

Is it just motion that silences awareness of other visual changes?

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When an array of visual elements is changing color, size, or shape incoherently, the changes are typically quite visible even when the overall color, size, or shape statistics of the field may not have changed. When the dots also move, however, the changes become much less apparent; awareness of them is “silenced” (Suchow & Alvarez, 2011). This finding might indicate that the perception of motion is of particular importance to the visual system, such that it is given priority in processing over other forms of visual change. Here we test whether that is the case by examining the converse: whether awareness of motion signals can be silenced by potent coherent changes in color or size. We find that they can, and with very similar effects, indicating that motion is not critical for silencing. Suchow and Alvarez’s dots always moved in the same direction with the same speed, causing them to be grouped as a single entity. We also tested whether this coherence was a necessary component of the silencing effect. It is not; when the dot speeds are randomly selected, such that no coherent motion is present, the silencing effect remains. It is clear that neither motion nor grouping is directly responsible for the silencing effect. Silencing can be generated from any potent visual change.

Introduction

Suchow and Alvarez (2011) showed a powerful demonstration of how motion can silence awareness of other concomitant changes to an array of features. For instance, an array of randomly colored dots that are very obviously changing color apparently cease to change color if they are simultaneously rotated around the fixation point. Motion can similarly “silence” awareness of changes to the size, luminance, or shape of the features from which the array is constructed. Suchow and Alvarez show that the effect is dependent on the speed of the motion, and it has since been shown that the effect also depends on the crowded nature of the arrays of dots (Turi & Burr, 2011). The effect

appears to demonstrate a dominance of motion in our perceptual awareness. Similar effects, such as motion-induced blindness (Bonneh, Cooperman, & Sagi, 2001), in which subjects fail to see some objects entirely when other objects are present and moving in the visual scene, might support such a theory of motion being a dominant signal.

On the other hand, the effect might simply represent the dominance of any highly visible change in the scene over another less-conspicuous change. In the color version of the Suchow and Alvarez display, subjects must detect the rate of color change, and in this dimension (let us call it the “task”), the scene changes in an incoherent manner; all elements have a different color and change independently, so that one dot is transitioning red > blue, whereas another is changing blue > green, and so forth. Conversely, the motion of the dots (which we might consider the distractor dimension) was entirely coherent; all dots moved in the same direction with the same radial velocity. Thus, another possibility is that the silencing effect is not dependent on motion per se but on coherent changes, which might dominate over noncoherent changes in the scene.

Saiki and Holcombe (2012) have shown that coherent color changes in a display of moving dots are substantially more detectable than incoherent color changes. In their study, half of the dots in an array were moving left and half moving right; half were red and the other half green. If a coherent color change is introduced (all the leftward-moving dots switch from green to red, whereas all the rightward dots change red to green), then the switch is easily detected. However, when an incoherent change was applied (the leftward dots are half green and half red as are the rightward dots, so that the switch does not alter the summary statistics for either population), performance in detecting the switch was poor. The data suggest that the coherence of change in the task dimension can be important in determining whether change is detected.

There is also evidence to suggest that coherent structure in the distractor dimension can affect per-

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ceived changes in a stimulus. Poljac, de-Wit, and Wagemans (2012) have shown that color changes in a dot array are less apparent if the dots are organized into a spatially coherent pattern, such as a human body shape, even when that array is spatially static. When the array moves simulating biological motion, the silencing effect is a factor of four greater but only a factor of two greater if the biological motion figure is inverted (Poljac et al., 2012). These data indicate a potential role for grouping in the Suchow and Alvarez (2011) effect.

We sought to separate the importance of motion and coherence/grouping in the silencing illusion. To test for the necessity of motion, we tested whether some other form of dynamic coherent changes can produce silencing effects (Experiments 1–3). To investigate the necessity of coherence, we sought a silencing effect similar to that of Suchow and Alvarez (2011) but using incoherent dot motions (Experiment 4).

Methods

Subjects

Five participants (four men, one woman) took part in the study. One of these was the author. One was aware of the aims of the study (had seen data from a pilot version) but was not involved in it. The remaining three observers were naïve to the aims of the study.

Apparatus and stimuli

Stimuli were presented by an Apple Mac Pro computer (2x3 GHz quad core processors, running OSX 10.5.8, Apple, Inc., Cupertino, CA) on a cathode ray tube screen (Iiyama Vision Master Pro 513, 1280 × 1024 at 85 Hz, Iiyama, Hoofddorp, The Netherlands). The monitor was gamma-corrected using a photo-spectrometer (Photoresearch PR655, Photo Research Inc., Chatsworth, CA). Stimuli were generated and controlled in real time by PsychoPy v1.73 (Peirce, 2007), using a modified version of the ElementArrayStim. Full source code to use these stimuli and run the experiment, and also to perform the complete analysis on the raw data, is available from <http://opsciencframework.org/project/nqWSs/>.

The stimulus layout can be seen in Figure 1. On each trial, two fields of 300 circular dots (each with a diameter of 0.5° visual angle) were presented. The fields had dimensions of 20° (H) × 4° (W) visual angle high with a smooth Gaussian fringe (*SD* of 1°) applied to the top and bottom, such that subjects would not notice dots leaving and entering the field. Fixation was maintained on a black circular point with diameter of 0.1°. Stimuli in

all trials were presented for 1.5 s, although the observer could terminate a trial and move onto the next trial at any point by making their response. There was an intertrial interval of 500 ms. The fixation point remained visible for the entire experiment.

Procedure

In all variants of the experiment, the dots in both fields were altered frame by frame in some dimension (e.g., color), and the participant was asked to report which field was changing more rapidly in that dimension. This is referred to as the “task” dimension. In addition, there was a change along some dimension (e.g., a motion) applied to one of the fields (*distractor*) but not the other (*comparison*). The location (L/R) of the fields was determined randomly on each trial. The rate of change in the task dimension was manipulated in the *comparison* field according to a 1-up, 1-down adaptive staircase designed to home in on the point of subjective equality. In all conditions, the staircases began with step sizes of 0.2 log units, reducing by half at each reversal, until the fourth reversal, when they remained at 0.025 log units. Each staircase ran for 40 trials, and the final six reversals were averaged as a measure of the perceived rate of dimension change in the *distractor* field. In most of the experiments, we compared the effects of three different rates of distractor changes. These conditions were controlled by six independent staircases, two for each distractor rate, starting at half and double the veridical point of equality. The 40 trials from these six conditions were interleaved to create a run of 240 trials. In each experiment, two runs were collected, and the estimated points of subjective equality from the four resulting staircases were averaged. Runs from the different experiments were interleaved pseudo-randomly. The only exception to this was the final condition of the final experiment, which was collected separately as a single run of four staircases.

Experiment 1: Color task with motion distractor

This version of the study was included to verify that we could replicate the silencing effect using our modified simultaneous two alternative-forced-choice (2AFC) staircase procedure, where Suchow and Alvarez (2011) used a method of adjustment with alternating intervals and a single circular annulus of dots.

Dots in the *distractor* field moved with a speed of 2°/s, 4°/s, or 8°/s in the three conditions, either all upward or all downward (the direction was randomly selected on each trial). This is slower than Suchow and Alvarez’s (2011) maximal speed; they used rotational speeds of up to 120°/s around an annulus with mean

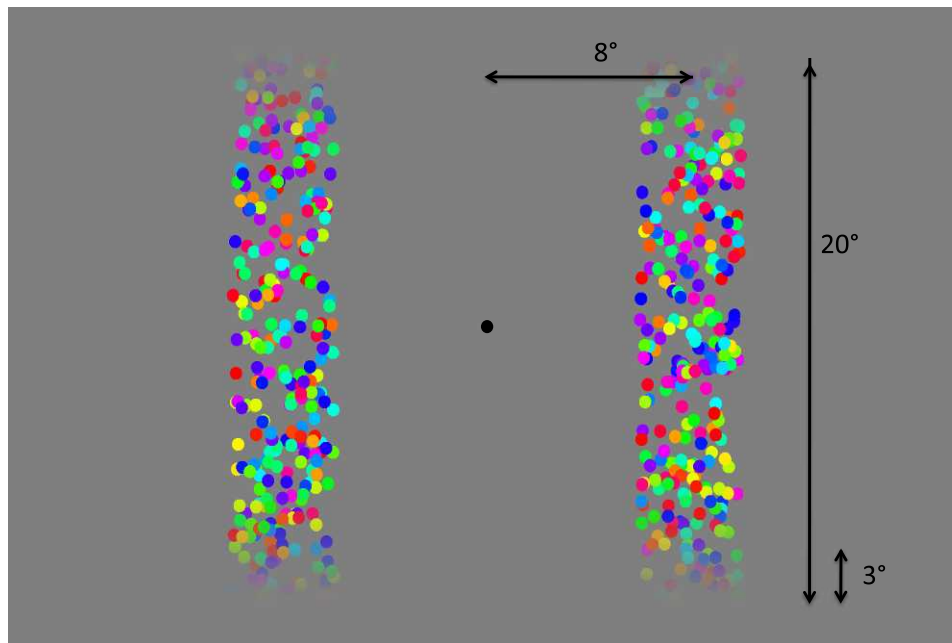


Figure 1. Stimulus configuration. Stimuli in all versions of the study had the same spatial configuration, as above. Judgments were made about in which array (left or right) the dots were changing most rapidly in some task dimension, such as color or location. Each array contained 300 dots, with dot diameters of 0.5° . Dot motions were always vertical. A Gaussian blur was applied to the top and bottom edges of the array to reduce awareness of the dots entering or leaving the field. In all cases, degrees refer to degrees of visual angle on the monitor.

radius of 6.5° visual angle, giving an equivalent linear velocity of roughly $13.6^\circ/s$.

The dots in both fields were given a random initial color (chosen from a continuous uniform distribution over the whole range). As with Suchow and Alvarez (2011), the hue-saturation-value (HSV) color space was used, and each dot started with a random hue, with saturation = 1 and value = 1. The dots in the *distractor* field cycled through the color space at a rate of 0.5 Hz ($180^\circ/s$ change in hue value). This is more rapid than Suchow and Alvarez, who used a color change rate of 0.2 Hz ($75^\circ/s$). The dots in the *comparison* field altered their hue at a rate determined by the subjects' responses.

It should be noted that although the dots are moving in the same direction according to this arbitrary color space, in any other color space (e.g., RGB or DKL space), the direction and rate of change in the dots is irregular. The percept is certainly that the dots are changing color in an incoherent manner with no general pattern to the change. This, and the effect of the motion silencing on the stimulus, can be seen demonstrated in Movie 1.

Experiment 2: Motion task with color distractor

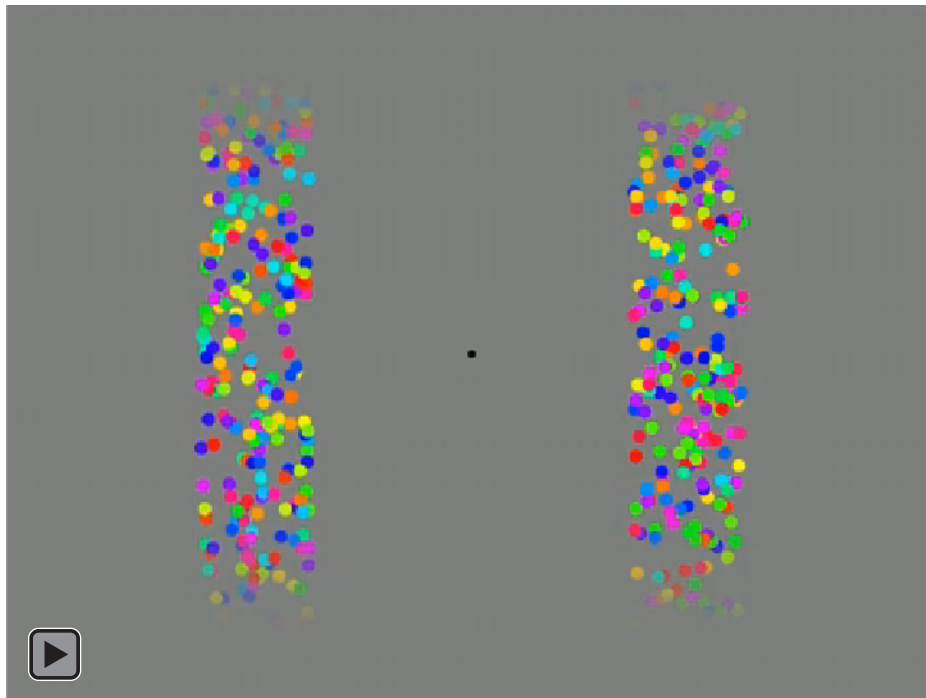
This tested one converse variant of the silencing effect, testing whether intense, coherent color changes can silence incoherent dot motion.

Dots in the *distractor* field all started off with a red hue (HSV = [1,1,1]) and cycled through the hues in the color space coherently at a rate of 1, 2, or 4 Hz. Each dot in both fields was given a random direction (up/down) but the same speed, which was $0.5^\circ/s$ in the *distractor* field and altered according to the staircase procedure in the *comparison* field. A demonstration of the effect can be seen in Movie 2.

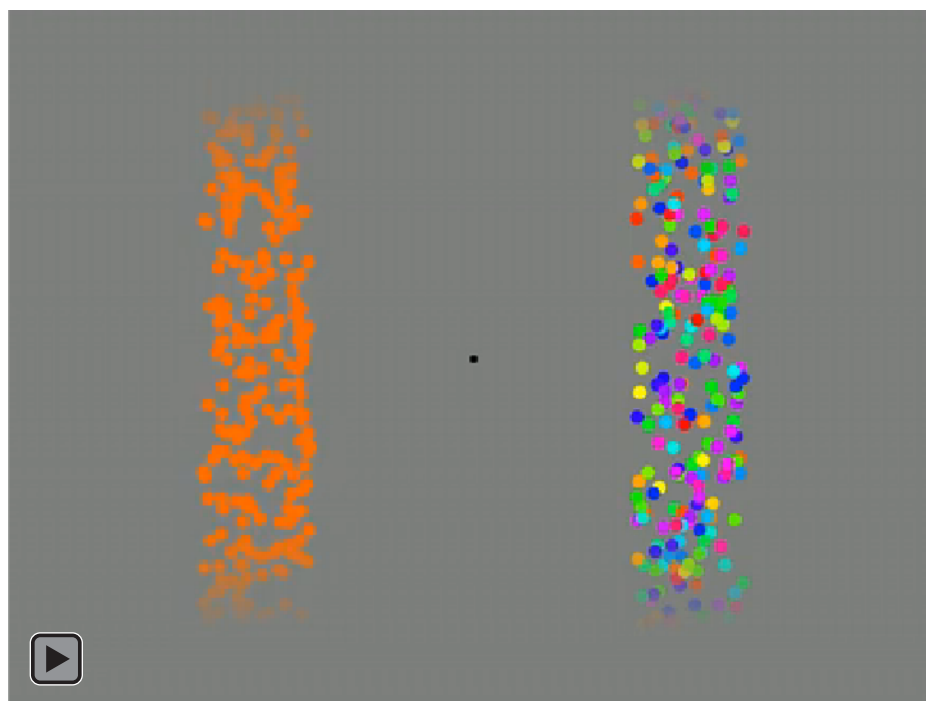
Experiment 3: Motion task with size-change distractor

This tested another converse variant of the silencing effect, testing whether intense, coherent dot size changes can silence incoherent dot motion.

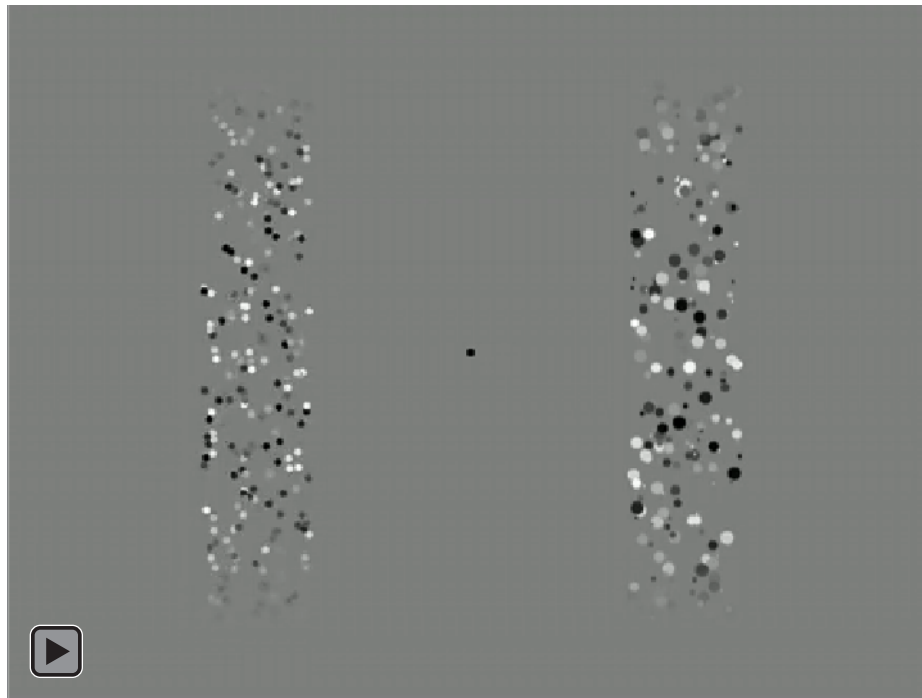
Dots in the *distractor* field varied their size sinusoidally 0.1° to 0.5° diameter, coherently at a rate of 1, 2, or 4 Hz. Each dot in both fields was given a random direction (up/down) but the same speed, which was $0.5^\circ/s$ in the *distractor* field and altered according to the staircase procedure in the *comparison* field. To prevent any luminance artifact as the dots changed size, each dot was given a random luminance. Because the monitor had been gamma-corrected, both dot fields had a mean luminance that matched the mean luminance of the screen. A demonstration of the effect can be seen in Movie 3.



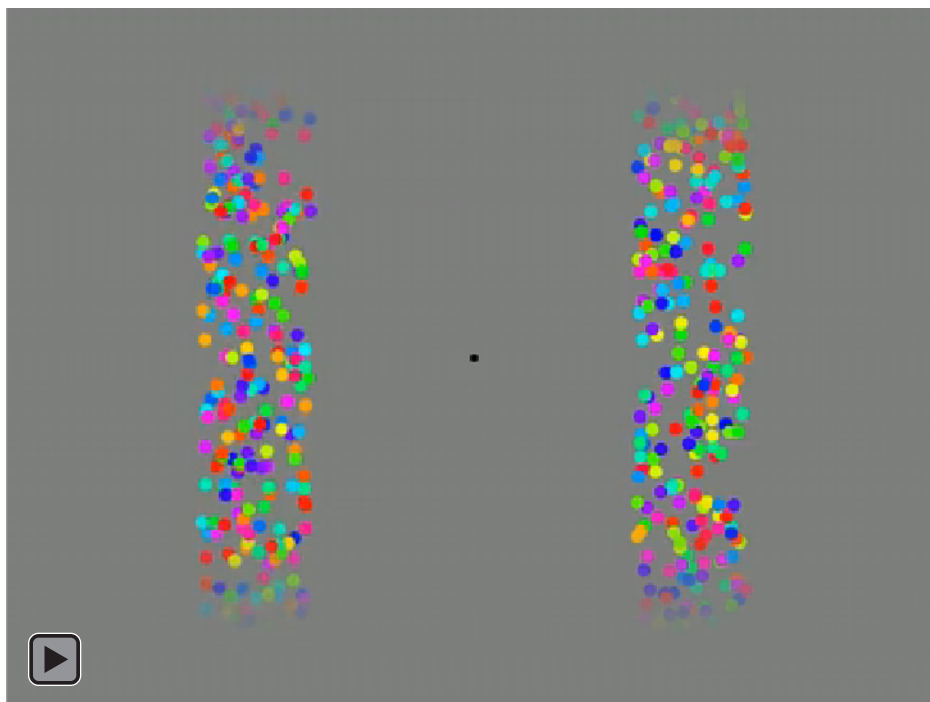
Movie 1. The standard effect of motion silencing awareness of color changes, converted to use a 2AFC task and a rectangular element array, rather than an annulus. In this demonstration, the color is changing in both fields at a rate of 0.5 Hz (0.5 cycles of HSV color space per second). The color changes are harder to detect in the array that also moves (left of fixation).



Movie 2. A demonstration of the converse effect, in which coherent color changes reduce awareness of the dot motions. In this demonstration, the dots in the two fields are moving with identical speeds. In the distractor field (left of fixation), the dots are also changing color at a rate of 2 Hz (cycles of the HSV color space per second). The motion is harder to detect in the distractor stimulus.



Movie 3. A demonstration of another reverse silencing effect, in which coherent size changes reduce awareness of the dot motions. In this demo, the dots in the two fields are moving with identical speeds. In the distractor field (left of fixation), the dots are also oscillating between large and small at a rate of 4 Hz. The motion is harder to detect in the distractor field.



Movie 4. A demonstration of the effect using incoherent motion signals. In this demonstration, the color is changing in both fields at a rate of 0.5 Hz. The speed of each distractor dot is drawn from a uniform random distribution. The color change is harder to detect in the array that contains the incoherent motion (left) than the static array (right). This silencing effect is as strong as for entirely coherent motion (see Movie 1).

Experiment 4: Color task with incoherent motion distractor

This experiment tested whether the silencing reported by Suchow and Alvarez (2011) was dependent on the motion of the dots within their array being coherent. The experiment was identical to that in Experiment 1, using a color change as the task and dot motion as the distractor, but dots were randomly assigned to move either up or down to break the coherence. In keeping with Experiment 1, we tested three dot speeds (2, 4, and 8°/s) to test the dependence of the effect on distractor speed. Although that maximally maintained similarity with the previous experiments, it could be that it did not sufficiently break the coherence; the distractor field could be perceived as *two* coherent fields of dots simply moving in opposite directions. To control for this, we tested a further condition in which the dots were assigned a random speed from a uniform distribution as well as a random direction (up/down). This ensured no coherent groups of dots would be seen in the display. A demonstration of the effect can be seen in Movie 4.

Results

Experiment 1: The color task with a motion distractor

The clear effect of the work of Suchow and Alvarez (2011) was very easily replicated despite a number of modifications to the original paradigm (notably the use of a spatial 2AFC task and linear rather than radial motion). We found a clear effect of the distracting motion on the awareness of the color changes in the dot array (see Figure 2). At the highest distractor speeds, we perceive dots that are actually rotating through the HSV color space at 180°/s to be changing at a rate of only 52.8°/s. This, in Suchow and Alvarez's terms, is a "silencing factor" of 3.6, which appears comparable to their measurement of the effect.

Experiment 2: The motion task with a color distractor

More surprisingly, there was also a clear effect of coherent color changes preventing observers from being aware of dot motion (see Figure 3). The pattern of the results was identical with a small degree of silencing at relatively slow color change rates and a very potent effect for rapid color changes. For the most potent distractors, dots with an actual speed of 0.5°/s

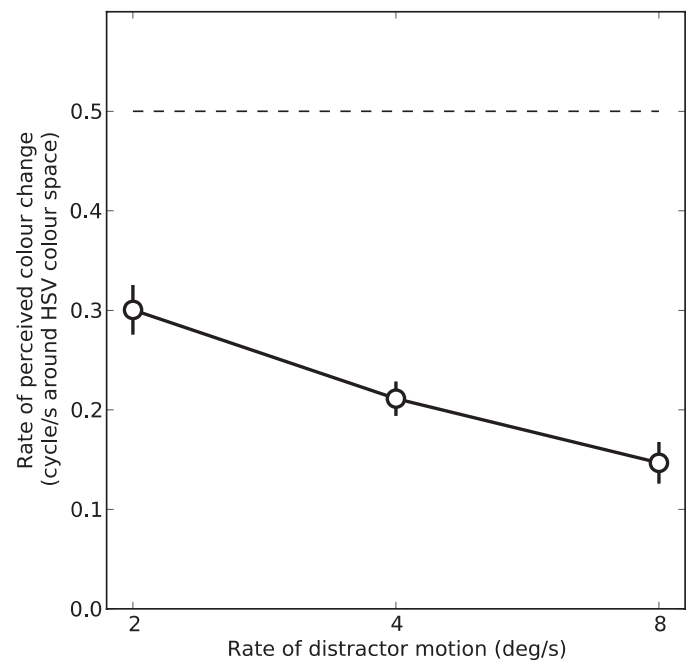


Figure 2. The effect of dot motion on awareness of color change. The data show the perceived rate of color change (point of subjective equality with a static reference stimulus) resulting from the dot motion at a range of speeds. The dashed line gives the actual rate of color change for the dots. All data fall substantially below this line, and the effect also depends on the speed of the distracting stimulus. Error bars represent ± 1 SEM across five observers.

were perceived to move at a speed of 0.16°/s, a factor of 3.12 reduction in perceived speed.

Experiment 3: The motion task with a size-change distractor

We also tested the effect of coherent size changes on the perception of motion and found a similar result (see Figure 4). In fact, this was larger than the previous two effects, with an actual dot speed of 0.5°/s having an apparent speed of only 0.08°/s (a factor of 6.2 reduction).

Note that in the color-changing experiment, there would have been a net luminance change across the stimulus because the HSV color space is not controlled to be isoluminant. In this size-changing version of the stimulus, all dots were given a random luminance, and the monitor had been gamma-corrected, such that the net luminance of the stimulus did not alter during the presentation period. The potential strobe effect that can result from these rapid changes is not, therefore, responsible for the silencing of motion perception that we have observed.

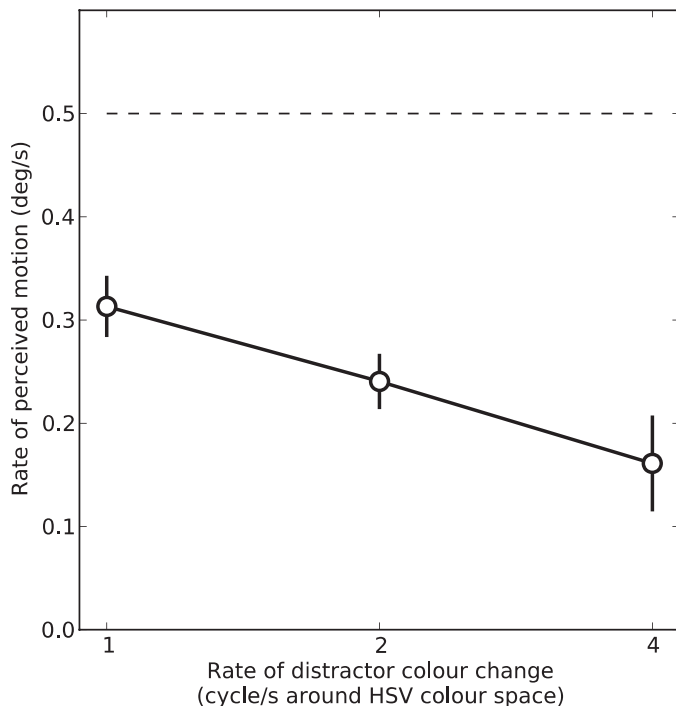


Figure 3. The reverse effect of dot color changes on awareness of motion. The silencing effect remains, with color changes reducing the perceived rate of motion of a set of dots. The dashed line gives the actual rate of motion. All data fall substantially below this line, and the effect also depends on the rate of change in the distracting stimulus. Error bars represent ± 1 SEM across five observers.

Experiment 4: The color task with an incoherent motion distractor

Thus far, all of the experiments in this series, as well as in Suchow and Alvarez's (2011) work, have used coherent changes as a distractor. To test whether that coherence is necessary for the silencing effect to be observed, we repeated our initial replication of the Suchow and Alvarez effect but with dots that were randomly selected to move either upward or downward to break the overall coherence of the dot motion. We find the same effect as in the previous versions of the task with a potent, speed-dependent effect of the distractor (see Figure 5). For the fastest-moving dots, the color was perceived to change at $30.7^\circ/\text{s}$ when the actual rate of change had been $180^\circ/\text{s}$ (a factor of 5.86 reduction).

This might have been explained by the fact that in order to measure a speed-dependence curve in keeping with the previous conditions, dots all had the same speed and only one of two directions. In effect, rather than breaking coherence, we might have created a pair of coherent sets of dots traveling past each other. As an additional test, we used dots that took a random speed

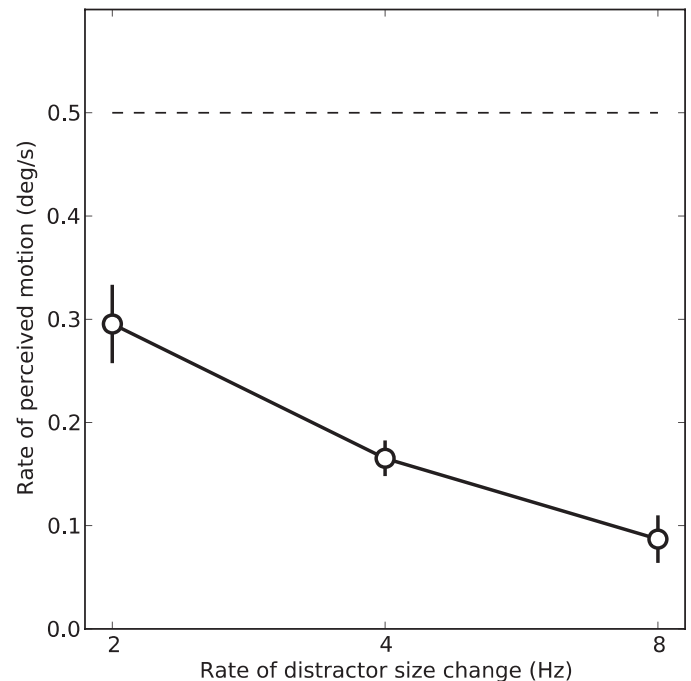


Figure 4. The effect of dot size changes on awareness of motion. The silencing effect is, again, pronounced, with an actual speed of $0.5^\circ/\text{s}$ being perceived as a speed of $0.1^\circ/\text{s}$. The dashed line gives the actual rate of motion. All data fall substantially below this line and, as with previous demonstrations, the effect also depends on the rate of change in the distracting stimulus. Error bars represent ± 1 SEM across five observers.

(from a continuous uniform distribution from $8^\circ/\text{s}$ upward to $8^\circ/\text{s}$ downward) such that no two dots have the same speed. Although some residual grouping may remain from the fact that dots are arranged as a rectangular field, it is greatly reduced by this manipulation, as can be seen by comparing the motions in Movie 1 and Movie 4. We found an almost identical silencing effect to the fastest of the coherent motion conditions, with a perceived color change rate of $33.3^\circ/\text{s}$ (a factor of 5.45 reduction). Thus, although there is clear evidence that grouping without motion can give rise to some degree of silencing (Poljac et al., 2012), it appears not to be necessary.

Discussion

The studies above set out to determine whether motion is really necessary for the silencing effect discovered by Suchow and Alvarez (2011; Turi & Burr, 2011). A number of changes that were made to the experimental design—notably, a switch to linear motions from rotational, a 2AFC task, and less

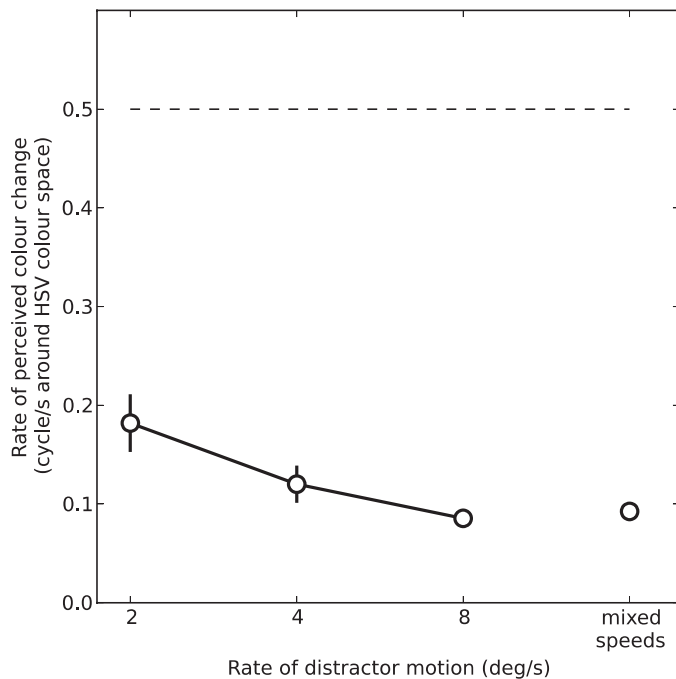


Figure 5. The effect of *incoherent* dot motion on awareness of color change, testing the necessity of coherence in silencing. The data show the perceived color change of dots that are also moving at a range of speeds. Each dot moved at the given speed either upward or downward in the field. As a further test of coherence, in the mixed speed condition, dots were given a random speed and direction (a continuous uniform distribution ranging from $8^\circ/\text{s}$ upward to $8^\circ/\text{s}$ downward). As with previous conditions, a profound effect was observed, indicating that coherence is also not necessary for silencing to occur. Error bars represent ± 1 SEM across five observers (the error bars are occluded by the data symbols in some conditions).

extreme speeds—but the effect was clearly very robust to these changes. We find a potent silencing in which participants perceived the dot array stimulus to be changing color at less than half its actual rate of change. In keeping with Suchow and Alvarez, this was dependent on the rate of change in the distractor, with faster motions giving greater silencing. Subsequent experiments aimed to test the necessary conditions for the silencing to have occurred.

In Experiments 2 and 3, we measured a pair of converse effects in which the awareness of motion was silenced by coherent color changes of the dots or by coherent size changes. These effects of motion being silenced by other dynamic changes revealed similar potent silencing, with the dots having an apparent speed as little as one-fifth their actual speed.

The effect cannot be attributed to any apparent motion effect, such as phi or beta motions (Anstis, 1970; Bonneh et al., 2001; Steinman, Pizlo, & Pizlo, 2000; Wertheimer, 1912), counteracting the genuine motion of the dots. To generate such an apparent

motion, the dots would need to change color out of phase (for example, one dot changing *from* blue as a nearby dot changed *toward* blue). In Experiment 2, using color change as the silencing dimension, the dots changed uniformly and simultaneously, such that no apparent motion was generated. When size was used as a silencer (Experiment 3), each dot kept the same color, and so, again, no apparent motion was present. The effect with the color silencer might, potentially, be attributed to some luminance strobe artifact that obscured all motion signals, because the HSV color space we used does not keep the dots at a constant luminance. That would not, however, explain the effect in the size-change version of the effect; in that case, the luminance of each dot was chosen randomly, with an average that matched the luminance of the screen. One might contest that the size changes introduced a small amount of motion *noise* because the edges of the dots, as they expand and contract, are essentially moving. To show that this is not sufficient to explain the effect, I provide a further movie (Supplementary Movie S1) that is identical to the demonstration in Movie 3, except for having one-tenth the dot density. The signal-to-noise ratio of the motions is identical, being determined by the rate of motion versus the rate of size change, not by the number of dots. Therefore, any effect of the motion noise should be the same in Movie 3 and Supplementary Movie S1. On the other hand, if the effect were caused by silencing, of the type described by Suchow and Alvarez (2011), then we do expect it to be dependent on dot density (Turi & Burr, 2011). It should be clear from Supplementary Movie S1 that the effect is substantially reduced, in keeping with a silencing effect rather than motion noise.

Although it seems clear that motion is not *necessary* to produce silencing, one might still argue that it is *superior* in producing silencing if, for example, the effect were seen for slower motion distractors than the equivalent color- or size-change distractors. Certainly, in all the cases tested, there was a dependence on the rate of change of the silencing stimulus. It is unclear, however, how one would equate them in order to compare potency across domains. Qualitatively, in all cases, the changes in the *task* dimension were relatively slow but comfortably suprathreshold, and in all cases, the point at which almost complete silencing is experienced when the *silencing* changes is rapid and very salient. This is also the case in the silencing demonstrated by Suchow and Alvarez (2011); their dot motion (the distracting dimension) was slightly faster than used here and the rate of color change (task dimension) slightly slower. Although there is no clear way to compare the relative intensities of a motion signal with a color/size change, there seems to be no reason to think that motion signals are qualitatively different from other signals in producing silencing.

The fourth experiment tested whether the silencing effect could be explained simply in terms of coherence or grouping signals. It might be simply that coherent changes (all dots moving together in the same direction) override incoherent changes (dots changing to different colors). Poljac et al. (2012) have shown that silencing effects can be induced even in static stimuli if the dots are formed into a coherent figure, such as a human form. Those effects are somewhat weaker than the effects produced by motion signals, but if we are to postulate Gestalt grouping as the cause for the effect, this might simply indicate that motion signals give rise to particularly strong grouping. To test the importance of grouping in the silencing effect of Suchow and Alvarez (2011), we have used a motion stimulus but removed the coherence by having dots move in different directions and/or speeds. Some residual perceptual grouping may occur between individual pairs of neighboring dots that happen to have similar speeds, but it is very substantially reduced. When this incoherent motion was used as a distractor, the silencing remained at least as strong as when the motion was perfectly coherent, with very pronounced grouping signals.

Taken together, the results indicate that neither motion nor coherence is *necessary* to generate silencing of awareness to change. The question remains as to what causes the effect. Potentially, the effects are caused by attentional modulation. The most potent silencing occurred when the changes in the silencing dimension are very intense, and these would certainly capture attention. Effects of attention on motion perception have previously been reported, although these have typically used *endogenous* attentional shifts, in which the subject is deliberately attending to some other stimulus characteristic to perform another task (Allen & Ledgeway, 2003; Ho, 1998; Poljac et al., 2012; Sahraie, Milders, & Niedeggen, 2001). Even then, the effects tend to be stronger for second-order motion signals with only weak or nonexistent attentional effects on first-order (luminance-based) motion signals (Allen & Ledgeway, 2003). In our tasks, the subjects were instructed that the silencing stimulus characteristic was to be ignored and so any attentional effects would be caused by exogenous attentional shifts always to first-order stimulus changes and are likely to be relatively small.

It might be simply that the effect arises in situations in which there is high confusability between individual dots that reduce the ability of the visual system to track the changes. This might also explain why the effect is dependent on the degree of crowding (Turi & Burr, 2011); a dense array of dots will increase the confusability between elements. Subjects in the present study certainly report that they felt the task was easier in trials in which they were able to isolate a single dot to

track. At an extreme level, it might be that the motion of dots becomes so fast that they become indistinguishable. This was clearly not the case at the speeds used here, however.

The explanation that Suchow and Alvarez (2011) themselves propose is that the limited spatial extent of the receptive fields of visual neurons might prevent the effective tracking of elements moving at high speeds because they spend too little time in any one receptive field. In our case, the motions were relatively slow and were silenced by other (rapid) changes within the spatial extent of the receptive fields. By extending their notion slightly to consider the limited *spatiotemporal* extent of the receptive fields, however, we might use a similar explanation. Each dot at these speeds remains spatially within the receptive field for a prolonged period, but if the rate of color (or other) change is too rapid for the temporal integration window of the neurons, then tracking of the dot as a single entity may not be possible.

A quantitative, mechanistic account of the Suchow and Alvarez (2011) effect has been developed by Choi, Bovik, and Cormack (2012) in which the combined chromatic and spatial changes in the dots result in a breakdown of structure in a space-time representation of the stimulus. Their model captures very nicely the Suchow and Alvarez effect, and such a model might well also be applied to the reverse effects described here.

Conclusions

It is clear that neither motion nor coherent changes are necessary to generate silencing effects. It appears that any potent visual change is capable of silencing weaker dynamic signals. The mechanism by which that occurs, however, remains unknown.

Keywords: pattern motion, complex stimuli, color, illusions, grouping, attention

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