

## Effects of orientation and spatial frequency on monocular and binocular rivalry

Robert P. O'Shea

Department of Psychology, University of Otago, PO Box 56, Dunedin, New Zealand, r\_oshea@otago.ac.nz

### Abstract

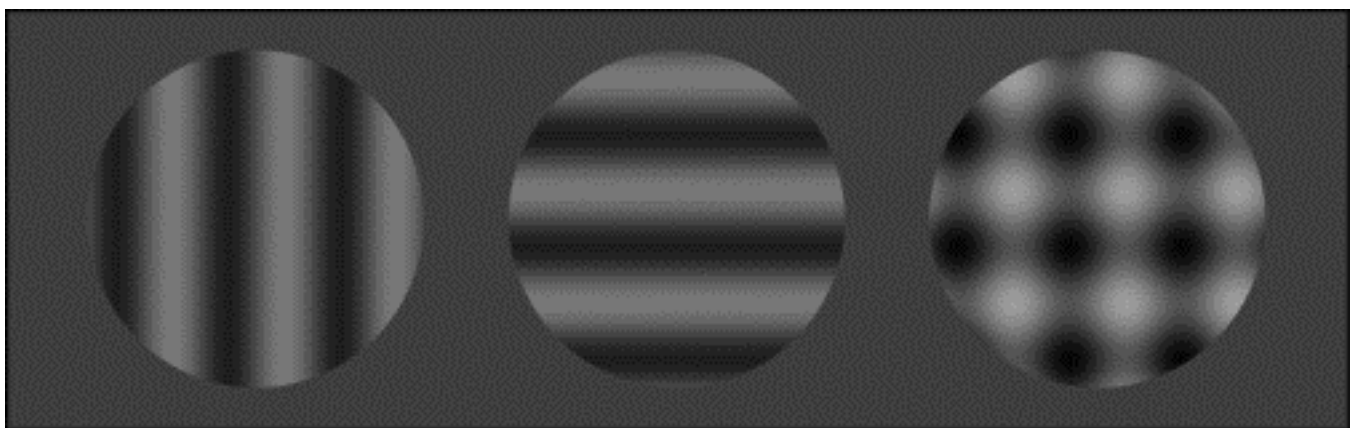
When different images are presented to the two eyes, binocular rivalry occurs, that is, the images alternate in visibility. When different images are presented to the same eye, monocular rivalry occurs, that is, the images also alternate in visibility. I report two experiments comparing the effects of differences in orientation and spatial frequency of the two images on monocular and binocular rivalry. As orientation or spatial frequency difference between the two images increases, so does the rivalry rate, although monocular rivalry rates are less than binocular rivalry rates. The similarity between the two phenomena suggests that binocular rivalry may consist of two components, alternations between two images that are independent of eye of origin (as revealed by monocular rivalry), and alternations between two images that depend on eye of origin.

### 1. Introduction

A remarkable phenomenon of visual consciousness occurs when each eye views very different images. Instead of the two images combining in perception, as usually happens with similar images, one or the other image will become completely invisible for about a second. The two images alternate randomly in consciousness for as long as one cares to look. This phenomenon is called binocular rivalry.

Despite being discovered in 1760 by Dutour, the explanation of binocular rivalry still eludes us. Readers can experience binocular rivalry by stereoscopically viewing the first two panels of Figure 1.

Recently there has been debate about whether binocular rivalry is between images [Kovács *et al.*, 1996], or between eyes [Blake *et al.*, 1997]. To demonstrate that rivalry is between images, Kovács *et al.* [1996] first showed an image of a monkey's face to one eye of an observer, and an image of a jungle scene to the other eye. As expected with such complex, different images, observers reported alternations in visibility between the face and the jungle scene; that is they reported traditional binocular rivalry. Critically, however, Kovacs *et al.* then cut up the images into equal numbers of pieces, and exchanged half the pieces between the two eyes. That is, one eye viewed a composite image of a monkey's face with half of its area replaced by pieces of the jungle scene, and the other eye viewed a complementary composite image. If observers were to experience rivalry between the images presented to the two eyes, they should have reported alternations between the two composites. Yet observers reported alternations between the monkey's face and the jungle scene. Somehow, the brain selects all the pieces belonging to each image from between the two eyes, and alternately offers these images to consciousness.



**Figure 1.** An illustration of one condition of Experiment 1. The first panel shows a vertical sine-wave grating, the second panel shows a horizontal sine-wave grating. When free-fused from 84 cm so that one eye views panel 1 and the other eye views panel 2, the conditions of Experiment 1 will be simulated, and binocular rivalry observed between the two panels. Free fusion

can be accomplished by crossing the eyes either about 42 cm in front of the page, or about 84 cm behind the page. Panel 3 shows the optical superimposition of panels 1 and 2. If it is stared at for some time with normal viewing, alternations in the clarity of the vertical and horizontal gratings will be perceived. This is monocular rivalry.

I wanted to take an alternative approach to deciding whether images can rival. I decided to present both images to one eye, and compare this to when the images are presented to different eyes. It is already known that when simple images are optically superimposed, their visibility fluctuates in a manner reminiscent of binocular rivalry. Readers can experience this in panel 3 of Figure 1. This phenomenon is called monocular rivalry and was discovered by Breese in 1899.

First, however, I should address, and reject, a simple explanation for monocular rivalry proposed by Georgeson [1984]. Georgeson suggested that with fixation, afterimages of the two gratings could build up that would cancel the original images. A horizontal eye movement equal to half the period of the vertical grating, however, would cause the vertical afterimage to sum with the vertical grating, enhancing its contrast, while leaving the horizontal grating invisible. Similar vertical eye movements would lead to reappearance of the horizontal grating. According to Georgeson, random eye movements could produce the random fluctuations in visibility characteristic of monocular rivalry.

Although Georgeson's is an ingenious proposal, there are several lines of evidence to suggest it cannot be a complete explanation of monocular rivalry. Bradley and Schor [1988] measured eye movements during monocular rivalry. Despite finding many alternations that were correlated with eye movements, some followed the opposite eye movements (e.g., reappearance of a vertical grating following a vertical eye movement). Moreover, monocular rivalry occurs between images stabilized on the retina that are immune to the effects of eye movements [Crassini and Broerse, 1982]. Finally, Sindermann and Luddeke [1972] reported that occasionally part of one image appears in one region of the field, and, at the same time, a part of the other image appears in a different region. This observation is impossible to account for by eye movements. Along with the other evidence, it suggests that monocular rivalry alternations involve similar processing to those of binocular rivalry alternations [Breese, 1899].

Binocular and monocular rivalry seem to be affected similarly by stimulus properties of the two images. For example, binocular rivalry becomes more vigorous as the orientation or spatial frequency of the two images is made more and more different [Schor, 1977]; similar behaviour is shown by monocular rivalry [Atkinson *et al.*, 1973; Campbell *et al.*, 1973]. Nevertheless, these two phenomena have never been compared on these stimulus properties in the same observers (cf. [Wade, 1975]). I performed these experiments.

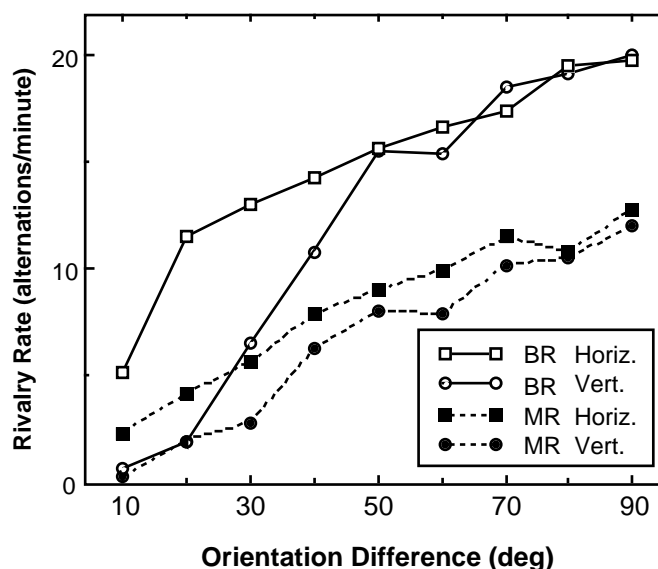
## 2. Experiment 1: Effects of orientation on rivalry

Three observers viewed sinusoidal gratings of 1 cycle/degree (cpd) through a circular aperture of 3 degrees diameter. In the case of binocular rivalry, the left eye was presented with either a vertical or a horizontal grating, and the right eye with a grating of variable orientation. In the case of monocular rivalry, both gratings were presented to the right eye. Observers tracked rivalry by pressing one button whenever one grating was seen with no trace of the other grating, and

another button for the opposite situation. Neither button was to be pressed if a mixture of the two gratings was perceived. Rival stimuli were observed for one minute, followed by at least one minute of rest before the next trial. The number of button presses per minute gives an index of how vigorously and completely two stimuli rival; I shall refer to this as the rivalry rate.

In Figure 2, I have plotted rivalry rate against orientation difference for the two sorts of rivalry at each absolute orientation. Both monocular and binocular rivalry show approximately monotonically increasing functions with orientation, consistent with the idea that image differences affect the two sorts of rivalry similarly. Yet there are two notable differences. First, the rate of monocular rivalry is less than that for binocular rivalry at virtually every orientation difference. Observers found binocular rivalry to be much crisper, and easier to report, than monocular rivalry. Second, binocular rivalry rate is much greater between near-horizontal stimuli than between near-vertical stimuli, and this difference disappears at large orientation differences, yet there is no such pattern of results for monocular rivalry.

The difference in the overall level of binocular and monocular rivalry suggests that there may be two rivalry processes: one between images which is engaged in both sorts of rivalry, and another between the eyes which increases rates of binocular rivalry. The difference in the patterns of results for the two sorts of rivalry is easy to explain. Near-vertical gratings presented to opposite eyes engage stereopsis, and a single grating is seen tilted in depth [Wheatstone, 1838/1852]. Stereopsis appears to inhibit binocular rivalry [Blake and Boothroyd, 1985]. Near-horizontal gratings presented to opposite eyes do not engage stereopsis, and neither do gratings presented only to one eye.



**Figure 2.** Rivalry rates plotted against orientation difference between gratings presented to opposite eyes (BR; empty symbols), or to the right eye (MR; filled symbols), as a function of absolute orientation (Vert. or Horiz.). Each point is the mean of 12 observations (3 observers by 4 trials).

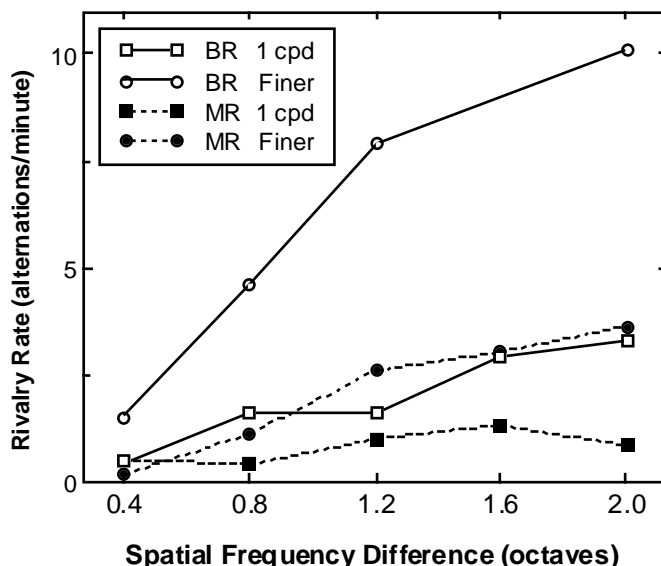
### 3. Experiment 2: Effects of spatial frequency on rivalry

The method was similar to that of Experiment 1, except that all gratings were vertical. During binocular rivalry, the right eye was presented with a 1 cpd grating, and the left eye with a grating of finer spatial frequency in 0.4 octave steps up to a maximum of two octaves difference (4.0 cpd). During monocular rivalry, both gratings were presented to the right eye.

I have plotted the rivalry rates against spatial-frequency difference for monocular and binocular rivalry in Figure 2. I have plotted results for the 1 cpd and the finer grating separately. There are two points to glean from this figure. First, both sorts of rivalry show monotonically increasing functions with spatial-frequency difference. Again, the rate of increase for binocular rivalry is much greater than for monocular rivalry. Second, most of the increase in rate for both sorts of rivalry is carried by the finer grating. This is a well-known property of binocular rivalry, but not reported before for monocular rivalry. This close similarity in the two sorts of rivalry again is consistent with the idea that they share processing. The greater increase with binocular rivalry suggests some extra inhibition when the stimuli are presented to opposite eyes. For example, binocular rivalry rate increases as the contrast of rival stimuli increases [Alexander and Bricker, 1952].

### 4. Discussion

Can we construct a plausible neural model of these results? We know that when a binocular cell is stimulated by its preferred orientation via one eye, and an orthogonal orientation via the other, the activity of the cell is low, similar to that when its preferred stimulus is presented to one eye [Sengpiel and Blakemore, 1994].



**Figure 3.** Rivalry rates plotted against spatial frequency difference between gratings presented to opposite eyes (BR; empty symbols), or to the right eye (MR; filled symbols). The rates are plotted individually for the finer and standard (1 cpd) gratings. Each point is the mean of 6 observations (3 observers by 2 trials).

Binocular rivalry, therefore, will create two populations of binocular cells, ones receiving their preferred orientation via the left eye (e.g., vertical) and others receiving their preferred orientation via the right eye (i.e., horizontal). Maybe under these circumstances, these two populations compete to offer their processing to consciousness.

Monocular rivalry will also recruit two populations of binocular cells, ones receiving their preferred orientation via one eye (e.g., vertical) and ones receiving their preferred orientation via the same eye (i.e., horizontal). These two populations of cells would compete each other in exactly the same way as with binocular rivalry.

Blake [1989] recognized that presenting two gratings either to opposite eyes or to the same eye would engage the same populations of binocular cells, and attributed binocular rivalry to inhibition between populations of cells receiving input solely from one or the other eye (monocular cells). It is possibly this action that enhances binocular over monocular rivalry. If so, we have the apparently paradoxical situation in which binocular rivalry is effected mainly by interactions between monocular cells, and monocular rivalry is effected mainly by interactions between binocular cells.

If there are two components of binocular rivalry, this would reconcile at least two puzzles. First, we have the evidence of Kovács *et al.*, [1996] that two images having their components scattered between the two eyes nevertheless are reconstituted during binocular rivalry so that alternations between complete images are seen. Perhaps these image-specific processes occur in binocular cells that have lost eye-of-origin information. Second, there is some evidence that binocular rivalry suppression is selective for orientation [O'Shea and Crassini, 1981], although this is contradicted by other research [Blake and Fox, 1974]. It is possible different methods have probed different components of rivalry.

In conclusion, I have shown that orientation and spatial frequency differences affect binocular and monocular rivalry in similar ways. This is consistent with binocular rivalry consisting of two components, one representing alternations between images, and another representing alternations between eyes.

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