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How temporal frequency affects global form coherence in Glass patterns

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ABSTRACT

Glass patterns are textural moirés from random dots. Sequential presentation of Glass patterns induces a sense of illusory motion. We evaluated how changes in temporal frequency affected the detection of global form in Glass patterns. We found linear improvement in coherence thresholds with increasing temporal frequency (Experiment 1), particularly in stimuli with large dot-pair separations (Experiment 2). These results support the notion that temporal and orientation information sum to boost sensitivity to visually obscure objects, and are discussed within the framework of "motion streak" detectors.

1. Introduction

Motion is an important cue for identifying the boundaries of object boundaries, and tracking object shape across space and time is used to compute motion direction. While the functional segregation of form and motion mechanisms is generally supported (Hubel & Livingstone, 1987; Livingstone & Hubel, 1987; Mishkin & Ungerleider, 1982), they also interact. Evidence of form and motion interaction is exemplified by "dynamic Glass patterns".

A useful set of stimuli to study global structure is Glass patterns, which are moirés from random dots paired with their rotated, dilated or translated copies (Glass, 1969). Interestingly, sequentially presenting independent frames of Glass patterns induces an illusory percept of global coherent motion (Ross, Badcock, & Hayes, 2000), and is referred to as "dynamic" Glass patterns. While static Glass pattern perception has been associated with mechanisms of form perception (Dakin & Bex, 2001; Ostwald et al., 2008), dynamic Glass patterns perception is associated with mechanisms of motion perception (Burr & Ross, 2002; Krekelberg et al., 2003; Krekelberg, Vatakis, & Kourtzi, 2005). These dynamic Glass patterns interact with real motion psychophysically (Ross, 2004) and physiologically as they have shown some sensitivity in the motion processing area of hMT+ (Krekelberg et al., 2003; Krekelberg, Vatakis, & Kourtzi, 2005). Directed attention also modulated VEP responses to dynamic Glass patterns in hMT+ (Palomares et al., 2012). As in motion coherence thresholds, form coherence thresholds to dynamic Glass patterns are lower than thresholds to static Glass patterns in typical adults (Burr & Ross, 2006; Or, Khuu, & Hayes, 2007) as well as typically developing children and in people with Williams Syndrome, a genetic disorder associated with visual and spatial difficulties (Palomares & Shannon, 2013), implying that the enhancement of global integration of orientation signals by dynamic presentation is a foundational phenomenon, robust from developmental effects.

Illusory motion from dynamic Glass patterns supports the notion that "motion streaks" (Geislers, 1999), residual neural activity from fast moving objects, are detected by orientation mechanisms that aid motion processing. Dot pairs in Glass patterns bias the random direction signals that arise from sequential presentations. Thus in dynamic presentations, circular Glass patterns appear to rotate and radial Glass patterns appear to expand.

In the current study, we characterized how, and to what extent, dynamic presentation improved the sensitivity to form information. According to Geislers (1999), combining orientation and direction information is particularly useful at high speeds, when orientation of motion streaks is easier to compute than velocity components. This idea predicts that thresholds would improve with temporal frequency increased.

In Experiment 1, we assessed how temporal frequency affected form coherence thresholds to characterize temporal sensitivity to dynamic form stimuli. Do coherence thresholds linearly improve with increasing temporal frequency or is there a critical temporal frequency that needs to be reached before coherence thresholds improve? In Experiment 2, we evaluated whether or not dynamic presentation of Glass patterns interacted with dot pair separation, which determines the visibility of global form. Geisler's account also predicts that hard-to-detect form would be ameliorated better

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by dynamic presentation than easy-to-detect form since motion streaks would provide supplementary orientation signals. The detection of camouflaged (i.e., hard-to-detect) objects improves with the addition of motion (Hall et al., 2013). Although there is no net motion energy, would hard-to-detect Glass patterns disproportionately benefit from dynamic presentations?

2. Methods

2.1. Participants

Thirty-nine adults (18–31 years of age) from the University of South Carolina volunteered to participate in this study for extra credit in psychology classes. All participants had self-reported normal or corrected-to-normal vision. There were 20 participants in Experiment 1 and 19 participants in Experiment 2.

2.2. Stimuli and procedure

Stimuli were presented on a Lacie 22" monitor with a resolution of 800 × 700 and refresh rate of 72 Hz driven by a Power Macintosh G4 computer. Stimuli were created using PowerDiva, 3.6, an in house software (Vildavski, 2011). The viewing distance was about 60 cm. Mean luminance was about 50 cd/m^2 and contrast was 90%. Random dot kinematograms covering a 23.33 × 23.33 deg square with 4% density or approximately 0.93 dots per deg^2 of visual angle comprised the Glass pattern stimuli. Dots were white squares, 12.4 × 12.4 min of arc. In Experiment 1, dot pairs were separated by 24.8 min of arc (dot center to dot center). Glass patterns were updated at 1, 2, 4, 8, 18 and 36 Hz, which corresponded to a new array of dots presented every 1000, 500, 250, 125, 56 and 28 ms. (See Fig. 1). The condition with the update rate of 1 Hz is a static presentation.

In Experiment 2, Glass patterns were presented at 1 and 36 Hz. Dot pairs were 12.4, 24.8, 49.6 and 74.4 min of arc (see Fig. 2). Conditions were blocked by temporal frequency and dot pair separation. The stimulus parameters were similar to previous studies using EEG (Hou et al., 2009; Palomares et al., 2010).

For every trial in each block, two 1000-ms intervals were presented in sequence for each trial in random order: one with the random pattern and one with the circular pattern. Participants chose which of two intervals contained coherent form (2IFC). The delay between the two intervals was 2000 ms. A black screen remained displayed until response after the presentation of both intervals. Responses were indicated using the arrow keys on keyboard, the left arrow for first interval and the right arrow for second interval. Dot coherence varied by substituting a different proportion of the coherently aligned dot pairs with randomly oriented dot pairs. Form coherence thresholds were the proportion of dots coherent with a circular pattern that corresponded with performance at 82% correct. Coherence thresholds were determined using a 1-down, 2-up staircase procedure to adjust subsequent trial difficulty (dot coherence), resulting in the variation in the number of trials per block from participant to participant. Each staircase step size was one-tenth of the total range selected. The staircase ended when the standard error of the last ten measurements was less than two step sizes and when the slope was close to zero. Since Mauchly's tests of sphericity were non-significant (p-values > 0.10), thresholds were analyzed using repeated measures ANOVAs in SPSS v. 20 (2012). To ensure that the observers understood the task, there were explicit illustrations and directions before the study was run. The first staircase finished was considered a practice block, which was observed by an experimenter. In the experimental blocks, the observer was alone in a dark and quiet testing room. A similar protocol was conducted with school-aged children (Englund & Palomares, 2012) and with individuals who have Williams Syndrome (Palomares & Shannon, 2013).

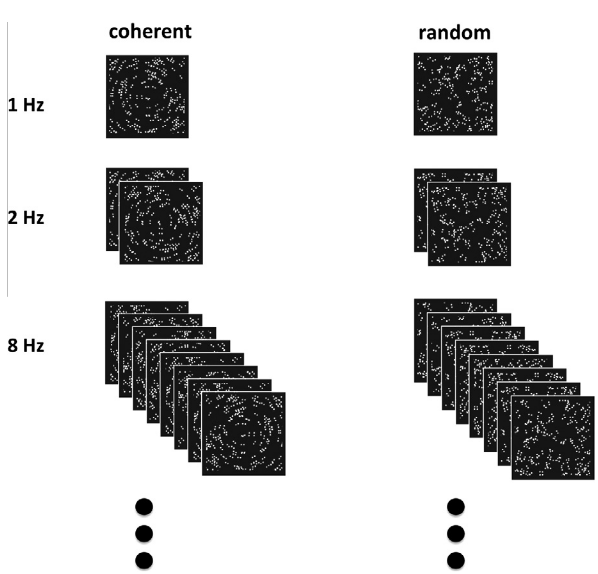

Fig. 1. Representation of Glass patterns updated at 1, 2, and 8 Hz conditions, which corresponded with a new array of dots every 1000, 500, and 125 ms. Experiment 1 presented Glass patterns up to 36 Hz, in which dot arrays were presented every 28 ms.

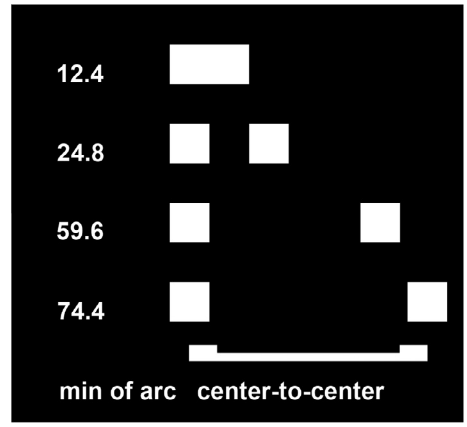

Fig. 2. Depiction of increasing dot pair separation for conditions in Experiment 2, which shows the size of the dots relative to the inter-element separation.

3. Results

Across two experiments, we aimed to characterize how global form thresholds of Glass patterns were affected by changes in local temporal frequency and dot pair separation. Experiment 1 showed that form coherence thresholds linearly decreased as a function of temporal frequency, while Experiment 2 showed that dot pair separation combined non-additively with temporal frequency. Together these results indicate that the illusory motion improves the sensitivity to coherent form, especially when sensitivity to form coherence is low, consistent with the model of motion streaks.

3.1. Experiment 1: Effect of temporal frequency

Glass patterns induced an illusory sense of rotation even with just two frames (2 Hz). Participants described the illusory motion at this temporal frequency as "jerky motion". We evaluated