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The effect of stimulus strength on binocular rivalry rate in healthy individuals: Implications for genetic, clinical and individual differences studies

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ABSTRACT

Binocular rivalry (BR) occurs when conflicting images concurrently presented to corresponding retinal locations of each eye stochastically alternate in perception. Anomalies of BR rate have been examined in a range of clinical psychiatric conditions. In particular, slow BR rate has been proposed as an endophenotype for bipolar disorder (BD) to improve power in large-scale genome-wide association studies. Examining the validity of BR rate as a BD endophenotype however requires large-scale datasets (n = 1000 s to 10,000 s), a standardized testing protocol, and optimization of stimulus parameters to maximize separation between BD and healthy groups. Such requirements are indeed relevant to all clinical psychiatric BR studies. Here we address the issue of stimulus optimization by examining the effect of stimulus parameter variation on BR rate and mixed-percept duration (MPD) in healthy individuals. We aimed to identify the stimulus parameters that induced the fastest BR rates with the least MPD. Employing a repeated-measures within-subjects design, 40 healthy adults completed four BR tasks using orthogonally drifting grating stimuli that varied in drift speed and aperture size. Pairwise comparisons were performed to determine modulation of BR rate and MPD by these stimulus parameters, and individual variation of such modulation was also assessed. From amongst the stimulus parameters examined, we found that 8 cycles/s drift speed in a 1.5° aperture induced the fastest BR rate without increasing MPD, but that BR rate with this stimulus configuration was not substantially different to BR rate with stimulus parameters we have used in previous studies (i.e., 4 cycles/s drift speed in a 1.5° aperture). In addition to contributing to stimulus optimization issues, the findings have implications for Levelt's Proposition IV of binocular rivalry dynamics and individual differences in such dynamics.

1. Introduction

Binocular rivalry (BR) is an intriguing visual phenomenon in which conflicting images presented to each eye are perceived in alternation rather than being superimposed. For example, simultaneously presenting a vertical grating to one eye, and a horizontal grating to the other eye, induces perception of the vertical grating for a few seconds, followed by perception of the horizontal grating for a few seconds, and so on (Fig. 1). BR and other perceptual rivalry types such as ambiguous figures have previously been examined, particularly with respect to alternation rate, in the context of clinical psychiatric disorders from the early to mid-20th Century (e.g., [14,17,20,21,25,27,37,51,58,74]). The modern clinical focus on BR emerged with reports from Australia that BR rate was slow in the heritable psychiatric condition, bipolar disorder (BD), relative to healthy individuals (e.g., [53,68]) — a finding that has since been independently replicated in populations from Japan [57], New Zealand [82] and China [87].

Following Pettigrew and Miller's [68] original study on BD, other clinical psychiatric conditions have been examined including schizophrenia and major depression [39,53], autism spectrum conditions [4,26,42,71–73], attention deficit hyperactivity disorder (e.g., [3,6]), and generalized social anxiety disorder [5]. Although some researchers (e.g., [82]) have attempted to use the same testing protocol as that of Pettigrew and Miller [68], so that data may be directly compared between clinical studies, other researchers have employed different test protocols (e.g., shorter viewing durations, different stimulus characteristics, different

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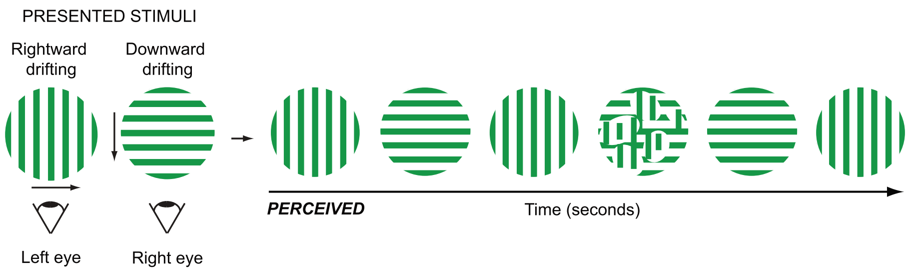

Fig. 1. Binocular rivalry. Presenting dissimilar images simultaneously — such as rightward-drifting vertical gratings and downward-drifting horizontal gratings — one to each eye (i.e., dichoptic presentation), causes each image to stochastically alternate in perception. Mixed or piecemeal percepts (i.e., portions of both eyes' presented images are simultaneously visible) occur occasionally during the transition between perception of the presented images. Arrows adjacent to the presented stimuli denote the direction of grating drift.

response options), making comparisons difficult. Such issues become particularly relevant when considering potential applications of BR findings in genetic studies of clinical psychiatric disorders.

Pettigrew and Miller [68] and Miller et al. [53] demonstrated high sensitivity and reliability of the BR rate trait in BD. This earlier work was followed by a large twin study demonstrating high heritability of the trait and confirming its high reliability ([54]; see also [76]). This heritability study supported the original proposal [68] that slow BR could be used as an endophenotype for BD (reviewed in [59,60]). Endophenotypes — or intermediate phenotypes — can enhance power in gene-finding studies of complex psychiatric diseases by using the relevant quantitative trait to classify a genotype as affected rather than manifestation of the clinical disorder (see [30,31,33,43]). However, such application requires large-scale studies of thousands to tens of thousands of subjects (see [24,36,45,50,86]). Elsewhere we have discussed prospects for an online platform of BR testing to address these large sample-size requirements [46]. Such a platform not only facilitates the collection of very large sample-sizes, but also enables the prospect of standardized BR testing across clinical conditions and research centres, for purposes of direct comparison between clinical studies.

For any such endeavor striving for large-scale, standardized BR testing in clinical conditions, the optimal stimulus parameters also require examination. Changing stimulus parameters can change the signal strength of the stimulus or its *stimulus strength*, which can in turn modulate BR rate. For example, higher contrast, faster drift speed, and brighter luminance are all considered to induce greater stimulus strength (see below). However, the sensitivity function of stimulus-strength rate modulations is not always monotonic (e.g., [44]). In the study by Pettigrew and Miller [68], a high-strength stimulus (i.e., orthogonally drifting gratings of high spatial frequency; 8 cycles/°) induced significantly slower BR rate in a group of euthymic subjects with BD relative to healthy controls, with wide group separation. The finding was independently replicated using the same high-strength stimulus [82] and using an intermediate-strength stimulus [57]. Following Pettigrew and Miller's [68] original study, a subsequent study by Miller et al. [53] using a low-strength stimulus (i.e., stationary gratings of lower spatial frequency; 4 cycles/°) also demonstrated significantly slower BR rate in BD than in healthy individuals, though with less evident group separation. Comparing the data in these two studies (i.e., [53,68]) suggested that the greater group separation in the earlier study may have been due to the high-strength stimuli producing a faster average BR rate in healthy individuals, while BD subjects remained robustly slow whether viewing high- or low-strength stimuli. On this interpretation, BD subjects would be relatively insensitive to stimulus-related BR rate modulation compared with healthy individuals (discussed in [53]; see also [59]), and therefore viewing of higher-strength stimuli should maximize group separation. However, this comparison between the data of Miller et al. [53] and Pettigrew and Miller [68] is limited by the fact that control subjects were *different* between the two studies, as were the BD subjects. What is needed to directly assess the hypothesis that individuals with BD have robustly slow BR rates (i.e., relatively insensitive to stimulus-related BR rate modulation) is varying stimulus strength in the *same* BD and control subjects (i.e., a within-subject design).

Here we report a within-subject study in healthy individuals that aims to determine whether viewing higher-strength stimuli — using grating drift speed as the stimulus strength factor — can induce faster BR. The predominance of drifting gratings over stationary gratings increases with drift speed ([83]), suggesting that changing from stationary to drifting stimuli increases stimulus strength (in accordance with [48]; see below). It is not clear, however, whether the sensitivity function for drift speed is non-monotonic and whether gratings drifting at 4 cycles/s as used in previous studies [54,68,82] are the peak of such a non-monotonic function. Hence 8 cycles/s gratings are also assessed in the current study to examine whether this particular drift speed drives BR rate faster than 4 cycles/s gratings, or whether the 4 cycles/s gratings represent a ceiling effect for BR rate. Here we report a comparatively large within-subject BR dataset of healthy individuals (n = 40) to directly assess and clarify the effect of stimulus strength on BR rate.

The study protocol also enabled assessment of a secondary aim, i.e., the effect of stimulus size on mixed-percept duration (MPD). MPD is the total time spent perceiving mixed percepts in a given BR viewing period, and provides a measure of the degree of perceptual mixing between each eye's presented image. BR rate is derived by dividing the total number of perceptual alternations by the total BR viewing period, excluding responses to mixed percepts. As such, reducing an individual's total MPD provides more data on which to base the calculation of BR rate and thus improves accuracy of the BR rate measure. There have been reports that smaller BR stimuli between 0.5° and 2° of visual angle increase exclusive percept visibility ([63]; see also [8,78]), which corresponds to a shorter MPD. The current study thus aimed to examine whether reducing the size of a BR stimulus from 1.5° [53,54] to 1° or 0.5° of visual angle would produce a shorter MPD. We did not assess stimuli subtending larger than 1.5° so as to avoid inducing a longer MPD. Furthermore, because earlier studies examining the effect of stimulus size on exclusive visibility used only small samples ([8,64,78]; n = 3 and 4 and 11, respectively), the current study employed a comparatively large dataset (n = 40) to clarify the effect of stimulus size modulation on MPD. However, interpretation of these MPD data will require caution as the mixed-percept response option also included subjects' erroneous responses (see Methods and Discussion).

The current experiment is also relevant to the historical literature because stimulus-related modulation of BR temporal dynamics has been a focus for rivalry researchers since Breese [12] (see also Wade & Ngo, [84]) and especially since the seminal four-proposition framework of BR dynamics by Levelt [48]. Recently reviewed in detail by Brascamp et al. [11], these propositions have mostly been examined experimentally by assessing contrast-modulated dominance duration (i.e., the time a percept maintains exclusive dominance). Such experiments involve keeping constant the stimulus strength presented to one eye, while manipulating the stimulus strength presented to the other eye (see Levelt's Proposition III discussed in [11]). Relevant to the current study, Levelt's Proposition IV holds that increasing the stimulus strength *matched between both eyes* should induce a faster BR rate, and this has indeed been observed using dominance duration as the dependent variable and contrast as the stimulus strength factor (e.g., [2,12,13,19,69]). Moreover, two earlier reports indicated that