論 文 内 容 の 要 旨

For stereo-curvature aftereffects (sCAE), after prolonged inspection of stereoscopic surfaces curved in depth, stereo-curvature adaptation gives rise to shifts in perceived curvature for subsequently shown 3D surfaces. Stereo-curvature adaptation has been confirmed to affect estimation of depth structure. However, there has been no agreement on whether the adaptation occurs at the disparity-specified stage, the percept-specified stage, or both. Moreover, the related studies have not drawn definite conclusions on the dependency of sCAE on retinal-position and scale so far. For these reasons, it is worth investigating the adapting mechanism of stereo-curvature aftereffects in order to find out more about how a 3D shape is perceived.

In our study, sCAE was predicted to be due to multi-level adaptation - not solely to shape- curvature adaptation - based on previous findings of multi-stage adaptation found for sDAE and sSAE. A major challenge for the prediction is to separately examine each possible adaptation source. Unlike previous studies, we did not directly isolate adaptation to disparity and shape curvature. Instead, two new 3D shape properties, namely, disparity-specified ADI (Average Disparity Information) and percept-specified PSI (Primitive Shape Index), were originally investigated as possible adaptation sources of sCAE. The purpose of our study is to find evidences to verify the prediction of multi-level adaptation for sCAE using psychophysical and hemodynamic methods，which were assigned into two different parts of the dissertation.

This dissertation is organized into eight chapters. It begins, in Chapter 1, with introducing background and proposing hypotheses. After that, we listed and ranked, in Chapter 2, all possible adaptation sources we reviewed or defined. The subsequent five chapters are divided into two parts, with Part I including Chapter 3 - 5 and with Part II containing the following two chapters. As mentioned above, Part I provides detailed information for our psychophysical study, and Part II for our fMRI study. Lastly, the conclusion of our study is drawn in Chapter 8.

Chapter 1 firstly reviews previous psychophysical studies on stereoscopic aftereffects (including sDAE, sSAE and sCAE) from the aspects of adapting mechanism as well as dependency on retinal-position and sale. For adapting mechanism, the review showed disagreement on what adaptation sources were adapted, disparity, shape curvature or both. To tackle this question, multi-level adaptation was predicted for sCAE in our study. Moreover, we suggested to use dynamically- presented surfaces as adaptation stimuli, for one reason that static stimuli used in previous studies are obviously suitable to separately examine each possible adaptation source.

Another disagreement indicated from the review concerned on whether or not sCAE was dependent on retinal-position and scale. We predicted that there may be two parallel adaptation processes with opposite dependency on retinal position for sCAE. In detail, adapting to percept-specified sources may induce retinal-position independent sCAE, while adapting to disparity- specific sources may produce retinal-position dependent sCAE. Another reason why we used dynamic adaptation stimuli is just to verify the prediction.

The next work in Chapter 1 is to review previous neuro-related studies on possible cortical areas involved for disparity-defined 3D shape. According to the review, ROIs (Region of Interest) to be examined in our fMRI study should contain 14 areas for each hemisphere at least. That is, early visual areas (V1, V2v, V2d, V3, VP, V3A, V4, V7), dorsal areas (KO/V3B, VIPS/V7*, POIPS, DIPS) and ventral areas (hMT/V5+, LOC (LO & pFs)).

Chapter 2 lists all possible adaptation sources for sCAE, including those examined in previous studies and two other our-defined sources. These newly-defined sources include disparity-specified ADI and percept-specified PSI. Besides, all of the adaptation sources are ranked into different adaptation levels, in terms of disparity order and their dependence on dynamic changes mentioned above.

Part I, covering Chapter 3 - 5, details our psychophysical study including two main experiments. Chapter 3 describes the details of Experiment 1, aiming to investigate dependency of sCAE on retinal position and scale. Adaptation stimuli were presented with dynamically changed retinal- position, scale or PSI, when test stimuli were always presented at the central position. Result showed that aftereffect magnitude among conditions with different ADI configurations was significantly different and showed a positive correlation with overlapping extent between adaptation and test stimuli, suggesting that sCAE is dependent on retinal position. That means, there should be retinal-position dependent adaptation for sCAE, in addition to retinal-position independent adaptation to percept-specified sources such as shape curvature. Result also indicated that size scaling did not systematically influence adaptation strength, suggesting that sCAE can be independent of scale.

Chapter 4 provide the detailed information about Experiment 2 consisting of three sub-experiments, with purpose to investigate adapting mechanism of sCAE. Experiment 2.1 used static adaptation stimuli with different eccentricities in order to examine the influence of eccentricity on adaptation strength of sCAE. Unlike Experiment 1, test stimuli in Experiment 2.1 were always presented at the same location with adaptation stimuli during each trial. Result showed that the eccentricity imposed due influence on adaptation strength, resulting into retinal-position dependent sCAE to some extent. Experiment 2.2, adopting adaptation stimuli with dynamically-changed size, aimed to verify a hypothesis a hypothesis of adaptation at a higher level of PSI than shape curvature. Result indicated that no statistical difference on aftereffect magnitude was found among condition with different scale ranges for dynamically-changed size, verifying the prediction of PSI adaptation. Experiment 2.3 was conducted in order to test another hypothesis regarding adaptation at a lower level of ADI than shape curvature, by virtual of adaptation stimuli with dynamically- changed PSI. Result showed an aftereffect with magnitude significant larger than zero for adaptation condition with near disparity pedestal, support our prediction of ADI adaptation. It was noted that Adaptation and test stimuli were always presented at the central position in both Experiment 2.2 and Experiment 2.3. Therefore, sCAE can result from adaptation to both disparity-specified ADI and percept-specified PSI - not just widely-supported shape curvature. And it was found that PSI adaptation contributed much more to sCAE than ADI adaptation. Furthermore, the retinal-position dependence of sCAE can be due to ADI adaptation and possible eccentricity effect on adaptation strength, while scale independence of sCAE can result from PSI adaptation.

Chapter 5 summarizes the results of our psychophysical study, which support the prediction of parallel adapting processes for sCAE. One process is independent of retinal position, and the retinal-position independence can be induced by adaptation to percept-specified sources, such as shape curvature and PSI. The other process is dependent on retinal position, and the retinal-position dependence can be caused by adaptation to disparity-specified sources, like ADI. That means, sCAE is due to multi-level adaptation, including not only adaptation to percept-specified sources but also adaptation to disparity-specified sources.

Besides, we clarified the hypothesis under which ADI adaptation was true. That is, during adaptation phase, the lower level of zero-order disparity information can be averaged in space, and the averaged disparity information can be further adapted. Admittedly, it is beyond our knowledge to verify the hypothesis. However, no significant difference on aftereffect magnitude in Experiment 2.2 supported no such averaging process on percept-specified adaptation sources to some extent.

In addition, it still keeps uncertain about adaptation to absolute disparity, disparity gradient and shape index. Also, we cannot assure whether or not the stimulus edge effect decreased adaptation strength in Experiment 2.1, leaving open the question of how the visual system adapts to static stimuli in peripheral area. However, these unsolved problems do not invalidate any conclusion we drew on dependency and multi-level adaptation of sCAE.

Part II, covering Chapter 6 - 7, details our fMRI study. The study consists of experiments for localizing disparity-related ROIs and one stereoscopic experiment for examining stereo-curvature adaptation using fMRI adaptation (fMRIa) paradigm. For 3D structure data, freesurfer was used to extract brain from skullcap and to compute white matter for each subject, and Brainvoyager QX was used to implement the preprocessing and to create flatten brain mesh.

Chapter 6 provides detailed information of ROI localization. Early visual areas was identified on the flattened cortex representations, achieved in each observer with functional data from at least 12 separate runs. The stimuli for the localization was a rotating single- or double-wedge (angle) and an expanding ring (eccentricity). Linear correlation analysis was performed in Brainvoyager QX to identify the border between each two adjacent areas on the flattened mesh.

Instead, overlay GLM analysis was performed for the localization of other ROIs. Among dorsal areas, KO/V3B is identified according to the fact that the area is activated much more by kinetic contours than by uniformly moving of random texture pattern. SFM-related areas (VIPS/V7*, POIPS and DIPS) were localized based on the fact that the area is activated much more by 3D structure perceived from rigid motion in depth rather than that perceived from static cue for moving stimuli consisting of nine interconnected lines.

Among ventral areas, hMT/V5+ was localized using a moving random dot pattern alternated with its static counterpart, under the reason that the area is activated much more by the former compared to the latter. The stimuli for LOC localization were objects (grayscale images or line drawings, familiar or novel) and their scrambled version for the reason that the area is activated much more by intact objects than their scrambled counterpart, independent of both whether they appeared in the same or different format and whether they are novel or familiar.

Chapter 7 details our fMRI study on stereo-curvature adaptation. We used event-related fMRIa paradigm to investigate change in BOLD activity in ROIs localized in Chapter 6. All stimuli counterphase-flickered to maintain activation strength. Adaptation stimuli were presented stationarily, or with dynamic change in size or PSI. A high-contrast fixation point is either centrally fixed or moving along a Lissajous path in depth. This resulted into six different adaptation conditions in our study. The test stimuli kept the same across different adaptation conditions. We used such design to investigate stereo-curvature adaptation based on a fact. That is, if a 3D shape property is quantitatively the same between adaptation and test stimuli, then adaptation to the property can decrease cortex response activated by test stimuli. To measure adaptation effect, we subtracted per- cent signal change between peak value of test stimuli and the value of the time point at which test stimulus onset. A smaller result of the subtraction indicated a stronger stereo-curvature adaptation.

For each ROI, Brainvoyager QX was firstly used to compute and export time course of each functional run. After that, we used Matlab to separate and average time course data for each adaptation condition. Result showed a larger adaptation occurred for adaptation stimuli with dynamic size change than those with dynamic PSI change under static fixation in KO/V3B, VIPS, POIPS, DIPS, LOC, hMT/V5+. This suggested that there was indeed adaptation to PSI invariant of size change in these ROIs. In contrast, no significant larger adaptation occurred between these two conditions in early visual areas, showing these areas do not involve processing of high-level 3D shape property like PSI.

Chapter 8 concludes for all of our studies. For evidences to multi-level adaptation of sCAE, we conducted two psychophysical studies and one fMRI study. The conclusion we drew from the psychophysical studies is that sCAE is due to parallel adapting processes, of which one is retinal-position dependent owing to disparity-specified adaptation and the other is retinal-position independent resulted from percept-specified adaptation. The fMRI study further provided the neuro evidence to PSI adaptation in high cortical areas along both dorsal and ventral stream.