How to Create and Use Binocular Rivalry

Video Article

How to Create and Use Binocular Rivalry

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Abstract

Each of our eyes normally sees a slightly different image of the world around us. The brain can combine these two images into a single coherent representation. However, when the eyes are presented with images that are sufficiently different from each other, an interesting thing happens: Rather than fusing the two images into a combined conscious percept, what transpires is a pattern of perceptual alternations where one image dominates awareness while the other is suppressed; dominance alternates between the two images, typically every few seconds. This perceptual phenomenon is known as binocular rivalry. Binocular rivalry is considered useful for studying perceptual selection and awareness in both human and animal models, because unchanging visual input to each eye leads to alternations in visual awareness and perception. To create a binocular rivalry stimulus, all that is necessary is to present each eye with a different image at the same perceived location. There are several ways of doing this, but newcomers to the field are often unsure which method would best suit their specific needs. The purpose of this article is to describe a number of inexpensive and straightforward ways to create and use binocular rivalry. We detail methods that do not require expensive specialized equipment and describe each method's advantages and disadvantages. The methods described include the use of red-blue goggles, mirror stereoscopes and prism goggles.

Video Link

The video component of this article can be found at http://www.jove.com/video/2030/

Protocol

(1) Introduction: What is binocular rivalry?

Normally, each of our eyes sees a slightly different image. Our brain combines the information it gets from the eyes to create a single coherent, three-dimensional representation of the visual scene. But what would happen if each eye were artificially presented with an irreconcilably different image at corresponding retinal locations? What conscious perceptual experience would such stimulation evoke? Many people's intuition is that the brain would still attempt to fuse the two images. However, this is not what happens. What actually transpires is a pattern of perceptual alternations, in which each eye's image dominates conscious perception for a certain period while the other image is suppressed, and periods of dominance and suppression reverse periodically, with only brief periods of mixed perception. This is known as binocular rivalry.

Binocular rivalry is considered a useful method for investigating the processes underlying perceptual selection and visual awareness, as stable input (the same images shown constantly to each eye) leads to alternating conscious percepts [1,2]. Thus, binocular rivalry can be used to examine such questions as:

a. **The locus of awareness:** At what stages within the visual processing hierarchy do neural events correlate with conscious experience?
b. **Perceptual selection:** How does the brain resolve competition between stimuli and choose which one to bring into awareness?
c. **Unconscious processing:** What aspects of an image that is suppressed from awareness can nonetheless be processed, and how can such processing affect behavior?

These questions are the focus of much ongoing research.

There are several simple methods for creating a binocular rivalry display, but many newcomers to the field are unsure how to select and use the method that is most suitable to their needs. In this article we outline some of the most popular methods for making binocular rivalry displays, including each method's advantages and shortcomings. We also describe some important considerations when creating and using a binocular rivalry stimulus.

(2) Creating a binocular rivalry display

Creating a binocular rivalry display is simple. Any method that presents completely different images to corresponding locations of the two retinas will lead to rivalry.

1. **Maintaining stable vergence:** Before going into specific methods for creating rivalry, it is important to note the issue of stable vergence, which is an important consideration in all the methods that will be described.

    Normally, our eyes turn (make vergence movements) in a way that makes the same fixated image fall on each fovea. However, successful vergence depends on each eye seeing the same things. If each eye is presented with an entirely different image, vergence will be disrupted, as the brain won't have sufficient information to decide on the correct vergence angle. This may disrupt binocular rivalry, as the two images may not fall on corresponding retinal locations. Therefore, in addition to the different images, the display should contain elements that are identical for both eyes. This enables the eyes to maintain stable gaze despite the difference between the rivaling elements of the images.
    1. Usually, vergence-stabilizing identical elements include a fixation point at the center of the rivaling images and a frame around the images; the frame can be either uniform (Figure 1A) or textured (Figure 1B; some consider a textured frame more powerful in preventing non-vergent eye movements). The frame can have any shape as long as it is identical in both eyes.
    2. Uncorrelated horizontal eye movements are more likely than vertical ones. Therefore, a textured bar on either side of each image can be used instead of a full frame (Figure 1C; refs [3,4]).
    3. Finally, in some studies a frame may be undesirable (for example, if the experiment requires that stimuli appear on a uniform background). In such cases, it is possible to use nonius lines (lines that center on the image from several directions) and/or an image that appears further out from the stimulus, such as dartboard rings (Figure 1D; ref [5]).
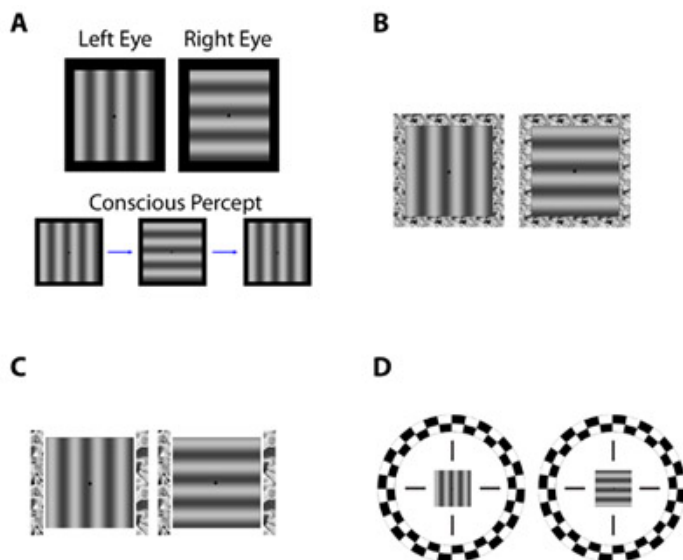

Figure 1: Examples of binocular rivalry displays with different kinds of identical elements enhancing stable vergence. In all panels, the left eye is presented with a vertical grating and the right eye with a horizontal one. The different kinds of identical elements include: (A) Fixation dot and solid frame. A timeline depicting the alternations of the conscious percept is also shown; (B) Fixation dot and textured frame; (C) Fixation dot and textured bars, to reduce non-vergent horizontal eye movements; (D) Fixation dot, nonius lines and dartboard ring.

2. **Methods for inducing binocular rivalry:** There are several popular methods for creating a binocular rivalry display. Here we will review three inexpensive and straightforward options: Using color goggles, a mirror stereoscope, and prism goggles.
    1. Red-blue goggles: This is a popular method, preferred by many researchers because it is the easiest and cheapest to implement. All one needs is a pair of red-blue cellophane goggles, available at most toy stores (the explanation here will assume the use of red-blue goggles, though other color combinations, such as red-green, can also be used).
        1. Most of the work involved in using this method goes into stimulus preparation. It is not essential to present the stimuli on a computer screen (some binocular rivalry studies have used images printed on cardboard-mounted paper), but it usually is most straightforward to present the images on a monitor. Prepare one image that is displayed solely by the monitor's blue gun (or the printer's blue cartridge, if the stimuli are printed on paper) and another that is displayed, at the same location on the screen, solely by the red gun (or red printer cartridge; e.g., ref [7]). Each of the lenses will only pass one of the images, so the two different images will fall on corresponding retinal locations in the two eyes and start to rival each other (Figure 2).
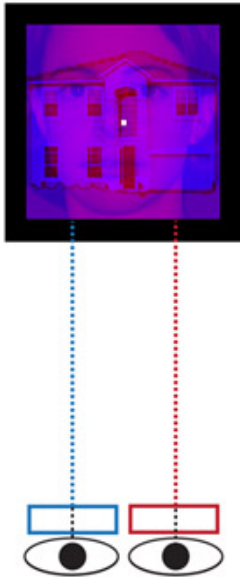
Figure 2: Red-blue goggle display. The image consists of a red-only picture of a face and a blue-only picture of a house. When viewed through red-blue goggles, represented here schematically, the two pictures should engage in rivalry.

2. Note that the two images should contain identical information - e.g., a frame and fixation cross - as despite the fact that the stimuli are physically overlapping, stable vergence (see above) must still be ensured. These identical elements should be in a color that both lenses will let through, such as black.
3. The main advantages and disadvantages of using red-blue goggles.

Advantages:
   a. The equipment is very inexpensive, and stimuli are very easy to prepare.
   b. Red-blue goggles can be easily used with all neuroimaging methods, including MRI.
   c. Red-blue goggles do not require head stabilization or individual adjustment of the viewing device for each observer.

Disadvantages:
   a. Each image can only contain shades of a single color- no chromatic (colorful) stimuli.
   b. The lenses are not perfect (even much more expensive ones than toy-store lenses would still slightly overlap in the wavelengths of light they let through); therefore, there will always be at least some 'bleed-through' - each eye will see some of the other eye's image. This creates a problem for claiming that the suppressed image was entirely unseen.
   c. Red-blue goggles do not work well with most current eye-trackers.

2. Mirror stereoscope: Mirrors can easily be set up to deliver a different image to each of the observer's eyes.
   1. Stimuli: Prepare two different images that have some identical elements (for maintaining stable vergence, as explained above). As with red-blue goggles, stimuli so not have to be presented on a computer screen, but presenting the images side by side on a monitor is usually the most straightforward method.
   2. A mirror stereoscope consists of four mirrors (Figure 3A). It is possible to buy a commercially produced stereoscope. It is also easy to construct a stereoscope. To do so, position two mirrors so that each is near one eye and at a 45° angle to that eye's line of viewing (use a chin-rest to stabilize the location of the observer's head). Place another mirror on either side of each of the first two mirrors, facing the stimuli at a 45° angle (Figure 3B). This arrangement will make each image fall on a corresponding location in each eye. The dissimilar images should now rival each other.
   3. Each observer's eyes are a little different, so when placing an observer in front of the display, it may be necessary to adjust the mirrors' angles to attain stable vergence. Though most mirror stereoscopes work well when the mirrors are fixed, it is possible to enhance adjustability to each observer's eyes by allowing the mirrors to rotate and/or slide back and forth (blue arrows in Figure 3B).
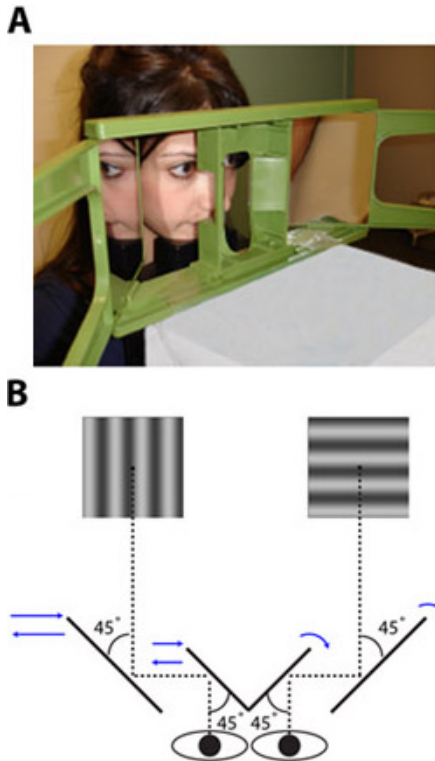
Figure 3: Mirror stereoscope. (A) An observer looking through a commercially-available mirror stereoscope. (B) A schematic representation of a mirror stereoscope. Solid lines represent mirrors. Dotted lines represent line of vision, and blue arrows represent possible adjustments to either the location (straight arrows) or angle (curved arrows) of mirrors. Each type of arrow is only shown on one side for simplicity, but the same adjustments can be made on both sides.

4. When using a mirror stereoscope, it is important to make sure that each eye can only see the image it is supposed to, and that this image is only seen at the location where it rivals the other image. However, in many cases each eye will also have a line of vision to the other image (Figure 4A). To block this undesired line of vision, place a divider (for example, a sheet of cardboard) extending from the stereoscope's midline, between the observer's eyes, toward the center of the display in such a way that it will block the line of vision to the other eye's stimulus (Figure 4B). The divider can be made of any material, as long as it serves this purpose. However, it is preferable to make the divider out of matte material, as shiny material will reflect light emitted by the monitor and create glare.
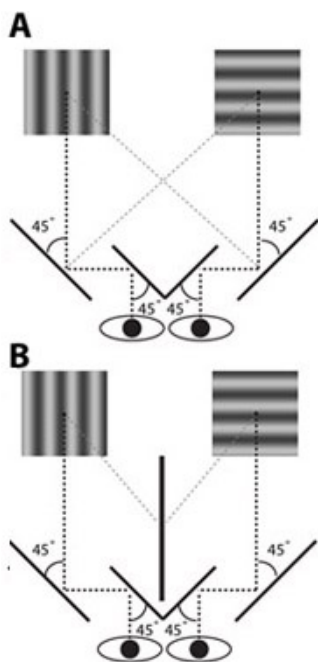
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Figure 4: Blocking the line of vision to the other eye's stimulus. Each eye may have a clear line of vision to the stimulus intended for the other eye. (A) Thick black dotted lines represent the line of vision to each eye's intended stimulus. Thin grey dotted lines represent the line of vision to the other eye's stimulus. (B) The line of vision to the other eye's stimulus can be blocked with a divider (thick solid line).

5. An additional problem that may occur is that each eye might see the image it is supposed to see twice - once through the mirror, and once again directly (Figure 5A). This will cause an additional image of each stimulus to appear next to the location where rivalry occurs. To avoid this, adjust the relation between the image's location and the observer's distance from the screen (Figure 5B).
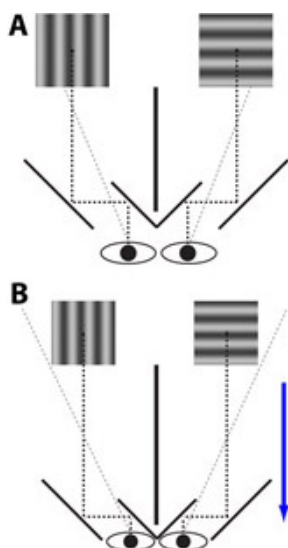
Figure 5: Making sure each eye has only a single line of vision to its stimulus. (A) In addition to the line of vision that goes through the mirrors (thick black dotted line), each eye may also have a direct line of vision to it's intended stimulus (thin grey dotted line), causing the stimulus to be seen twice. (B) This problem can be avoided by adjusting the relative position of the stereoscope and placement of stimuli.

6. In order to make the above adjustments before the experiment begins, prepare an image showing only the parts of the display that are identical in both images, and use it to set the stereoscope up for each observer before displaying the rivalry stimulus.

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7. The main advantages and disadvantages of using mirror stereoscopes.

   Advantages:
   a. Separate images allow for use of chromatic (colorful) stimuli.
   b. The images are totally separate and cannot 'bleed into' each other', unlike with red-blue goggles.
   c. Stimulus preparation is easy and simple - any two pictures presented side-by-side can rival each other.
   d. Stereoscopes can be used in combination with eye-tracking.

   Disadvantages:
   a. Stereoscopes only allow for presentation of fairly small stimuli, as only half of the visual field can be used to present each image, and the need to maintain stable vergence makes it hard to present stimuli subtending more than a few degrees of visual angle.
   b. Stereoscopes cannot be easily used in an MRI scanner, as this would require all elements of the stereoscope to be non-magnetic, and the setup would also have to incorporate the additional tilt of the mirror through which stimuli are normally viewed in the scanner. Mirror stereoscopes are also likely to be too large for the cramped scanner environment. However, stereoscopes are compatible with other methods such as EEG, MEG and NIRS.
   c. Stereoscopes require head stabilization and individual adjustment for each observer.

3. Prism goggles: This is a variation on the idea of the stereoscope, using goggles in which the lenses are prisms instead of mirrors. As with a mirror stereoscope, images are presented side by side (usually on a monitor).
   1. Prism lenses can be purchased from any commercial optics supplier, along with plastic frames.
   2. Each of the prisms bends light, making objects that are off to the side seem to be straight ahead (Figure 6). Two such prisms, oriented in opposite directions, act in the same way as a mirror stereoscope would - they create the illusion that two images that are, in fact, physically side by side overlap in space [6].
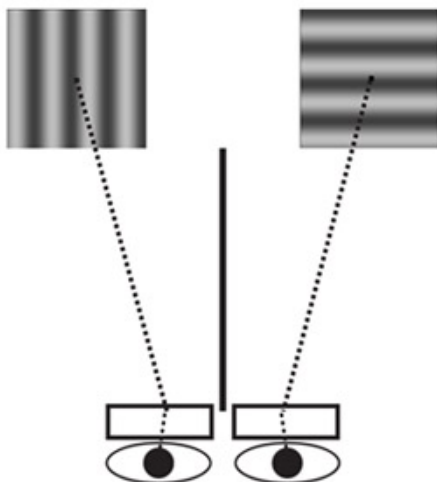

Figure 6: Prism goggles. Each prism lens bends light, causing stimuli that are physically side-by-side to appear to be in the same spatial location. Note that a divider is required to prevent additional lines of vision.

   3. Note that when using prism goggles, you still need to use a divider (see Figure 4) as each eye can see the other eye's image. However, you need not worry about adjusting the distance and size of the display as you would with a mirror stereoscope (see Figure 5), as each image has only one line of vision to each eye.
   4. The advantages and disadvantages of prism goggles are similar to those of mirror stereoscopes, with one big difference: It is easy to use prism goggles in an MRI scanner as the goggles and lenses can be made of plastic and are more compact than a mirror stereoscope.

   Advantages:
   a. Separate images allow for use of chromatic (colorful) stimuli.
   b. The images are totally separate and cannot 'bleed into' each other' (unlike red-blue goggles).
   c. Stimulus preparation is easy and simple - any two pictures presented side-by-side can rival each other.
   d. Prism goggles can easily be used in an MRI scanner.
   e. Prism goggles can be used in combination with eye-tracking (though eye-tracker calibration may be difficult due to distortion of the pupil's image by the lens).

   Disadvantages:

   a.   Prism goggles only allow for presentation of fairly small stimuli, as only half of the visual field can be used to present each image, and the need to maintain stable vergence makes it hard to present stimuli subtending more than a few degrees of visual angle.
   b.   For large stimuli, or stimuli presented far from fixation, prism presentation may cause image distortion.
   c.   Prism goggles require head stabilization.

4. Additional methods, which we will not go into in detail here, can require expensive specialized equipment. These include the following:
    1. Shutter goggles: These are LCD goggles in which each lens can become opaque independently. Binocular rivalry can be created by alternating lens opacity rapidly, in time with alternating images at the same location on the monitor.
    2. Display goggles: In these, each eyepiece is fitted with an independent display screen. Binocular rivalry can be created by showing different images at the same location on each screen.

(3) Representative results A: Considerations in creating a binocular rivalry display

Many of the publications in this field are aimed at an audience that is already highly familiar with binocular rivalry. These papers thus tend not to go into certain details regarding the experience of rivalry. This may be misleading to a newcomer. Therefore, here we will explicitly describe some characteristics of rivalry.

1. Incomplete suppression: In ordinary rivalry involving images with roughly equal contrast, suppression is often not entirely complete. The suppressed image is often still somewhat visible.
    1. Piecemeal rivalry: Incomplete suppression can occur, for example, through small patches of the suppressed image being dominant, a phenomenon known as 'piecemeal rivalry' (Figure 7; ref [8]) which tends to occur more the larger the rivaling images are; in such cases, observers tend to report dominance according to which image's dominant patches add up to cover a greater area. When this is the case, the criteria for declaring an image dominant can vary greatly across observers. The best way to avoid piecemeal rivalry is to use small stimuli (e.g., subtending 1° of visual angle or less).
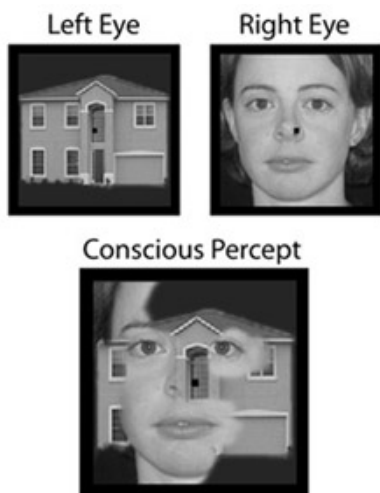

Figure 7: Piecemeal rivalry. In some cases, one of the stimuli will dominate some parts of the image while the other stimulus dominates other parts. Such piecemeal rivalry can occur either as a transitional stage between periods where one stimulus is completely dominant, or continuously, with neither stimulus managing to dominate entirely.

2. Reduced apparent contrast: The suppressed image is also sometimes reported to not be entirely suppressed but merely to appear to have reduced contrast. Although there are claims that at any given point in the visual field only one image can be dominant [9], such points may be small enough for a general feeling of seeing a full, but 'weaker' version of the suppressed image to occur. For the same rivalry display, reduced apparent contrast may occur for some observers but not for others.
3. Afterimages: In some cases, an afterimage of the stimulus presented to the suppressed eye may be formed. To avoid this, use a monocular mask at the end of stimulus presentation. Alternatively, in the case of grating stimuli, prevent afterimage formation by changing the phase of the grating (the location of bright and dark lines) at a rapid rate, either randomly or by having the gratings move.
4. Independent verification of full suppression: In light of the previous three sub-sections, it is easy to see why full invisibility of the suppressed image cannot be assumed. If one wants to report that suppressed stimuli were invisible (for example, when claiming that unconscious processing has occurred), it is important to independently verify that observers could not see the suppressed image. To do so, use forced-choice questions after each trial (i.e., "which of these two images was just presented?"), to demonstrate that success

rates are at chance [3,4]. As above-chance performance may occur even in the absence of awareness (e.g., as in the phenomenon of blindsight, ref [10]), additional measures such as confidence ratings [11] or wagers on accuracy [12] should ideally be employed.

2. Ensuring complete suppression: If the research question concerns how a particular manipulation affects durations of dominance and suppression, then binocular rivalry of the type described so far is most suitable. However, rather than dominance and suppression durations, many researchers are interested in examining whether the content of the suppressed image can be processed. As we have seen, complete suppression is hard to ensure with ordinary binocular rivalry. Therefore, to address research questions concerning the processing of the suppressed image, a strong form of rivalry, known as continuous flash suppression (CFS), is most suitable [13].

    1. To create a CFS stimulus, present a relatively low-contrast (but still visible) image to one eye; this will be the suppressed image. Present a high-contrast, rapidly changing image to the other eye; this will be the dominant CFS mask. To be maximally effective, the CFS mask should change at a rate of 10-20 Hz.
    2. CFS can be induced using all of the methods for creating rivalry that we described above. When using a mirror stereoscope or prism goggles, CFS masks composed of many small colorful elements ("mondrians") are highly effective (Figure 8). When using red-blue goggles, the CFS mask can be composed of many elements (rectangles, ellipses, lines, dots) that are all the same color [14].
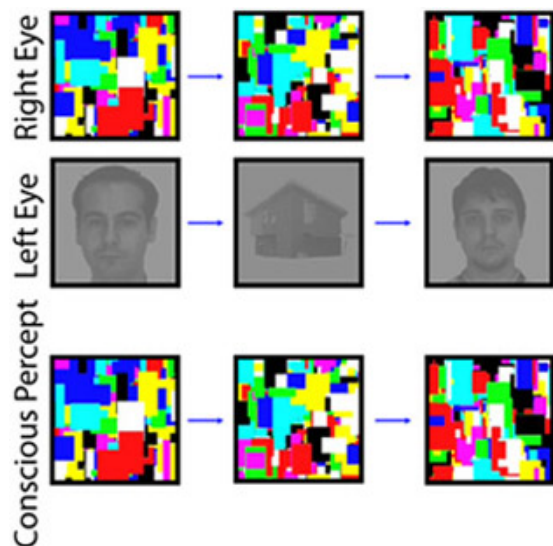

Figure 8: Continuous flash suppression (CFS). One eye (here, the right one) is shown a high-contrast dynamic stimulus. In this example, this stimulus is an image composed of rectangles in many colors (a 'Mondrian'; different images of this kind should alternate at 10-20 Hz to ensure suppression). The other eye is presented with a low-contrast image, which can remain suppressed for long periods (several minutes).

    3. CFS can completely suppress the weaker image for a very long time (several minutes). Note that even then, the suppressed image might occasionally 'break through', especially if it is a meaningful picture such as a face. Therefore, be sure to adjust the contrast level of the suppressed image before the experiment begins, to maximize the chances of complete suppression.
    4. As detailed above (Representative results A: Incomplete suppression), to allow conclusions about unconscious processing of the suppressed image in CFS, independently verify that observers are at chance when asked what was presented to the suppressed eye.

3. Experience of rivalry alternations: Most published research on rivalry reports only dominance and suppression durations, giving the impression that the alternations between the dominant and suppressed image are immediate, all-or-none events. But this is not the case: Alternations are usually gradual and can be rather slow, meaning that quite a bit of the viewing time can be taken up by 'mixed' phases. The specific form of mixed phases varies between observers and for different stimuli. The following are two common forms.

    1. A mixed phase can consist of the suppressed image gradually becoming dominant through an increasing number of dominant patches (piecemeal rivalry, see Representative results A: Incomplete suppression) across the stimulus.
    2. A mixed phase may also occur through a 'wave' of dominance sweeping across the image. To induce such a wave, introduce a contrast increment to a specific part of the suppressed image (Figure 9; ref [15]).

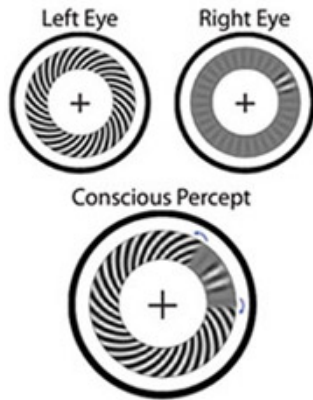November 2010 | 45 | e2030 | Page 8 of 10

Figure 9: Traveling waves of dominance. When one of the two images is suppressed, increasing its contrast in a small region will cause a wave of dominance to spread out from that region. In annular images such as those shown here, dominance will spread as indicated by the blue arrows. Note that once the contrast increment has been introduced, it does not have to remain (the contrast can go back to the original, low level) for the wave of dominance to be initiated.

(4) Representative results B: Duration of dominance phases in binocular rivalry

Binocular rivalry alternations occur at random, independent-duration intervals. This means that the duration of the last dominance interval does not predict how long the next one will be. If dominance durations are divided into bins with an equal width (e.g., 500 ms), a histogram showing how many dominance durations of each length occurred tends to be well-fit by a skewed distribution known as a gamma function [8].

In general, the effects of experimental manipulations on durations in rivalry tend to manifest themselves in the shape of the best-fit gamma function, meaning that in each condition many different dominance durations will occur, but the probability of these might be altered by the manipulation.

The specific parameters of the best-fit gamma function differ between different observers for the same stimulus (Figure 10A) and between different stimuli for the same observer.

Factors such as the two images' low-level features are known to affect the relative durations of their dominance and suppression periods[1]. For example, if the two images differ in contrast, the higher-contrast image will have, in general, longer dominance durations, leading to a best-fit gamma distribution with a greater median (Figure 10B). The effect of high-level cognitive functions (such as attention to one of the images) on dominance durations in rivalry is still controversial [16].

It is possible to use the parameters of the gamma function as dependent variables in an experiment, but the relationship between these parameters and the shape of the distribution is not readily transparent. Therefore, many researchers prefer to use a more accessible central tendency measure. Because the gamma distribution may be highly skewed, the median duration rather than the mean is often more representative of the results. Using the median of a non-Gaussian distribution also means that unless there is a large number of data points, the relevant statistical tests should be non-parametric.
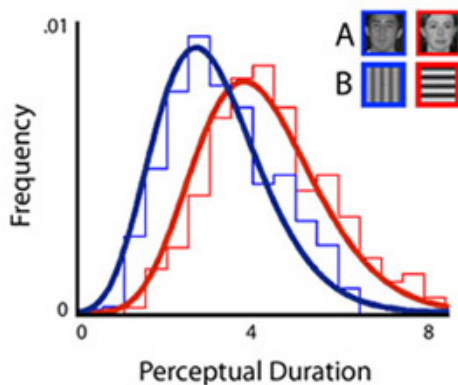

Figure 10: Gamma distributions of dominance durations. The histograms represent binned dominance durations, and the curves represent the best-fit gamma distributions to each color's data. The same distributions illustrate two different possible sets of measurements: (A) Two different

observers' dominance durations in response to the same stimuli; or (B) The effect of different stimulus features on dominance durations. In this case, the red-framed grating has a higher contrast, leading to longer dominance durations and thus to a gamma distribution with a higher median.

Discussion

We have described the nature of binocular rivalry, several methods for creating it, and what considerations must be taken into account when it is used. As detailed in the Introduction, appropriate use of binocular rivalry makes it possible to experimentally address questions regarding the locus (or loci) of awareness, perceptual selection and unconscious processing. To carry out such investigations properly, however, one must be aware of issues such as the importance of maintaining stable vergence, and, if investigating unconscious processing, the necessity of using displays that are likely to yield complete suppression.

When choosing which method to use in order to create rivalry, it is important to take into account the advantages and disadvantages of each method. There is no point, for example, in using red-blue goggles if one is interested in using multi-colored stimuli; but on the other hand, this method is probably the easiest to use in an MRI scanner. Similarly, a mirror stereoscope is a very reliable way of ensuring that separate images fall on corresponding retinal locations; but the individual adjustments required for each observer and the technical difficulties involved in putting a stereoscope in an MRI scanner might make this method less attractive for some studies.

Finally, it is important to be aware of the characteristics of the experience of binocular rivalry in order to employ the appropriate dependent measures. When the research question concerns unconscious processing, independent verification that participants were indeed unaware of the suppressed image is essential. When one is interested in how an experimental manipulation affects dominance and suppression durations, it may be more illuminating to examine the (gamma-shaped) distribution of durations rather than just a central tendency measure such as the mean or median; and it may be important to ascertain whether the observers experienced sharp or gradual (piecemeal or wave-like) transitions of dominance.

We hope researchers interested in employing this fascinating phenomenon will find this introduction helpful.

Disclosures

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Acknowledgements

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