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Title: Neural and computational foundations of human symmetry processing

Abstract: Recent advances in stimulus design, high-definition EEG recording and functional Magnetic Resonance Imaging have lead us to a new understanding of how symmetry is extracted and represented in human visual cortex. Symmetries over the plane comprise 17 groups – the so-called wallpaper groups. The groups are compositions of basic symmetry operations, translation, reflection, rotation and glide and different fundamental lattices. An essentially infinite set of examples from each wallpaper group can be generated by using random noise sets within the fundamental region used to generate the full wallpaper pattern. In a first experiment, we selected 4 wallpaper groups that contained only rotations and used them in parallel Event-Related Potential (ERP) and fMRI recordings. We found responses that depended parametrically or the order of rotation present in the image in both ERP and fMRI data. This dependence was found as early as the third visual area (V3), but was widespread across ventral and lateral cortex. In experiments where the participants' task was to discriminate rotation patterns, we found that area VO1 on the ventral surface had activity that was correlated with the participants' decision time. Finally, we used machine learning techniques to classify ERP responses to 16 of the 17 wallpaper groups. The output of the classification created a highly structured confusion matrix depicting which groups produced a more similar, and thus confusable brain response. Decomposing the structure of the confusion matrix using scaling techniques produced a geometric representational structure for the brain data that is similar to that predicted from group-theoretic sub-group relationships. Symmetry is thus robustly represented in the brain in a way that reflects the fundamental relationships of group theory.