Form 3

Synopsis of Thesis

〔Title〕

Representation of Stereoscopic Depth in Pooled Neural Responses of Macaque Visual Area V4

（マカクザル視覚皮質 V4 野の細胞集団による両眼性奥行きの表現）

Stereopsis employs two types of disparity representations, correlation-based and match-based representations, each characterized by unique disparity-tuning properties. In correlation-based representation, the amplitude and sign (shape) of disparity tuning curves are governed by % binocular correlation, while in match-based representation the amplitude of the tuning curves monotonically reduce by reduction of % binocularly contrast-matched features. Weighted combination of these representations support stereoscopic task performances. For instance, depth perception is as vivid for half-matched random dot stereograms (RDSs with zero binocular correlation) as for correlated RDSs (cRDSs, 100% binocular correlation) while it is deteriorated or reversed for anticorrelated RDSs (aRDSs, -100% binocular correlation). Neurophysiological studies suggest that correlation-based computation is carried out in earlier visual area, such as V1, while match-based representation is observed in higher visual areas, such as inferior temporal (IT) cortex. However, it is not clear how correlation-based representation in earlier areas is transformed into match-based representation in higher areas that support stereo depth perception. Here, I studied the role of visual area V4, an intermediate area along the ventral visual pathway, which is likely to have a critical role in this transformation. I recorded single-neuron responses of macaque visual area V4 to graded anticorrelation of RDSs (gradually reducing % contrast-matched dots, ‘% correlation level’). Binocular disparity and graded anticorrelation were applied to the central patch of bipartite RDSs. More than half the tested (92/171) cells were disparity selective for cRDSs. Slight reduction of correlation level (from 100% to 30%) markedly decreased the amplitude of disparity tuning curves to a constant level, where further anticorrelation did not change the tuning amplitude. The phase (shape) of disparity-tuning curves did not change when correlation levels were ≥ 0%, whereas it

shifted by random quantities across neurons for correlation levels below 0%. These tuning properties implied that pooling responses of cells with congruent would improve the disparity sensitivity of the population responses, while pooling neurons with inconsistent tuning shapes across population would deteriorate the disparity selectivity. For instance, pooled responses can signal disparity for half-matched RDSs (0%) because the shapes of the attenuated disparity-tuning curves are consistent within the pool. The population tuning curves gradually lost disparity selectivity, as predicted by match-based disparity representation. I performed simulations to explore the mechanisms by which V4 neuronal pools underlie stereopsis. I devised a standard neuron-antineuron pooling model that consisted of two pools of neurons with opposite disparity preferences (near vs. far). The model calculated decision variables by comparing the activity of the two pools. The pool with larger response determined the decision. The simulated performances were consistent with prediction of match-based representation in both fine and coarse disparity discrimination tasks. The results suggest that neurons downstream of V4 may pool disparity-selective responses of V4 neurons and create decision signals for in a match-based framework.

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論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

Mohammad Abdolrahmani 君は、大脳皮質視覚領野 V4 野が果たす両眼立体視における役割の解明を目指して、固視課題を遂行中のサルの視覚大脳皮質 V4 野の単一神経細胞の活動の解析を行った。ランダムドットステレオグラム (RDS) に含まれるドットの一部を輝度反転した graded anticorrelation と呼ばれる新規の刺激セットに対する反応を調べ、V4 野細胞の反応特性がどの程度、ヒトがこれらの刺激を見たときの奥行き判断成績を説明するかを検討した。

V4 野細胞の多くが、V1 野や MT 野細胞よりも、奥行き知覚と相関した活動を示した。しかし、V4 細胞の単一細胞活動に基づいて、奥行き判断を予測するシミュレーションを行ったところ、ヒトの心理学的成績のすべての側面を説明することはできなかった。一方、V4 細胞「集団」の活動に基づいた計算モデルによる予測はヒトの奥行き知覚をよく説明した。以上の結果は、V4 野細胞集団の活動を集めて意思決定シグナルを生成する領野が、両眼奥行き判断に関わることを強く示唆している。また、視差チューニング曲線の振幅のみならず、位相が、その下流の細胞における情報読み出しと知覚への貢献において重要な意味を持つことを示した。本研究の成果は、両眼立体視の神経機構の理解に新しい一歩を加えるものであり、博士号を授与するのにふさわしいものと考える。