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An illusion of 3-D motion with the Ternus display

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Abstract

We attempted to eliminate the percept of element motion in the Ternus display by connecting the display elements so that they appeared to be a single object. On each trial, the display elements (two discs) appeared either separated or connected (either via a white line or side by side) and subjects reported whether they observed element motion or group motion at various ISIs. Although it was hypothesized that element motion would be eliminated in the connected condition, subjects observed element motion at short ISIs in the form of a three dimensional illusion in which one element appeared to rotate out in front of (or behind) the other. Implications for short range and long range motion processes are discussed.

Keywords: Apparent motion; Ternus display; Visual illusion; 3-D motion

1. An illusion of 3-D motion with the Ternus display

Eight decades ago, Ternus (1926, 1938) observed a bistable percept of apparent motion using a display consisting of three sequentially presented frames. In Frame 1 of a classic Ternus display, three discs appear equally spaced along a horizontal plane. Frame 3 consists of the same three discs shifted to the right, such that the outer disc from the first frame now appears in the location originally occupied by the center disc in the first frame (see Fig. 1). The first and third frames are separated by a blank interval (Frame 2) for a variable duration, which serves as the interstimulus interval (ISI). When the three frames are presented sequentially, subjects often report seeing one of two types of apparent motion, which are dependent on the duration of the ISI. When a brief ISI (e.g., ISIs < 50 ms) is used, subjects report seeing *element motion* in which the outer disc in the display is perceived as "jumping over" the other two (inner) discs in the display and landing in the location on the right. When a longer ISI (e.g., ISIs > 50 ms) is used, subjects report seeing *group motion* in which all of the discs in the display appear to move together to the right (Pantle & Picciano, 1976).

Braddick and Adlard's (1978; see also Braddick, 1974, 1980) distinction between short-range and long-range motion processes has generally been used to explain the percepts of motion in the Ternus display. Element motion is thought to be attributable to the lower level short-range motion process signaling non-motion in the two inner elements in the display between Frames 1 and 3 at short ISIs. This leads the higher level long-range motion process to signal element movement, with the outer element jumping from one side of the display to the other (Braddick & Adlard, 1978). At longer ISIs, however, the short-range process signals motion in the inner elements in the display, leading the long-range process to signal group motion with the three elements moving together in unison (Braddick, 1980; Braddick & Adlard, 1978; Pantle & Petersik, 1980; Pantle & Picciano, 1976; Petersik & Pantle, 1979).

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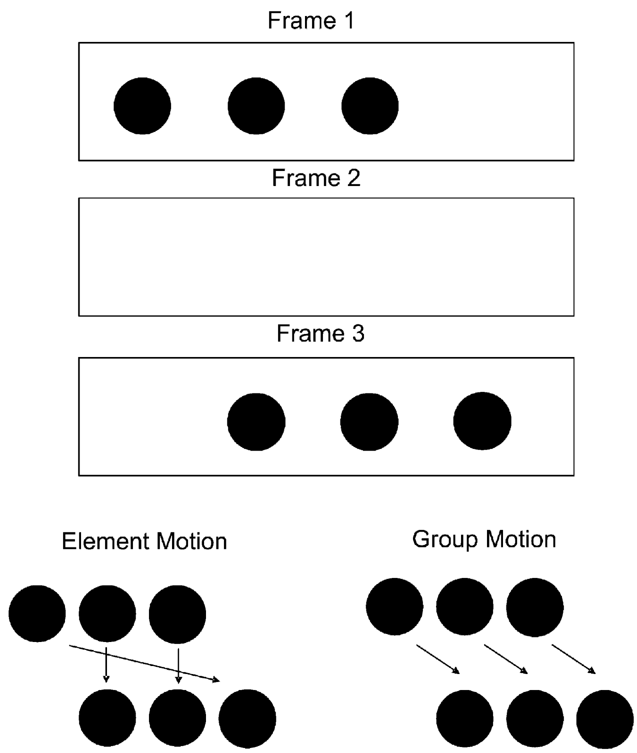

Fig. 1. A typical Ternus motion display. The three frames are presented sequentially. Element motion is observed when Frame 2 is shown for a short duration (less than 50 ms). Group motion is observed when Frame 2 is shown for a relatively longer duration (greater than 50 ms). The error bars represent the standard error of the mean.

Although Braddick's (1974, 1980; Braddick & Adlard, 1978) two-process distinction provides one explanation of apparent motion in the Ternus display, other accounts have recently emerged. For example, Scott-Samuel and Hess (2001) have demonstrated that the perception of element motion is influenced by changes in the spatial appearance of the elements in the Ternus display. They used displays consisting of elements that were defined either by static or dynamic noise and observed a reduction in the percept of element motion on dynamic noise trials: element motion was only perceived about 50% of the time with an ISI of 0 ms and was rarely perceived at any other ISI. On the basis of these results, along with data from other studies, Scott-Samuel and Hess (2001) argued that apparent motion in the Ternus display is mediated solely by long-range motion processing.

Researchers have also argued that the perception of motion in the Ternus display may be dependent on the degree to which the elements in the display lend themselves to perceptual grouping. For example, Kramer and Yantis (1997) reported an increase in the percept of group motion when the items in a modified Ternus display formed a coherent group relative to when the items appeared independent of one another. Moreover, Kramer and Yantis observed differences in the percept of group vs. element motion as a function of whether the displays were grouped with a stationary or moving context (see also Dawson, Nevin-Meadows, & Wright, 1994). Additionally, He and Ooi (1999) manipulated factors such as similarity, proximity, and common surface in modified Ternus displays and were able to consistently decrease the perception of element motion relative to similar displays in which the perceptual grouping of display elements was unlikely. Despite an increase in the percept of group motion with grouped displays, however, there was still a strong tendency to observe single element motion at short ISIs (e.g., ISIs < 40 ms). More recently, Alais and Lorenceau (2002) have demonstrated that the percept of group motion varies as a function of whether collinear or parallel displays are used (with more group motion being observed for collinear displays).

Although various grouping manipulations have substantially reduced the percept of element motion in Ternus displays at short ISIs, they do not eliminate the percept of element motion altogether. It should be possible, however, to completely eliminate element motion in a Ternus display by conjoining the separate elements into a single object. Simply put, element motion should not occur if there are not at least two separate and distinct elements in the display. In the present experiment, this was accomplished by using a principle of perceptual organization known as uniform connectedness in which closed regions of homogenous properties are perceived initially as a single unit (Palmer & Rock, 1994). Thus, the elements in the present experimental displays appeared either separated as in a standard Ternus experiment (separate condition), connected via a thin line (connect-line condition), or side by side with no space separating the elements (connect-touch condition). To increase the likelihood that the connected elements in our display would be viewed as a single object, we used two discs rather than three. Given that uniform connectedness has been shown to override powerful grouping principles such as proximity and similarity (Palmer & Rock, 1994) and given that grouping has already been shown to reduce the percept of element motion (e.g., Alais & Lorenceau, 2002; He & Ooi, 1999; Kramer & Yantis, 1997), we hypothesize that connecting the items should eliminate element motion altogether. Since there is only a single object in the two connected conditions, element motion should not be perceived even at the briefest ISI.

2. Method

2.1. Subjects

Fifteen undergraduate students from the University of Toronto volunteered to participate in the experiment, and received course credit for their participation. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment, which took place in a single one-hour session. The subjects were randomly selected into one of three conditions.

2.2. Apparatus and procedure

All experimental programs were written by the experimenters using Visual C++ 6.0. The experiment was conducted on a Pentium 4 PC with VGA monitor (85 Hz) in a dimly lit, sound attenuated testing room. Subjects were seated 44 cm from the front of the computer monitor with their heads held steady by a chin and headrest. A keyboard was placed directly in front of the subjects, and they made responses using the "*z*" and "/" keys on the keyboard (representing single element motion and grouped element motion, respectively). To familiarize the subjects with the procedure, they were initially shown five demo trials at a short ISI (ISI of 12 ms)—which consistently elicits the percept of element motion—and five demo trials at a long ISI (ISI of 108 ms)—which consistently elicits the percept of group motion—from a normal (i.e. not connected) Ternus display. Across the conditions, all stimuli were drawn in 1-pixel width white lines (75.3 cd/m^2) on a black (0.43 cd/m^2) background.

At the beginning of each trial, a display consisting of two white outline discs (each subtending 1.0° and separated by 1.0° in the separate and connect-line conditions) appeared at fixation for 500 ms (Frame 1). In the *connect-touch condition*, the discs appeared side by side. In the *connect-line condition*, the discs were connected by a white line (subtending 1.0°); no such line appeared in the *separate condition* (see Fig. 2). Following the initial display, the screen appeared blank for a variable ISI (Frame 2: ranging between 0 and 108 ms) and then the initial display reappeared with the discs having been shifted 2.0° to the right in the separate and connect-line conditions, and 1.0° to the right in the connect-touch condition (Frame 3). Thus, the disc on the right side of the display in Frame 1 appeared in the exact same location as the disc on the left side of the display in Frame 3. Subjects were required to indicate whether they perceived element motion or group motion by pressing the appropriate key on the keyboard. After all experimental trials, each participant was asked by the researcher whether they had observed single element motion on any of the trials and if so, how the disc appeared to move.

2.3. Design

Each experimental session consisted of 400 trials, with short breaks given after every 135 trials. The 10 ISIs (0, 12, 24, 36, 48, 60, 72, 84, 96, or 108 ms) were randomized across each session (40 trials per ISI). Each of the three conditions (separate, connect-line, connect-touch) were completed by five participants.

3. Results

The proportion of trials on which subjects reported seeing single element motion as a function of ISI are presented in Fig. 3, and were analyzed with a 10 (ISI) × 3 (display: separate, connect-line or connect-touch) analysis of variance (ANOVA). There was a significant main effect of ISI, $F(9,108) = 57.10$, MSe = 186.75, $p < .001$ with more single element motion being observed at the shorter ISIs relative to the longer ISIs. There was no effect of experimental display, however, $F(1,12) < 1$, nor was there an interaction between ISI and experimental

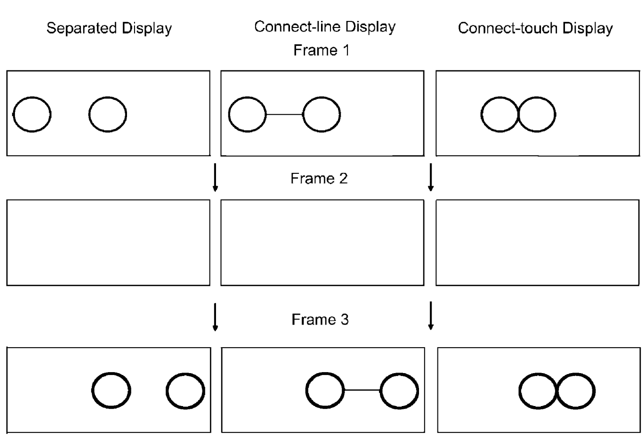

Fig. 2. The trial sequence for the separate, connect-line and connect-touch conditions for both the separated (standard) and connected Ternus displays. Frame 2 represents the variable ISI (0, 12, 24, 36, 48, 60, 72, 84, 96, or 108 ms) between Frames 1 and 3 during which the screen is blank.

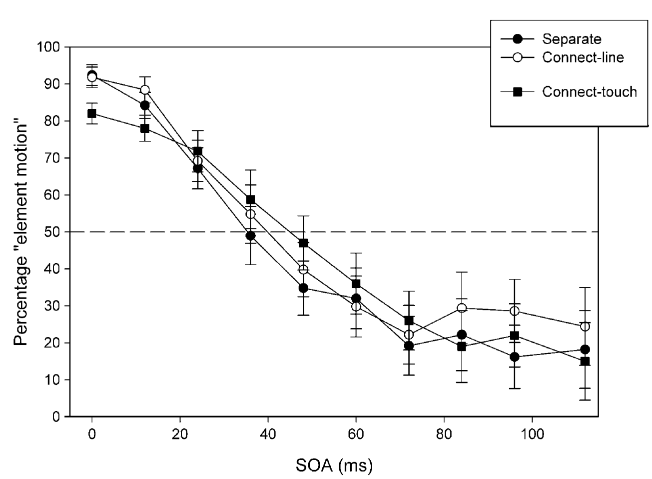

Fig. 3. Amount of perceived element motion vs. grouped motion as a function of ISI and display condition (separate vs. connect-line vs. connect-touch), as well as standard error of the mean for each ISI (error bars).

display, $F(9,108) < 1$. Thus, subjects perceived single element motion at short ISIs irrespective of whether the elements were connected.

Following the experiment, all of the subjects reported having seen single element motion. Interestingly, when asked to describe how the outer element (left) appeared to move in the connected condition, all five subjects in the connect-line condition and two of the subjects in the connect-touch condition reported the appearance of three dimensional movement with the outer element rotating out front or behind the inner element (right). Moreover, the inner element was seen to pivot in the z-plane as the outer element moved in front of or behind it. In other words, subjects saw the connected elements pivot in the z-plane on the inner element with the outer element changing position.

4. Discussion

The present experiment demonstrates that element motion in a modified Ternus display is such a profound percept that it cannot be eliminated even when the elements are connected to form a single object. Indeed, the crossover point between element and grouped motion was almost identical between subjects in the separate, connect-line, and connect-touch conditions. The finding of element motion with connected discs was unexpected. Both He and Ooi (1999) and Kramer and Yantis (1997) observed a substantial increase in the percept of group motion when the elements in their display could be perceptually grouped. Given that uniform connectedness has been shown to override powerful grouping principles such as proximity and similarity (Palmer & Rock, 1994), we had expected that connecting the items would eliminate element motion altogether. The discrepancy between our results and those of He and Ooi (1999) and Kramer and Yantis (1997) is likely attributable to differences in the display being used. Many of the grouping displays in He and Ooi's experiments were figure/ground manipulations, as were the manipulations used by Kramer and Yantis (1997), and both observed differences in the percept of group and element motion as a function of whether the displays were grouped with a stationary or moving context. Thus, manipulations of both the elements in the display and the context in which they appear seem to influence whether group or element motion is perceived. Our displays did not contain any figure/ground or context manipulations, which may explain why we did not see an increase in group motion with the connected display.

The unexpected finding of element motion with the connected displays is inconsistent with Braddick's (1974, 1980) two-process account of apparent motion in the Ternus display. According to this account, element motion is the result of a short range motion process which signals non-motion in the inner elements, leading the long range motion process to signal element motion, with the outer element jumping over to the right side of the display. In the present experiment, subjects perceived element motion despite the percept of motion in each of the connected elements. Specifically, the outer element was perceived as rotating out in front of (or behind) the inner element and the inner element was perceived as rotating in place to facilitate the 3-D illusion. These findings are consistent with the account of apparent motion proposed by Scott-Samuel and Hess (2001). They argued against any role for a short range motion process in apparent motion in the Ternus display and instead posited that the percept of apparent motion was solely attributable to the higher-level long range process. While it is unclear why the connect-line condition was more conducive to the 3-D illusion than the connect-touch condition, the critical finding is that subjects in both of these conditions observed movement that is inconsistent with Braddick's (1974, 1980; Braddick & Adlard, 1978) two-process account. Thus, the present results add support to the notion that Ternus displays do not involve short range motion processing, but rather rely on long range processes.

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