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学位論文題目 Tactile-visual cross-model motion direction matching: A  
functional MRI study

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Visual motion strongly influences tactile motion judgments. When visual motion was presented simultaneously but in the opposite direction to tactile motion, the accuracy of the tactile motion judgments were substantially reduced. These psychophysical observations suggest that crossmodal interaction occurs during motion direction judgment, although the neural substrates of this are largely unknown. Motion-direction discrimination requires (a) the coding of motion in the two sensory modalities and (b) a decision stage that compares the two motion direction signals. Therefore cross-modal interference could occur at either stage. One candidate locus for the integration of visual and tactile motion information in the coding stage is the human middle temporal (MT)/V5 area. According to visual mediation heuristics, the tactile system is less efficient than the visual system at processing the spatial attributes of an object; hence, tactile inputs are translated into corresponding visual representations, which are further processed by the visual system. It is therefore predicted that the visual cortex is the site of crossmodal interaction. Instead, such neural mechanisms might involve multisensory areas in the decision stage, because our space perception is highly integrated across modalities. Hence, an alternative candidate area for crossmodal integration is the multisensory posterior parietal cortex. To explore these alternatives, they conducted a functional magnetic resonance imaging (fMRI) experiment. Our hypothesis was that spatial analysis of the direction of movement via visual and tactile modalities activates both sensory-specific areas and multisensory areas. Brain areas participating in crossmodal integration should show signs of convergence and interaction. They initially performed independent tactile and visual unimodal experiments involving motion direction matching tasks to define the common multimodal areas activated during each of the independent tactile and visual tasks (convergence). They then carried out tactile and visual crossmodal experiments with event-related designs, to identify the areas in which the crossmodal response was enhanced by comparing stimuli whose direction of motion were congruent and incongruent (interaction).

Fifteen healthy volunteers (seven men and eight women; mean age  $\pm$  standard deviation [SD] =  $27.9 \pm 6.7$  years) participated in this study. In the unimodal experiments, they used a block design. The subjects performed two different tasks: a tactile-tactile (T), and visual-visual (V) motion-direction matching task, and searched for commonly activated areas. In the cross-modal experiment, they used an event-related design to analyze crossmodal congruency effects. The design consisted of four conditions: tactile-visual (TV), tactile-tactile (TT), visual-visual (VV) matching tasks, and a still condition (ST). To analyze congruency effects, they divided TV, TT, and VV into two conditions respectively, the congruency, and the incongruency condition (TVc, TVi, etc). And, they searched for areas that showed crossmodal congruency effects, that is, areas where TVc showed greater activation compared with TVi within bimodal areas.

In the unimodal experiments, Tactile motion direction discrimination activated the

bilateral inferior parietal lobule (LPi), LPs, secondary somatosensory area (SII), dorsal premotor cortex (PMd), ventral premotor cortex (PMv), inferior frontal gyrus (GFi), insula, putamen, left primary sensorimotor area (SM1), postcentral gyrus (GPoC), supplementary motor area (SMA) and pre-SMA. Deactivation was observed in the occipital cortices including the MT/V5, medial prefrontal, orbitofrontal, parietal and temporal cortices. Visual motion orientation discrimination activated the bilateral cuneus (Cu), fusiform gyrus (GF), lingual gyrus (GL), MT/V5, inferior occipital gyrus (GOi), middle occipital gyrus (GOM), precuneus (PCu), LPs, IPS, PMv and right GPoC. The MT/V5 area was identified using the previously reported Talairach's coordinates and anatomical criteria. Deactivation was observed in the right prefrontal cortex, left MT gyrus, right superior temporal gyrus and right PMd. Areas that were activated by both tactile and visual tasks were found within the bilateral posterior parietal cortex, including the left LPs, bilateral PMd and PMv, and right cerebellum. Task-related activities specific to tactile motion direction matching (T-V, masked with T) were seen in the bilateral parieto-premotor cortices, SII, insula, left putamen and right cerebellum. Visual-specific activities (V-T, masked with V) were observed in the occipital cortices. In the areas implicated in matching the direction of visual motion, the bilateral GOM, MT gyrus (GTm) and superior occipital gyrus (GOs) showed significantly less activity during tactile motion discrimination than during the rest conditions. No significant deactivation was found during visual motion direction matching in the areas implicated in tactile motion direction matching.

In the crossmodal experiment, within the polymodal areas defined by the unimodal block design experiment, the left LPs and the PMv showed significant activation during the TV condition in the event-related design experiment. The left LPs showed a congruency effect specific to the TV. No congruency effect was found during the VV or TT conditions. To identify brain areas with significantly lower activity during crossmodal matching than during intramodal matching, the following contrasts were used: TT–TV masked with T and (T-V), and VV–TV masked with V and (V-T). Compared with the TT condition, the TV condition showed a decrease in signal in the left secondary somatosensory cortex, bilateral LPi and bilateral PMd. Compared with the VV condition, the activities in the bilateral MT/V5, GOM and right Cu were significantly reduced during the TV condition.

In the unimodal experiment, the tactile task deactivated the visual cortical areas including MT/V5. The deactivation of cortical regions that are not directly related to task modalities might be functionally significant, in that it reduces the probability that there will be interference due to information from other sensory modalities. Crossmodal deactivation is therefore an essential component of the selective attention mechanism, playing a complementary role to the activation of cortical areas that are required for the performance of a given task. This may explain the apparently discrepant results of previous functional neuroimaging studies which have found that tactile motion activated MT/V5, as the tasks in neither of these studies required a motion-direction discrimination. The current findings go against the visual mediation heuristics hypothesis, but are consistent with the idea that

the association of features with tactile entities occurs primarily within the tactile modality.

They also found that the left LPs, and the PMd and PMv, were activated by both visual and tactile motion direction discrimination. These areas should represent the processes common to both visual and tactile intra-modal motion direction discrimination.

In the crossmodal experiment, among the areas showing visuo-tactile convergence, the posterior portion of the left LPs demonstrated more prominent activation under congruent conditions than incongruent conditions. This congruency effect was specific to the crossmodal condition. Thus, the crossmodal congruency effect observed in this study seems to reflect the interaction at the decision stage that requires the comparison of the two motion signals that have been coded in the modality-specific areas. In this regard, the left posterior LPs may represent a node through which the senses can access each other directly from their sensory-specific system.

They also found that the motion-related MT/V5 activity was suppressed in the TV condition compared with the VV condition. The activity in the tactile unimodal areas was also reduced compared with the TT condition. This pattern was not observed in the parieto-premotor areas that showed activation during the tactile and visual tasks.

These findings support the notion of different roles for the modality-specific areas and the polymodal areas in crossmodal motion discrimination: the coding of motion is modality-specific, whereas a decision stage might be represented by the polymodal parieto-premotor networks with 'competitive' interaction between modality-specific areas. In this regard, the left posterior LPs might represent a node through which the senses can access each other directly from their sensory-specific systems.

## 論文の審査結果の要旨

運動方向判断における視触覚統合の神経基盤を同定するため、15人の被験者に対して機能的MRI実験を施行した。まずはじめに、単一感覚特異的領域と多感覚領域を同定するため、ブロックデザインで視覚及び触覚各々の単一感覚運動判断実験を行った。多感覚領域は、触覚単一感覚実験と視覚単一感覚実験で共通に活動した領域と定義された。次に、多感覚領域内で視触覚統合を司る脳領域を同定するため、事象関連デザインで視触覚クロスモーダル運動方向判断実験を行った。視触覚統合を司る脳領域は、視触覚運動方向一致条件で視触覚運動方向不一致条件よりも強く活動が見られる（方向一致効果）領域と定義された。クロスモーダル運動方向判断実験において、被験者は視覚-触覚運動方向判断課題、触覚-触覚運動判断課題、視覚-視覚運動判断課題を行った。単一感覚運動判断実験において、触覚運動方向判断課題では両側頭頂葉、両側運動前野に活動が見られたが、MT/V5を含む視覚野に活動抑制が見られた。視覚運動方向判断課題では両側後頭皮質から上頭頂小葉後部、両側運動前野に活動が見られた。両側運動前野と左上頭頂小葉は触覚運動方向判断課題と視覚運動方向判断課題で共通に活動が見られ、多感覚領域と考えられた。クロスモーダル運動方向判断実験では、視覚-触覚運動方向判断課題で、多感覚領域のうち、左上頭頂小葉の後部において視触覚運動方向一致条件で視触覚運動方向不一致条件よりも強く活動が見られた。この方向一致効果は、触覚-触覚運動判断課題や視覚-視覚運動判断課題といった同一感覚判断課題では見られず、クロスモーダル視覚-触覚運動方向判断課題に特異的なものと考えられた。単一感覚実験で触覚特異的及び視覚特異的に活動が見られた領域では、クロスモーダル運動方向判断実験の視覚-触覚クロスモーダル運動方向判断課題で、同一感覚判断課題施行時よりも活動が低下していた。これらの結果から、異なる感覚から同時に入力される運動方向の信号の相互作用が起こる根底には、左後部上頭頂小葉の多感覚領域と単一感覚領域の、相互的で競合的な連携があると考えられた。

上記の内容は、既に申請者が第1著者として英文原著論文にまとめられ、欧米の一流誌に掲載予定である。研究内容は非常にすぐれており、国際的にも高いレベルであると、審査委員全員が判断した。