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Binocular rivalry after right-hemisphere stroke: Effects of attention impairment on perceptual dominance patterns

Kjersti Mæhlum Walle[a,b,*], Hillary Lynn Kyler[a,b], Jan Egil Nordvik[a], Frank Becker[a,c], Bruno Laeng[b]

[a] Sunnaas Rehabilitation Hospital, Nesoddtangen, Norway
[b] Department of Psychology, University of Oslo, Oslo, Norway
[c] Institute of Clinical Medicine, University of Oslo, Oslo, Norway

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A B S T R A C T

Binocular rivalry is when perception fluctuates while the stimuli, consisting of different images presented to each eye, remain unchanged. The fluctuation rate and predominance ratio of these images are regarded as information source for understanding properties of consciousness and perception. We administered a binocular rivalry task to 26 right-hemisphere stroke patients and 26 healthy control participants, using stimuli such as simple Gabor anaglyphs. Each single Gabor image was of unequal spatial frequency compared to its counterpart, allowing assessment of the effect of relative spatial frequency on rivalry predominance. Results revealed that patients had significantly decreased alternation rate compared to healthy controls, with severity of patients' attention impairment predicting alternation rates. The patient group had higher predominance ratio for high compared to low relative spatial frequency stimuli consistent with the hypothesis that damage to the right hemisphere may disrupt processing of relatively low spatial frequencies. Degree of attention impairment also predicted the effect of relative spatial frequencies. Lastly, both groups showed increased predominance rates in the right eye compared to the left eye. This right eye dominance was more pronounced in patients than controls, suggesting that right hemisphere stroke may additionally affect eye predominance ratios.

1. Introduction

Binocular rivalry is a compelling phenomenon causing fluctuations in visual awareness. Two different images are presented simultaneously, one to each eye, resulting in conflicting information in the brain. Instead of perceiving a meaningless blend of the two images, only one image is perceived at a time, as fluctuating neural activity leads to alternating phases of suppression and dominance for each of the two percepts (Blake, 2005). Although external stimuli remain the same and the visual system is stimulated by unchanging information or visual input, the perceptual experience alters. Hence, any change in perception ought to reflect fluctuation of visual consciousness.

Attention processes involved during binocular rivalry have been carefully examined in the past (see Dieter & Tadin, 2011; Paffen & Alais, 2011), though uncertainty remains regarding the role of attention in conscious and unconscious processing in patients with attention deficits. Investigating patients with attention impairments provides an opportunity to learn more about the underlying mechanisms involved in binocular rivalry.

Stroke commonly results in attention deficits, with right-hemisphere stroke more often resulting in unilateral neglect, a syndrome affecting the patient's ability to attend to and perceive stimuli on the side of space/body contralateral to the injured hemisphere (Cherney, Halper, Kwasnica, Harvey, & Zhang, 2001; Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; Denes, Semenza, Stoppa, & Lis, 1982; Jehkonen et al., 2000). Additionally, sustained attention required during binocular rivalry has been associated with the right hemisphere and could thus be compromised in right-hemisphere stroke patients (Robertson, Ridgeway, Greenfield, & Parr, 1997).

Damage to the attention system can cause non-spatial, or global, attention deficits (Priftis, Bonato, Zorzi, & Umilta, 2013), and these impairments might in turn alter the dynamics of perceptual processing. During binocular rivalry the conflicting scenes are in the same location in the visual field, making the paradigm ideal for investigating the effects of brain damage on changes in non-spatial attention. The task allows assessment of changes in neural competition due to hemispheric injury.

However, little research has been conducted on binocular rivalry in

* Corresponding author at: Sunnaas Rehabilitation Hospital, Department of Research, Bjørnemyrveien 11, 1450 Nesoddtangen, Norway.
E-mail address: stiprust@sunnaas.no (K.M. Walle).

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stroke patients. Right hemisphere stroke patients have been found to experience a slower rate of alternations between the two percepts compared to healthy controls (Bonneh, Pavlovskaya, Ring, & Soroker, 2004; Daini et al., 2010), but these studies had differing results when comparing alternations of patients with and without neglect. Bonneh et al., 2004 found neglect patients to have a slower alteration rate compared to patients without neglect, indicating that attention mechanisms likely play a role in perception during binocular rivalry. However, Daini et al. (2010) did not find significant differences between the patient subgroups, suggesting that mechanisms compromising rivalry alternations in right hemisphere stroke patients are independent of unilateral spatial neglect. The current study made an effort to increase the sample size of this type of investigation to more reliably reflect the population in question, and re-examined whether level of attention impairment, as measured in scores from the Behavioral Inattention Test (BIT), affects rivalry rates.

A novel research objective of this study is to explore how the relative spatial frequencies of the images simultaneously presented might affect rivalry alternations in stroke patients. Although with somewhat weak and inconsistent findings, several studies have reported hemisphere lateralization between the perceptual processing of differing spatial frequencies. Specifically, faster and more accurate identification and discrimination of high spatial frequencies were revealed when presented in the right visual field and the same was found for low spatial frequencies in the left visual field (Christman, Kitterle, & Hellige, 1991; Christman, Kitterle, & Niebauer, 1997; Kitterle, Christman, & Hellige, 1990; Peyrin, Chauvin, Chokron, & Marendaz, 2003). Although, several studies assumed that this lateralization reflected absolute spatial frequencies (Peyrin, Baciu, Segebarth, & Marendaz, 2004; Peyrin et al., 2003), it seems that relative differences between frequencies can just as well bring about these laterality effects (see Ivry & Robertson, 1998, for a review).

In particular, a study by Christman et al. (1991) showed that visual field asymmetries in healthy participants depend on relative spatial frequencies. They had participants watching images consisting of two sine-wave gratings superimposed, or the two gratings in combination with a third one. Participants were instructed to report whether the third grating was present or not in each image as they, one by one, were presented in either the left or right visual field. The two sine-wave gratings were both of equally low or equally high spatial frequency while the third component would always be of an intermediate spatial frequency, relatively high or relatively low, as compared to the other sine-wave gratings in the image. The results showed that the third component lead to opposite effects of processing advantages in left and right visual field, depending on whether it was the relatively low or the relatively high spatial frequency component of the image presented.

Thus, we would expect that, given the asymmetry between hemispheres in relative spatial frequency processing, damage to one hemisphere could possibly disrupt this processing. We therefore assessed how a right hemisphere brain injury affects rivalry processing of competing stimuli containing unequal spatial frequencies. The stimuli were Gabor grid anaglyphs (i.e., differently colored images viewed via glasses with colored lenses) that were presented centrally in the visual field (as opposed to the previous mentioned studies), so that both hemispheres of the brain would be receiving signals from both eyes. Gabor grid anaglyphs of only low spatial frequencies were used. The pairs of images in the anaglyphs contained one image of a relatively higher spatial frequency compared to the other (see Fig. 1 for examples). We then assessed whether the disrupted processing of the right hemisphere would bias the predominance ratios between competing stimuli of relatively low and relatively high spatial frequencies.

We reasoned that each hemisphere should receive signals from both eyes and accordingly process both relatively high and relatively low spatial frequencies simultaneously. However, patients are expected to reveal a processing bias between relative spatial frequencies since the spared left hemisphere evidently specializes in processing of the relatively higher spatial frequencies, giving them an advantage in the competition for dominance. With both hemispheres intact, the controls are not expected to show any bias on rivalry predominance ratios.

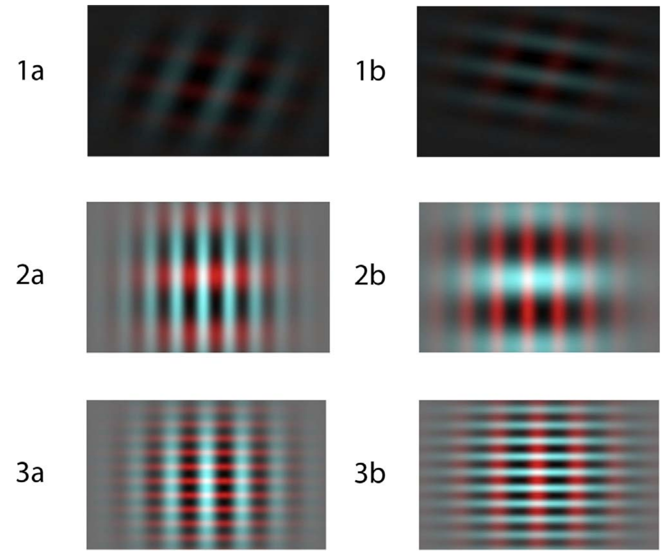

Fig. 1. Examples of the Gabor stimuli used and presented at a 42-degree viewing angle in the experiment. Each anaglyph (indicated by the number at the left side) was presented twice (a and b) in opposing red-cyan colors (both versions illustrated; left and right). In addition, each Gabor anaglyph contained two images of different spatial frequencies.

Recent binocular rivalry studies (e.g., Kalisvaart, Rampersad, & Goossens, 2011; for a review see Stanley, Forte, Cavanagh, & Carter, 2011) have found that at the onset of the task, observers show an onset bias in certain parts of the visual field, in such a way that one eye is more likely to achieve dominance first. Such an initial strong bias for either the left or right eye reduces during sustained rivalry and develops into a more equally shared dominance pattern between the eyes. Thus, we expected that patients in our study would demonstrate slowed rivalry switches, which could possibly perpetuate such onset biases in the patient group compared to the controls. Moreover, a substantial part of the right hemisphere stroke group should have a tendency to attend more to the right visual field. Given that the right visual field is slightly better represented by the right eye due to additional inputs from the right monocular visual fields, this could possibly constitute an additional source of bias for the patient group, favoring onset asymmetries towards the image presented to the right eye, which could be maintained also during the sustained phase of rivalry.

The present study also included anaglyphs with pictures of a face presented to one eye and a house to the other. As Blake and Logothetis (2002, p.1) pointed out, rivalry can be seen "as a series of processes, each of which is implemented by neural mechanisms at different levels of the visual hierarchy". Gabor stimuli are known to be optimal stimuli for neural cells in the primary visual areas (Devalois, Albrecht, & Thorell, 1982) and to be fully processed already early in the visual stream (Enroth-Cugell & Robson, 1984). In contrast, face/house stimuli have content that is interpretable as meaningful and that can be verbally categorized. Thus, their perception would also be dependent on interplay of higher-level visual areas that support categorization and semantic processes (Gross, Rochamir, & Bender, 1972; Kravitz, Peng, & Baker, 2011). Because areas of the right hemisphere have been specifically linked with perceptual processing of faces (De Renzi, 1986; De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994; Rangarajan et al., 2014; Tong, Nakayama, Vaughan, & Kanwisher, 1998) and of houses (O'Craven and Kanwisher, 2000; Tong et al., 1998), we surmise that a right-hemisphere stroke may particularly affect rivalry rates for face/house anaglyphs in patients. Also, since the right-hemisphere's functional lateralization and anatomical size of the FFA is more pronounced