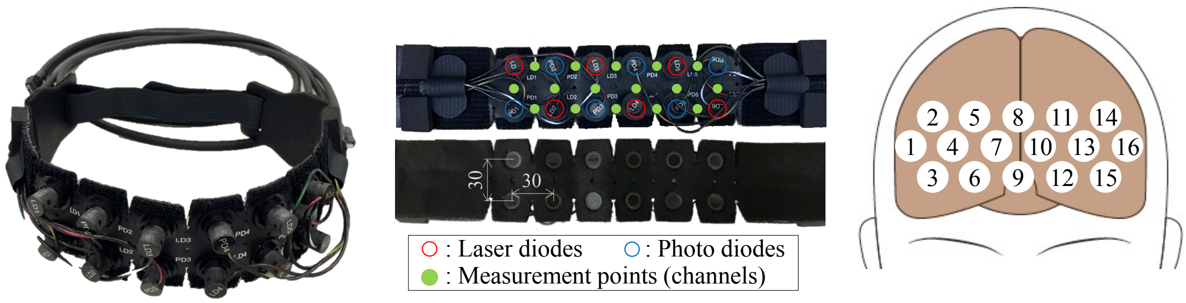
Figure 1. Examples of idea generation types using sketches

3 Brain activity measuring and analysis

3.1 Methods to measure brain activities

This study employed NIRS because NIRS is a no-invasive measurement and does not constrain the participant's movements (sketching). A NIRS apparatus is composed of some emitter-detector pairs of near infrared light whose wavelength is from 700nm to 1000nm and cannot be easily absorbed in a biological tissue. Each emitter has two continuous laser diodes and irradiates the near infrared light of two different wavelength in order to measure the concentration changes in both oxygenated hemoglobin (oxyHb) and deoxygenated hemoglobin (deoxyHb). While the amounts are calculated on the basis of the modified Beer-Lambert Law (Delpy et al., 1988), which gives the relation equation between the attenuation of light and the density changes in light absorber.

This study employed a NIRS device (SpO2, Spectratech Inc., Tokyo, Japan, Figure 2(a)). This device includes six pairs of laser and photo diodes (illuminators and detectors) whose distance is 30mm (Figure 2(b)). The number of the measurement points is sixteen, and they locate between each pair of laser and photo diodes. The measurement brain regions corresponding to the points, termed as channels (CHs), are in the PFC (Figure 2(c)). The sampling frequency is 1.6Hz.



(a) NIRS (OEG-16)

(b) Location of laser and photo diodes

(c) Measured regions termed as channels (chs)

Figure 2. NIRS device and its measured region in prefrontal cortex

3.2 Method to analyze NIRS signal

This study adopted the change in oxyHb which is the most sensitive indicators of the change in regional cerebral blood flow (Hoshi et al., 2011) and analyzed the signal using the following four methods

- Bandpass filter (Peña et al., 2003): this processing removes the components originating from the slow fluctuations of cerebral blood flow, heartbeat, and body motion. This study employed the bandpass filter whose pass band is between 0 and 0.2 Hz.
- Base line correction (Peña et al., 2003): this processing removes the component originating from the fatigue of a participant which changes the oxyHb caused linearly with respect to time. In this study, the line connecting the average values of the two control tasks conducted before and after the target task was calculated and was subtracted from the oxyHb signals.
- NIRS signals separation method (Yamada, Ueyama, & Matsuda, 2012): this method can separate the NIRS signals into cerebral functional and systemic (physiological) components based on differences in hemodynamic. This study extracted the cerebral functional components using the method.
- Grand-average event related potential wave form (Hoshi et al., 2011): this processing derives the averaged partial-wave of each event (task) and enables us to visualize the features of each event. This study derived the partial-wave of the three idea generation types whose time range is from 20s before the start point of the sketch to 40s after the point.

The following section presents the brain activity measurement experiment to confirm the relation between the three idea generation types and their brain activities.

4 Experiment to measure the brain activity of idea generation using sketch

4.1 Experimental conditions and procedures

The twelve, right-handed healthy graduate/undergraduate university students, who are in product design course, participated in this experiments (8 male and 4 female). Before each experiment, informed consent was obtained from all of them. The participants were asked to conduct control and idea generating tasks, alternately. In the control task, they stared at a target (black cross mark) on the desk for 60 seconds. Whereas, in the idea generating task, they generated ideas of new products by sketching without limiting the time, on the basis of the five design themes (design objects): scissors, mechanical pencil, USB flash memory, cutter knife, and stapler. They were chosen as everyday things in order to minimize the difference of the knowledge about them between the participants. Additionally, the participants were asked to conduct sketch of the displayed real objects of them before the experiment, in order to minimize the extra brain activity to remind/imagine them using long term memory during the experiment. The presentation order of the design themes was randomized to minimize the order effect.

This study utilized a NIRS apparatus described in the preceding section to measure the cerebral blood flow (the concentration changes in oxyHb). And, an eye tracking system (Talk Eye Lite, Takei scientific instrument Co., Ltd., Niigata, Japan) was employed to measure the points of gaze of the participants. Then, the experimenter performed an interview in order to get the information to classify the idea generations in the tasks into the three types described in Section 2. Note that the measured points of gaze were displayed to the participants for reminding them of the idea generation during the interview. In the interview, the experimenter asked the following two questions for classifying each sketch (idea):

Q.1. Is this sketch/idea related to (generated according to) the previous one?
Q.2. (If the answer of Q.1 is “Yes”,) Is this sketch/idea different from the previous one?

This experiment cannot equalize the start time and the implementation time of each sketch generation because the participants freely generate idea using sketch without time limitation. Additionally, all the sketch generations cannot be arranged between the control tasks. This means that the cerebral blood flow measurement data (the concentration change in oxyHb Δc_{oxy}) of a task (sketch generation) is influenced by that of the previous task. This study, therefore, calculated the grand-average event related potential wave forms using the extracted data on the basis of the following conditions: 1) each event (NG/LT/VT) repeats at least 5 times; 2) the time of sketching is more than 40s; 3) the time gap between events is more than 10s.

4.2 Results and discussions

Figures 3-5 show the calculated the grand-average event related potential wave forms of a participant (No.4). Figures 3, 4, and 5 correspond to the wave forms when the participant conducts NG, LT, and VT, respectively. These waves are standardized by subtracting the average value of the data for 30s before starting drawing. These figures indicate that NG (idea generation with the sketch based on LTM (i.e., without previous drawings)) activates the PFC more than LT/VT (that based on a previous drawing). Additionally, LT activates PFC more, compared with VT. In some previous studies, the activation of PFC was confirmed in creative tasks: furniture layout design (Alexiou et al., 2011) and shape design of pen (Kowatari et al., 2009). This suggests the more the task becomes creative, the more the PFC activates and indicates the possibilities to differentiate the sketch idea generation types on the basis of the creativity. However, the relationship between the types and creativity has not been clearly confirmed because of the following reasons: 1) the lack of the sample number for statistical test (i.e., the need to conduct the experiment whose task types and time are controlled; 2) the lack of the correlation analysis between creativity and brain activities (e.g., comparison of drawings based on the qualitative evaluation of the ideas and comparison of the professional and amateur designer’s brain activities). They are the future tasks.

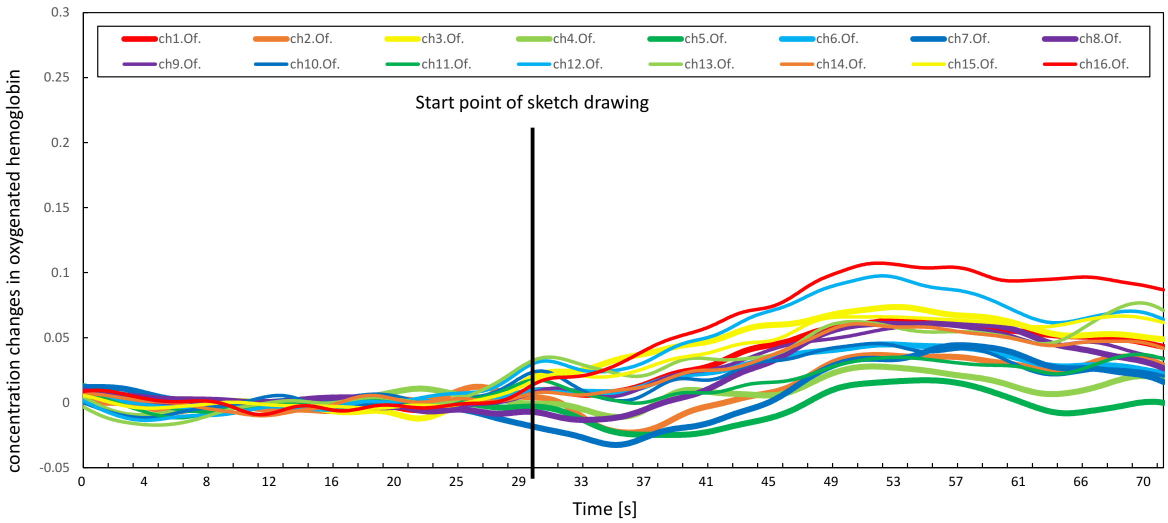


Figure 3. Grand-average event related potential wave form of NG (participant No.4)

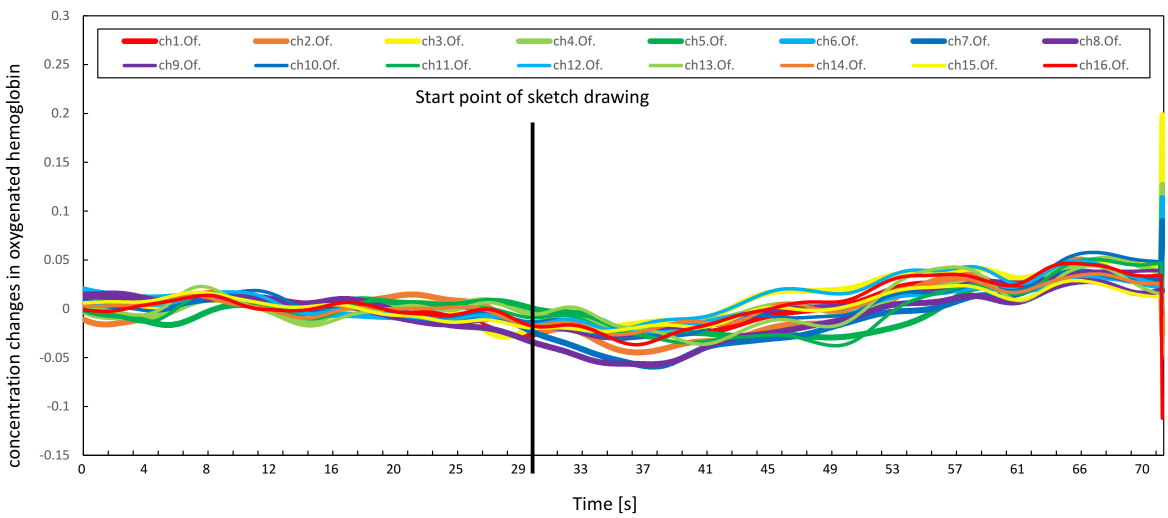


Figure 4. Grand-average event related potential wave form of LT (participant No.4)

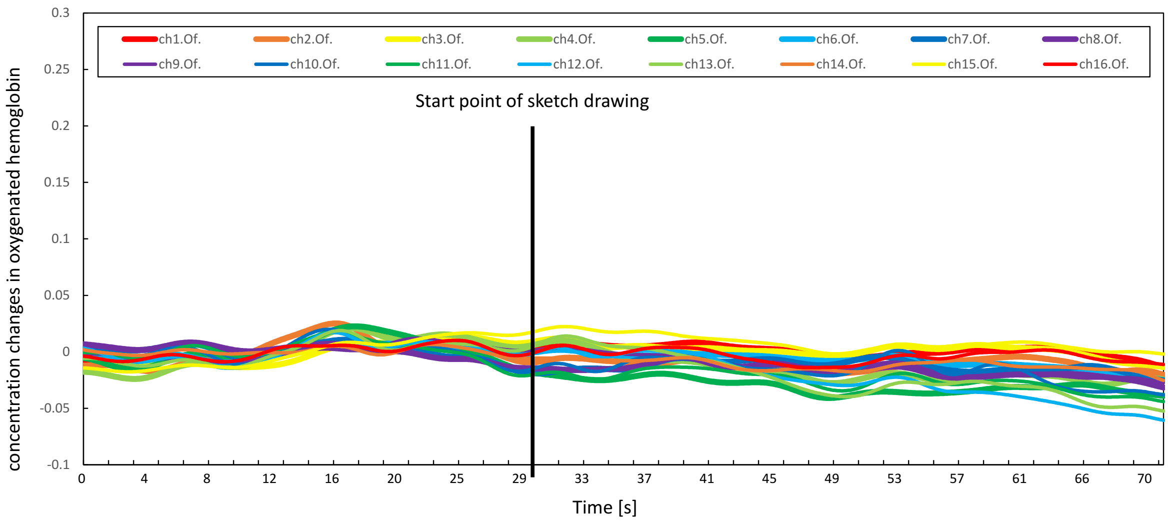


Figure 5. Grand-average event related potential wave form of VT (participant No.4)

5 Conclusions

This study defined the three types of idea generation for product design using sketch based on the Goel's classification and compared the brain activities (the concentration change in the oxygenated hemoglobin of the prefrontal cortex) of the participants conducting them using a NIRS apparatus. The grand-average of the NIRS signal of the three types were calculated and suggests the more the task becomes creative, the more the PFC activates. This indicates the possibilities to differentiate the sketch idea generation types on the basis of the creativity. However, there is a possibility that the difference between the NIRS signals is caused by the use of LTM, and the comparison between the previously and newly generated sketches from LTM is needed. And, if the difference is confirmed, the result of this study can apply to evaluate the skill of idea generation using sketch.

The future tasks are to define some representative values of brain activities calculated from NIRS signals to conduct the statistical test by defining, and to conduct the experiment in which the idea generation types and task time are controlled by experimenter in order to confirm the repeatability of the results of this study. Advanced research includes the followings: 1) comparison of professional and amateur designers' brain activities to analyze the features of creative people; 2) analysis of the correlation between the qualitative evaluation of generated ideas and brain activities; 3) comparing the brain activities of the participants using some idea generation methods/tools to classify them/differentiate from sketch.

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