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Research report

Functional dissociation between action and perception of object shape in developmental visual object agnosia

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ABSTRACT

According to the two visual systems model, the cortical visual system is segregated into a ventral pathway mediating object recognition, and a dorsal pathway mediating visuomotor control. In the present study we examined whether the visual control of action could develop normally even when visual perceptual abilities are compromised from early childhood onward. Using his fingers, LG, an individual with a rare developmental visual object agnosia, manually estimated (perceptual condition) the width of blocks that varied in width and length (but not in overall size), or simply picked them up across their width (grasping condition). LG's perceptual sensitivity to target width was profoundly impaired in the manual estimation task compared to matched controls. In contrast, the sensitivity to object shape during grasping, as measured by maximum grip aperture (MGA), the time to reach the MGA, the reaction time and the total movement time were all normal in LG. Further analysis, however, revealed that LG's sensitivity to object shape during grasping emerged at a later time stage during the movement compared to controls. Taken together, these results demonstrate a dissociation between action and perception of object shape, and also point to a distinction between different stages of the grasping movement, namely planning versus online control. Moreover, the present study implies that visuomotor abilities can develop normally even when perceptual abilities developed in a profoundly impaired fashion.

1. Introduction

One of the most influential models regarding the organization of the cortical visual system proposes a segregation between a ventral pathway, which mediates object recognition, and a dorsal pathway, which supports spatial representations (Ungerleider & Mishkin, 1982) and goal-directed actions (Goodale & Milner, 1992). Consistent with this division of labor, many behavioral studies, with healthy adults as well as with neuropsychological patients, have demonstrated a functional dissociation between vision-for-action and vision-

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for-perception (for a recent review see Goodale, 2014, but see Glover & Dixon, 2001; Himmelbach & Karnath, 2005; Schenk & McIntosh, 2010 for critics and alternative models). Additionally, neuroimaging and electrophysiological studies, in human and non-human primates, further demonstrate the involvement of occipitoparietal regions in visually-guided actions while occipitotemporal regions are involved in mediating object perception (for a recent review see Gallivan & Culham, 2015).

Nevertheless, it is unclear whether normal emergence of each of these two predominantly separated functional networks depends on normal development of the visual system, or whether one functional network could normally emerge even when the other does not due to abnormal visual system development from early childhood or even from birth. This question is particularly of interest given the rich anatomical and functional connections between the ventral and dorsal pathways (Himmelbach & Karnath, 2005; van Polanen & Davare, 2015; Yeatman et al., 2014). In the present study, we examined this question in the context of object shape representation and asked whether the vision-for-action system, which is presumably mediated by the dorsal pathway, could develop normally even when the vision-for-perception system, presumably mediated by the ventral pathway, was compromised from an early age.

Only a few studies have examined the developmental association between the vision-for-action and vision-for-perception systems and these yielded mixed results. For example, Hadad and colleagues have found that similarly to adults (Ganel, Chajut, & Algom, 2008; Ganel, Freud, & Meiran, 2014, but see Smeets & Brenner, 2008; Utz, Hesse, Aschenneller, & Schenk, 2015 for critics), children at the age of five show a dissociation between action and perception (Hadad, Avidan, & Ganel, 2012). In particular, like adults, children adhere to Weber's law (Stevens, 1975) in a perceptual task but not in a grasping task. On the other hand, Schum, Franz, Jovanovic, and Schwarzer (2012) utilized the Garner speeded classification task to show that in childhood, both action and perception rely on integral processing of the stimulus (i.e., processing the object as a whole) while in adulthood, action relies on analytical processing of the stimulus (i.e., piecemeal processing of a given dimension) whereas perception relies on integral processing (Ganel & Goodale, 2003).

These inconsistencies were also reflected in a study that examined children's sensitivity to the Ebbinghaus illusion in perceptual and grasping tasks. In particular, similarly to adults, children were affected by the illusion in the perceptual task but during grasping, the illusory effect on their motor control was in a direction opposite to that of adults and to their own perceptual effect (i.e., discs of the same size were grasped with a smaller aperture when surrounded by small distractors, while perceived as being larger; Hanisch, Konczak, & Dohle, 2001).

The development of a neurofunctional dissociation between the two pathways was examined in a neuroimaging study in congenitally blind human adults. In that study, "visual" stimuli were presented via audition by means of a sensory substitution device while participants performed "visual" localization ("where") or identification ("what") tasks. The results revealed that in the congenitally blind, similar to the neurotypical controls, regions within the dorsal 'visual' pathway showed higher selectivity to the localization ("where") task, while regions along the ventral 'visual' pathway showed higher selectivity to the identification ("what") task. While that study focused on a "Where/What" distinction (Ungerleider & Mishkin, 1982) between the dorsal and ventral pathways rather than on a How/What distinction (Goodale & Milner, 1992), which is the focus of the current investigation, the findings suggest that a neuro-functional dissociation between the dorsal and ventral pathways might be innately wired (Striem-Amit, Dakwar, Reich, & Amedi, 2012).

Visual object agnosia can also provide significant insights about the ventral–dorsal pathways relationship, as this condition mainly affects ventral pathway function. Visual object agnosia refers to a deficit in visual object perception which cannot be attributed to deficits in low-level vision, general loss of knowledge about the object (i.e., auditory/tactile recognition are preserved) or to impaired intelligence (Farah, 1994). Most research on visual object agnosia comes from acquired cases following ventral pathway lesions and has focused on perceptual aspects associated with ventral pathway functions (e.g., Farah, 1994; Moscovitch, Winocur, & Behrmann, 1997). In one patient (DF), however, who acquired visual form agnosia in adulthood following brain damage, visuomotor performance has been extensively studied. Even though DF shows a profound vision-for-perception deficit, she exhibits remarkably intact vision-for-action (e.g., Goodale, Milner, Jakobson, & Carey, 1991; James, Culham, Humphrey, Milner, & Goodale, 2003; Whitwell, Milner, Cavina-Pratesi, Barat, & Goodale, 2015; but see Hesse, Ball & Schenk, 2012; Schenk, 2012 for critics). In addition, a recent study with acquired visual agnosia patients also demonstrated a dissociation between dorsal and ventral visual cortices for perceptual tasks. In particular, preserved sensitivity to object 3D structure was found in the dorsal cortex of these visual agnosia patients, while the sensitivity to this type of information along the ventral cortex was significantly reduced (Freud et al., in press). Nevertheless, developmental cases of visual agnosia may offer unique and novel perspective about the nature of the dissociation between action and perception. In particular, if vision-for-action could develop normally, even when vision-for-perception is profoundly impaired, it would suggest that the perception-action dissociation is apparent early in-life and reflects a fundamental organizational principle of the visual system.

To the best of our knowledge, only one case of early acquired object agnosia was investigated in a developmental context of the action and perception dissociation. That case is patient SB, who suffers from object agnosia acquired at the age of 3, after massive bilateral lesions to the ventral pathway and a unilateral lesion to the dorsal pathway (Dijkerman, Lê, Démonet, & Milner, 2004; Lê et al., 2002; Rice et al., 2006). Lê et al. (2002) extensively investigated different visual and cognitive abilities including vision-for-action and concluded that the patient had intact visuomotor control. This conclusion was supported by later studies by Rice et al. (2006) and Dijkerman et al. (2004) who showed that SB exhibited preserved visuomotor abilities. Yet, even given these important