Neural Representation of 3D Orientation of Objects: an fMRI study

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1 Introduction

The representation of three-dimensional (3D) orientation is a fundamental feature of human vision which has been broadly studied in recent years [1]. The cortical representation of stereoscopic 3D surface was investigated in the previous study [2], and the result showed that some regions of interest (ROI) in intraparietal sulcus (IPS) had a tendency for 3D shape orientation classification. Since it is well known that IPS area is involved in vision for action, we adopted different stimuli that were expected to produce a better classification to verify that the action related graspable feature has effected on objects orientation perception. In this study, the 3D objects related to action were used for orientation classification with two different types of orientation, (1) slant-tilt 3D orientations and (2) 2D rotations, while the blood oxygen level-dependent signal was recorded from visual cortices. Multivariate pattern analysis (MVPA) classification was utilized on functional magnetic resonance imaging (fMRI) data to find relation between object orientation and ROIs in visual cortices.

2 Methods and Experimental Design

Five participants (2 females) between age of 20 and 24 were recruited and had normal or correct-to normal vision. They were shown 3 types of stimuli categorized by the type of action to be performed onto object. The three types of stimuli (i.e abstract cylinder shape, coarse grip axe, and precision grip ballpoint pen) were presented at four orientation around horizontal and vertical axis (x axis, y axis) as following pairs; O1(45°, 45°), O2 (45°, -45°), O3 (-45°, 45°), O4 (-45°, -45°) [Figure 1]. The stimuli were presented to participants in random order from 12 conditions (3 types x 4 orientations) by using block design. The stimuli were shown for 8000 ms and was flickering during this period for 500 ms repetitively [Figure 2]. After each stimulus block, a single square dot appeared on the position of object's end ('near' or 'far' depth perceived) as a response task for 2000 ms [Figure 2]. The participants were required to press the corresponding assigned button of each depth position of the object's end. The response task was followed by a 4000 ms fixation block. The 6000 ms fixation block was shown at the beginning and the end of each run, the total time of each run was 348 s. Each session had 10 runs. All participants were required to keep their head still and look at the fixation in the center of the screen. A high resolution T1-weighted anatomical scan (1 mm^3) was acquired for the participants and regions of interest(ROI) were localized in the previous study's sessions [2]. In each run of experiments, BOLD signals were measured with an echo-planar imaging (EPI) sequence (echo time [TE]: 58 ms; repetition time [TR]: 2000 ms; volumes per run: 174) from 34 slices covering the visual cortex, posterior parietal cortex, and posterior temporal cortex.

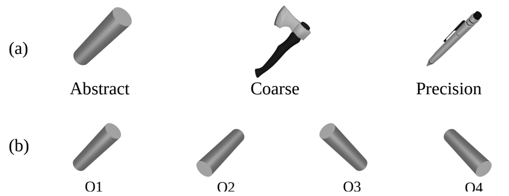

Figure 1 (a) Stimuli and (b) Orientations illustration

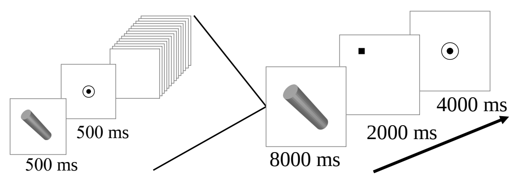

Figure 2 The experiment block design overview

3 Analysis

After the EPI data were collected, preprocessed and co-registered with T1-weighted scan, we performed MVPA for the EPI data for each ROI with MATLAB. A linear support vector machine (SVM) was used as a classifier for MVPA. The classifier pairs were arranged into 2 types, (1) 3D orientation classification composed of (O1, O2) and (O3, O4) pairs, (2) 2D orientation classification composed of pairs of (O1, O4), (O2, O3), (O1, O3), and (O2, O4). All classifications were grouped into 4 categories according to the stimuli data, abstract only, coarse only, precision only, and generalized from three categories. In each classification, the leave-one-run-out method was used to assess the performance of MVPA classification. The data for test were the separated by one run while the rest of data from other runs were used as training data. This method was repeated for total of number of all runs. The classification accuracies of all participants were averaged across participants for each ROI. The statistical significance of MVPA was performed with permutation test. Each pattern was permutated then was used as a training data on real testing data, the accuracy across participants was averaged as a permutation accuracy and this permutation test was repeated 1000 times on each ROI. The baseline for statistical significance was 99.6 percentile (one-tailed, 12 ROIs).

4 Result

In the first pair (O1, O2) from 3D orientation classification in the generalized category, the result showed no significant prediction accuracy in all ROIs. In contrast, the pair of (O3, O4) had high accuracy of ROIs in dorsal areas; V7, KO, MT+, VIPS, and DIPS, passed the baseline by each lower standard error of the mean. The top three prediction accuracy were from on KO, VIPS, and V7 area with 60.5%, 59.3%, and 59.1% [Figure 3].

In orientation pair from 2D orientation classification [Figure 4], the result of the pair (O2, O3) showed high prediction accuracy in V3V that passed the baseline and had the accuracy of 57.8%. The result from (O1, O3) showed high prediction accuracy in KO area (60.7%) and passed the baseline. The other orientation pairs resulted differently. In (O1, O4), the prediction accuracy from LOC and DIPS fell behind the baseline while other areas had high accuracy and passed the baseline. The prediction accuracies from V2, V3V, V7, KO, and POIPS were all above 60%. The result from (O2, O4) had similar trend with the (O1, O4) pair. The prediction accuracy from V1, and LOC fell behind the baseline while other areas had high accuracy and passed the baseline. The area KO showed highest accuracy (61.1%).

5 Discussion

From the result in 3D orientation classification, the (O3, O4) pair had significantly high prediction accuracy from MVPA in dorsal areas; V7, KO, VIPS and DIPS. These results suggest that the dorsal areas have the feature for 3D orientation classification particularly on this orientation pair. The area KO was previously studied on [3] and shown intricately involved in texture and depth cues. On the other hand, in 2D orientation, pairs of (O1, O4) and (O2, O4) showed high prediction accuracy in some early visual areas and dorsal areas as well. There is an interesting

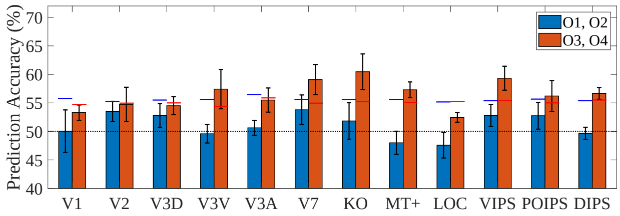

Figure 3 3D orientation classification accuracy each ROI

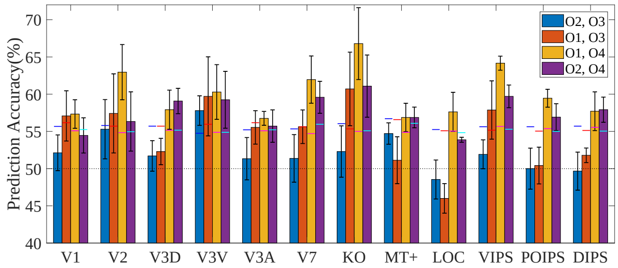

Figure 4 2D orientation classification accuracy each ROI

aspect to both 2D and 3D classifications from pairs involving O4; (O1, O4), (O2, O4), and (O3, O4). These classifications had high accuracy in KO and IPS areas. The alignment of objects in O4 may relate to participant's right hand posture that was holding a controller during the experiment. This suggest that there may be special process for 3D orientation related to action and self-body and need to study further for a better explanation.

6 Conclusion

This study investigated a representation of 3D orientation in object related to action by using MVPA for classification in each area of ROI. The results showed significantly high prediction accuracies in 2D and 3D orientation from ROIs in dorsal area, including, KO and IPS areas. This study suggests a potential approach to investigate 3D orientation feature that relates to action from dorsal areas in visual cortex.

References

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