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# The suggestible nature of apparent motion perception

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## Abstract

We introduce a novel class of visual illusion -- *motion pareidolia* -- in which sequential presentations of random textures can trigger percepts of coherent apparent motion. In two experiments we presented observers with sequences of random 140x140 pixel arrays refreshing at 2.5Hz. In Experiment 1, observers were primed with a coherent motion pattern, such as fixed texture shifting up-and-down across frames. After 8 priming frames, the textures became completely random from frame to frame. Participants were instructed to indicate when they could no longer perceive the primed motion pattern. Participants' responses were delayed by an average of 6 frames (or 2.4 seconds). In Experiment 2, observers detected motion patterns in 6-frame sequences under different noise levels and falsely identified coherent motion in 39% of the purely random sequences. To account for this phenomenon, we propose a *selective visual attention* process that is biased to detect expected motion.

**Keywords:** apparent motion, visual illusions

## Background

We tend to think of ourselves as expert pattern recognizers, but our visual system often detects patterns where they do not exist. *Pareidolia* refers to the tendency to detect familiar shapes or patterns in otherwise random stimuli. Famous examples include seeing a face on the surface of Mars (Fig. 1A) or religious figures on toast (Fig. 1B). But even purely random textures, when properly cued, can elicit familiar percepts. For example, it is not difficult to find a hidden face among the pixels of Fig. 1C (even though the pixels were generated randomly). In general, pareidolia tends to be idiosyncratic and is influenced by an observer's suggestibility and sense of control (Whitson & Galinsky, 2008). Here we report a phenomenon we term *motion pareidolia*, in which the sequential presentation of randomly changing textures, such as the one in Fig. 1C, gives rise to illusory percepts of coherent apparent motion. Unlike regular pareidolia, motion pareidolia is experienced by nearly all observers and can be manipulated by suggestion.

Apparent motion is the percept created by two or more sequentially presented images in which one or more salient features shift position across frames (Wertheimer, 1912; Ramachandran & Anstis, 1986). For example, when the two frames in Fig. 1D are presented in alternation at about twice a second, they give rise to a percept of two moving dots

(rather than four asynchronously flashing dots). The direction of motion, however, is ambiguous: depending on how we attend to the display, the dots may appear to move vertically or horizontally. Research has shown that such bistable percepts can be resolved by attention (Ramachandran & Anstis, 1986; Lu & Sperling, 1995; Hsieh et al., 2005). Intriguingly, if we are presented with a collection of such motion quartets across our visual field, how we resolve an ambiguity at the fovea spreads to the rest of our visual field (Anstis & Kim, 2011). Thus, attentional mechanisms may serve to create coherent percepts of motion in otherwise ambiguous scenes.

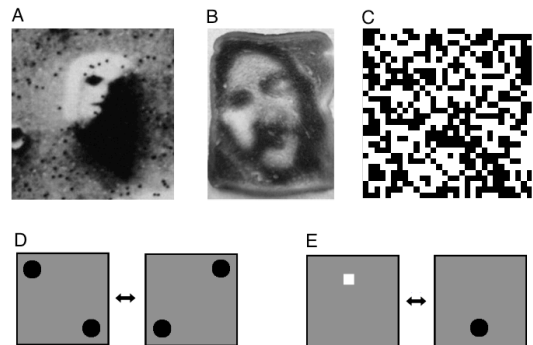


Figure 1: (A) An image of the Cydonia region of Mars taken by the Viking 1 orbiter; (B) a piece of toast; (C) an array of randomly generated pixels. (D) A: Two static images that give rise to directionally ambiguous apparent motion when shown sequentially. (E) Apparent motion is perceived even without low-level feature correspondence across frames.

Moreover, coherent motion can be perceived even when there is no strict correspondence between salient features across frames. Lu & Sperling (2001) delineated three mechanisms for apparent motion perception: a first-order luminance-dependent mechanism, a second-order contrast-sensitive mechanism, and third-order processes that track salient features over time and is sensitive to attention. In third-order motion perception, even if the salient features in a display change in contrast, size, and shape between successive frames, apparent motion will still be readily perceived (see Fig. 1E).

If apparent motion is influenced by attention and is invariant to low-level feature properties, what (if any) are the constraints for a sequence of random images to be

interpreted as coherent motion? Here we present evidence that people systematically perceive coherent apparent motion in the complete absence of coherence between successive images. Specifically, we show that when sequences of random textures (like the one shown in Fig. 1c) are refreshed around twice a second, they consistently elicit illusory percepts of coherent apparent motion. In two experiments, we quantify this phenomenon by measuring *persistence* (the tendency to keep perceiving an entrained motion pattern in random noise) and *false identification* (the tendency to falsely identify a repetitive motion pattern in random noise).

### Experiment 1: Persistence

#### Methods

Participants were 46 UC Santa Cruz undergraduates (76% female, ages 18-21) who gave written consent and received course credit for completing the study. Participants completed 160 trials in which they observed sequences of up to 33 frames of random pixel arrays refreshing at a frame rate of 2.5Hz. The initial 8 frames served to entrain one of 4 repetitive motion patterns: up-down, right-left, up-up, or right-right motion. We generated these motion patterns by shifting a single random pixel array by 4 pixels along one of the cardinal axes across subsequent frames (see Fig. 2-top). The level of noise during these 8 priming frames was set to 20%; that is, in each frame, 20% of pixels were randomized, producing a hazy, but still clearly discernable motion pattern. Beyond the 8th frame, the noise level increased to 100%; all pixels were randomized from frame to frame, until the end of the trial (Fig. 2-bottom). Participants were instructed to fixate on a central cross and press a button when they could no longer perceive the primed motion pattern, at which point the trial ended. In the absence of any illusory perception, we would expect most responses to occur during frames 9 and 10, allowing up to 800ms for individuals to produce the required motor response.

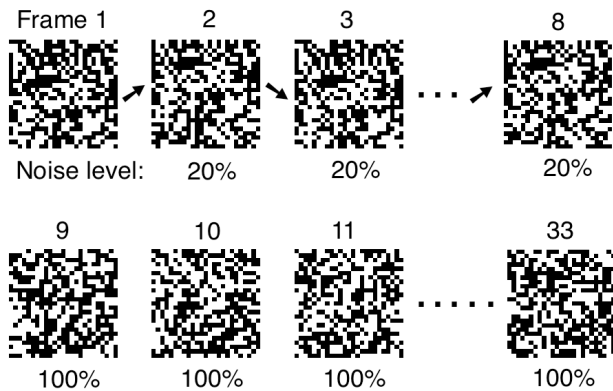


Figure 2: Example frames from a trial of Experiment 1, shown at a resolution of 30x30 pixels for clarity (the actual experimental stimuli were 140x140 pixels). Top row: 8 frames depicting up-down motion as indicated by the arrows, with 20% noise. Bottom row: subsequent 25 frames are purely random, with 100% noise.

### Results

Strikingly, only 12% of responses occurred during the predicted time window; the vast majority of responses (86%) occurred well after the end of the motion prime (Fig. 3A). In fact, the median response occurred during frame 14, a full 6 frames (or 2.4 seconds) after the end of the motion prime. Taking into consideration the reaction time to produce a response, the data suggests participants typically perceived between 4 and 6 frames of illusory motion in each trial before they realized the motion had stopped. There was substantial variability in participants' susceptibility to this illusion. To quantify this, we defined an individual measure of *median persistence* as a person's median response lag, measured in frames from the end of the prime. The distribution of median persistence across participants is shown in Fig. 3B. As the distribution shows, some 24% of participants showed little persistence (3 or fewer frames), while another 28% of participants had a median persistence of above 7 frames.

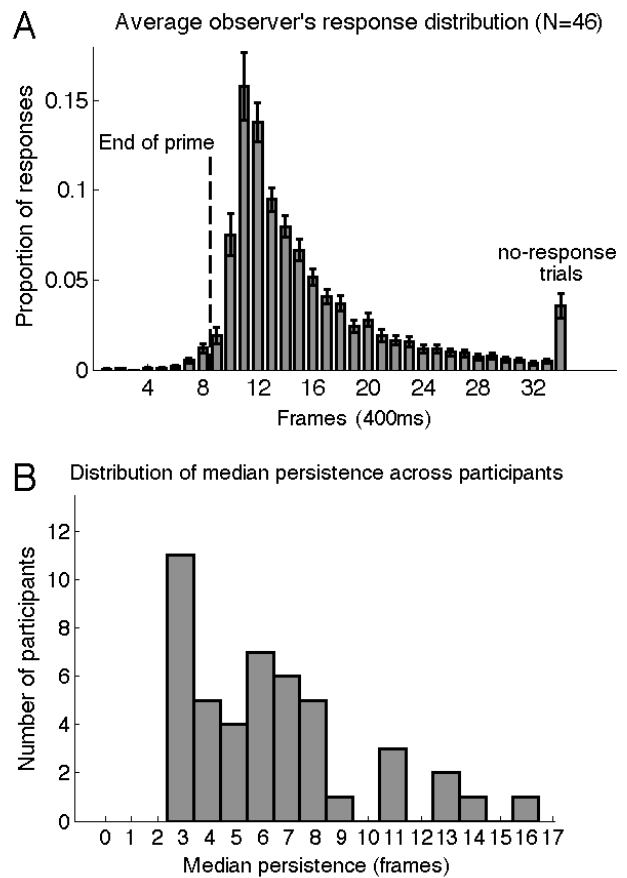


Figure 3: (A) Results of Experiment 1. The distribution of responses averaged over 46 participants, indicating when the primed motion could no longer be perceived. The actual motion pattern ended at the onset of frame 9, but the median response occurred during frame 14. Error bars denote SEM across subjects. (B) The distribution of median persistence scores across participants, measured in frames beyond the end of primed motion.

These results demonstrate that simple motion patterns, such as up-down or right-right motion, can be entrained and subsequently perceived in randomly changing textures. We modeled persistence as an exponential decay function, with a fixed probability  $P$  of persistence from one frame to the next. The best-fit parameter was  $P=0.85$ , indicating that when observers expect to see motion from one random frame to the next, they will indeed see the expected motion 85% of the time. In Experiment 2, we designed a motion identification task to measure motion pareidolia in a more objective task and test whether illusory motion percepts can arise spontaneously, without entrainment.

## Experiment 2: False Identification

### Methods

Participants were 46 UC Santa Cruz undergraduates (61% female, ages 18-22) who gave written consent and received course credit for completing the study. Participants completed 192 motion identification trials in which they were shown 6-frame sequences of random pixel textures refreshing at 2.5Hz, similar to the stimuli in Experiment 1. After each sequence, participants were instructed to click on one of 5 buttons on the screen to indicate whether the sequence depicted one of 4 motion patterns (again, up-down, right-left, up-up, or right-right) or whether the sequence was "random". Across trials, we manipulated the noise level present in each frame, from 0% (pure motion), 33%, 67%, to 100% (pure noise). We measured performance in the motion identification task and the distribution of responses as a function of noise.

### Results

As expected, average performance on the 5-AFC task decreased as a function of noise level: proportion correct ( $\pm$ SEM) was .93 (0.01) at 0% noise, .61 (.02) at 33% noise, and .15 (.01) at 67% noise. But the distribution of responses revealed a more intriguing result. Fig. 4A shows the proportion of "motion" responses (summed across the 4 motion patterns) versus "random" responses, as a function of noise level. Even though participants were nearly perfect (.99) at detecting pure-motion trials as motion, they were only .61 correct at detecting pure-noise trials as random. In other words, participants falsely identified 39% of pure-noise sequences as one of the four motion patterns. As with Experiment 1, there was considerable variability in participants' propensity to falsely identify motion patterns. To quantify this, we defined an individual measure of *false identification rate*, as the proportion of pure-noise trials falsely identified as depicting a motion pattern. As shown in Fig. 4B, there was a wide range of false identification rates across participants, with 11% of participants rarely reporting illusory motion and some 30% of participants reporting motion in the majority of pure-noise trials.

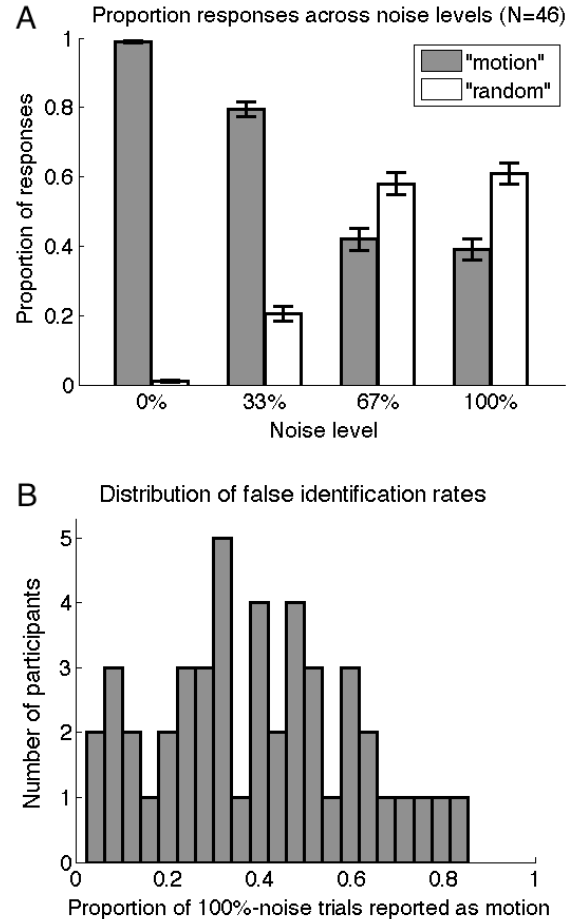


Figure 4: Results of Experiment 2. (A) Distribution of responses across noise levels. Gray bars indicate the proportion of "motion" responses (summed across the 4 types of motion) and white bars indicate the proportion of "random" responses. The proportion of motion responses remains relatively high (.39) even during 100%-noise trials. Error bars indicate SEM across subjects. (B) The distribution participants' false identification rates (i.e. the proportion of 100%-noise trials reported as one of the 4 motion patterns).

## General Discussion

The results of Experiments 1 and 2 demonstrate that sequential presentations of random textures can give rise to illusory percepts of coherent apparent motion. The specific motion pattern that is perceived by an individual can be entrained with a motion prime, or it can arise spontaneously when the observer expects to see certain motion patterns. The phenomenon is robust, experienced by most naive observers across two very different experimental paradigms, and the illusion was vivid. In fact, many of our participants were incredulous that they had been experiencing illusory motion until we demonstrated to them that they the direction of the perceived motion during the random frames could be changed by instruction, or even by volition. What mechanisms might explain motion pareidolia, and what functions might it serve?

We argue that motion pareidolia *cannot* be explained as a type of motion adaptation. Normally, adapting to motion in one direction produces illusory motion aftereffects in the opposite direction (for example, watching a waterfall for 30 seconds will cause a stationary scene to appear to move upward; see Culham et al. 2000). Instead, the illusory motion percepts reported in the current studies were always in the same direction (or following the same alternating pattern) as the primed motion patterns. If motion adaptation were driving these illusory percepts, being primed with up-up motion would have led to perception of downward motion, rather than persistence of upward motion.

Another possibility is that motion pareidolia could result from local resolutions of ambiguous motion cues at the center of the visual field. For example, when focusing on a small cluster of pixels, one might interpret a white pixel changing into a black pixel as consistent with motion in some direction. An attention-driven ambiguity resolution at the fovea might spread into a global percept of motion (Anstis & Kim, 2011). To test this possibility, we conducted a follow-up to Experiment 1 with 65 new participants, in which a static gray disc masked the central 7 degrees around fixation throughout the experiment. The pattern of results was nearly identical to Experiment 1 (median persistence = 6 frames;  $P=0.86$ ), indicating that motion pareidolia can operate entirely in the visual periphery, without input from the fovea.

We propose that motion pareidolia is best characterized as a top-down process in which visual attention is biased to confirm expectations of motion. When an observer anticipates seeing upward motion from frame 1 to frame 2, visual attention is drawn to regions of frame 2 that are consistent with upward motion from frame 1. Previous work has shown that attentional processes can resolve ambiguous correspondences in apparent motion (e.g., Lu & Sperling, 1995). Our displays, which were entirely random, provided statistically equivalent evidence for (or against) any type of motion across subsequent frames. By attending to pixel clusters that appear to shift in the predicted direction (while ignoring pixel clusters that do not), our visual system tricks itself into seeing the motion we are expecting to see. Further work is needed to test the predictive power of this selective attention model.

Many properties and constraints of motion pareidolia remain to be explored. For example, our experiments used 140x140 pixel displays refreshing at 2.5Hz, as these parameters produced strong effects in pilot studies. Reports of illusory motion were weaker with much bigger or smaller pixel arrays (regardless of the visual angle they subtended) or when the frame rate was faster than 4Hz or slower than 1Hz. It is still unclear exactly how motion pareidolia is affected by frame rate and display resolution, or whether these factors interact. In our experiments, we entrained simple motion patterns, such as up-down or right-right motion, with a repetition cycle of at most two frames. Future studies may investigate the complexity of motion patterns that can be entrained and subsequently maintained.

Finally, our data indicated large individual variability in the propensity to report illusory motion, with some individuals rarely reporting it and others reporting it in the majority of trials. What are individual factors that distinguish *high-perceivers* from *low-perceivers*? Past research in static pareidolia (Whitson & Galinsky, 2008) implicates a role of suggestibility and sense of control (or lack thereof). Given the spatiotemporal nature of apparent motion processing, predictors of motion pareidolia may also include individuals' visual attention and short-term visual memory capacity.

## Conclusion

Motion pareidolia can be thought of as the propensity to see expected motion patterns in random noise, or alternatively as the failure to detect randomness when expecting motion. Whichever way it is construed, motion pareidolia demonstrates a remarkable bias in our apparent motion perception system to see motion when there is none there. One can speculate about whether over-interpreting visual noise as coherent motion may serve an adaptive purpose. Carl Sagan once suggested that there may be an evolutionary advantage to over-interpret ambiguous patterns as faces: "Those infants who a million years ago were unable to recognize a face smiled back less, were less likely to win the hearts of their parents, and less likely to prosper. These days, nearly every infant is quick to identify a human face, and to respond with a goony grin" (Berenbaum, 2009). In the case of motion pareidolia, it may be safer to assume that a random flicker behind a bush indicates the movement of a potential predator and be wrong, than the other way around.

Regardless of its origins and potential functions, motion pareidolia may provide a useful tool for neuroscientists studying top-down mechanisms of vision. It is known that apparent motion recruits similar cortical mechanisms as smooth motion (Goebel et al., 1998) and that signals in these cortical regions are directionally sensitive (Muckli et al., 2005). Since motion pareidolia is driven by the expectations of the observer (rather than by image properties), neural correlates of motion pareidolia will likely reflect top-down mechanisms initiated by our high-level expectations.

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