EFFECTS OF TEMPORAL AND SPATIAL SEPARATION ON VELOCITY AND STRENGTH OF ILLUSORY LINE MOTION

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Abstract

Effects of line length and of spatial or temporal distance between the cue and the line on perceived velocity and on perceived strength of illusory line motion (when a stationary line is perceived as unfolding or expanding away from a previously presented stationary cue) were examined in four experiments. Ratings of perceived velocity decreased with increases in stimulus onset asynchrony between appearance of the cue and appearance of the line (from 50 to 450 milliseconds), whereas ratings of perceived strength increased with increases in stimulus onset asynchrony (from 50 to 250 or 450 milliseconds). Ratings of perceived velocity increased with increases in length of the line, whereas ratings of perceived strength were not influenced by increases in length of the line. Ratings of perceived velocity and ratings of perceived strength were not influenced by increases in distance of the near end of the line or the far end of the line from the cue. Implications of the data for theories of illusory line motion that involve an attentional gradient or apparent motion are discussed.

In illusory line motion (ILM), a cue appears, and shortly thereafter, a stationary line appears (e.g., Downing & Treisman, 1997; Fuller & Carrasco, 2009; Hikosaka et al., 1993). The entirety of the line is presented simultaneously, but observers perceive the line to be presented sequentially such that the line appears to "unfold" or "be drawn" from the near end (closest to the cue) to the far end (most distant from the cue). Accounts of ILM have not usually addressed perceived velocity of ILM, although some studies used matching or cancellation of illusory motion as an investigative tool (e.g., Fuller & Carrasco, 2009; von Grünau et al., 1996). In an attentional gradient theory of ILM (e.g., Hikosaka et al., 1993; Shimojo et al., 1999), attending to the cue produces an attentional gradient such that portions of the line closer to the cue are processed more quickly (and enter perceptual awareness earlier) than are portions of the line more distant from the cue, and so the line is perceived to unfold or extend from the initially perceived location closest to the cue toward the subsequently perceived location most distant from the cue. In an apparent motion theory of ILM (e.g., Downing & Treisman, 1997), impletion processes involved in apparent motion bind successive presentations of the cue and the line into a representation of a single object. The studies reported here examined how perceived velocity of ILM and perceived direction and strength of ILM were influenced by temporal separation and spatial separation of the cue and the line.

General Methods

A schematic of the stimulus sequence in each trial is shown in Figure 1. A horizontally-centered fixation point appeared in the bottom half of the display. A cue appeared in the upper left or upper right, and after a brief delay, a horizontal line appeared to the right or left of the cue. After a brief delay, the display cleared, and a scale for rating perceived velocity of (illusory) motion or for rating perceived direction and strength of (illusory) motion appeared.

Participants. Participants were students from the University of South Carolina, Upstate, (N = 20, 19, 21, and 16, in Experiments 1, 2, 3, and 4, respectively) who received partial course credit. All were naïve to the hypotheses, and none participated in more than one experiment.

Apparatus. Stimuli were displayed upon and data collected with a Gateway desktop computer equipped with a 15-inch monitor (60 Hz refresh rate; 1024 x 798 pixels resolution). Viewing distance was approximately 60 cm.

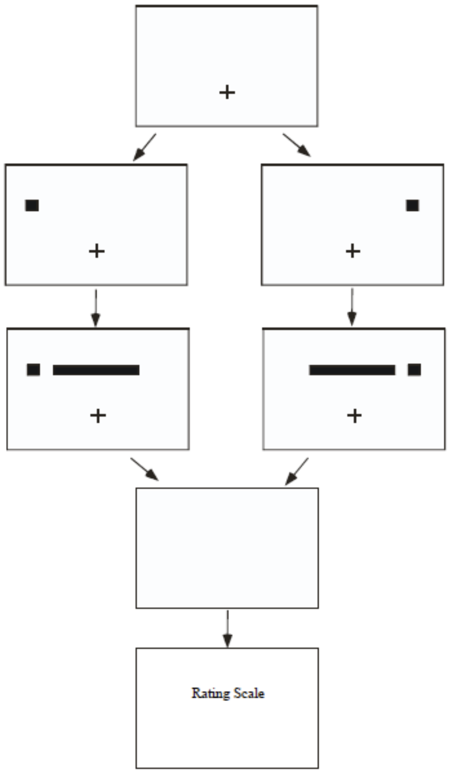

Figure 1. Sequence of stimuli in each trial in Experiments 1, 2, 3, and 4.

Stimuli. The cue was a black square 20 pixels (0.83 deg) in width and height. The line was a black rectangle 20 pixels in height, and the line varied in width and in distance from the cue across experiments. The cue and the line were presented on a white background, vertically aligned, and above the vertical midpoint of the display. The fixation point was a plus shape 20 pixels in width and height, located at the horizontal center of the display, and one-third of the vertical distance from the bottom to the top of the display. Ratings of perceived velocity used a 1-7 scale (1 was "very slow", 7 was "very fast"), and ratings of perceived direction (and strength) used a 1-7 scale (1 was "clearly expanded from the left", 4 was "appeared all at once", 7 was "clearly expanded from the right").

Procedure. Ratings of perceived velocity were collected in one block of trials and ratings of perceived direction (and strength) were collected in another block of trials (order of blocks was counterbalanced across participants). Before each block, participants were given 10 practice trials randomly drawn from experimental trials for that block. Participants pressed a designated key to begin a trial. The cue appeared, and the line appeared 50, 250 or 450 ms (Experiment 1) or 250 ms (Experiments 2, 3, and 4) later. The cue and line were visible an additional 250 ms and then simultaneously vanished. A rating scale appeared and remained visible until participants responded. Ratings were entered by pressing the appropriate keys on a numeric keypad.

Experiment 1

As shown in Figure 2, length of the line was constant (196 pixels, 8.13 deg), but SOA between appearance of the cue and appearance of the line varied (50, 250, or 450 ms). There was a separation of 20 pixels (0.83 deg) between the closest edges of the cue and the line. In each block, participants received 42 trials (2 [cue: left, right] x 3 [SOA: 50, 250, 450 ms] x 7 replications) in a different random order. Ratings are shown in Figure 3.

Ratings of perceived velocity were analyzed in a 2 (cue) x 3 (SOA) ANOVA. Neither cue, $F(1,19) = 0.11$, $p > .74$, nor Cue x SOA, $F(2,38) = 1.72$, $p > .19$, were significant. SOA was significant, $F(2,38) = 73.09$, $p < .0001$, and all pairwise comparisons between 50 ms (M = 6.58), 250 ms (M = 4.51), and 450 ms (M = 3.05) SOAs were significant.

Ratings of perceived direction were analyzed in a 2 (cue) x 3 (SOA) ANOVA. Cue, $F(1,19) = 193.66$, $p < .0001$, and Cue x SOA, $F(2,38) = 18.80$, $p < .0001$, were significant. When cues were on the left, lines were rated as expanding from the left ($M = 1.93$), and when cues were on the right, lines were rated as expanding from the right ($M = 6.14$). Differences in ratings of direction for cues on the left and for cues on the right were less when SOA was 50 ms than when SOA was 250 ms or 450 ms (i.e., direction ratings were more extreme when SOA was 250 ms or 450 ms). SOA was not significant, $F(2,38) = 0.65$, $p > .52$.

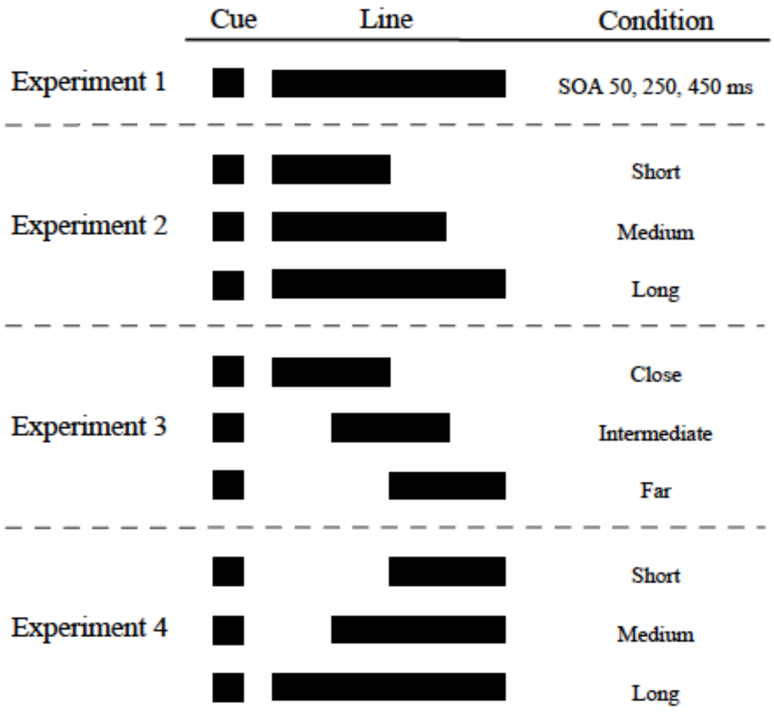

Figure 2. Schematic of stimuli.

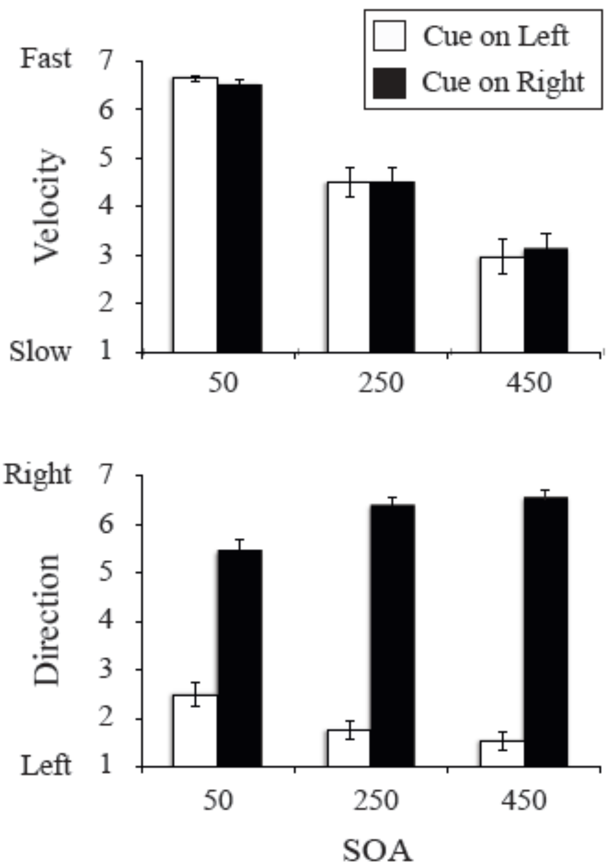

Figure 3. Ratings in Experiment 1.

Ratings of perceived direction were tested against a null rating of 4 (Bonferroni correction of .05/6 = .0083). When cues were on the left for SOAs of 50 ms ($M = 2.49$), $t(19) = -6.10$, $p < .0001$, 250 ms ($M = 1.76$), $t(19) = -11.38$, $p < .0001$, and 450 ms ($M = 1.54$), $t(19) = -13.45$, $p < .0001$, ratings were less than 4, indicating lines were perceived as expanding from the left. When cues were on the right for SOAs of 50 ms ($M = 5.47$), $t(19) = 6.60$, $p < .0001$, 250 ms ($M = 6.40$), $t(19) = 14.14$, $p < .0001$, and 450 ms ($M = 6.56$), $t(19) = 17.33$, $p < .0001$, ratings were greater than 4, indicating lines were perceived as expanding from the right.

Experiment 2

As shown in Figure 2, distance of the near edge of the line to the cue was constant, but length of the line and distance of the far end of the line from the cue varied. Length was short (96 pixels, 3.98 deg), medium (146 pixels, 6.06 deg), or long (196 pixels, 8.13 deg). Distance of the near end of the line from the cue was 20 pixels (0.83 deg). In each block, participants received 42 trials (2 [cue: left, right] x 3 [length: short, medium, long] x 7 replications) in a different random order. Ratings are shown in Figure 4.

Ratings of perceived velocity were analyzed in a 2 (cue) x 3 (length) ANOVA. Neither cue, $F(1,18) = 0.11$, $p > .51$, nor Cue x Length, $F(2,36) = 0.90$, $p > .91$, were significant. Length was significant, $F(2,36) = 7.42$, $p < .003$, and least squares comparison revealed long lines ($M = 5.08$) and medium lines ($M = 4.64$) were rated as faster than were short lines ($M = 4.13$), and long lines were rated as marginally faster than were medium lines.

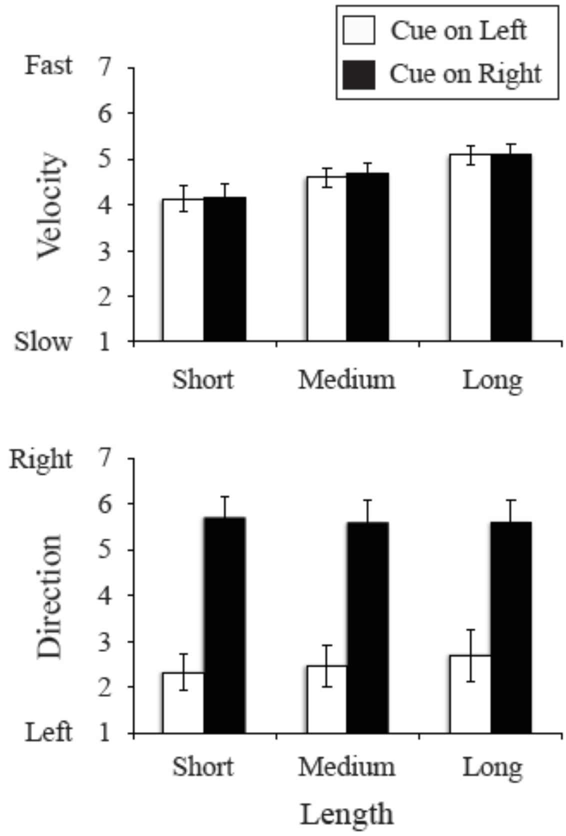

Figure 4. Ratings in Experiment 2.

Ratings of perceived direction were analyzed in a 2 (cue) x 3 (length) ANOVA. Cue was significant, $F(1,18) = 12.08$, $p < .003$; when cues were on the left, lines were rated as expanding from the left ($M = 2.49$), and when cues were on the right, lines were rated as expanding from the right ($M = 5.64$). Neither length, $F(2.36) = 1.19$, $p > .31$, nor Cue x Length, $F(2,36) = 1.06$, $p > .35$, were significant.

Ratings of perceived direction were tested against a null rating of 4. When cues were on the left for short lines ($M = 2.32$), $t(18) = -4.21$, $p < .0005$, medium lines ($M = 2.47$), $t(18) = -3.42$, $p < .003$, and long lines ($M = 2.69$), $t(18) = -2.41$, $p < .03$, ratings were less than 4, indicating lines were perceived as expanding from the left. When cues were on the right for short lines ($M = 5.71$), $t(18) = 3.93$, $p < .001$, medium lines ($M = 5.59$), $t(18) = 3.33$, $p < .004$, and long lines ($M = 5.61$), $t(18) = 3.28$, $p < .005$, ratings were greater than 4, indicating lines were perceived as expanding from the right.

Experiment 3

As shown in Figure 2, length of the line was constant (96 pixels, 3.98 deg), but distance of the near end of the line and the far end of the line from the cue varied. Distance between the closest vertical edge of the cue and the closest vertical edge of the line was close (20 pixels, 0.83 deg), intermediate (70 pixels, 2.91 deg), or far (120 pixels, 4.98 deg). In each block, participants received 42 trials (2 [cue: left, right] x 3 [distance: close, intermediate, far] x 7 replications) in a different random order. Ratings are shown in Figure 5.

Ratings of perceived velocity were analyzed in a 2 (cue) x 3 (distance) ANOVA. Neither cue, $F(1,20) = 0.10$, $p > .75$, Cue x Distance, $F(2,40) = 0.17$, $p > .79$, nor Distance, $F(2,40) = 0.31$, $p > .73$, were significant.

Ratings of perceived direction were analyzed in a 2 (cue) x 3 (distance) ANOVA. Cue was significant, $F(1,20) = 22.54$, $p < .0001$; when cues were on the left, lines were rated as expanding from the left ($M = 2.23$), and when cues were on the right, lines were rated as

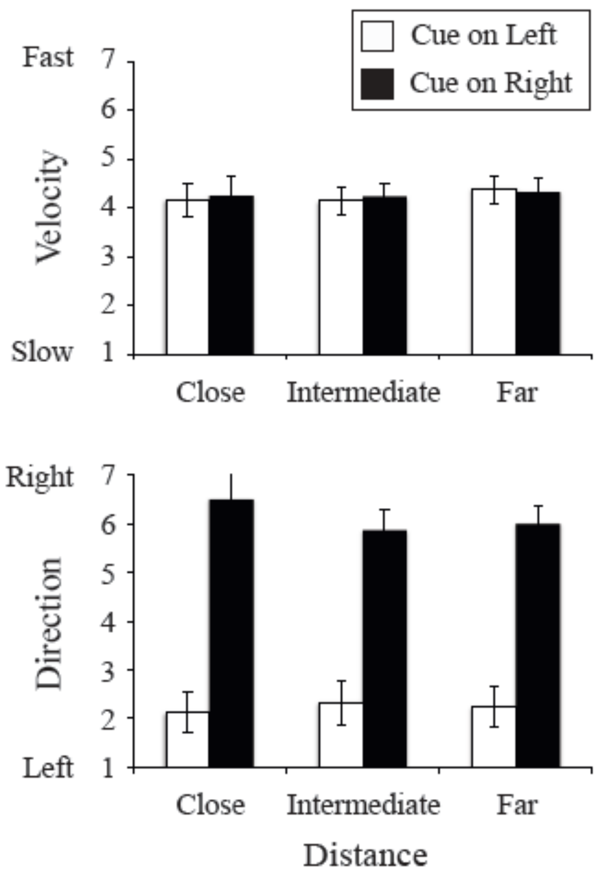

Figure 5. Ratings in Experiment 3.

expanding from the right (*M* = 6.11). Cue x Distance, *F*(2,40) = 1.86, *p* > .16, and Distance, *F*(2,40) = 0.97, *p* > .38, were not significant.

Ratings of perceived direction were tested against a null rating of 4. When cues were on the left for close distances (*M* = 2.13), *t*(20) = -4.42, *p* < .0003, intermediate distances (*M* = 2.32), *t*(20) = -3.72, *p* < .0014, and far distances (*M* = 2.24), *t*(20) = -4.25, *p* < .0004, ratings were less than 4, indicating lines were perceived as expanding from the left. When cues were on the right for close distances (*M* = 6.49), *t*(20) = 4.03, *p* < .007, intermediate distances (*M* = 5.86), *t*(20) = 4.47, *p* < .0002, and far distances (*M* = 5.59), *t*(20) = 5.38, *p* < .0001, ratings were greater than 4, indicating lines were perceived as expanding from the right.

Experiment 4

As shown in Figure 2, distance of the far end of the line from the cue was constant (216 pixels, 8.96 deg), but length of the line and distance of the near edge of the line from the cue varied. Lengths of the short, medium, and long lines were the same as in Experiment 2. Distance between the closest edge of the cue and the closest edge of the line for the short line was 120 pixels (4.98 deg), for the medium line was 70 pixels (2.91 deg), and for the long line was 20 pixels (0.83 deg). In each block, participants received 42 trials (2 [cue: left, right] x 3 [length: short, medium, long] x 7 replications) in a different random order. Ratings are shown in Figure 6.

Ratings of perceived velocity were analyzed in a 2 (cue) x 3 (length) ANOVA. Length was significant, *F*(2,30) = 4.24, *p* < .003, and least squares comparison revealed long lines (*M* = 4.80) were rated as faster than were short lines (*M* = 4.29) and medium lines (*M* = 4.51) did not differ from long lines or from short lines. Cue was significant, *F*(1,15) = 6.48, *p* < .03; when cues were on the left, velocity was rated as slower (*M* = 4.32) than when cues were on the right (*M* = 4.74). Cue x Length was not significant, *F*(2,30) = 0.53, *p* > .94.

Ratings of perceived direction were analyzed in a 2 (cue) x 3 (length) ANOVA. Cue, *F*(1,15) = 45.75, *p* < .0001, and Cue x Length, *F*(2,30) = 4.09, *p* < .05, were significant. When cues were on the left, lines were rated as expanding from the left (*M* = 2.02), and when cues were on the right, lines were rated as expanding from the right (*M* = 6.10). Differences in ratings of direction for cues on the left and for cues on the right were larger (more extreme) for long lines than for short lines. Length was not significant, *F*(2,30) = 0.20, *p* > .81.

Ratings of perceived direction were tested against a null rating of 4. When cues were on the left for short lines (*M* = 2.13), *t*(15) = -5.10, *p* < .0001, medium lines (*M* = 2.05), *t*(15) = -5.98, *p* < .0001, and long lines (*M* = 1.86), *t*(15) = -6.26, *p* < .0001, ratings were less than 4, indicating lines were perceived as expanding from the left. When cues were on the right for short lines ($M = 5.96$), $t(15) = 6.48$, $p < .0001$, medium lines ($M = 6.03$), $t(15) = 7.06$, $p < .0001$, and long lines ($M = 6.33$), $t(15) = 8.14$, $p < .005$, ratings were greater than 4, indicating lines were perceived as expanding from the right.

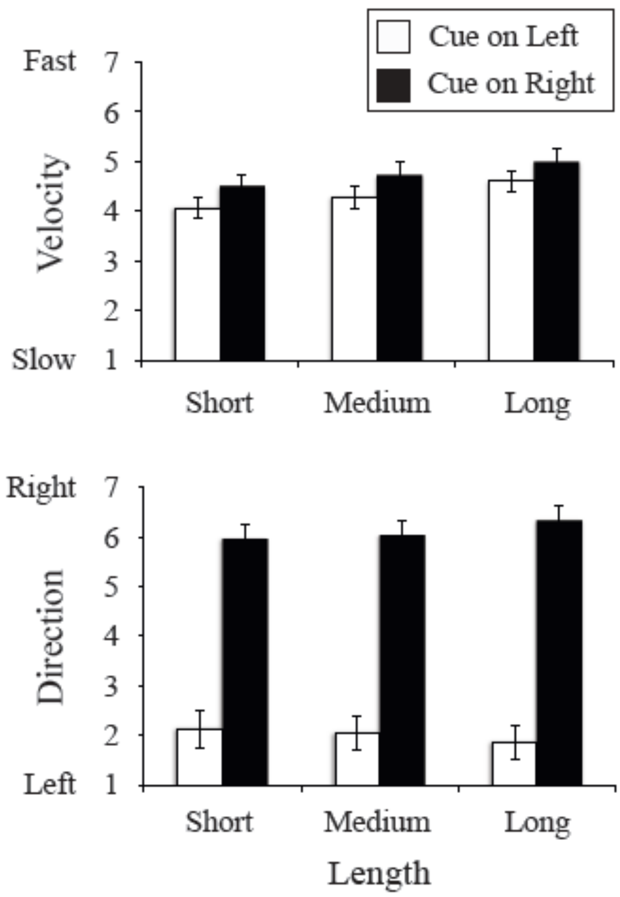

Figure 6. Ratings in Experiment 4.

General Discussion

Increases in SOA between appearance of the cue and appearance of the line led to decreases in perceived velocity of ILM and increases in perceived strength of ILM. Increases in line length led to increases in perceived velocity of ILM but no change in perceived strength of ILM. Increases in distance of the near end of the line or the far end of the line from the cue did not influence perceived velocity or perceived strength of ILM. Perceived velocity is not the sole determinant of perceived strength of ILM (cf. Christie & Klein, 2005; von Grünau et al., 1996). Effects of line length on perceived velocity are consistent with an attentional gradient theory of ILM; however, lack of effects of line length on perceived strength, and effects of SOA on perceived strength and on perceived velocity, are not consistent with an attentional gradient theory of ILM. Increases in perceived velocity with changes in line length but not with changes in distance, and lack of effects of distance on perceived strength and on perceived velocity, are not consistent with an apparent motion theory of ILM.

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