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Research report

Neural correlates associated with superior tactile symmetry perception in the early blind

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ABSTRACT

Symmetry is an organizational principle that is ubiquitous throughout the visual world. However, this property can also be detected through non-visual modalities such as touch. The role of prior visual experience on detecting tactile patterns containing symmetry remains unclear. We compared the behavioral performance of early blind and sighted (blindfolded) controls on a tactile symmetry detection task. The tactile patterns used were similar in design and complexity as in previous visual perceptual studies. The neural correlates associated with this behavioral task were identified with functional magnetic resonance imaging (fMRI). In line with growing evidence demonstrating enhanced tactile processing abilities in the blind, we found that early blind individuals showed significantly superior performance in detecting tactile symmetric patterns compared to sighted controls. Furthermore, comparing patterns of activation between these two groups identified common areas of activation (e.g. superior parietal cortex) but key differences also emerged. In particular, tactile symmetry detection in the early blind was also associated with activation that included peri-calcarine cortex, lateral occipital (LO), and middle temporal (MT) cortex, as well as inferior temporal and fusiform cortex. These results contribute to the growing evidence supporting superior behavioral abilities in the blind, and the neural correlates associated with crossmodal neuroplasticity following visual deprivation.

Abbreviations: EPI, echo planar imaging; IPS, intraparietal sulcus; FFA, fusiform face area; FLAME, FMRIB's Local Analysis of Mixed Effects; fMRI, functional magnetic resonance imaging; FWE, family-wise error; FWHM, full width at half maximum; GLM, general linear model; LO, lateral occipital; MT, middle temporal; TE, echo time; TR, repetition time; rTMS, repetitive transcranial magnetic stimulation.

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1. Introduction

Bilateral symmetry represents an organizational principle that characterizes many biological shapes and forms such as faces, animals and plants, as well as man-made objects like buildings and tools (see Treder, 2010 for review). Thus, it is not surprising that the human visual system has developed an exceptional ability to detect the presence of symmetry, even with very brief presentation times on the order of milliseconds (Carmody et al., 1977; Huang et al., 2004; Machilsen et al., 2009; Wagemans, 1995). The ability to detect symmetry may be related to our need to quickly recognize objects irrespective of their position or orientation in the visual field (Enquist & Arak, 1994). Indeed, the presence of symmetry has been shown to mediate figure-ground segregation and perceptual grouping, thereby facilitating object detection and recognition (Labonte et al., 1995; Machilsen et al., 2009). Furthermore, the salience of symmetry in organizing visually perceived information extends to complex object recognition and memory studies. For example, the presence of symmetry facilitates the recognition of faces (Little & Jones, 2006) and visuo-spatial working memory (Rossi-Arnaud et al., 2006; Rossi-Arnaud et al., 2012). Moreover, from an evolutionary perspective, it has been suggested that the exquisite sensitivity of the visual system to symmetry may have vital survival value in supporting crucial functions such as detecting predators, locating food, and even the selection of suitable mates (Enquist & Arak, 1994; Moller, 1992).

Given the importance of symmetry in visual perception, it is perhaps not surprising that studies have focused within this domain. However, symmetry has also been the subject of a number of tactile/haptic investigations. Early work by investigators such as Davidson (1972) and also Locher and Simmons (1978) explored the interaction between configural properties of shapes (e.g. curvature and symmetry) and haptic scanning strategies as they relate to performance in object detection and memory recognition. Specifically, in sighted (blindfolded) participants, the haptic identification of plastic nonrepresentational shapes with symmetrical configurations was found to be more difficult (quantified by increased number of identification errors and longer times for detection) than asymmetrical ones (Locher & Simmons, 1978). These observations were attributed to the serial nature of tactile/haptic exploration and encoding processes necessary for integrating global shape information (see also Loomis et al., 1991). More recent behavioral studies by Ballesteros and collaborators revealed that tactile patterns containing bilateral symmetry showed facilitatory effects during haptic exploration for the discrimination of shape as well as in memory tasks. Specifically (and contrary to earlier reports), judgments of symmetric raised line shapes and unfamiliar three dimensional (3D) objects were found to be more accurate than asymmetric ones (Ballesteros & Reales, 2004; Ballesteros et al., 1997).

A number of studies have also investigated the effect of prior visual experience on the tactile/haptic detection of shapes and tactile picture recognition by comparing performance in blind and sighted (blindfolded) individuals. For example, Heller (1989a, 1989b) reported similar performance in the congenitally blind and sighted, while tactile object recognition was more accurate in late blind individuals (Heller 1989a, 1989b). Other studies found contradictory findings, whereby congenitally blind showed superior performance (e.g. Heller et al., 1996; Lederman et al., 1990) suggesting that the role of prior visual experience on tactile object recognition remains unclear. To address the role of prior visual experience on tactile symmetry specifically, Cattaneo and colleagues carried out behavioral tests assessing the detection of tactile patterns in blind and sighted (blindfolded) individuals. Instead of using raised line drawings or 3D shapes, the authors employed a tactile memory matrix task for haptic exploration of tactile patterns and showed that the presence of symmetry facilitated memory retrieval in congenitally and late blind individuals as well as normally sighted controls (Cattaneo et al., 2010; Cattaneo et al., 2013). Thus, as has been reported for vision, the presence of symmetry may indeed have a facilitatory effect on the detection of patterns in the tactile domain. However, prior visual experience along with stimulus complexity, the exploratory strategies employed, and the nature of the task demands all appear to be important factors relating to overall performance.

The neural correlates associated with the detection of symmetry have been investigated in the visual domain using functional magnetic resonance imaging (fMRI) in humans (Sasaki et al., 2005; Tyler et al., 2005) as well as macaque monkeys (Sasaki et al., 2005). Using visual stimuli comprised of random dot patterns with different axes of symmetry, these studies reported that symmetry perception activates extrastriate retinotopic areas including V3, V4A, V7, and in particular, the lateral occipital (LO) cortex (Sasaki et al., 2005; Tyler et al., 2005). By comparison, early visual cortical areas (i.e. V1/V2) showed minimal activation with this same task (Sasaki et al., 2005; Tyler et al., 2005). This distributed pattern of cortical recruitment is consistent with the notion that the detection of visual patterns containing symmetry requires the integration of object features over a large visual field (Tyler et al., 2005). Finally, a more recent study using noninvasive brain stimulation [i.e. repetitive transcranial magnetic brain stimulation; (rTMS)] has provided causal support for the role of a targeted extrastriate visual area in visual symmetry detection. Using fMRI-guided rTMS (on-line, 10 Hz) to disrupt local cortical activity, stimulation delivered to either the left or right LO (but not striate) cortex was shown to impair visual symmetry detection in normally sighted humans (Bona et al., 2014).

It has yet to be clearly elucidated whether the same neural correlates are responsible for detecting the presence of symmetry in the tactile domain, particularly while employing random dot patterns similar to what have been used previously in visual perceptual studies (e.g. Sasaki et al., 2005). This would allow for an initial comparison to be made regarding associated neural processing mechanisms across these sensory modalities. Furthermore, comparing performance between sighted (blindfolded) and early blind individuals would allow for the role of prior visual experience on the ability to be explored. This issue is also relevant within the context of numerous reports documenting superior sensory abilities in the blind, as well as investigating the underlying compensatory and crossmodal neuroplastic changes associated with