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Visual imagery influences brain responses to visual stimulation in bilateral cortical blindness

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ABSTRACT

Mental imagery is a powerful mechanism that may facilitate visual perception as well as compensate for it. The role of V1 in mental imagery is still a matter of debate. Our goal here was to investigate whether visual imagery was still possible in case of bilateral V1 destruction behaviorally evidenced by total clinical blindness and if so, whether it might boost residual visual perception. In a factorial fMRI design, faces, scenes or scrambled images were presented while a rare patient with cortical blindness over the whole visual field due to bilateral V1-lesions (TN) was instructed to imagine either an angry person or a neutral object (tree). The results show that visual imagery of a person activates frontal, parietal and occipital brain regions similar to control subjects and hence suggest that V1 is not necessary for visual imagery. In addition, the combination of visual stimulation and visual imagery of socio-emotional stimuli triggers activation in superior parietal lobule (SPL) and ventromedial (vmPFC) and dorsolateral prefrontal cortex (DLPFC). Finally, activation during residual vision, visual imagery and their interaction overlapped in the SPL, arguing for a central role of feeling in V1-independent vision and imagery.

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1. Introduction

Visual imagery is a powerful mental mechanism and has been a research topic since the beginning of psychological science (James, 1890). Earlier, philosophers have argued that imagination involves the same processes as perception, albeit with lower intensity (Bain, 1855). However, as imagination is an intrinsically subjective phenomenon, there are little measures available today that allow its objective quantification. Psychometric instruments have been developed to quantify visual imagery, although they primarily assess some form of intensity of subjective experiences (Pearson, Deeprose, Wallace-Hadrill, Burnett Heyes, & Holmes, 2013). Currently, functional neuro-imaging is considered an important tool to investigate imagination and the results have partly supported the early claims, namely that visual perception and imagination of a particular stimulus activate the same areas in V1. This has led to the hypothesis that V1 is necessary for visual imagery (Kosslyn et al., 1993; Le Bihan et al., 1993). The critical test for this hypothesis requires patients with destruction of V1, as they offer a unique opportunity to clarify the neurofunctional basis of visual imagery and the postulated necessary role of V1. There have been several imagery reports about patients with unilateral or bilateral V1-damage. For example, patient SBR shows bilateral damage and hypo-perfusion in the calcarine sulcus, yet imagery of particular stimulus categories like faces and houses activate the corresponding category-specific areas in the ventral stream (Bridge, Harrold, Holmes, Stokes, & Kennard, 2012, Bridge et al., 2010). This has been taken as counter-evidence for the postulated necessity of V1 for visual imagery. However, standard perimetry testing in this patient revealed incomplete visual field defects and moreover, he was able to detect high contrast Gabor patches throughout the visual field, questioning the extent and degree of his blindness. Partial visual field deficits do not fully support solid conclusions about the necessity of V1 for visual imagery as the contribution of the intact part of the visual field cannot be excluded. To our knowledge, only one imagery study was conducted on a patient with total bilateral V1-damage. The observation that he was able to draw objects was interpreted as reflecting intact imagery, hence evidencing the unnecessary role of V1 (Zago et al., 2010). However, this patient also showed Anton's syndrome, which is the denial of his blindness and is often associated with confabulations. Furthermore, no functional imaging data were reported. Thus, it is unclear whether and to what extent these findings can be informative about the relations between visual cortex and mental imagery and could be extended to other cases of complete cortical blindness in the absence of other concomitant neuropsychiatric symptoms. Support for the necessity of V1 for visual imagery was reported in a study with a patient with hypo-metabolism in the occipital cortex and also impaired visual imagery (Policardi et al., 1996). However, the lesion of this patient extended to the temporal cortex, which may contribute to the imagery deficit. With all these reservations in mind, a dominant current view is that V1 is not necessary for visual imagery, but imagery deficits may occur when the (structural and/or functional) damage extends to other areas (Bartolomeo, Bourgeois, Bourlon, & Migliaccio, 2013). However, the most solid evidence for the epiphenomenal role of V1 in visual imagery would come from an objective measure of preserved visual imagery function in a patient with totally a-functional V1 as behaviorally evidenced by complete clinical blindness. The results we present here from a patient (TN) with bilateral occipital lesions due to stroke may provide the best fit to the criteria reported so far.

Secondly, we were able to investigate imagery–perception interactions in this patient without the interference of conscious perception (Rode, Revol, Rossetti, Boisson, & Bartolomeo, 2007). There is accumulating evidence that cortically blind patients are able to process stimulus features like affective or social valence in the absence of conscious awareness of the stimuli (Buetti et al., 2013; Burra et al., 2013; de Gelder et al., 2008; Pegna, Khateb, Lazeyras, & Seghier, 2005, Pegna, Landis, & Khateb, 2008; Tamietto & de Gelder, 2010; Van den Stock, Tamietto, Hervais-Adelman, Pegna, & de Gelder, in press; Van den Stock et al., 2011; Van den Stock, Tamietto, Zhan, et al., 2014). We presented patient TN, the only available case in the literature with bilateral cortical blindness and "blindsight" (i.e., the ability to process stimulus features in the absence of conscious awareness), with intact and scrambled affective faces and scenes that where shown simultaneously with specific visual imagery instructions.

Based on the double dissociations that have been reported for visual imagery on the one hand and visual perception on the other hand at higher order levels of the visual processing stream like color and object categories (e.g., faces), in verbal material as well as in other modalities (Bartolomeo et al., 1998; Dulin et al., 2011; Guaita et al., 2009; Metcalf, Langdon, & Coltheart, 2010) we hypothesize intact imagery activation in higher order cortical regions (Mousikou, Coltheart, Finkbeiner, & Saunders, 2010).

2. Materials and methods

2.1. *Participants*

2.1.1. *Case TN*

TN is a 59-year-old right-handed male physician who suffered two consecutive occipital strokes at age 52, destroying the bilateral striate cortices. In summary, the lesion includes nearly the complete primary visual cortices in both hemispheres. There is some residual tissue visible on the ventral anterior calcarine sulcus, which appears completely deafferented on MRI (for a detailed MRI display, see Van den Stock, Tamietto, Zhan, et al., 2014). Furthermore, multimodal magneto-as well as electro-diagnostic investigations did not reveal any evidence for residual functioning of V1. Extensive visual perimetry testing with multiple stimulus conditions at the time of the present study confirmed blindness over the whole visual field, consistent with the case history (Van den Stock, Tamietto, Zhan, et al., 2014). Despite blindness over the whole visual field, residual vision has been documented in TN for several features, including navigation (de Gelder et al., 2008), categorization of body stimuli (Van den Stock, Tamietto, Hervais-Adelman, et al., in press; Van den Stock, Tamietto, Zhan, et al., 2014) and facial affect recognition (Pegna et al., 2005). Furthermore, on the basis of a localizer scan,

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