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PERCEIVED DEPTH FROM SIMULTANEOUS CHANGES IN LENGTH AND DIRECTION OF A SINGLE LINE [1]

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Summary.—Using a configuration of three lines joined like hands on a clockface, Brigner, Deni, and Hildreth in 1994 reported empirical support for Wallach, Adams, and Weisz's 1956 hypothesis regarding the elicitation of perceived depth by simultaneous changes in length and orientation of a configuration's elements. The current investigation extended these findings by showing that perceived depth can be elicited by simultaneous changes in size and orientation of either two lines or a single line.

Wallach, Adams, and Weisz (1956) hypothesized that the perceived depth of the kinetic depth effect was elicited by simultaneous changes in length and orientation of a configuration's elements. In an empirical test of this position, Brigner, Deni, and Hildreth (1994) had 12 observers judge the perceived depth of a computer-generated configuration of three lines which were joined like hands on a clockface and which were changing in length and orientation simultaneously. Ten of the 12 observers reported a perception of depth.

Given the perception of depth reported for the Brigner, *et al.* (1994) configuration, it was appropriate to ask whether depth would be perceived were there simultaneous changes in length and orientation of only one or only two lines. The current investigation addressed this question.

METHOD

Observers

Observers were 24 undergraduate volunteers from classes in general psychology.

Stimuli

There were 12 stimuli—all computer-generated to simulate apparent motion. The computer was an IBM PS2 Model 25, and the monitor was an IBM VGA having a refresh rate of 60 Hz. Nine stimuli (X1, X2, X3, C1-OC, C1-SC, C2-OC, C2-SC, C3-OC, and C3-SC) consisted of a single line while three (X4, C4-OC, and C4-SC) consisted of two lines. Please refer to Table 1 below (p. 583) for a summary of stimuli characteristics. Stimulus X1 was a single line rotating around its midpoint at the center of the computer's monitor. X1 began as a horizontal line at nine o'clock and was 150 mm long and 3 mm wide. As it rotated clockwise to vertical at twelve

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o'clock, it gradually diminished in size to 38 mm long and 1 mm wide. As its clockwise rotation continued, it increased gradually in size to 185 mm long and 3 mm wide at four o'clock, then decreased gradually in size to 73 mm long and 1 mm wide at seven o'clock, and finally increased gradually in size to return to its 150 mm length and 3 mm width at nine o'clock as noted above. There were 15 complete rotations in about 17 seconds or a rotation rate of about 317° per second.

Stimulus C1-OC was a control for Stimulus X1 and was like X1 in all ways except that size was held constant at 110 mm long and 2 mm wide as the line rotated about its midpoint 15 times in about 17 seconds or a rotation rate of about 317° per second.

Stimulus C1-SC was also a control for Stimulus X1 and was like X1 in all ways except that there was no rotation. A horizontal orientation was maintained as the size changes described for X1 occurred for 15 times in about 17 seconds.

Stimulus X2 was a single line rotating like the hand on a clockface; that is, one end of the line was anchored at the center of the computer's monitor while the other end moved. X2 began as a horizontal line at nine o'clock and was 75 mm long and 3 mm wide. As it rotated clockwise to twelve o'clock, it gradually decreased in size to 19 mm long and 1 mm wide. As its clockwise rotation continued, it gradually increased in size to 92 mm long and 3 mm wide at four o'clock, then gradually decreased in size to 36 mm long and 1 mm wide at seven o'clock. Finally, it increased gradually in size as it returned to nine o'clock where it was 75 mm long and 3 mm wide as described above. There were 15 complete rotations in about 11 seconds or a rotation rate of about 490° per second.

Stimulus C2-OC was a control stimulus for X2 and was like X2 in all ways except that size was held constant at a length of 57 mm and a width of 2 mm as the line rotated like the hand on a clockface for 15 times in about 11 seconds or a rotation rate of about 490° per second.

Stimulus C2-SC was also a control for Stimulus X2 and was like X2 in all ways except that there was no rotation. The line remained in a horizontal position at nine o'clock, and only the size changes described above for X2 occurred for 15 times in about 11 seconds.

Stimulus X3 was a single line rotating around an axis of rotation that was located at a third of the line's length; that is, one-third of the line was on one side of the axis of rotation and two-thirds were on the opposite side for all sizes of X3 and its control stimuli. X3 began as a horizontal line at nine o'clock and was 110 mm long and 3 mm wide. As it rotated clockwise to twelve o'clock, it gradually decreased in size to 28 mm long and 1 mm wide. As its clockwise rotation continued, it gradually increased in size to 139 mm long and 3 mm wide at four o'clock, then gradually decreased in

size to 55 mm long and 1 mm wide at seven o'clock. Finally, the line increased gradually in size as it returned to nine o'clock and its 110 mm length and 3 mm width at that position as given above. The line made 15 complete rotations in about 15 seconds or a rotation rate of about 360° per second.

Stimulus C3-OC was a control stimulus for X3 and was like X3 in all ways except that size was held constant at a length of 84 mm and a width of 2 mm. Like X3, C3-OC rotated 15 times in about 15 seconds or a rotation rate of about 360° per second and its axis of rotation was located at one-third of the line's length.

Stimulus C3-SC was also a control for X3 and was like X3 in all ways except that there was no rotation. The line remained horizontal while the size changes described above for X3 occurred 15 times in about 15 seconds.

Stimulus X4 consisted of two lines which were joined like hands on a clockface at the center of the computer's monitor. One line changed in orientation and size exactly as described for Stimulus X2. Referring to this line as the first line, it began at nine o'clock and rotated clockwise to twelve o'clock. Simultaneously, a second line began at one o'clock and was 115 mm long and 3 mm wide; it decreased in size as it rotated counterclockwise to 11:45 o'clock to become 95 mm long and 3 mm wide, and then gradually decreased to 90 mm long and 2 mm wide as it rotated clockwise to 12:15 o'clock. The first line then continued its clockwise rotation from twelve o'clock towards four o'clock, and the second line simultaneously rotated counterclockwise from 12:15 o'clock to 9:15 and decreased gradually to 58 mm long and 1 mm wide. The first line continued a clockwise rotation from four o'clock to seven o'clock and, simultaneously, the second line rotated clockwise from 9:15 to 12:15 and gradually changed in size to become 90 mm long and 2 mm wide. Finally, as the first line rotated clockwise from seven o'clock back to nine o'clock, the second line rotated counterclockwise from 12:15 to 11:45 and increased in size to 95 mm long and 3 mm wide and then rotated clockwise back to 12:15 and decreased in size to 87 mm long and 1 mm wide. The foregoing pattern of movements repeated 15 times in about 29 seconds or a rotation rate of about 186° per second.

Stimulus C4-OC was a control stimulus for X4. Stimulus C4-OC was like X4 in all ways except that size was held constant. The first line, which began at nine o'clock and rotated 360° clockwise, was maintained at 55 mm long and 2 mm wide. The second line was held at 115 mm long and 3 mm wide. The lines of C4-OC changed in orientation in the same way as described for Stimulus X4, and the pattern of these movements occurred 15 times in about 29 seconds or at a rotation rate of about 186° per second.

Stimulus C4-SC was also a control for Stimulus X4. Stimulus C4-SC was like X4 in all ways except that no changes in line orientation occurred.

The first line began at nine o'clock and did not change from that position, but it did change in size as described for the first line of Stimulus X4. Similarly, the second line began at one o'clock and did not change from that orientation, but it changed size as described for the second line of X4. As described for Stimulus X4, the pattern of size changes repeated 15 times in about 29 seconds. [2]

Procedure

Each observer viewed each of the twelve stimuli, and the order of presentation was according to a balanced square design. Viewing distance was about 66 cm. Before each stimulus was presented, instructions appeared on the computer's monitor which indicated that a changing pattern would be presented and that the observer was to judge whether the changing pattern appeared to be flat or 3-dimensional. The observer was also instructed to make the judgment in the form of a rating, and the following rating scale appeared on the monitor—1 = sure the pattern appeared to be 3-dimensional and not flat; 2 = pretty sure the pattern appeared to be 3-dimensional; 3 = not sure whether the pattern appeared to be flat or 3-dimensional; 4 = pretty sure the pattern appeared to be flat; 5 = sure the pattern appeared to be flat. There was a time for questions, and, when the observer was ready, the observer initiated the stimulus presentation. Subsequent to each stimulus presentation, the aforementioned rating scale reappeared on the monitor, and the observer was asked to rate the flatness or 3-dimensionality of the stimulus which had been presented. The observer typed a response, and it was recorded by printer.

Results

Using the Friedman two-way analysis of variance, a statistically significant difference was found among the observers' ratings of depth or 3-dimensionality for the twelve stimuli ($\chi_{11}^2 = 83.29$, $p < .001$). Since it was conceivable that markedly different ratings of a single stimulus could have led to the foregoing results, the Friedman two-way analysis was also used to evaluate the ratings given to each stimulus and its associated controls. Consider first Stimulus X1 and its associated controls, C1-OC and C1-SC. The Stimulus X1 was a single line changing in size and rotating about its midpoint. There was a statistically significant difference among the ratings given to X1 and to its controls C1-OC, rotation only, and C1-SC, size changes only ($\chi_2^2 = 14.6$, $p < .01$). Using the Wilcoxon signed-ranks test to evaluate the differences between the ratings given to each of these stimuli, the ratings for X1 and C1-OC were significantly different ($z = 3.71$, $p < .01$), and ratings for

[2]Computer programs for Stimuli X1, X2, X3, and X4 were written in BASICA and are available from Dr K M. Steele, Psychology Department, Appalachian State University, Boone, NC 28608. Minor changes in these programs yield the control stimuli.

C1-OC and C1-SC were significantly different ($z = -3.33$, $p < .01$), but ratings were not significantly different for X1 and C1-SC. The median ratings for these stimuli reflect these findings as the median ratings for X1, C1-OC, and C1-SC, respectively, were 2, 4, and 2. Please refer to Table 1 for a summary of median ratings for each stimulus. The implication is that perceived depth can be elicited by size changes alone for a single line rotating around its midpoint.

TABLE 1
CHARACTERISTICS AND MEDIAN RATINGS OF STIMULI

Stimulus	Line	Axis of Rotation	Size Change	Orientation Change	Median Rating
X1	One	Midpoint	Yes	Yes	2
C1-OC	One	Midpoint		Yes	4
C1-SC	One	Midpoint	Yes		2
X2	One	LineEnd	Yes	Yes	2
C2-OC	One	LineEnd		Yes	4
C2-SC	One	LineEnd	Yes		4
X3	One	One-third	Yes	Yes	2
C3-OC	One	One-third		Yes	4
C3-SC	One	One-third	Yes		3
X4	Two	Vertex	Yes	Yes	2
C4-OC	Two	Vertex		Yes	3
C4-SC	Two	Vertex	Yes		3

Friedman two-way analysis of the data from X2 and its associated controls, C2-OC and C2-SC, indicated a significant difference among the ratings for these stimuli ($\chi_2^2 = 10.89$, $p < .01$). The Stimulus X2 was a single line changing in size and rotating like the hand on a clockface at the monitor's center. The control C2-OC only rotated, and the control C2-SC changed in size only. Using the Wilcoxon signed-ranks test to evaluate differences between the ratings given to each of these stimuli, the ratings for X2 and C2-OC were significantly different ($z = 3.68$, $p < .01$), and ratings for X2 and C2-SC were significantly different ($z = 2.9$, $p < .01$), but ratings were not significantly different for C2-OC and C2-SC. The median ratings for these stimuli reflect these findings as the median ratings for X2, C2-OC, and C2-SC, respectively, were 2, 4, and 4. Please refer to Table 1 for a summary. Hence, simultaneous changes in both size and orientation seemed necessary for the elicitation of perceived depth when only one end of a single line moved in space. This result agreed with the Brigner, *et al.* (1994) finding using a similar clock-like configuration.

Friedman two-way analysis of the data from X3 and its associated controls, C3-OC and C3-SC, indicated a significant difference among the ratings for these stimuli ($\chi_2^2 = 21.89$, $p < .01$). Stimulus X3 was a single line changing in size and having an axis of rotation at one-third the line's length. The

Control C3-OC rotated only, and the Control C3-SC changed in size only. Using the Wilcoxon signed-ranks test to evaluate differences between the ratings given to each of these stimuli, the ratings for X3 and C3-OC were significantly different ($z = 3.9$, $p < .01$), and ratings for X3 and C3-SC were significantly different ($z = 2.6$, $p < .01$); in addition, ratings between C3-OC and C3-SC were significantly different ($z = 2.6$, $p < .01$). The median ratings for these stimuli reflect these findings as the median ratings for X3, C3-OC, and C3-SC, respectively, were 2, 4, and 3. A summary of median ratings is given in Table 1. The latter median values indicate the essentialness of simultaneous changes in both size and orientation for the elicitation of perceived depth with this configuration.

Friedman two-way analysis of the data from Stimulus X4 and its associated controls, C4-OC and C4-SC, indicated a significant difference among the ratings for these stimuli ($\chi_2^2 = 9.75$, $p < .01$). Stimulus X4 consisted of two lines joined like hands on a clockface, and the two lines simultaneously changed in size and orientation. For the Control Stimulus C4-OC, the two lines changed in orientation only. For the Control Stimulus C4-SC, the two lines changed in size only. Using the Wilcoxon signed-ranks test to evaluate differences between the ratings given to each of these stimuli, the ratings for X4 and C4-OC were significantly different ($z = 2.83$, $p < .01$), and the ratings for X4 and C4-SC were significantly different ($z = 3.07$, $p < .01$), but the ratings for C4-OC and C4-SC were not significantly different. Reflecting these findings, the median ratings for X4, C4-OC, and C4-SC, respectively, were 2, 3, and 3. See Table 1 for a summary of median ratings. These median ratings for two lines were consistent with the data from single-line configurations, namely, the perception of depth required simultaneous changes in size and orientation.

The combination of length and orientation changes produced a depth effect for all test stimuli. Only with Stimulus X1 (a single line rotating around its midpoint) did changes in size alone elicit the perception of depth. The current investigation agrees with the Brigner, *et al.* (1994) findings, and the current study also supports Wallach, *et al.*'s (1956) hypothesis regarding simultaneous changes in length and orientation as the necessary and sufficient conditions for perceived depth. The current investigation has extended these findings by showing that perceived depth can be elicited by changes in size and orientation of a single line.

REFERENCES

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