Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting.
Santa Monica, CA: Human Factors and Ergonomics Society. 2005.

STATIC REPRESENTATION OF OBJECT MOTION

Douglas J. Gillan and Merrill V. Sapp
New Mexico State University
Las Cruces, New Mexico
gillan@crl.nmsu.edu; msapp@nmsu.edu

Displaying motion information is useful in dynamic tasks, such as tracking or predicting the course of moving objects or systems (e.g., unmanned ground or air vehicles, troops, or weather). Static representations of object motion may be useful when technological limitations prevent use of dynamic displays. The present experiment examined people's interpretations of a variety of static cues to represent object motion. Participants viewed and rated two static types of representation of object motion -- motion lines and arrows. The features of object motion that participants rated were distance traveled, direction, path, speed, and acceleration. The results show that observers reliably interpret certain static cues to represent features of object motion, especially distance, direction, path and speed; the cues examined were not interpreted as representing acceleration. The results are interpreted as guidelines for design of displays that include object motion information.

The importance of motion in information displays was recognized early, as evidenced by theater marquees that used apparent motion to attract viewers' attention to their static message. More recently, motion of objects has become an important component of computer-based information displays for tasks like tracking the course of weather systems, monitoring changes in dynamic systems, or controlling robots (e.g., Earnshaw & Watson, 1993; Tufte, 1997).

An object in motion has both dynamic features -- speed and acceleration -- and static features -- direction of the object, distance traveled, and its path. Under certain conditions, displaying any of the dynamic or static features may require a static display. For example, printed maps (or their reproduction on a computer display) necessarily exclude the use of a dynamic display. Likewise, low bandwidth technology may prevent the use of dynamic displays. Devices with limited memory (e.g., handheld computing devices) may not be capable of providing a dynamic display; or designers may choose to reserve limited bandwidth for task-related functions rather than the dynamic display of motion. Finally, even when a dynamic display could be an option, a designer may choose static displays. For example, visual artists such as painters or graphic novelists choose to represent motion by a variety of static cues (see McCloud, 1993). Accordingly, understanding how to use static representations to accurately represent motion to a viewer may be critical to the successful completion of a task under certain conditions.

Those visual artists who have chosen to create static representations of motion may point designers of computer-based displays towards the best ways to use static cues to represent motion. Graphic novelists, specifically, have developed a repertoire of static cues to depict motion. For example, McCloud (1993) describes the use of static cues like motion lines or zip ribbons, blur, multiple images, and positional changes across frames to portray motion (see Figure 1).

Following a demonstration that static cues to motion can be valuable in a task that made use of motion information (Strickland, et al, 2003), we recognized that designers would need empirically based guidance in the use of static cues to represent motion. Accordingly, the following experiment was an initial investigation into how specific static cues might represent motion.

Figure 1. Motion of a runner shown by multiple images, motion lines, and blur.

METHOD

Participants

Thirty undergraduates at New Mexico State University participated in the study in exchange for research credits in a Psychology course.

Stimuli

Twenty-five different displays were shown to each participant. Each display had a representation of an object on both sides of a sheet of paper, with static cues to motion between the two object images. The displays used minimal lines, with a simple wire-frame version of the object. The object used in all of the displays (i.e., the object in putative motion), was a figure that resembled an unpiloted ground vehicle (UGV), somewhat like a PackBot, but with no features indicating a front-rear orientation (Figure 3 shows an example of the object). The distance between the objects varied (4.8, 8.8, 12.2, and 16 cm) on different displays.

Lines and arrows represented motion in the displays. The display design was manipulated in a nonfactorial manner. One set of displays varied number of lines (3, 4, or 7 lines); another set varied the width (.2, 1.0. and 1.5 mm). Arrows varied by number (3, 6, 9, 12), space between the arrows (either consistent spacing, increasing space going left-to-right, or increasing space going right-to-left; see Figure 9 for examples), and orientation --pointing left (<) or right (>).

Procedure

Participants were told that the displays were intended to show that the object had moved from one place to the other place on the page, but that if they did not interpret the display as representing motion, such a response was acceptable.

Participants were asked the following questions about each display:

(1) In what direction is the path of the motion?

(2) On a scale from 1-7 (1 = extremely slow and 7 = extremely fast), how fast is the indicated motion?

(3) On a scale from 1-7 (1 = has not moved at all and 7 = has traveled a great distance), how far has the object traveled?

(4) Is the path of the object straight or curved?

(5) If curved, is it a simple or complex curve?

(6) Does the object appear to be moving at a constant speed, speeding up, or slowing down?

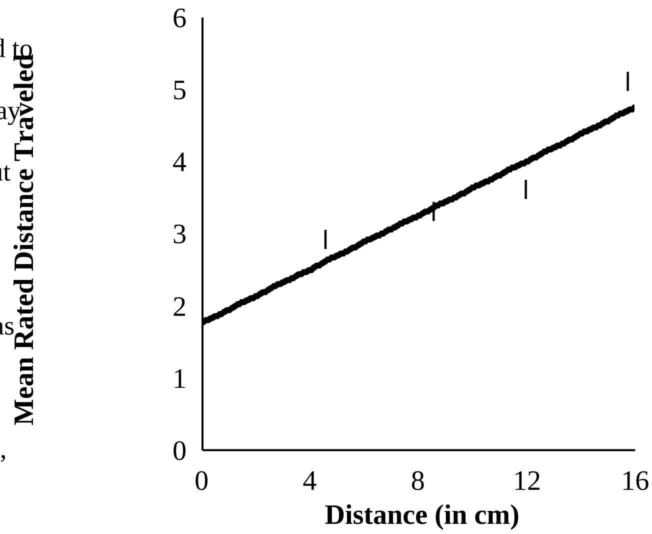


Figure 2. Mean distance ratings as a function of the actual distance between objects.

RESULTS

Distance

As expected, estimations of the distance traveled increased as the displayed distance between the objects increased, no matter the motion cues. Figure 2 shows the data combined for both arrows and motion lines. The regression function relating rated distance traveled and the actual distance between the objects is

Rated Distance = 1.8 + .2(Distance),

with the actual distance accounting for 86% of the variance in the rated distance. Thus, both the arrows and the motion lines permit the viewer to make reasonable estimates of the distance traveled.

Direction

When the arrows pointed right (>), the direction of motion was interpreted as left to right by all participants (p<.01, Sign test). When the arrows pointed left (<), the direction of motion was interpreted as right to left, by all participants (p<.01, Sign test).

A display such as Figure 3A, with the lines equidistant from the left and right robots, was perceived as representing left to right motion by all participants (p<.01, Sign test). However, the displays designed specifically to look at cues to direction did influence the judgments of direction. In these displays (Figure 3B - E) the direction was usually seen as moving towards the object that was closest to the lines. In Figure 3B, all participants interpreted the object as moving left-to-right (Sign test, p < .01). In Figures 3C - E, 51 of 74 choices were that the object was moving right-to-left (Sign test, p < .01) (16 of 24 judged Figure 3C as right to left; 19 of 25 judged Figure 3D as right to left; 16 of 25 judged Figure 3E as right to left).

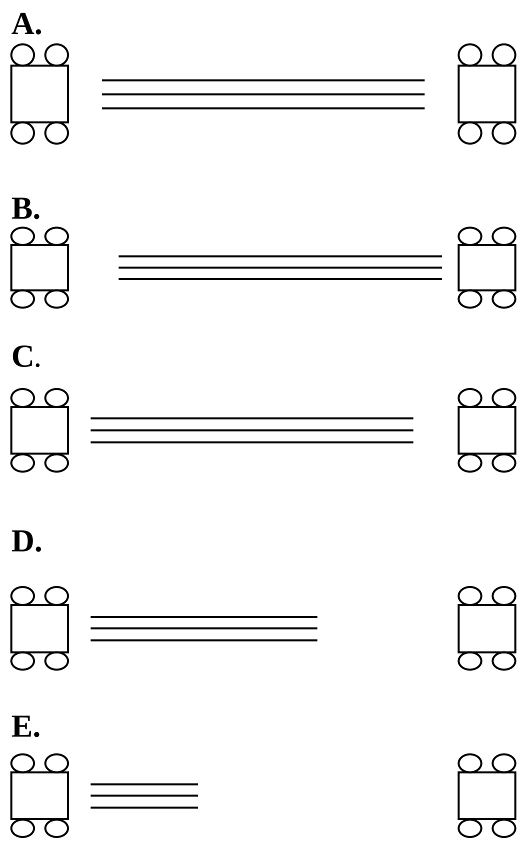


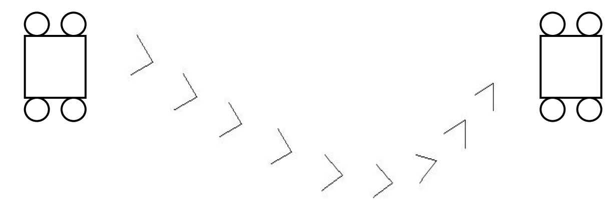
Figure 3. Examples of lines used in examining judgment of direction. Direction was most influenced by the distance between the object and the trailing lines.

Path

Two arrow displays provided cues for a curved path. One of the displays had a large curve from the first figure to the second. The other curved display had two curves in between the first and second. Figures 4A and B were perceived to represent curved paths by 29 of 30 participants

(Sign test, $p < .05$), with 25 of 29 participants identifying the path shown in Figure 4A as simple; and 24 of 30 identifying a path like that shown in Figure 4B as complex (Sign test, $p < .05$).

A.



B.

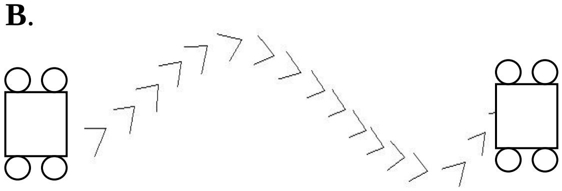


Figure 4. Curved paths: A. Simple. B. Complex. Participants tended to interpret the path complexity in accordance with the figures.

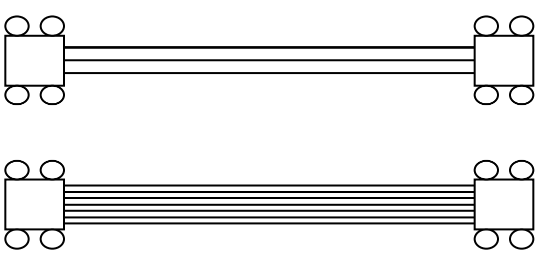
Speed

The number of motion lines (see Figure 5A for examples) influenced the mean rating of speed. Figure 6 shows the mean speed ratings as a function of the number of lines (3, 4, or 7). The regression function relating rated speed and motion lines is

Rated Speed = 2.0 + .6(Number of Lines),

with the number of lines accounting for 99% of the variance in rated speed.

A.



B.

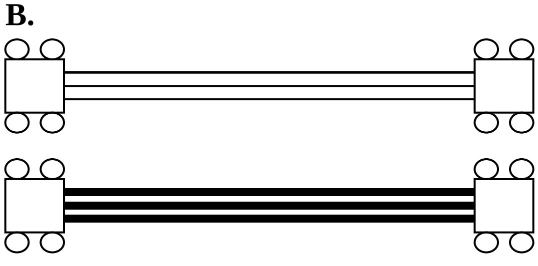


Figure 5. Examples of variations in the number (Fig 5A) and in the thickness (Fig 5B) of lines. Participants interpreted increases in the number, but not the thickness, of lines to represent increased speed.

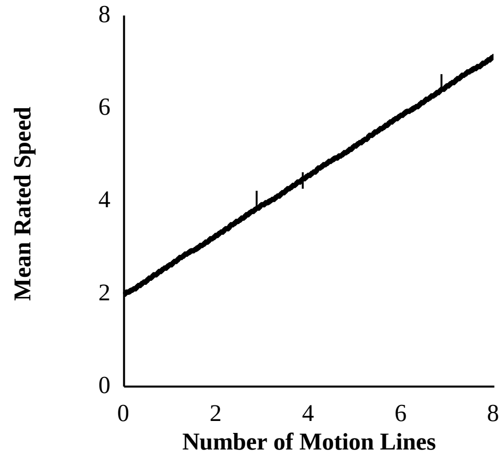


Figure 6. Mean speed ratings as a function of the number of motion lines.

In contrast to the *number* of lines, the relation between the variations in the *thickness* of the motion lines (see Figure 5B) had essentially no effect on the mean speed ratings. The mean speed ratings for the thin, medium, and thick lines were 4.31, 3.92, and 4.10, respectively.

As with motion lines, increases in the number of arrows (see Figure 7 for examples) resulted in increases in the mean speed rating, as can be seen in Figure 8. The regression function relating the number of arrows and the rated speed is

Rated Speed = 2.4 + .3(Number of Arrows),

with the number of arrows accounting for 99% of the variance in the mean ratings of speed.

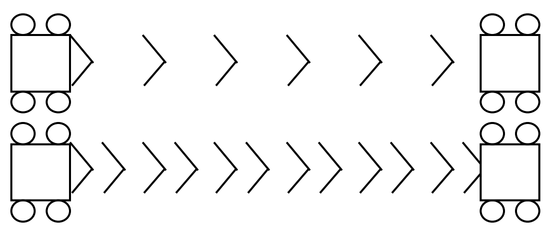


Figure 7. Examples of variations in the number of arrows. Participants interpreted increases in the number of arrows to represent increased speed.

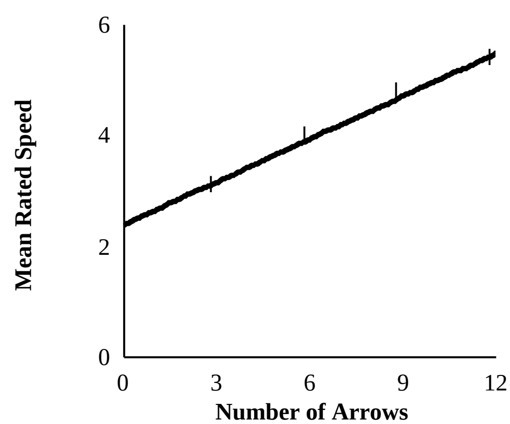


Figure 8. Mean speed ratings as a function of the number of arrows.

Acceleration

Figures 9A and B were judged by all 30 participants as representing a change in speed (Sign test, $p < .01$). However, 15 of the participants judged Figure 9A to indicate acceleration, whereas 14 of 30 judged that It represented deceleration. Likewise 14 of 30 participants interpreted Figure 9B to represent acceleration but 15 of 30 interpreted it to represent deceleration. Interestingly, for some participants, the interpretation of the number of arrows apparently depends on the consistency of spacing between arrows: when the spacing changed in the display, a number of participants interpreted closer arrows (and the related increased number of arrows) to indicate a reduction in speed; when the spacing between arrows was constant, those same participants judged an increased number of arrows to indicate higher speed.

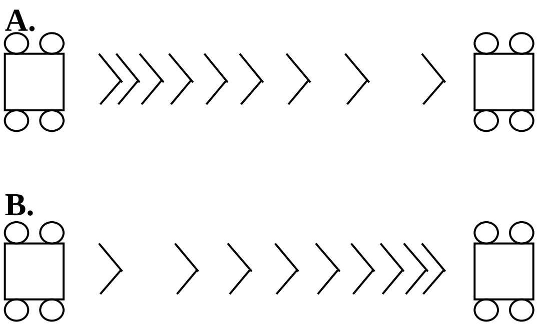


Figure 9. Examples of changes in the spacing between arrows. Participants interpreted both to indicate a change in speed but did not agree as to whether 9A or 9B represented acceleration.

DISCUSSION

Strickland, et al, (2003) showed that certain static cues for object motion can be as effective in communicating static features of motion to a display reader as are dynamic displays. The present research extends that work to compare different static cues for their efficacy in displaying both static and dynamic features of motion. The present research combined with the Strickland, et al, (2003) work leads us to begin to answer two questions – (1) *how* can display designers represent an object in motion via static cues, and (2) *why* are static cues effective in representing motion?

The present results help us in formulating initial guidelines for the use of static cues for representing features of motion, which are provided in Table 1 below. Clearly, a more detailed and complete set of guidelines will require additional research that examines additional cues and specific tasks.

Unlike pictorial depth cues, which can produce some sensation of depth from a two-dimensional display, static cues for object motion are unlikely to produce the subjective feeling of motion. Rather, they are likely to be interpreted as an index of motion. Accordingly, such indices are probably learned because they resemble a residual effect of motion perception (e.g., motion lines) or because they suggest aspects of motion like direction (e.g., arrows). If static cues are indices and their effects are learned, then any generalizations of research like this may be conditional on the viewer's age and culture (see McCloud, 1993 for examples from Japanese graphic novels or *manga*).

Table 1.
Guidelines for the use of static cues to display object motion

Static Features

(1) *Distance Traveled*

- Use of either arrows or motion lines between two representations of an object will permit viewers to estimate the distance traveled by that object.

(2) *Direction*

- Interpretation of the direction of a moving object will be based on the direction of a set of arrows' points.
- Motion lines will tend to be interpreted as indicating left-to-right motion

  -- unless the lines are shifted close to an object on the left side of the display and appear to be trailing from that object.

(3) Path

- Viewers will accurately interpret a moving object's path from the position of arrows.

Dynamic Features

(1) *Speed*

- Viewers will interpret an increased number of motion lines as an increase in speed.
- Viewers will interpret an increased number of arrows as an increase in speed, if the arrows are evenly spaced

(2) *Acceleration/Deceleration*

- Viewers will interpret arrows with increasing or decreasing spacing as a change in speed, but across viewers are not reliable in their interpretation of these cues as acceleration or deceleration.

ACKNOWLEDGEMENTS

Prepared through participation in the Advanced Decision Architectures Collaborative Technology Alliance sponsored by the U.S. Army Research Laboratory under Cooperative Agreement DAAD19-01-2-0009. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U. S. Government.

REFERENCES

Earnshaw, R. A., & Watson, D. (Eds.). (1993). *Animation and scientific visualization: Tools and applications*. San Diego: Academic Press.

McCloud, S. (1993). *Understanding comics*. New York: Harper Collins.

Strickland, J., Gillan, D. J., & Chadwick,. R. (2003). Static and dynamic representations of motion. In *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting* (pp. 755 – 759). Santa Monica, CA: Human Factors and Ergonomics Society.

Tufte, E. R. (1997). *Visual explanations: Images and quantities, evidence and narration*. Cheshire, CT: Graphics Press.