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VERIFICATION FOR COMMONALITY OR SPECIFICITY OF BRAIN REPRESENTATIONS RELATED TO THE DIFFERENT EVALUATION CRITERIA

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Abstract. *Today people have far greater opportunities to experience innovative products through technological developments. However, it is difficult to choose products that satisfy the consumer requirements because of the immense quantity of products that exist. Neuro-marketing, which explores the human decision-making process, is attracting attention by measuring the reaction of the brain in an objective way, and taking advantage of progress in brain science and psychophysics. Numerous studies have been conducted to date on preference-based decision-making, and the evaluation criteria of the decision-making process are diverse, such as food preferences, product costs, or facial features. In this research, decision-making experiments by several evaluation criteria were conducted using a functional magnetic resonance imaging (fMRI) scanner in order to elucidate the brain regions comprehensively involved in decision-making and specific brain regions related to each evaluation criterion. This experiment measured brain activity during paired comparison tasks based on a single evaluation criterion by fMRI, and attempted to identify specific brain regions related to decision-making based on each evaluation criterion. Participants performed a decision-making task that involved choosing a smartphone by referring to information such as price, color or year as an evaluation criterion. As a common activation region in the choice tasks by all evaluation criteria, the bilateral occipital gyri had significant activation. The result is consistent with reports of previous studies which indicate that the occipital gyrus is the brain region related to a visual processing and preference rated tasks. Conversely, with specific activation regions involving color choice tasks, the left fusiform gyrus, left insula and right precuneus are significantly activated. The result suggests that attention to color choice becomes greater than other choices.*
Keywords: fMRI, Decision-making, Evaluation criteria, Preference, Occipital gyrus, Ventromedial prefrontal cortex

1. **Introduction.** In recent years, people have far greater opportunities to experience innovative products though technological developments. In addition, they are able to choose and browse product information with pictures when shopping online. However, it is difficult to choose products that satisfy the consumer requirements because of the immense quantity of products that exist. There are many situations in which it is necessary to make a decision from among multiple alternatives.

As a method to elucidate decision-making, researchers in the mainstream marketing field are using methods such as existing questionnaires and group interviews. However, it is known that a choice blindness is characteristic of the human selection process that appeared at a later point in brain science and psychology research. Therefore, it is difficult

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to determine the reason at purchase decision-making using only a questionnaire. Investigation of the mechanism of human decision-making is limited only by a subjective and an introspective survey. Thus, neuro-marketing, which explores human decision-making process, is attracting attention by measuring the reaction of the brain in an objective way and taking advantage of brain science and psychophysics knowledge [1, 2]. The instruments such as the magnetic resonance imaging (MRI), the near infra-red spectroscopy, the positron emission tomography and the electroencephalography are used in the field of neuroscience in order to explore the human decision-making process [3, 4]. The MRI has the advantage that the spatial resolution is higher than other equipment. In this study, MRI experiments were conducted for making the main purpose of specifying activation regions for the whole brain.

Numerous studies have been conducted to date on preference-based decision-making, and the evaluation criteria of the decision-making are diverse such as food preferences or product costs, facial attractiveness. Neuroimaging experiments over the last several years have shed light on the neural mechanisms associated with the valuation of abstract rewards. One area that has been shown repeatedly to be activated by diverse rewarding stimuli is the ventromedial prefrontal cortex (vmPFC). This brain region has been shown in several neuroimaging studies to be active for a variety of primary and abstract rewards including sports cars [5], cola preference [6], pleasant odors [7], wine price [8], facial attractiveness [9], and money [10]. Mounting evidence in these studies and others supports the idea that this region is involved in converting the value of these diverse stimuli to a common scale for action selection [11].

In this research, decision-making experiments by several evaluation criteria are conducted in the functional MRI (fMRI) scanner, in order to elucidate the brain regions comprehensively involved in decision-making and specific brain regions involved in each evaluation criterion. This experiment measured brain activity during a paired comparison based task with a single evaluation criterion by fMRI, and attempted to identify specific brain regions related to making a decision based on each evaluation criterion.

This paper is structured as follows. Section 2 introduces the materials and methods of the fMRI experiment and analysis. Section 3 presents analysis results. Section 4 discusses the results based on related work. Section 5 concludes the paper.

2. Materials and Methods.

2.1. **Participants.** In Japan, the young generation has a high ownership rate of smartphones. Therefore, subjects in their late teens to twenties were targeted as sample groups for this experiment. Twenty-five participants (five female; two left-handed; aged from 19 to 22 with the average age of 20.60, the standard deviation of 1.26) participated in the fMRI experiment. One participant did not complete the experiment, leaving 24 subjects in the data analysis. As required by the Human Ethical Review Board of Kochi University of Technology, all subjects signed informed-consent forms agreeing to take part in the experiment.

2.2. **Task and stimuli.** Participants performed a decision-making task that involved choosing a smartphone by referring to each evaluation criterion. Figure 1 shows the experimental timeline. This experiment is constructed based on a block design. The block design is the most commonly used experimental paradigm in fMRI studies. It consists of several discrete periods of on-off blocks, with the "on" representing a task condition, and the "off" referring to a rest state or a different task condition. Several neuroimaging studies related to decision-making have incorporated the block design [12, 13]. In this task, participants viewed a screen which is illustrated in the lower part of Figure 1. The screen

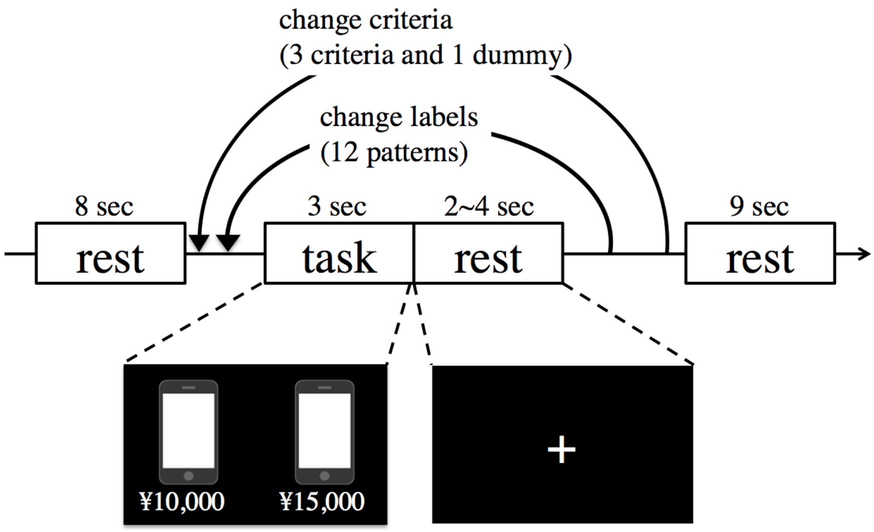

FIGURE 1. Experimental timeline

presented two identical smartphone images with different evaluation criteria under each of the image. Participants pushed a left or right button to select the smartphone which they felt they wanted more. A price, a body color and a produced year were set as the evaluation criteria on the experimental conditions. These choices were selected as criteria because they can be easily evaluated regardless of the presence or absence of smartphone knowledge by the participants. It is considered that each participant has a different priority for each evaluation criterion. In this experiment, it was hypothesized that there is a specific brain-related region when referring to the impression for each evaluation criterion that included priority differences in participants. In addition, a dummy (four squares as meaningless symbols) was set on the control condition. Each criterion had 4 types of content. The evaluation criteria appeared in a different order for each participant. Each run, which was performed twice, contained 8 blocks of four separate tasks that included the price choice, the color choice, the year choice, and the dummy choice. Each choice was shown for 3 seconds followed by a 2-4 second rest period. The screen presented two smartphone images on the left and right, and presented two different labels representing the evaluation criterion under each smartphone image. In the choice tasks, participants were required to push the left or right button to select the desired object. In the dummy tasks, participants were required to push either button intuitively and non-directivity. The total time of one-run was 306 seconds.

Stimuli images and words were rear-projected onto a screen placed in the scanner bore using an LCD projector. The screen shows two identical smartphone images and two different labels as an evaluation criterion as in Figure 1. Table 1 shows the list of evaluation criterion labels used in this experiment.

TABLE 1. List of evaluation criterion contents

Evaluation Criteria	Labels			
price	¥10,000	¥15,000	¥20,000	¥25,000
color	black	white	red	blue
year	2004	2008	2012	2016
dummy	□□□□			

Note: ¥ sign means monetary unit in Japan.

2.3. **MRI acquisition.** Scanning was performed on a 3.0-Tesla scanner (Siemens MAGNETOM Verio) using a 16-channel head coil at the Kochi University of Technology. Functional scans were acquired with a standard gradient-echo echo-planar imaging (EPI) sequence to cover the whole-brain (FOV = 192 × 192 mm; TR = 3,000 ms; TE = 30 ms; flip angle = 90 degrees; slice thickness = 3.0 mm; voxel size = 3.0 × 3.0 × 3.0 mm). Each run of the functional scans obtained 102 volumes over a total duration of 306 seconds. A high-resolution T1-weighted anatomical scan was acquired for each subject (1.0 mm^3 resolution).

2.4. **Functional MRI data preprocessing.** The first two scans (six seconds) in each run were discarded to avoid the instability of the fMRI scanner. The SPM12 software (Wellcome Department of Cognitive Neurology, London) was used to process and analyze the functional data. Functional images were corrected for differences in slice acquisition time and motion corrected. The data were realigned, normalized to the Montreal Neurological Institute (MNI) standard brain model, and smoothed with an 8-mm full-width half-maximum Gaussian filter. The brain activation degrees were analyzed on the MNI coordinates.

2.5. **fMRI analyses.** The following four conditions were modeled: price choice, color choice, year choice and dummy choice. Common and specific brain regions involved in each condition were identified by creating contrasts. With the first level (single subject analysis), contrasts (price vs. dummy, color vs. dummy and year vs. dummy) were created to identify the brain regions, which are commonly activated for all contrasts. Price choice vs. the two other choices, color choice vs. the two other choices and year choice vs. the two other choices were created to identify the brain regions, which are specifically activated for each contrast. With the second level (group analysis), the one sample t-tests were performed to examine the significant brain activation of the group during the contrasts mentioned above. The statistical parametric map generated using the price, color and year vs. dummy choice contrasts. Clusters were corrected for multiple comparisons across the whole brain using Family-Wise Error correction (FWE) and a threshold of p-statics: $p < 0.05$ [14]. The statistical parametric maps generated using color vs. (price & year) choice contrast. Clusters were defined using a height threshold of $p < 0.001$ uncorrected for multiple comparisons with a cluster size threshold being $k = 171$ voxels. In the contrasts of price vs. (color & year) and year vs. (price & color), there were no suprathreshold clusters.

3. **Results.**

3.1. **fMRI analysis results: common and specific brain activity regions.** We performed a whole-brain analysis to identify regions that have common significant activation in each choice. Table 2 shows MNI peak coordinates in each contrast, which are price vs. dummy and color vs. dummy, year vs. dummy. MNI peaks were reported for voxels at $p < 0.05$ FWE corrected for multiple comparisons; L = left and R = right hemisphere. Significant differential activities in the contrast of price vs. dummy were observed in left occipital gyrus and right calcarine. In the contrast of color vs. dummy, significant differential activities were observed in left fusiform gyrus, birateral occipital gyri, right lingual, bilateral superior frontal gyri, left insula, right cerebelum, left triangular part of inferior frontal gyrus, right calcarine, right middle frontal gyrus and right angular. In the contrast of year vs. dummy, significant differential activities were observed in bilateral occipital gyri, right inferior temporal gyrus, right cerebelum.

Table 2. Common significant brain activation in each contrast

Region Label	Cluster Size	T-statistic	MNI Coordinates		
			x	y	z
Price vs. Dummy					
Occipital Mid L	482	9.35	−22	−96	0
Calcarine R	363	8.80	24	−92	2
Color vs. Dummy					
Fusiform L	484	8.94	−40	−54	−10
Occipital Inf R	59	8.41	36	−84	−12
Lingual R	91	8.01	12	−90	−4
Frontal Sup Medial R	15	7.60	6	24	42
Occipital Mid R	31	7.38	32	−66	26
Insula L	16	7.13	−30	18	−4
Cerebelum 9 R	5	6.90	6	−56	−40
Frontal Inf Tri L	4	6.83	−38	38	10
Calcarine R	7	6.83	6	−62	12
Occipital Sup R	8	6.81	30	−72	46
Frontal Sup 2 L	1	6.78	−12	50	38
Frontal Mid 2 R	1	6.75	36	52	−2
Occipital Mid L	24	6.67	−30	−78	24
Frontal Mid 2 R	1	6.53	30	54	4
Occipital Mid L	1	6.50	−28	−80	18
Angular R	1	6.44	34	−70	46
Year vs. Dummy					
Occipital Inf L	464	10.26	−38	−82	−10
Occipital Inf R	527	9.80	22	−92	−4
Occipital Mid L	23	7.69	−30	−80	24
Temporal Inf R	19	6.95	50	−64	−12
Cerebelum 6 R	1	6.45	10	−74	−18

Note: Region labels were named on the basis of the automated anatomical labeling (AAL) template [15] which is a software and a digital human brain atlas with a labeled volume. The labels indicate macroscopic brain structures. Cluster size is reported in voxels. The T-statistic value is the total average, which was calculated for each voxel from MRI data of each subject, divided by the standard deviation of all subject.

Significant activity was observed commonly for all the contrasts only in the occipital gyrus. Figure 2 shows the significant activities in the occipital gyrus (coodinate: $z = -12$) of price choice, color choice and year choice versus dummy choice ($p < 0.05$ corrected).

Difference among price, color and year choice on bilateral occipital gyri were investigated. Firstly, a contrast of (price & color & year) vs. dummy was set to determine the voxel (coordinate) for comparing activation degree. Then, activation degrees among the price, color and year choice were compared on the same voxel of the determined coordinate. As a result of the analysis of this contrast, peak coordinate of significant activation located (32, −86, −12) and (−40, −80, −10) in bilateral occipital gyri. In these two voxels, brain activation degrees during each choice (price, color, year and dummy) were calculated. Figure 3 shows activation degrees during each choice on left and right occipital gyri. The occipital gyrus is located in the visual cortex; therefore, this activity was considered a possible influence by seeing the stimulus. However, brain activation

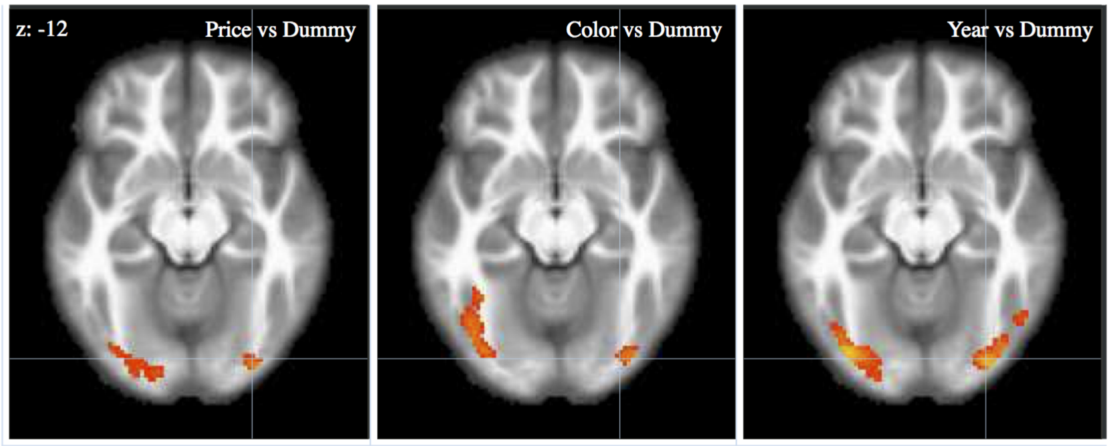

Figure 2. Brain regions with stronger activation in response to price vs. dummy, color vs. dummy and year vs. dummy

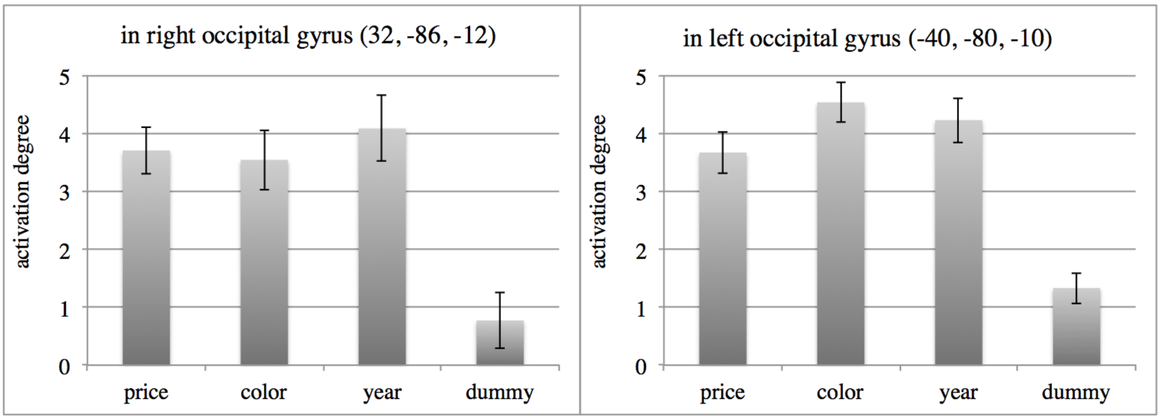

Figure 3. Activation degree during each choice, left: right occipital gyrus, right: left occipital gyrus

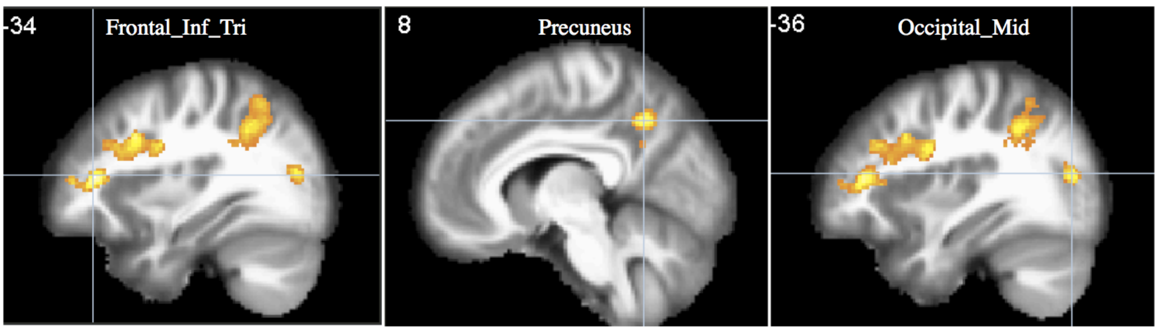

Figure 4. Brain regions with stronger activation in response to color vs. price and year

degrees during the price, the color and the year choice were significantly higher than dummy choice, and this brain activation is considered to be a decision-making activity. No significant activation difference was observed among the price, the color and the year choice.

In addition, specific significant activation in each choice was investigated. The results of color vs. (price & year) are depicted in Figure 4 and the peak coordinates are given

TABLE 3. Specific significant brain activation in color vs. (price & year)

Region Label	Cluster Size	T-statistics	MNI Coordinates		
			x	y	z
Color vs. Price and Year					
Frontal Inf Tri L	1531	6.37	−34	38	12
Precuneus R	1312	5.51	8	−56	44
Occipital Mid L	171	5.21	−36	−80	14

in Table 3 ($p < 0.001$ uncorrected, $k = 171$). In this contrast, the left inferior frontal gyrus, right precuneus and left occipital gyrus had significant activation. There was no significant activation in the contrasts of price vs. (color & year) and year vs. (price & color).

3.2. **fMRI analysis results: brain activity in the vmPFC.** In the analyses of common and specific brain activity region, significant activation in vmPFC was not observed, so region of interest (ROI) analysis was performed for the purpose of identifying differences among each choice in the vmPFC. The ROI analysis used the Brodmann area 10, 14, 25, and 32 defined by Finger et al. [16] as the region of vmPFC in the PickAtlas toolbox [17]. Figure 5 shows the significant activation in vmPFC during price, color and year choice from the ROI analysis. The regions with strong activation in each condition are projected in the three views and the color intensity indicates the brain activity strength. These peak coordinates were given in Table 4 ($p < 0.001$ uncorrected). Significant activation was observed on vmPFC during each choice. In the price choice, a cluster with strong activation was observed (shown by the red circles in the left part of Figure 5). In

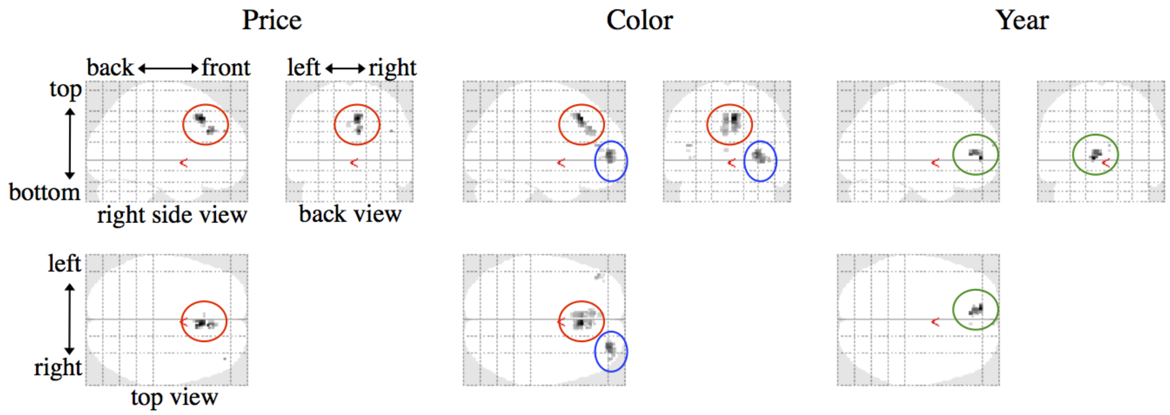

FIGURE 5. (color online) Brain regions with strong activation on the vmPFC

TABLE 4. Significant brain activation on the vmPFC during price, color and year choice

Evaluation Criterion	T-statistics	MNI Coordinates		
		x	y	z
Price	7.12	6	20	42
Color	7.60	6	24	42
	6.10	30	54	6
Year	4.56	−10	50	0

the color choice, two clusters with strong activation were observed (shown by red circles and blue circles in the middle part of Figure 5). In the year choice, a cluster with strong activation was observed (shown by the green circles in the right part of Figure 5). The color of the circle in the Figure 5 is classified according to the approximate coordinates of the activation region in vmPFC, and strong activation with similar coordinates indicated by the red circle was observed in the price and color conditions.

This result shows the possibility that detailed regions with activation on the vmPFC differ by type of evaluation criteria at the decision-making. In previous studies, there are many reports that vmPFC is involved in the decision-making or the preference selection tasks. O'Doherty et al. conducted evaluation tasks based on differences in attractiveness of a human face. In this result, vmPFC had a significant activity when selecting a heterosexual face with a higher attractiveness [9]. McClure et al. reported that vmPFC activated significantly when participants drank a cola of more favorite brands in the case of drinking it which were had different preference degrees by them [6]. On the other hand, vmPFC had no activity in studies that were evaluation tasks due to differences in attractiveness for car models by Klaus et al. and selection tasks due to differences in aesthetic preferences for paintings by Vartanian et al. [5, 18]. In common point of these studies, these results were brain activity during decision-making for alternatives with different attractiveness or value based on a single evaluation criterion. The results of our study are the brain activity by the different evaluation criteria, not the brain activity by the differences in the value of each evaluation criterion.

4. **Discussion.** This study investigated brain activation during the decision-making process of preference while using different evaluation criteria, and identified common and specific activation regions related to each evaluation criterion. As for common activation regions, the bilateral occipital gyri had significant activation during price choice, color choice and year choice. The occipital gyrus is thought to be the brain region related to visual processing. Conversely, as for specific activation regions, the left fusiform gyrus was activated significantly during color choice. The fusiform gyrus is thought to be the brain region related to color processing [19]. Moreover, Vartanian and Goel reported that these regions are related to preference rated tasks [18]. They concluded that the differential patterns of activation observed in bilateral occipital gyri and bilateral fusiform gyri in response to preference ratings are specific examples of their roles in evaluating reward-based stimuli that vary in emotional valence. However, this study investigated common brain activity by type of the evaluation criteria. There is no report that occipital gyrus and fusiform gyrus are involved in the influence on the brain activity due to the difference in evaluation criteria, this result made the relationship between these gyrus function and decision-making clearer. During color choice, the left insula was also activated. The insula is known for its involvement in value-based decision-making. It integrates the internal state, sensory signals, information about the salience and relative value of stimuli during response selection [20]. Furthermore, the right precuneus was found to be more active during color choice compared with price and year choice. The precuneus is especially documented for its involvement in attention [21]. This suggests that the increased activation in the precuneus reflects an increased attention to the color pairs compared with the price or year pairs. Therefore, it is possible that the participants made a simple numerical value comparison between the left information and the right information. In the case of color choice, it is thought that the two color names displayed on the screen were processed based on the preference of the subjects. Therefore, it is considered that attention to color choice was higher than price and year choice, and the precuneus was activated.

The vmPFC has been shown in several neuroimaging studies to be active for a variety of primary and abstract rewards. These findings suggest that the vmPFC in the representation of complex appetitive states has several roles. However, all decision-making studies did not report that vmPFC is involved in decision-making. It suggests that the activated region differs depending on the evaluation criteria in the case of evaluating based on a value of alternative or preference by the individual. In this study, the analysis was performed based on our hypothesis that brain activity difference by evaluation criteria appears in vmPFC. Our results show that vmPFC was activated in all of the tasks by different evaluation criteria during the decision-making process. From the investigation of different activations on vmPFC for each evaluation criterion of alternatives, there were no differences in activation levels in the choice of each category. However, the activated detail regions on the vmPFC varied by each criterion. Some investigators have suggested that subjects preference judgments stem result from "a competition between hedonic and utilitarian aspects of each choice alternative [22]", "competition between subjective emotional states such as desire and willpower [23]", "the selection of a specific dimension that enhances the contrast between the alternatives [24]", or "habit-based processing [25]". Therefore, the brain performed different processes with price, color and year choice. As a result, it is believed that choices by each alternative category represented brain activation on specific coordinates.

5. **Conclusions.** This study focused on brain activation during the decision-making process, which was selected based on a single evaluation criterion and by conducting fMRI experiments. The experiment measured brain activity during a paired comparison based on the price, color or product year as a single evaluation criterion by fMRI, in order to elucidate the brain regions comprehensively involved in decision-making and to identify the specific brain regions involved in each evaluation criterion. From the scanned fMRI data of the choice tasks in each evaluation criterion, common brain activation and specific brain activation were performed by whole-brain analysis. As a common activation region in choice tasks by each evaluation criterion, the bilateral occipital gyri had significant activation. Vartanian and Goel reported that the occipital gyrus is thought to be the brain region related to a visual processing and preference rated tasks [18]. This result had shown that the difference in preference rate reflected the brain activity difference in occipital gyrus. This study investigated the common brain activity by type of the evaluation criteria, occipital gyrus was significantly activated at decision making by all evaluation criteria. Therefore, this result suggests that occipital gyrus is a region comprehensively related to decision-making. As for specific activation regions in choice tasks by each evaluation criterion, the left fusiform gyrus, left insula and right precuneus were activated significantly during color choice. During price and year choice, specific activation was not observed. The results suggest that attention to color choice becomes greater compared to price or year choice. With the vmPFC, which has been reported to be involved in decision-making, significant activation was not observed from the results of the whole-brain analysis. The tasks of previous reports are decision-making for alternatives with different attractiveness or values based on a single evaluation criterion. This study analyzed the brain activation differences among each evaluation criterion on decision-making, so these results did not focus on the differences in attractiveness or values. An ROI analysis for vmPFC was performed in order to confirm the differences of the brain activation in the vmPFC by evaluation criteria. In the ROI analysis result, significant activations on the vmPFC were observed with all tasks by each evaluation criterion, and these detailed coordinates were located in different coordinates. This result suggests a possibility that detailed activity regions in vmPFC differs by the types of evaluation criteria. In future

work, in order to understand the relationship between the brain activated regions and the types of evaluation criteria on decision-making, we will continue to experiment with other types of evaluation criteria, and also verify the relevance of brain regions other than the vmPFC.

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