Judgments of Size Change Trends in Static and Animated Graduated Circle Displays

John C. Kostelnick
Dept. of Geography-Geology
Illinois State University
kostelnick@gmail.com

J. Devin Land
Dept. of Psychology
University of Kansas
formerly affiliated with
Haskell Indian Nations Univ.

James F. Juola
Dept. of Psychology
University of Kansas
Dept. of Human-Technology Interaction
Technical Univ. of Eindhoven

Despite the abundance of research on the perception of information presented as graduated or proportional circles on static maps, such experiments have been rare for animated map displays. However, such experimental results might be beneficial for selecting optimal methods for depicting temporal change on graduated circle maps. In the present experiment, participants judged whether a greater number of circles in an n x n array increased or decreased during a 1500-millisecond (ms) observation interval. The variable n represented values of 6, 8, and 10, and all circles changed size (some larger, some smaller) from a common starting size either in a discrete shift (static condition) in the middle of the observation interval, or in a smooth, apparently continuous shift (animated condition) over the same interval. In addition, the size changes were relatively small, moderate, or large. The proportion of "more bigger" judgments, plotted against the actual proportions of enlarged circles, produced an ogive function (a cumulative normal) with similar slopes in all conditions. However, the bias towards "bigger" judgments increased with the size discrepancies between the initial and final circle diameters, and the bias towards "bigger" judgments was greater for animated than for static circle diameter changes. The results are interpreted in terms of attentional precedence for larger items and also for those that appear to be continuously increasing in size (looming). These results have implications for the presentation of information on static and animated graduated circle maps.

Keywords: graduated or proportional circles, map animation, perception.

INTRODUCTION

The graduated, or proportional symbol is a common form of map symbolization for quantitative data that occur or may be conceptualized to occur at point locations. Graduated symbols are constructed by scaling the size of each symbol proportional to some data value (e.g., population for U.S. cities). Although a variety of graduated symbols such as squares, bars, triangles, spheres, and cubes may also be displayed on maps, the circle is perhaps the most commonly used symbol (Figure 1). Meihoefer (1969) cited a number of reasons for their popularity: circles use map space efficiently, are easy to construct, and map readers often prefer the visual aesthetics of circles over other shapes.

"Animated graduated circle maps are common for depicting changes in geographic patterns over time."

Animated graduated circle maps are common for depicting changes in geographic patterns over time. Animation may be beneficial for displaying temporal changes since the passage of time is depicted directly by the temporal length of an animated map display. The successive display of static frames in a map animation can create apparent motion, a visual effect in which objects appear to move continuously in the display. Apparent mo-

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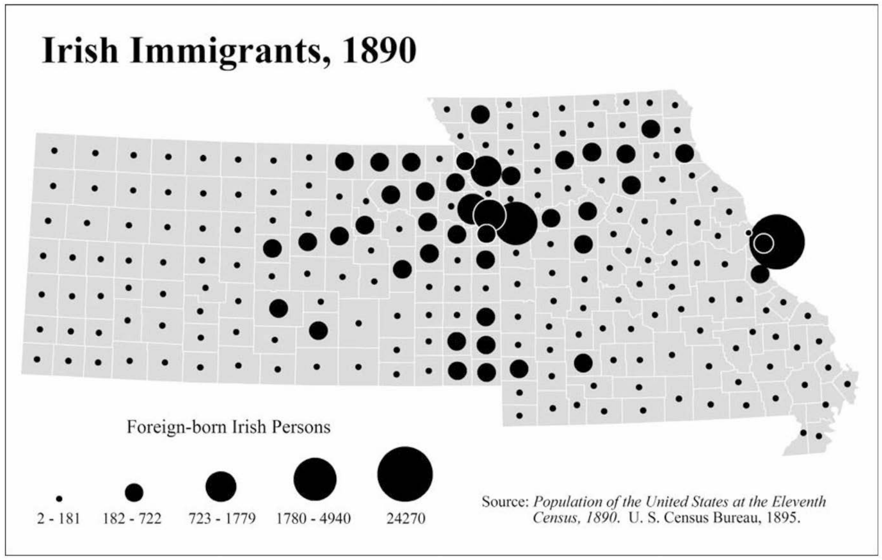

Figure 1. An example of a graduated or proportional circle map, this one shows Irish immigrants in Kansas and Missouri counties in 1890.

tion is evident in animated graduated circle maps as circles dynamically increase or decrease in size. Yet, it remains uncertain whether the apparent motion in animation aids the viewer in detecting change between graduated circles, or rather serves as a detriment since in some contexts animation may increase the cognitive demands associated with comprehension of a display (Tversky, Morrison, and Betrancourt, 2002).

"Yet, it remains uncertain whether the apparent motion in animation aids the viewer in detecting change between graduated circles . . ."

Background and Literature Review

As with all other forms of map symbolization, the effectiveness of graduated circles in both animated and static displays is limited by the perceptual constraints of human vision. Detection of the overall trend change (i.e., more total circles increasing in size or more total circles decreasing in size) between two graduated circle map displays may be described by the basic laws of psychophysics. For example, the discrimination threshold is the weakest stimulus change that can be detected. In the case of overall trend changes in graduated circle map displays, it would be the smallest proportion of increasing circles for one to judge an "increasing" trend change reliably, or the smallest proportion of decreasing circles for one to judge a "decreasing" trend change reliably. According to Weber's Law, the larger the physical intensity of a stimulus, the higher the discrimination threshold. Fechner's Law more precisely describes the relationship between the actual physical intensity and its perceived intensity as a decelerating, or logarithmic function.

". . . if the apparent motion in animation is indeed beneficial to the viewer, we would expect a lower discrimination threshold or sensitivity . . ."

By applying these psychophysical laws to graduated circle map displays in a general manner, we would expect that the number of circles either increasing or decreasing in size, respectively, must increase in number as the total number of circles in a display increases in order for subjects to detect the overall trend change between displays. Furthermore, if the apparent motion in animation is indeed beneficial to the viewer, we would expect a lower discrimination threshold or sensitivity in the task compared to static displays. Conversely, if animation increases the cognitive load associated with the task, we would expect a lower discrimination threshold or sensitivity for static displays.

Research in cognitive psychology and in cartography has revealed important characteristics of how individuals detect general and specific attributes of scenes, as well as any changes that might occur between displays. Some statistical properties of complex visual displays appear to be extracted by a more or less automatic and parallel process. The gist, or overall meaning, of a briefly-presented scene or the central tendencies of some of its components can sometimes be reported, even when details of individual objects in the scene cannot (e.g., Oliva, 2005; Rousselet, Joubert, and Fabre-Thorpe, 2005).

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Several studies of how people extract information about the mean object size and its variation in a scene have used simple displays of geometric forms such as circles. For example, Ariely (2001) showed that the mean judged size of a set of filled circles of various sizes was influenced only slightly by the number of circles (from 4 to 16), and Chong and Treisman (2003) found that similar judgments showed only a small effect of exposure duration (50 to 1000 ms). Further, Chong and Treisman (2005) found that average circle size was estimated more accurately if the displays were viewed while observers were engaged in a concurrent distributed attention task than if they were viewed during a serial scanning task. Such results support the idea that certain aspects of meaning and statistical properties of complex displays can be estimated from global processes operating quickly and in parallel over large display areas.

In cartography, a number of psychophysical experiments with static graduated symbols on maps (e.g., Flannery, 1971; Crawford, 1973) have revealed that, when asked to estimate the magnitude of graduated symbols such as circles and squares, individuals consistently underestimate actual size. Such results are consistent with the findings of Stevens (1957) who argued that the psychophysical relationship between an actual stimulus magnitude and the perceived magnitude is neither linear nor logarithmic, but might be best described by a power function. Related experiments with graduated circles on static displays have examined the effects of other variables on magnitude estimations, including sizes of adjacent circles (Gilmartin, 1981), individual differences between map readers (Griffin, 1985), and visual contrast and color of circles (Griffin, 1990).

Despite the abundance of research with static displays, markedly fewer studies have compared how individuals detect magnitude changes of graduated circles in both static *and* animated conditions (although see Slocum et al., 2004 for a qualitative evaluation of static and animated graduated circle maps). The lack of such research is regrettable since Slocum et al. (2001) have noted inconsistent findings regarding the effectiveness of animated maps in various contexts. For example, Patton and Cammack (1996) compared sequenced (animated) and static choropleth maps and found that both response speed and accuracy improved with sequenced maps compared to static displays. However, a comparison of animated and static flow maps by Johnson and Nelson (1998) did not reveal any significant differences between animated and static displays for either response time (RT) or accuracy rates. In another study, Koussoulakou and Kraak (1992) found that map animation did not improve overall accuracy rates, but RT was shorter for animated maps than for static displays. An experiment by Griffin et al. (2006) found that RT was faster and accuracy rates were higher for animation compared to static small-multiple displays for the identification of clusters that changed over time and space. Fabrikant (2005) has suggested that a failure to link perceptual salience with thematic relevance on the map may be a reason why map animations have not proved effective in some controlled experiments.

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Inconsistent results regarding the general utility of animation have also been found by cognitive psychologists. For example, Morrison and Tversky (2001) found that animated graphics were not more effective than static graphics for learning purposes. In a review of several studies that compared animated and static displays, Tversky, Morrison, and Betrancourt (2002) concluded that animation does not improve comprehension of complex systems, and argued that the many studies that have found significant advantages to animation may be attributed to unfair comparisons between animated and static displays in the experiments. However, Tiritoglu and Juola (1994) discovered that animated icons in a computer-aided design (CAD) software package improved comprehension and retention of the functions represented by the icons.

". . . it seems necessary to define the specific conditions under which animation is effective, and just as importantly, when it is not."

Overview of Experimental Design and Results

Due to the mixed findings regarding the effectiveness of map animation compared to static displays, it seems necessary to define the specific conditions under which animation is effective, and just as importantly, when it is not. Such variables may include, among others, symbolization type, complexity of information in the display, and type of task performed by the map reader. In the present study, we investigated how two factors might influence the accuracy of size change judgments in graduated circle displays. Specifically, we were interested in the perceptual effects of relative degree of size change as well as whether the changes occurred continuously (animated) or all at once (static) during an observation interval. Rather than estimate the size of individual circles (i.e., a specific task), we devised a more general task to test both factors. Participants were instructed to judge if a greater number of circles increased or decreased in size in each display. The task was designed to replicate a general task that a map reader might perform when detecting geographic patterns in changes between maps. For example, in a comparison of graduated circle maps of populations for U.S. cities in two different time periods, a map reader might wish to determine if a greater number of U.S. cities increased or decreased in population.

". . . the bias toward "bigger" judgments was greater for large size changes than for small size changes, and there was an additional bias towards "bigger" judgments for animated over static size changes."

We used sets of filled circles that were presented in evenly-spaced arrangements of 36, 64, or 100 items of the same size. During an observation interval of 1500 milliseconds (ms; or 1.5 seconds), some proportion of them increased in size, and the remainder decreased. Further, the changes in size occurred over small (areas halved or doubled), medium (areas divided or multiplied by four), or large (areas divided or multiplied by six) ranges, and the size changes occurred either all at once (static condition) or continuously (animated condition) within the observation interval. The data of interest were the proportion of "more bigger" judgments as a function of the proportion of circles that increased in size during the observation interval. Psychometric functions revealed that sensitivities to the proportions of change were relatively constant across all conditions (number of circles, relative changes in size, and animated or static size changes). However, the bias toward "bigger" judgments was greater for large size changes than for small size changes, and there was an additional bias towards "bigger" judgments for animated over static size changes. The results are interpreted in terms of attentional priority for large items (a type of global precedence; e.g., Navon, 1977), and also for those that appear to be looming (continuously increasing in size; e.g., Franconeri and Simons, 2003).

Methods

Participants

There were 12 participants total, consisting of 11 students and 1 faculty member (10 males, 2 females) at the University of Kansas. Students were either graduate or upper level undergraduate students participating as lab members or as part of an advanced psychophysics laboratory course. The mean age of participants was about 24 years, and all but one were cartographic novices.

"The displays consisted of filled, black circles on a white background and arranged into evenly-spaced 6 x 6, 8 x 8, or 10 x 10 arrays."

Apparatus and Stimuli

Stimulus presentation and data collection were controlled using a 1600/66 Power Macintosh computer with a 17-inch monitor. A custom computer program was developed to present the stimuli and record participant responses. The displays consisted of filled, black circles on a white background and arranged into evenly-spaced 6 x 6, 8 x 8, or 10 x 10 arrays. Circles were spaced in a grid pattern to control for circle overlap and other factors. Likewise, political boundaries and other map features were not included in order to simplify the displays and to ensure that the circles were the most perceptually salient objects in the displays. At the start of any trial, all circles had a radius of 4 mm and an area of 50.3 mm^2. From a viewing distance of about 50 cm, their diameters subtended a visual angle of about .8 degrees. During a trial some proportion of the circles increased in size, and the remainder decreased. No circles remained the same size in order to minimize sources of noise in the data. Three ranges of final sizes were used, with the differences between the smaller and larger radii being 2.8 and 5.6 mm (initial areas multiplied by .5 or 2, respectively), 2.0 and 8.0 mm (initial areas multiplied by .25 or 4, respectively), and 1.6 and 9.8 mm (initial areas multiplied by .167 and 6, respectively) for the three size change conditions (Figure 2). In this regard, the circles were similar to range-graded or classed symbols found on graduated symbol maps in which a limited number of circle sizes represent specific ranges or classes of data. The outer boundaries of the initial circle size arrays measured 793

"During a trial some proportion of the circles increased in size, and the remainder decreased."

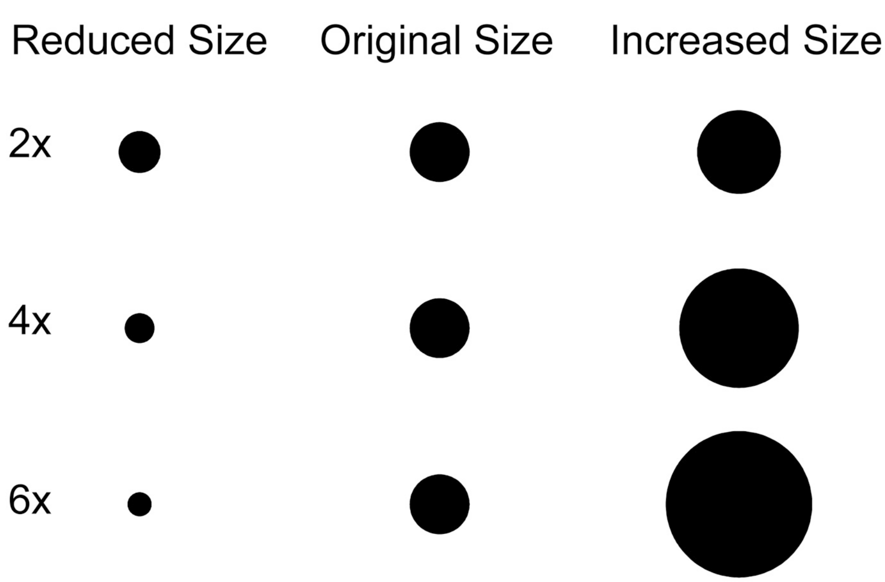

Figure 2. Circle sizes displayed in the trials. All circles started at the "Original Size" and then either decreased to the "Reduced Size" or increased to the "Increased Size." Circles increased or decreased in size by a factor of 2, 4, or 6.

mm per side for the 10 x 10 array, 624 mm per side for the 8 x 8 array, and 455 mm per side for the 6 x 6 array.

Procedure and Design

The changes in circle size occurred over a 1500-ms observation interval in either the animated or static condition. In the animated condition, the initial circle array appeared for 500 ms, after which all circles changed size gradually in a smooth, apparently continuous fashion over the final 1000 ms of the observation period. In the static condition, the initial array appeared for 500 ms, followed by a 500-ms blank screen and then a 500-ms exposure of the final array (Figure 3). The static condition was designed to replicate the process of how a map reader might compare two static maps by viewing each successively. The 500-ms blank field served to prevent the illusion of apparent motion during the size change in the static change condition as well as to equate the overall observation time of 1500 ms used in the animated condition. An important objective when designing the static and animated conditions was to develop comparable displays for both conditions and to control for other factors. Tversky, Morrison, and Betancourt (2002) have argued that one flaw in many experiments comparing animated and static representations is that both displays do not contain a similar amount of information necessary to ensure a fair comparison. Although the animations in the present experiment displayed continuous information or microsteps for the final 1000 ms of the 1500-ms interval, the final display in the static condition appeared in its final form for a longer period of time (500 ms) in an attempt to compensate for relative difficulty of the two conditions. In addition, the static condition was not designed as a small-multiples display (i.e., both displays viewed side-by-side simultaneously for comparison) in order to ensure that the tasks for the static and animated displays were as similar as possible and to control for other cognitive processes that may have influenced participant responses as a result of any significant differences.

"The changes in circle size occurred over a 1500-ms observation interval in either the animated or static condition."

At the end of the 1500-ms observation interval, the screen went blank, and the subjects depressed one of two keys on the keyboard labeled "more bigger" (/ key) or "more smaller" (z key) to indicate whether they judged most of the circles to have increased or decreased in size, respectively. In this way, the proportions of "bigger" and "smaller" judgments summed to 1.0 in all conditions for each participant. Participants were required to choose one of the responses on each trial, even if they thought they were guessing. The next trial began after a two-second interval. Participants received no feedback except for two beeps that sounded if a response was not registered within the two-second interval following the completion of a trial.

"At the end of the 1500-ms observation interval, the screen went blank, and the subjects depressed one of two keys on the keyboard labeled "more bigger" or "more smaller" . . ."

The trials were divided into blocks by array size, with the two display types (static or animated) and the three magnitude of size change conditions occurring randomly within each block. The proportion of circles that increased in size varied randomly from about 40% to 60% of the total, or from 13 to 23 (11 proportion changes) for the 36 circles in the 6 x 6 array, from 24 to 40 (17 proportion changes) for the 64 circles in the 8 x 8 array, and from 40 to 60 (21 proportion changes) for the 100 circles in the 10 x 10 array. These ranges were determined from pilot studies which showed that when the proportions of circles that increased in size was less than about 40% or more than about 60%, the overall trend in the display was easily recognized as changing respectively smaller or larger, regardless of the means of presentation. That is, when less than 40% of circles grew larger, subjects were nearly perfect at responding "more smaller," whereas when more than 60% of circles grew larger, subjects were nearly perfect

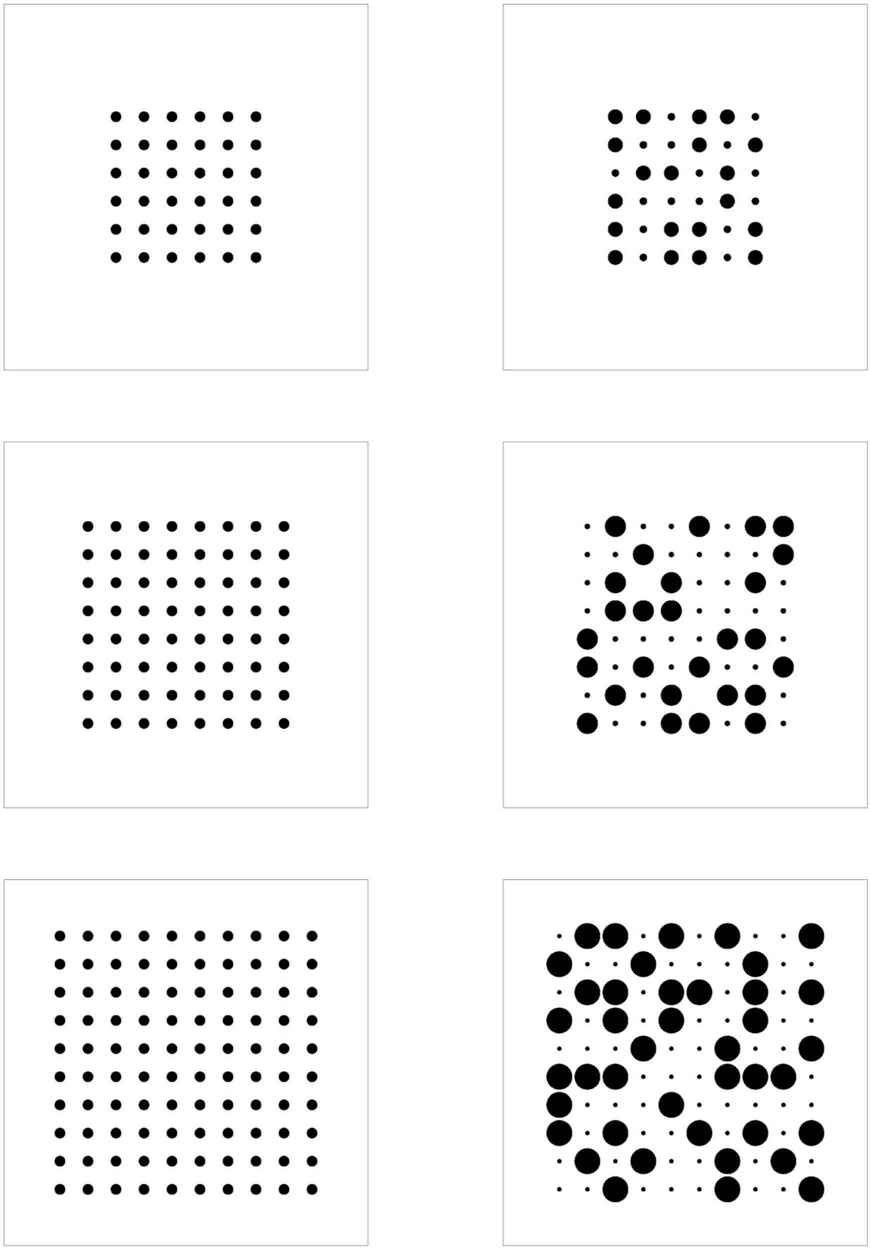

Figure 3. Illustration of the various displays used. The left column shows the three arrays with initial circle sizes. The right column shows the three circle size changes, with the smallest magnitude change in the top row and the largest magnitude change in the bottom row. In the static condition the initial array was displayed for 500 ms, followed by a 500 ms blank screen, followed by the 500 ms final array. In the animated condition the initial array was displayed for 500 ms, followed by the gradual change in circle sizes during the final 1000 ms of the 1500 ms observation period.

at responding "more bigger." The design was thus a 2 (display type) x 3 (magnitude of size change) x 11 (proportion changes) design in the 6 x 6 array block (66 cells), a 2 x 3 x 17 design in the 8 x 8 array block (102 cells), and a 2 x 3 x 21 design in the 10 x 10 array block (126 cells).

Each participant completed three experimental sessions and contributed an equal number of observations. Each session included one block of each array size, with order of block presentation counterbalanced across participants. Each block included four trials per cell, presented randomly. Thus, each participant completed 1,176 trials per session, or 3,528 total tri-

"Each participant completed three experimental sessions and contributed an equal number of observations."

als in the experiment. Each session included break opportunities between and within blocks of trials, and took about 80 minutes to complete including breaks.

Results

The main results are the mean proportions of "more bigger" judgments plotted against the proportion of circles in each display that increased during a trial. The data are shown separately for each array size (Figure 4), and within each size for displays that had small, medium, or large changes in the relative circle sizes (Figure 5), and for changes that were animated vs. static (Figure 6). Visual inspection of the psychometric functions in Figures 5-6 indicates general trends in all three arrays of a smaller proportion of circles increasing in size required for participants to give the correct response "more bigger" (i.e., a lower discrimination threshold) for animated changes and when the magnitude of size change was larger.

"Visual inspection of the psychometric functions indicates general trends in all three arrays of a smaller proportion of circles increasing in size required for participants to give the correct response . . . for animated changes and when the magnitude of size change was larger."

Two statistics are of interest. First, the slopes or gradients of the psychometric functions plotted in Figures 4-6 determine the relative sensitivity of subjects in making size change judgments. These sensitivities appear to be about the same in all conditions (number of circles, display type, and magnitude of size change). Second, the proportion of items that were increased in size that resulted in 50% "more bigger" judgments is the indifference point, and represents the "point of subjective equality" (PSE) for size change judgments. In the present case, the PSE is the actual proportion of size changes that appear to be balanced between increases and decreases. The PSE obviously changes across conditions. For example, note that the PSE is smaller (as indicated by its position further to the left on the x-axis) for large circle size changes than small size changes for all three grid sizes

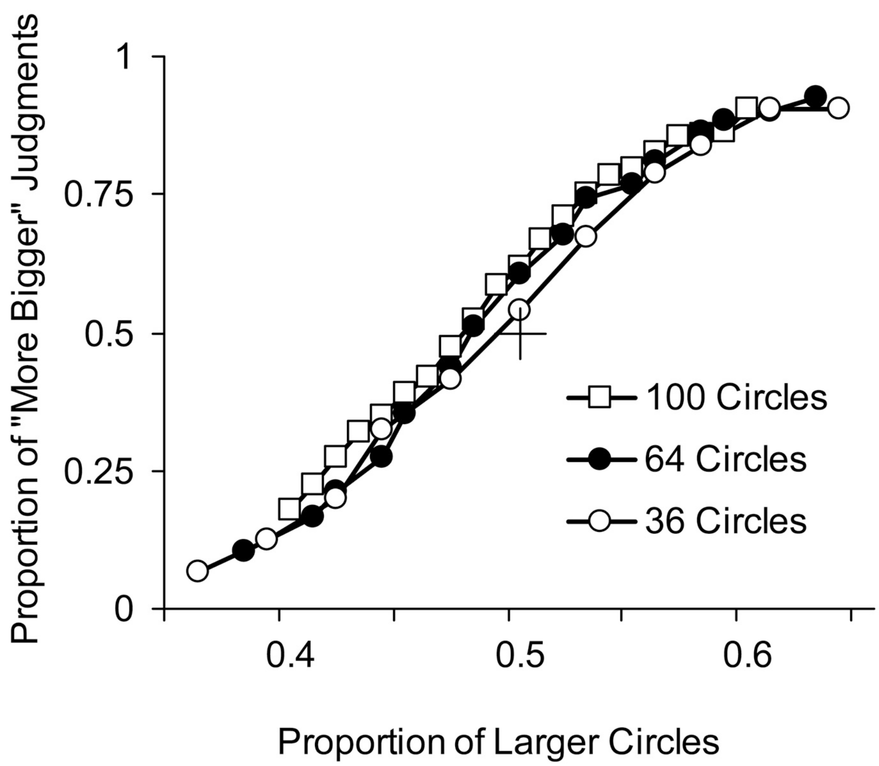

Figure 4. Mean proportions of "more bigger" judgments plotted against the proportion of circles that increased on any trial for arrays of 36, 64, or 100 circles.

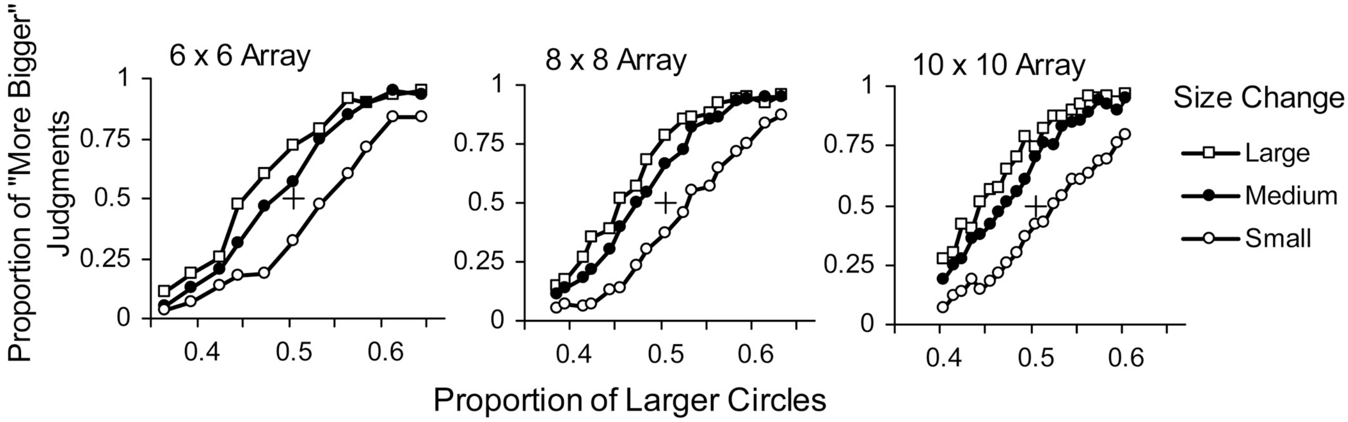

Figure 5. Mean proportions of "more bigger" judgments plotted against the proportion of circles that increased on any trial for small, medium, and large relative size changes.

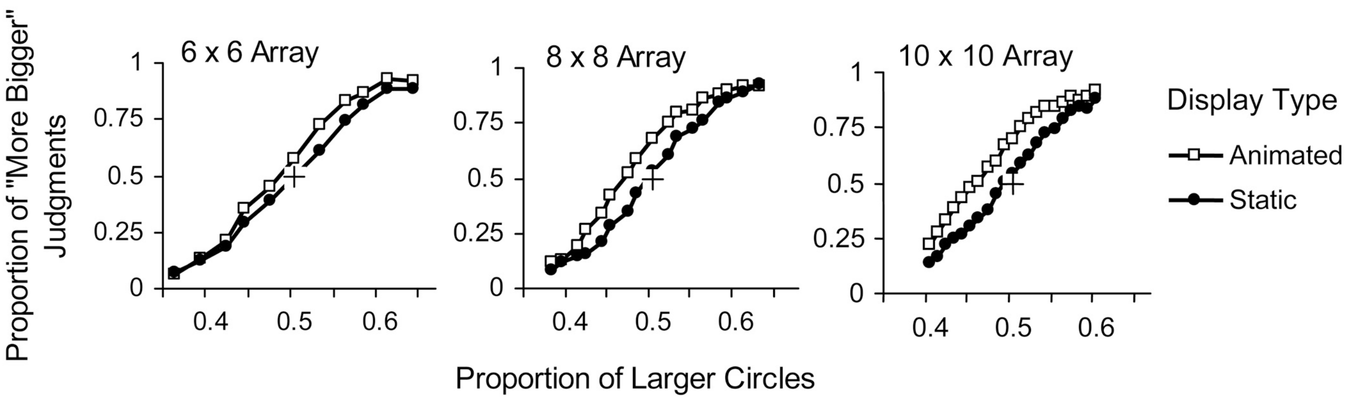

Figure 6. Mean proportions of "more bigger" judgments plotted against the proportion of circles that increased on any trial for animated vs. static size changes.

(Figure 5), and is also smaller for animated displays than static for all three grid sizes (Figure 6). The overall trends were confirmed by examining the data from individual participants. Due perhaps to the large number of observations collected, they showed remarkable uniformity in demonstrating the trends observed in the overall data.

In order to perform a statistical analysis of the results, the data for each participant in each cell of the design were fitted by a cumulative normal (Gaussian) distribution relating the proportion of "bigger" judgments to the actual proportion of circles that increased in size. These psychometric functions were fitted using the *psignifit* toolbox version 2.5.6 for Matlab (see http://bootstrap-software.org/psignifit/) that implements the maximum-likelihood method described by Wichmann and Hill (2001). The fits yield two parameter estimates for each subject in each cell, namely the means (μ) and the standard deviations (σ) of the assumed underlying normal distributions. The mean represents the 50% point of the judgments, or the PSE (i.e., the proportion of increasing circles that was as likely to be judged "smaller" as "bigger" in a given condition). The standard deviation corresponds to the sensitivity of the judgment, as a smaller standard deviation indicates a steeper slope of the psychometric function, and a greater ability to differentiate between small degrees of relative change in circle sizes.

". . . the data for each participant in each cell of the design were fitted by a cumulative normal (Gaussian) distribution relating the proportion of "bigger" judgments to the actual proportion of circles that increased in size."

"In the analysis of the means, there was no main effect of the number of circles, but the effects of magnitude of size change and type of change were both highly significant."

The resulting parameter estimates, averaged over participants, are shown in Table 1. These were submitted to two separate within-subject analyses of variance (ANOVAs), with the same three factors used in each design, namely, number of circles (36, 64, or 100), magnitude of size change (small, medium, or large), and type of change (static or animated). In the analysis of the means, there was no main effect of the number of circles, but the effects of magnitude of size change and type of change were both highly significant, $F(2,10) = 31.2$, $p < .001$, and $F(1,11) = 13.0$, $p = .004$, respectively. These results supported the conclusions that the tendency to report an increase in average size was greater as degree of circle size change increased and for animated rather than static changes.

The ANOVA of the means resulted in three significant two-way interactions, but these results did not limit the conclusions based on the main effects. That is, the interaction between number of circles and magnitude of size change showed that the PSE moved more to the left for large and medium size changes as the number of circles increased than for the small size change, for which the PSE remained fairly constant, $F(4,8) = 5.4$, $p = .021$. The difference in the PSE between animated and static changes increased with the number of circles, $F(2,10) = 6.1$, $p = .019$, and the difference in mean PSEs between the static and animated conditions decreased as the size change increased from small to large, $F(2,10) = 5.7$, $p = .023$.

	Number of Circles	36		64		100	
Degree of change	*Type of change*	μ	σ	μ	σ	μ	σ
Small	Static	.56	.09	.55	.08	.56	.11
	Animated	.51	.09	.51	.08	.51	.09
Medium	Static	.49	.08	.48	.08	.48	.08
	Animated	.48	.08	.46	.08	.44	.08
Large	Static	.45	.08	.46	.07	.45	.07
	Animated	.46	.09	.43	.09	.42	.09

Table 1. Statistics derived for all cells of the design using the curve-fitting methods described in the text. The results are the average points of subjective equality (PSE) for size change judgments (μ), and the average sensitivities of the judgments determined by the steepness of the discrimination gradients (σ).

The ANOVA of the standard deviations revealed two significant effects, a main effect of magnitude of size change, $F(2,10) = 4.5$, $p = .04$, and an interaction between magnitude of size change and type of change, $F(2,10) = 6.7$, $p = .014$. These results do not detract from the general conclusion that size change sensitivity was relatively constant across all conditions, because the data show relatively minor inconsistencies across conditions when compared with the consistent changes in the PSEs. Specifically, both the main effect and the interaction in the standard deviation ANOVA appear to be due to the relatively low sensitivity in the 100-item, small size change, static condition (see Table 1).

Discussion

Judgments of size changes for arrays of circles show smooth psychometric functions with sensitivity relatively unaffected by the number of circles in the display, the magnitude of size changes, and whether the changes were animated or static. However, the bias of these judgments was affected by the magnitude and manner of the size changes. Subjects were more likely to respond that there were "more bigger" items when the size changes were large (areas increased or decreased by a factor of 6) than when the changes were small (areas increased or decreased by a factor of 2). That is, the results showed a type of global precedence effect, in that as the ratio of areas of the large to small circles increased, the apparent numerosity of large circles also increased. Further, animated changes in size produced a greater proportion of "more bigger" responses than equivalent changes that occurred in a single discrete step. Both of these results can be explained by a perceptual bias for large display elements over smaller ones, and for continuous size increases (looming) over shrinking (e.g., Franconeri and Simons, 2003; but see also Abrams and Christ, 2005 and a response by Franconeri, Hollingworth, and Simons, 2005). That is, statistical judgments of display properties are determined in large part by what is attended to in a display, and there is an apparent attentional bias to select large or looming objects over small or receding ones.

"Subjects were more likely to respond that there were "more bigger" items when the size changes were large than when the changes were small."

These results have implications for both theoretical and practical reasons. First, it is obvious that the perception of global aspects of display elements, such as size change, depends on the extent and manner in which the changes are effected. Large changes in size are perceived differently than more subtle changes, and such differences affect numerosity or average size judgments such that large objects are perceived to be more numerous than smaller ones, and this bias increases with size discrepancy. Similarly, continuous (animated) changes also seem to affect relative numerosity judgments differently than static changes. Although a simple interpretation in terms of attentional bias to larger and looming objects neatly accounts for the results, it does not by itself explain the underlying differences in perception. Such differences are important in situations in which continuous changes (e.g., "morphing") are used to convey information. If attention and perception are affected by such changes, then it is possible that the same information can be perceived differently depending on the methods used to arrive at the final depiction of that information on maps.

". . . animated changes in size produced a greater proportion of "more bigger" responses than equivalent changes that occurred in a single discrete step."

In practical situations, it has been argued that animations could be more effective than single or even a succession of static views, particularly when the desire is to demonstrate changes that occur over time. Such arguments have been made, and validated with mixed success, in diverse domains such as cartography (e.g., Patton and Cammack, 1996; Johnson and Nelson, 1998; Slocum et al., 2001), computer-aided design (e.g., Tiritoglu and Juola, 1994), and rule learning (e.g., Morrison and Tversky, 2001). Perhaps one of the reasons for the mixed effects, sometimes showing advantages in perception of animated displays over their static counterparts and sometimes not, is that the information selected from the two presentation formats might result in different internal representations. Further, changes that involve increases in size or apparent looming appear to be more likely to attract attention and bias perception of the overall statistical properties of a scene and, by extension, change aspects of its meaning.

". . . the apparent motion in animation appears to be beneficial for attracting attention to overall circle size increases . . ."

These findings have practical relevance both to the general discussion of the effectiveness of map animation, as well as to the development of specific guidelines for the design of graduated circle map displays. Since the discrimination threshold for responding "bigger" was lower for animated displays compared to static displays, the apparent motion in animation appears to be beneficial for attracting attention to overall circle size increases in graduated circle map displays. None of the experimental results indicate that animation increased the cognitive demands associated with the task of identifying general trends in graduated circle size changes. In practical situations in which the cartographer wishes to emphasize a general trend that increases over time, animation may be utilized to enhance the figure/ground relationship as circles increasing in size will appear to emerge into the foreground of the display. However, by attracting attention to circles that become larger, animation may conversely detract attention from those circles that become smaller and therefore may go undetected as they recede into the background. For this reason, animated graduated circle map displays may be most appropriate for phenomena that generally increase over time, such as population of major U.S. cities over the last century, as animation is more likely than static displays to attract attention to the general patterns of population increase as represented by graduated circles larger in size. Likewise, static graduated circle displays may be more appropriate for phenomena that generally decrease over time, since static displays are not as likely as animated displays to detract attention from circles that decrease in size. Additionally, since larger size changes seem to bias judgments of the number of circles changing in a display, this may be another factor for consideration when a size scaling method (e.g., mathematical or perceptual) is selected for the construction of graduated circles.

". . . animation may be utilized to enhance the figure/ground relationship as circles increasing in size will appear to emerge into the foreground of the display."

CONCLUSIONS

Additional research is necessary in both cartography and cognitive psychology to assess the effectiveness of animated and static displays in various contexts. The current experiment examined the effects of three variables on size change trend judgments for graduated circle displays: magnitude of size change, display method, and number of items in the displays. Important findings include a bias toward "more bigger" judgments for large size changes, and an additional bias for changes presented with animation.

Useful follow-up experiments should include testing additional factors common to graduated circle maps. Such variables include specific items related to the map display, such as overlap of circles, and the addition of other map features, such as political boundaries. Research with unfilled circles as well as those filled with gray tones (light, medium, and dark) would also be valuable for determining the effect, if any, of luminance or degree of blackness on participant responses. Although range-graded or classed graduated circles were implemented in the present study, a follow-up experiment could present unclassed graduated circles, in which all circles are scaled in proportion to unique data values, to determine any differences between symbolization methods. It would also be useful to experiment with more complex displays that include circles of different sizes, rates of change, and variations in fluctuation (e.g., increasing in size, then decreasing). In addition, it is unclear whether the results from the present experiment were subject to any sequence effects (Stewart, Brown, and Chater, 2002), in which participant responses are biased by stimuli that immediately precede another stimulus. Additional research would be valuable for determining the effect, if any, of such sequence effects on participant responses for comparisons between animated and static displays.

"Useful follow-up experiments should include testing additional factors common to graduated circle maps."

Other follow-up experiments could include modifications and variations to the map task. For example, the static displays that were displayed sequentially in the present experiment could be displayed side-by-side for comparison, similar to small-multiple map displays that are commonly utilized to depict change over multiple time periods. Further, a more specific map task in which participants judged magnitude size changes for individual circles rather than overall size changes in the display would likely reveal other important differences between static and animated displays. Collectively, such research might uncover important characteristics of static and animated maps that cartographers could use as a guide for the design of graduated circle maps.

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