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Synchrony Does Not Promote Grouping in Temporally Structured Displays

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It has been hypothesized that the human visual system can use temporal synchrony to bind image regions into unified objects[1,2,3], as proposed in some neural models[4]. We present experimental results from a new dynamic stimulus suggesting that previous evidence for this hypothesis can be explained with the well-established mechanisms of early visual processing, thus obviating the need to posit new synchrony sensitive grouping mechanisms (see also[5] for a critique of the binding by neural synchrony hypothesis).

In a particularly compelling demonstration of the hypothesis for binding by temporal synchrony, Lee and Blake[3] constructed a dynamic texture display composed of randomly oriented Gabor elements (Fig. 1a). On each frame, the phase of each Gabor shifted forwards or backwards according to a random process. By using one random process for all the Gabors in a central rectangular region and a different process for all the Gabors in the surrounding region, the authors created a form cue which they claimed was defined solely by temporal synchrony. Subjects were readily able to distinguish the shape of the central region. This led the authors to conclude that the visual system must precisely register and correlate changes in motion across a spatially distributed area.

We have argued, however, that these results can be explained with the well-established filtering mechanisms of early visual processing[6]. Due to the stochastic nature of the reversal sequences, there were moments when the central Gabors rapidly alternated between forward and backward shifts (thus "jittering" in place), while the surrounding Gabors had a run of all forward or all backward shifts, or vice versa. We showed that a temporal bandpass filter (with a temporal integration window on the order of ten frames[7,8]) can convert these relatively large-scale temporal change differences into a contrast cue (Fig. 1b). This lead us to conclude that this cue, not a finer temporal synchrony cue, is responsible for the perception of form in these displays.

Here, we report on a new dynamic textured stimulus that dissociates the potential grouping cues of temporal synchrony and integrated contrast. Our basic stimulus, shown in Fig. 1c, consists of an array of small windows each containing dots drifting with a constant speed and direction. Across windows, the speed is constant, but the direction is randomized. On each frame the dots move randomly forward or backward along their specified direction (Fig. 2a). As with the original Gabor stimulus, a form cue defined by temporal synchrony is introduced: the motion reversals of all the dots in a central region are synchronized to one random process, while the reversals in the surround are synchronized to another process. The central region is a horizontally or vertically oriented rectangle, and subjects are asked to determine its orientation.

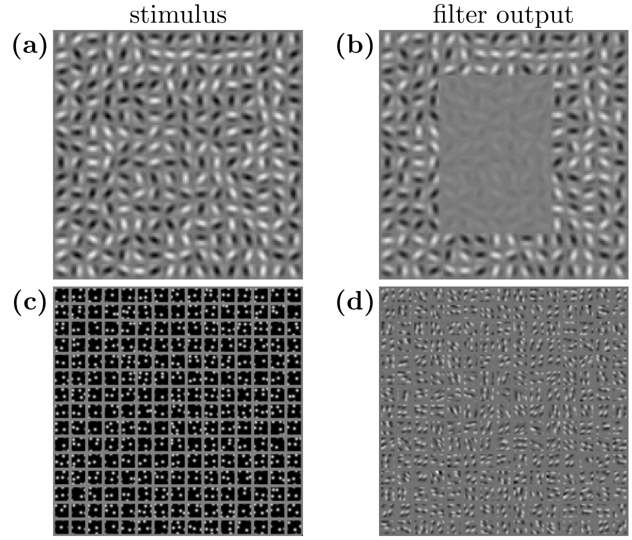

Fig. 1. One frame of the Gabor and dot stimulus and sample output of temporal bandpass filtering. **(a)** one input frame of a Gabor stimulus; **(b)** sample output of temporal bandpass filtering revealing a contrast cue; **(c)** one input frame of our dot stimulus (for clarity the region between windows is shown in gray, in the actual stimulus this region is black); and **(d)** a representative output of temporal bandpass filtering revealing the lack of a contrast cue (see 120 degree zig-zag condition, Fig. 2). The bandpass impulse response is: $h(t) = (kt/\tau)^n e^{-kt/\tau}[1/n! - (kt/\tau)^2/(n+2)!]$, with $\tau = 0.01$, $k = 2$ and $n = 4$, and $t \in [0, 10]$ frames. The particular choice of these parameters is not crucial to revealing the contrast cue.

As with the original Gabor stimulus, this dot stimulus contains a temporal contrast cue. The cue emerges when, for example, the central dots repeatedly alternate between forward and backward shifts, while the surround dots have a run of shifts in one direction. Just as before, the rapid reversals cause all the dots in one region to repeatedly fall back onto themselves (Fig. 2a) thus temporally integrating to low contrast, while the surround integrates to high contrast. This temporal contrast cue can be eliminated by simply changing the reversal angle, so that reversing dots no longer fall back onto themselves. In the first condition the reversal angle is, for example, 140 degrees, so that repeated reversals yield a zig-zag pattern (Fig. 2b). In the second condition the reversal angle is the same but the sign of each reversal is randomized yielding a random walk pattern (Fig. 2c). In both of these conditions the integration of a region rapidly reversing directions is now largely the

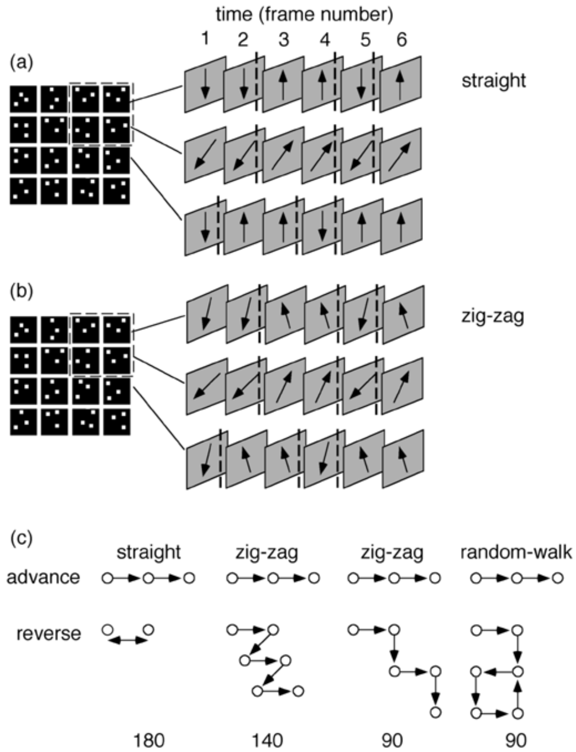

Fig. 2. Temporal properties of the dot stimulus. **(a)** A schematic of a portion of our dynamic dot stimulus. The dots in each window move in random directions, and on each frame the dots either continue along their specified direction, or reverse direction. The reversals of all the dots within the dashed rectangle are synchronized. Shown is the motion sequence of three windows, two are in synchrony and the third is not. The vertical dashed lines mark reversal points. **(b)** In the zig-zag condition, the synchronous motion reversals are preserved while slightly altering the reversal direction. **(c)** Shown are all three motion advance/reversal conditions. The angle of motion reversal is noted below each schematic. While all conditions preserve synchronous motion reversals, only the "straight" condition contains a strong temporal contrast cue.

same as an area repeatedly shifting along the same direction, Fig. 1d (we verified this by passing the various stimuli through a temporal bandpass filter). At the same time, we preserve the temporal synchrony cue that purportedly gives rise to the perception of form.

We asked subjects to judge the orientation of a horizontally or vertically oriented rectangle defined by synchronous motion reversals. When the motion reversal was 180 degrees, performance was nearly perfect, but when the reversal angle was decreased, subjects' performance fell to near chance levels (Fig. 3). Performance in the 140 degree zig-zag condition was slightly above chance because of a slight contrast cue remaining due to the spatial extent of the dots. If, as it has been argued, the perception of form in these displays is a result of grouping mechanisms and processes based on temporal synchrony, then performance should have been unaffected by these relatively minor changes in the angle of reversal. Instead, we find that the perception of form is

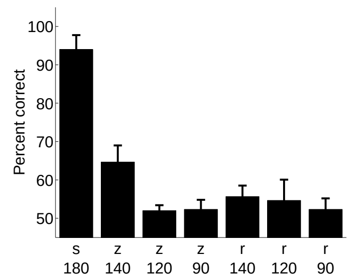

Fig. 3. Experimental results. Shown are subject's ability to judge the aspect ratio of a rectangular figure. The results are the average of three subjects (two naive, one practiced), each bar corresponds to the average across 50 trials per subject, and the error bars indicate one standard error. In the zig-zag (z) and random-walk (r) conditions (Fig. 2c) the reversal sequence was designed so as to e¡liminate the temporal contrast cue present in the straight condition (s). Subject's judgment is at or near chance (50%) when this cue is absent. The angle of motion reversal is noted below each condition. The motion reversals are synchronized in all conditions.

greatly diminished along with the temporal contrast cue. This result in combination with objections[9,10] to the conclusions of grouping by temporal synchrony based upon periodic motion stimuli[1,2] (as opposed to the stochastic stimuli discussed here), provides strong evidence that synchrony is not responsible for the perception of form in these or earlier displays.

Acknowledgments

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11. The dot stimulus consists of 15×15 windows each of size 16×16 pixels. On a black background, white dots generated as 2-D Gaussians with a standard deviation of 2 pixels, afforded subpixel motion. The initial placement of the dots within each window is determined by randomly jittering (by ± 2 pixels) a lattice of dots separated by 8 pixels. On each frame, the dots in each window move randomly (by 2 pixels) forward or backward along their specified direction. The direction of motion across windows is randomized. The stimuli were displayed for 0.75 sec. at 60 frames/sec. on a standard Apple monitor. The stimuli were generated in MatLab and displayed using the Psychophysics toolbox (D.H. Brainard, *Spatial Vision*, 10, 443-446 (1997)). A form cue is introduced by synchronizing the motion reversals of a horizontally or vertically oriented rectangle spanning 7×5 windows. The motion reversals in the surround are synchronized to a separate process. In the random-walk condition the sign of each reversal is randomized from frame to frame and across windows, but within a window, all the dots reverse along the same direction.
12. QuickTime movies of the dot stimuli are available at:
`www.cs.dartmouth.edu/farid/synchrony.html`.