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学 位 論 文 題 目　Coexistence of sensory qualities and value representations in human orbitofrontal cortex

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(form３)

Summary of Doctoral Thesis

Name in full　Yoshimoto, Takaaki

Title　Coexistence of sensory qualities and value representations in human orbitofrontal cortex

Decision making is a cognitive process in which multidimensional information must be integrated. For example, when people decide what to eat at a restaurant, they infer gustatory experience from the photos and descriptions on the menu while considering their current metabolic state (i.e., satiated or hungry). Even if the dessert options themselves are identical, inferred gustatory experiences are not the same at the time of the first course as when dessert is ordered, suggesting that the inferred sensory qualities and identity can be dissociated under certain conditions. By integrating such information, an individual estimates the value of each option in deciding what to eat. The orbitofrontal cortex (OFC) integrates sensory and visceral information, providing a basis for such decision-making. A growing body of research has shown that the OFC encodes the predicted outcomes that follow either sensory events or behavioral choices. In particular, abundant evidence exists on the role of the OFC in reinforcer devaluation tasks, which assess the ability to represent identity, sensory qualities, and subjective values of the expected outcomes. However, it remains unclear which aspect is specifically represented in this region.

To investigate whether the human OFC represents object identity, sensory qualities, or value, I conducted human functional magnetic resonance imaging (fMRI) experiments. Twenty-four healthy male adults completed four fMRI sessions in 2 days. Before and after the meal, the same fMRI experiments were conducted, and this was repeated on day 2. A total of 128 food photos were presented during the fMRI sessions. Participants were instructed to determine their rating for palatability of the food during the presentation of each photo. Employing many items enabled me to dissociate object identity from sensory qualities and values, while the inferred sensory qualities of the identical objects were manipulated by a change in the metabolic state.

The palatability of the food items decreased significantly after a meal. To investigate the composite representations of the visual food item, I applied the representational similarity analysis (RSA) to the fMRI data. First, we investigated

which brain region contributed to identical object representations and its association with the metabolic state change. To this end, the representational similarity metrics of the identical and non-identical object pairs, which were calculated by searchlight analysis, were averaged separately for pairs of the same metabolic state and different metabolic states. These metrics were submitted to a group analysis separately for these two metabolic state pairs. I found that identical items were represented similarly in the lateral OFC (lOFC) in a given metabolic state; however, these representations were altered by feeding. This result indicated that the representations in the lOFC do not reflect pure visual features, but rather the sensory qualities of the expected outcome, which are adaptively altered, reflecting changes in the metabolic states.

Next, because of the possibility that these representations were confounded by the value representations, we conducted the RSA to investigate representations of the subjective value. I found that representations of the subjective value were broadly distributed in both medial and lateral OFCs. These results suggest that to rigorously estimate the effect of identical object specificity, the effect of value distance must be analytically dissociated from that of the metabolic change, at least in value-related regions such as the OFC. Therefore, we investigated the effect of metabolic states on the representations of identical objects while controlling for the effect of value distance differences in cross-session pairs. I devised novel method to control for the effect inspired by age adjustment technique, which is broadly used in the field of epidemiology. Even after applying the distribution adjustment, we found a significant difference in identical object specificity between the same and different metabolic states in the lOFC. Our results clearly show coexistence of sensory qualities and value representations in human orbitofrontal cortex.

Previous studies suggest that the value of objects is represented in both the medial and lateral OFCs, whereas more complicated associations that cannot be explained by value alone are represented in the lateral OFC. Consistent with this, I replicated the value representations in the medial and lateral OFCs. I further demonstrated that object-specific features represented in the lateral OFC were not invariant, but rather, were flexibly altered, reflecting the internal metabolic states. This study revealed that the OFC represents the inferred perceptual experience linked with the current internal state, which supports flexible decision-making. These results support the idea that representations in the OFC have unique flexible functions required for updating an individual's moment-to-moment values based on the current internal state.

Form8 : Separate Sheet
（様式８・別紙１）

Results of the doctoral thesis defense

博士論文審査結果

Name in Full
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Title
論文題目　　Coexistence of sensory qualities and value representations in human orbitofrontal cortex

大脳の前方底面に位置する眼窩前頭皮質は、価値に基づく意思決定において重要な役割を果たすと考えられている。価値の評価においては、評価対象の客観的な「同一性」（食品を例にとれば、同じライス、カレー、バナナ等）に加え、主観的な要因として、対象がもつ「感覚的な質」（味わいや色つや等）や、身体の内部要因等も加味した「主観的価値」（総合的な美味しさ）が、意思決定変数として重要であると考えられている。しかし、眼窩前頭皮質が実際にどの意思決定変数を表象しているのかは、依然として未解明である。

この問題に取り組むため、申請者は健常成人男性の被験者 24 名を対象として、食品の価値を評価する行動学的実験と、その際の脳活動を機能的磁気共鳴画像法（functional magnetic resonance imaging, fMRI）により非侵襲的に計測する実験を遂行した。上記の意思決定変数の中で、「感覚的な質」と「主観的価値」は、空腹か満腹かなど、身体の栄養状態の影響を受けることから、同一実験日の朝食前後の２回にわたり、128 枚からなる同一セットの食品写真を被験者に順次提示することをおこなった。被験者には、各食品写真の提示直後に、その食べたさを 10 段階で評定させ、それを各食品に対する主観的価値の指標として用いた。また、各被験者内での行動と脳活動のデータの再現性を確認するため、同一の手続きによる実験を 7－41 日の間隔をあけて再度、実施した。

申請者は、被験者の評定を解析し、食品の主観的価値が、朝食を摂取することで有意に低下することを明らかにした。一方、実験日に関する要因は（1 度目か 7－41 日の間隔をあけた 2 度目か)、主観的価値に有意な影響を及ぼさなかった。fMRI 実験では、表象類似度解析を用いることで、後頭葉視覚皮質が食品の「同一性」を、眼窩前頭皮質が「主観的価値」を、それぞれ表象することを明らかにした。加えて、眼窩前頭皮質の外側部では、同一食品に対する表象類似度が、同一の栄養状態間に比し、異なる栄養状態間で有意に低下すること、さらにその低下は、主観的価値の相違による影響を排除した後においても認められることを明らかにした。この所見は、同部の神経活動が、「感覚的な質」を表象するという仮説と矛盾しない。以上の結果に基づき、申請者は、眼窩前頭皮質の外側部は、食品対象の「同一性」ではなく、「感覚的な質」および「主観的価値」を表象するものと結論づけた。

本研究は、眼窩前頭皮質の機能理解に資する新たな重要知見を提供するものである。申請者は、緻密な研究計画と独自の解析手法を考案することで、眼窩前頭皮質が表象する意思決定変数を特定することに成功した。本研究の成果は、申請者を筆頭著者として Neuroscience Research 誌に原著論文として受理されており、今後の神経科学および認知科学の発展に寄与する優れたものといえる。以上の理由により、審査委員会は本論文が学位の授与に値すると判断した。