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Impaired visual competition in patients with homonymous visual field defects.

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ABSTRACT

Intense visual training can lead to partial recovery of visual field defects caused by lesions of the primary visual cortex. However, the standard visual detection and discrimination tasks, used to assess this recovery process tend to ignore the complexity of the natural visual environment, where multiple stimuli continuously interact. Visual competition is an essential component for natural search tasks and detecting unexpected events.

Our study focused on visual decision-making and to what extent the recovered visual field can compete for attention with the 'intact' visual field. Nine patients with visual field defects who had previously received visual discrimination training, were compared to healthy age-matched controls using a saccade target-selection paradigm, in which participants actively make a saccade towards the brighter of two flashed targets. To further investigate the nature of competition (feed-forward or feedback inhibition), we presented two flashes that reversed their intensity difference during the flash. Both competition between recovered visual field and intact visual field, as well as competition within the intact visual field, were assessed.

Healthy controls showed the expected primacy effect; they preferred the initially brighter target. Surprisingly, choice behaviour, even in the patients' supposedly 'intact' visual field, was significantly different from the control group for all but one. In the latter patient, competition was comparable to the controls. All other patients showed a significantly reduced preference to the brighter target, but still showed a small hint of primacy in the reversal conditions.

The present results indicate that patients and controls have similar decision-making mechanisms but patients' choices are affected by a strong tendency to guess, even in the intact visual field. This tendency likely reveals slower integration of information, paired with a lower threshold. Current rehabilitation should therefore also include training focused on improving visual decision-making of the defective and the intact visual field.

1. Introduction

Vision is of critical importance during everyday life. This becomes especially evident in patients with primary visual cortex (V1) damage or post-chiasmatic lesions resulting in visual field defects (VFDs). These defects can involve up to a whole hemifield contralateral to the affected hemisphere. VFDs significantly disrupt patients' day-to-day activities, affecting reading, visual navigation (cycling, or driving a car) and visual identification (recognition of objects and persons). Currently, rehabilitation mainly focuses on compensation (Pambakian et al., 2000; Zihl, 1995), and treatment aimed at restoration of vision is still controversial and rarely used in clinics (Balliet et al., 1985; Horton, 2005; Lane et al., 2008). There is, however, a growing body of evidence suggesting that visual recovery by perceptual learning in regions at the border of the blind field is possible. These studies show that repetitive training can improve contrast sensitivity for simple visual detection tasks (Elliott et al., 2015; Jobke et al., 2008; Kasten et al., 1998; Kasten and Sabel, 1995; Pöppel et al., 1987; Sabel et al., 2004; Sabel and Kasten, 2000; Zihl, 1990; Zihl and Von Cramon, 1985) and even for more complex visual discrimination tasks (Bergsma and Van der Wildt, 2008; Huxlin et al., 2009; Pambakian et al., 2000; Poggel et al., 2011, 2008; Sahraie et al., 2013, 2008). Perceptual relearning therefore presents a promising novel approach for the rehabilitation of patients experiencing VFD.

However, the extent of recovery following training is highly variable between patients. Furthermore there can be discrepancies between clinical measurements of recovery and how this relates to an individual's functional recovery (Müller et al., 2004). For example. Sahraie et al. (2003) reported that although patients showed an improved sensitivity, as measured by the Humphrey perimetry, not all patients

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were aware of an extension of their regained visual field. There are a number of potential explanations for such discrepancies, which include; variability in expectations; the age and commitment of the patients; individual differences in brain anatomy and connectivity; as well as variability in age, shape, size and severity of the cortical damage and visual field defects. In addition discrepancies may also arise from assessment methods that lack ecological validity and do not appropriately capture requirements of visual tasks in daily life.

The size of the recovered visual field after training is usually established with a clinical conventional perimeter, the Tübingen automated perimetry, or it is also done with higher resolution perimetry (Kasten et al., 2006, 1998; Sabel et al., 2004), whereby visual recovery is determined by the accurate detection of a flashed dot. However, more complex tasks such as global visual motion discrimination (Huxlin et al., 2009), sine-wave grating discrimination (Sahraie et al., 2008, 2003), and letter recognition (Das and Huxlin, 2010) have also been used to assess visual recovery in a manner that is less dependent on a patient's individual threshold criterion. Patients' recovery is in these task, however, still assessed with the same, artificial stimuli used for training. It is therefore not well established in these studies to what extent this recovery can transfer to other visual modalities or its functional relevance. Other research has attempted to characterize the transfer of training to other untrained stimuli (Bergsma and van der Wildt, 2010; Das et al., 2014; Poggel et al., 2015) and more complex visual tasks, such as reading (Elshout et al., 2016; Gall and Sabel, 2012), and driving (Bergsma et al., 2011). But even the latter psychophysical assessments of the recovered visual field still ignore much of the complexity of the natural visual environment, in which multiple stimuli continuously interact.

In daily life, there is a continuous competition between the recovered and intact visual field for attention, or certain motor tasks (i.e. saccadic eye-movements). This visual competition is part of natural search tasks and detecting unexpected events. It is not well known how the visual field defect influenced the competition for perception. But there is evidence that targets in the blind field of patients can compete with targets in the intact visual field causing distractor effects on the saccadic trajectory and latency (Rafal et al., 1990; Van der Stigchel et al., 2008). It is unknown however to what extent the previously described assessments of visual recovery can capture performance in natural visual tasks and whether they appropriately reflect what the patients experience under natural conditions. For this reason, we investigate a decision-making task between targets in their recovered and intact visual field in trained patients.

We use a recent saccade target-selection task introduced by Kalisvaart et al. (2013). This task probes the decision-making mechanism by assessing the saccadic choice between two flashed targets that can reverse their intensity difference during the flash. Selection between two targets was influenced by the contrast as well as the temporal structure of the target flashes. Healthy controls showed a strong preference towards the initially brighter target, a so-called primacy effect. These results are in accord with a decision-making model assuming feedback cross-inhibition, where, under the circumstances of the task, feedback cross-inhibition predicts that the initially brighter target maintains an advantage by recurrent inhibition of the competitor. In this study, we investigated whether the recovered visual field upholds the primacy effect when competing with the intact visual field to direct a saccade.

2. Materials and methods

2.1. Participants

Nine adult participants (mean age 48 ± 13 years; 7 male) diagnosed with homonymous VFDs, caused by an unilateral post-chiasmatic cerebro-vascular accident were invited (see Table 1 for details and Supplementary material Fig. S1 for the individual MRI scans). They were recruited from an experimental group of 27 patients who previously underwent an intensive visual discrimination training. (For a more detailed description of the training see (Elshout et al., 2016)). The patients were selected based on the following inclusion criteria: (1) the VFD recovery had occurred as a result of the visual discrimination training and (2) they have a normal or corrected-to-normal visual acuity. Furthermore, seven healthy age-matched participants (average age, 45 ± 16 years; 5 male) were included as control group.

All participants gave informed consent before participating; the local ethics committee of Radboud University Medical Centre approved this study in accordance with the Declaration of Helsinki.

2.2. Pre-screening of patients

The selected patients were invited and underwent a monocular perimetric mapping. A central 30-2 threshold Humphrey map and an individually customized high-density perimetric map were used to check whether patients still had a stable recovered visual field that could be used for further analysis (see Fig. 1).

Patients needed to meet several requirements in order to complete all experimental conditions in this study. First, the extent and quality of the recovered visual field needed to be larger than the target size (> 2°) and the luminance sensitivity had to be close to normal (> 20 dB Humphrey threshold). Three patients (VFD3, VFD5 and VFD9) did not meet the requirements, and participated only in the intact intrahemispheric field competition condition. Secondly, patients had to be able to perform the behavioural task. Two patients had to be excluded completely from the study because of fixation loss due to head instability (VFD7) and because the simultaneously flashed targets were not perceived even in the intact visual field (VFD4). Thus, four patients participated in all experimental conditions and seven patients participated only in the intact intrahemispheric competition condition.

2.3. Experimental setup

The experiment took place in a dark room. Participants sat in front of a monitor at a viewing distance of 42 cm using a chin rest to minimize their head movements minimized. Visual targets were displayed on a 21″ CRT screen (Sony GDM-F520) with a resolution of 1280×1024 pixels, on a neutral dark background (0.01 cd/m^2) at a 75 Hz refresh rate. The maximum luminance level of the monitor was 131 cd/m^2. All luminance levels used in the experiment were confirmed with an LS-100 luminance meter (Konica Minolta).

The saccadic eye movements were monitored with an Eyelink II eyetracker (SR research Ltd, Canada) placed in front of one eye – summarized in Table 1 – while the other eye was covered with an eye patch. The Eyelink II measured eye positions at a sampling rate of 500 Hz with a stated spatial resolution of < 0.5°, with all measurements performed monocularly, to guarantee correct positioning in the recovered visual field during the trials. Furthermore, the Eyelink's standard nine-point calibration and validation procedure were performed before each block or when participants moved, to correct for offset and gain changes.

2.4. Procedure

Both the patients and healthy controls performed the behavioural measurements, as described below in the Section 2.5. The experiment was conducted in a block-randomized fashion, counterbalancing the presentation order of the two target-location (LT) conditions within participants. Condition LT1 is an assessment of interhemispheric competition between a target in the recovered visual field (RV target) and an opponent target (O target) in the intact visual field. Condition LT2 is an assessment of the intrahemispheric competition between the O target and a target at the vertically mirrored location of the RV target, i.e. at a location in the intact visual field (RV* target).