# Understanding Visual Cues in Visualizations Accompanied by Audio Narrations

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## ABSTRACT

It is often assumed that visual cues, which highlight specific parts of a visualization to guide the audience's attention, facilitate visualization storytelling and presentation. This assumption has not been systematically studied. We present an in-lab experiment and a Mechanical Turk study to examine the effects of integral and separable visual cues on the recall and comprehension of visualizations that are accompanied by audio narration. Eye-tracking data in the in-lab experiment confirm that cues helped the viewers focus on relevant parts of the visualization faster. We found that in general, visual cues did not have a significant effect on learning outcomes, but for specific cue techniques (e.g. glow) or specific chart types (e.g heatmap), cues significantly improved comprehension. Based on these results, we discuss how presenters might select visual cues depending on the role of the cues and the visualization type.

## CCS CONCEPTS

• **Human-centered computing** → **Visualization theory, concepts and paradigms**; *Empirical studies in visualization*.

## KEYWORDS

Visual cues; narrative visualization; learning



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## 1 INTRODUCTION

To perform effective presentation using data visualizations, presenters often enhance the viewers' experience through editorial layers such as visual cues [15]. Visual cues modify a visualization's appearance (e.g. transparency shown in Fig 1h) or introduce additional visual elements (e.g. callouts shown in Fig 1d) to a visualization [18]. These cueing techniques are widely used in presentation settings to guide the audience's attention to the relevant parts of a visualization.

Different types of visual cues have been studied across domains including education and psychology, and the results are mixed as the effectiveness of visual cues were only found for specific chart types and situations [3, 9, 13]. In the domain of data-driven storytelling, our understanding of the effects of visual cues has been limited. More specifically, do visual cues help deliver the intended message when the presentation includes a *verbal narration* of the visualization?

In this paper, we first present an in-lab study with 4 visualizations, 9 cueing conditions and 30 participants to examine whether visual cues improve the comprehension of the visualization and the recall of the cued material when people view visualizations accompanied by an audio narration. With the help of an eye-tracker, we also explore how various visual cues affect the eye gaze patterns of the viewers. We then conduct a second experiment on Amazon Mechanical Turk with 100 participants to evaluate the results on a larger scale.

Through our study, we seek to answer the following research questions:

RQ1. Do visual cues improve the recall of information that are cued?

RQ2. Do visual cues improve the comprehension of the visualization?

RQ3. Do different visual cues lead to different patterns of eye gaze?

RQ4. Do people's perceived effectiveness and aesthetic preference align with the actual effectiveness of the cues?

Our results show that visual cues help the audience focus on the relevant regions significantly faster. In general, cues do not have a significant influence on people's recall and comprehension of the visualizations that are accompanied by audio narration. However, in the in-lab study, glow significantly outperformed the uncued condition on comprehension, and in the online study, cued conditions significantly improved the comprehension score for one of the four charts. Through the interviews, we found a discrepancy between visualizations for which people perceived visual cues to be most useful versus the visualization that actually benefited from the cues. Based on the results, we conclude with suggestions on choosing visual cues based on the role of the cue, the visual characteristics of the highlighted regions, and the chart type.

## 2 RELATED WORK

We begin by discussing prior work on narrative visualization. Then, we provide an overview of research on the effectiveness of visual cues.

### Narrative Visualization

Segel and Heer analyzed the design space of data visualizations for storytelling and identified distinct genres, visual narrative tactics, and narrative structure tactics [24]. Their framework lists "Highlighting" as a visual narrative tactic category containing six tactics: close-ups, feature distinction, character direction, motion, audio, and zooming. In our work, we use visual cues as the feature distinction tactic and verbal narration as the audio component.

Kosara focused on the setting and the audience of storytelling visualization presenting three storytelling scenarios for visualizations: self-running presentation, live presentation in front of an audience, and individual presentation of results [19]. Our study covers the first category as we presented visualizations along with pre-recorded narrations to the study participants. Kosara states that the goal of these self-running presentations is to convey the main points in enough detail for the audience to understand the information while keeping them engaged. We measured the viewers' understanding of the visualization through multiple choice questions and asked about their experience during the interviews.

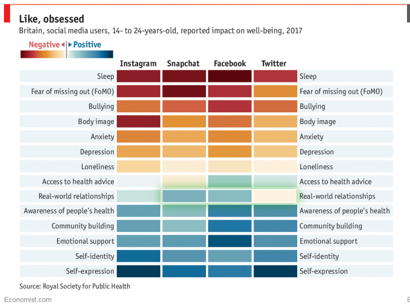
Other works have also studied various aspects of narrative visualization including Hullman's work on the sequence of visualizations [16], automatic annotations [10, 17], and visual rhetoric [10, 15, 16] and Boy's work on the impact of introductory stories on data exploration [2]. ChartAccent by Ren et al. allows people to quickly apply manual and data-driven annotations to augment charts [23]. In the majority of these works, the narrative was embedded in the visualization itself or accompanied by text. In our work, we explore visualizations that are accompanied by audio narrations. This integration of visualization and verbal explanation makes the work relevant to domains spanning from live presentations to online courses.

### Visual Cues

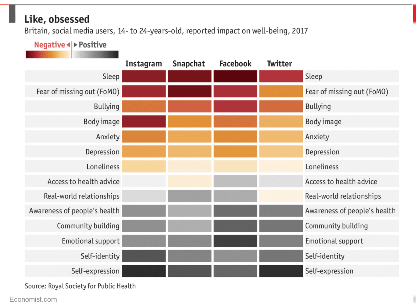
In this section, we review the existing literature on visual cues in learning and interpreting information. Cavender et al. studied the effects of four different visual cues on visual notifications for deaf and hard of hearing students who watched a prerecorded lecture online [3]. They studied the student's eye movement and preference of the cues, and found that most students favored visual cues as a way of guiding attention. Their study further showed that participants who liked notifications were more likely to notice them and to benefit from them. Our study also involves an eye tracker to distinguish eye movement patterns when people view a visualization with or without cues. In addition, we measure and compare the perceived effectiveness and participants' aesthetic preference along with the actual effectiveness for each of the cues.

The results on the effectiveness of visual cues have been mixed with some studies finding a significant influence and others finding none. Griffin and Robinson compared two visual cues – contour and leader line – in their effect on information extraction from coordinated multiple views by evaluating task completion time and eye fixation time. [13]. They did not find a significant difference between two highlighting methods in completion time, while leader lines took less fixation time in some cases. In De Koning et al.'s 2007 work, they found that cueing enhanced performance when learning from animations without a significant increase of mental effort [6]. However these results were not replicated in their follow up study, where they studied the effect of cues on the eye movement pattern and learning outcomes [7]. Their results showed that studying an animation with spotlight-cues did not lead to better comprehension and transfer performance, nor to a differentiation of mental effort. They also found that cues increased attention, but attention was not necessarily driven to the cued parts. Our work closely relates to this work as we also study the relationship between the eye movement patterns for different visual cues and the learning efficiency of the cues, but study them under a specific scenario of storytelling around a visualization. While De Koning et al. used animations without any narration [7, 8], we study the effect of visual cues when presenting visualizations with an audio narration.

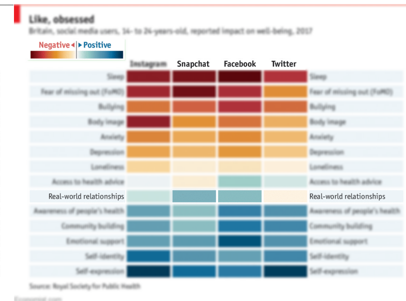
Previously Lin and Robert studied the effectiveness of using arrows to teach scientific concepts along with an audio



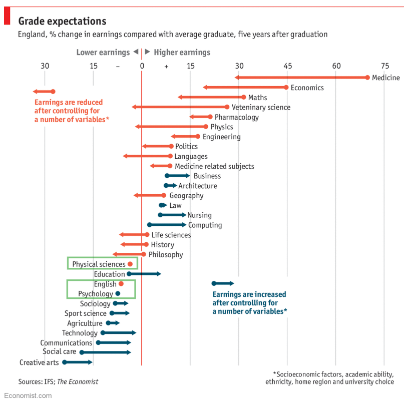

(a) Glow



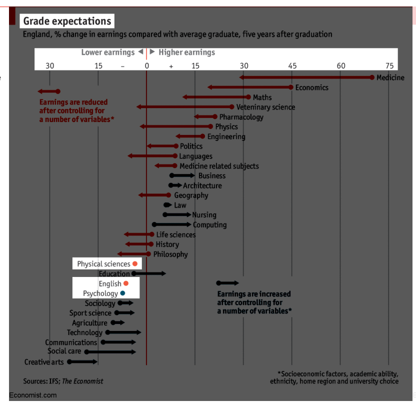

(b) Desaturation



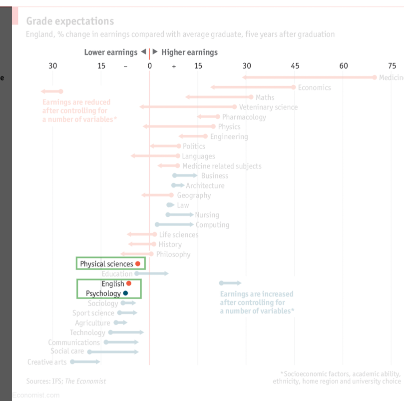

(c) Depth of field



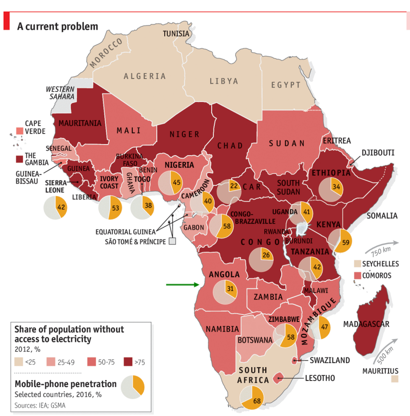

(d) Shape



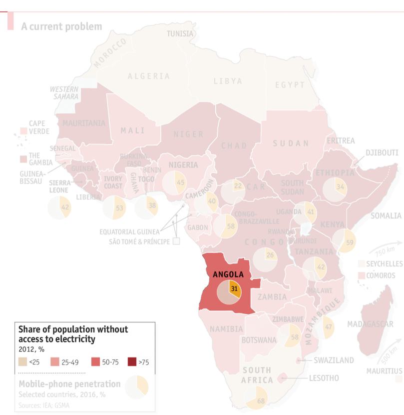

(e) Brightness



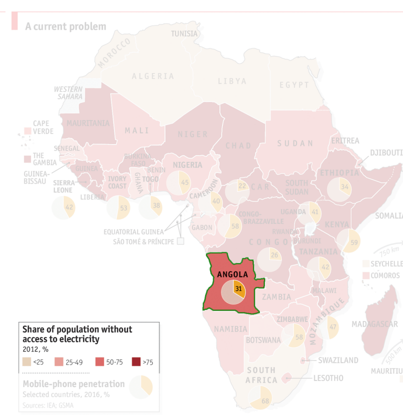

(f) Transparency + Shape



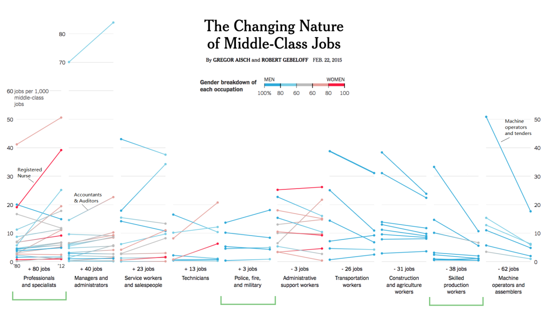

(g) Arrow



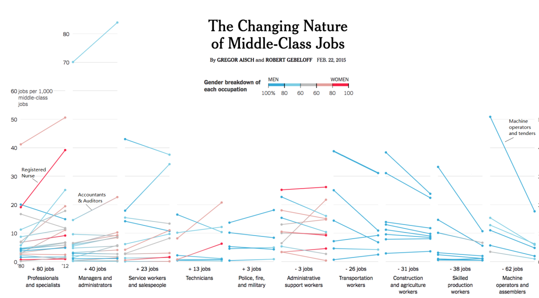

(h) Transparency




(i) Transparency + Shape/Contour




(j) Bracket




(k) No cue

**Figure 1: Four visualizations and eight visual cues used in the study**

narration [21], and they found no significant improvements in learning outcomes in the cueing conditions. However, people in the cued condition spent less time learning the material and the cues increased the learning efficiency. While we also examine the effect of visual cues for narrative visualizations, our study broadens the scope of research by examining eight different types of cues and a combination of two different cues for visualizations with audio narratives.

While several existing works have focused on the effectiveness of a single visual cue, others have evaluated combinations of visual cues [4, 14]. Cole et al. studied the allocation of visual attention when using a combination of desaturation, transparency, depth of field, and contour. They found all cues are effective alone, but cues are most effective when combined [4]. Hoffmann et al. studied the effectiveness of nine visual cues and different combinations of these nine cues. They found most of them are effective, and the combination of basic cues can be indeed effective [14]. Similarly, we begin our work with an evaluation of single visual cues and expand to test a combination of two cues. However, given our focus on visual cues for narrative visualization, we selected a different set of visual cues as some of the visual cues used for Hoffman et al.'s study were not applicable (e.g., beam and splash). Instead, we use visual cues from Kong et al. [18] since their study also focused on visual cues for presentations.

## 3 EXPERIMENTAL DESIGN

We investigated our research questions by conducting two complementary studies. The first study was an in-lab study and the second study was a larger scale online study. The in-lab study allowed us to collect eye movement data to assess people's gaze patterns when learning about a visualization with and without cues. We also gathered qualitative data on different cues through a face to face interview. In the online study, we scaled the study to one hundred participants with more diversity in age, occupation, geographic location, and visual literacy. We studied the participants' ability to recall and comprehend the information from the visualizations and their visual cue preferences in both of the studies.

### Visualizations

We used four visualizations for our in-lab and online studies. We began our search for the study materials by looking through visualizations in online news sites, such as the Economist and the New York Times. The criteria for the selected visualizations include that it was created within the last five years, did not involve any controversial or political topic, and was not interactive in the original source.

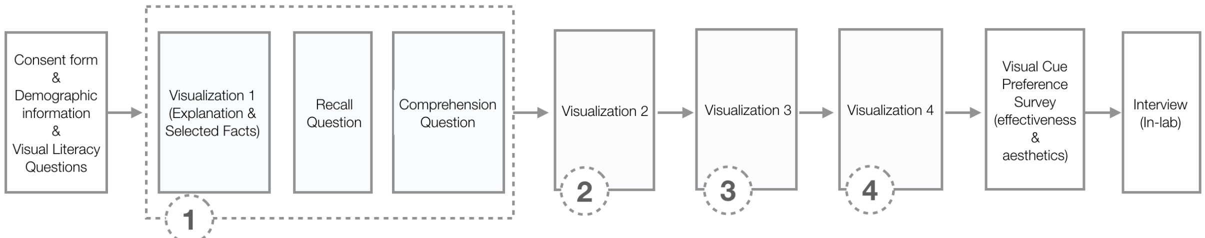
We further narrowed down the list to visualizations that do not require prior knowledge to understand, yet cover facts that the participants are less likely to know prior to the study. We also aimed to select visualizations that are more complex than the basic chart types (e.g., line graphs, bar charts, pie charts, etc.) since complex chart types are more likely to require a visual cue for attention and understanding compared to simple charts. We found fourteen visualizations that met each of the criteria. We conducted a pilot survey with 14 participants to evaluate the perceived complexity of the charts and selected four visualizations. These four visualizations included a heatmap, a choropleth map with small pie charts, a small multiple slope graphs, and an arrow plot (see Table 1).

We briefly describe the topic of each chart and some of the facts that we highlighted in the visualizations to convey the general scope of the narratives in the main section. The heatmap showed the effects of four social network sites (SNS) on 14 well-being categories (hereafter referred to as the "SNS heatmap") [26]. The narration mentioned the positive impact of SNS on self-expression while other categories (e.g. real-world relationships) were both positively or negatively impacted depending on the SNS. The choropleth map showed the share of the population in African countries without electricity access, and the accompanying pie charts showed mobile penetration in those countries (hereafter referred to as the "Africa choropleth map") [25]. One highlighted fact was that while more than 75% of the population in Kenya does *not* have access to electricity, 59% of the population has mobilephones. The small multiple slope graphs presented the shift in middle class workers since 1980 (hereafter referred to as the "Middle class slope graph") [12]. The key message was that registered nurses and healthcare occupations, which are female-dominated, have seen the biggest growth while the machine operators and assemblers sector, which is male-dominated, has seen a big drop over the years. Lastly, the arrow plot showed how earnings of graduates in different majors change when we control for other factors such as home region, socioeconomic status, and academic ability, hereafter referred to as the "Graduates arrow plot." [27]. We highlighted an occupation that saw a drop after controlling for the factors (e.g., doctors) and others that saw little change (e.g, physical sciences, English, and psychology). The narratives were based on the original articles in which the charts appeared, and included facts that covered different components and dimensions of the visualization (e.g., a cell, a row, and a column in the heatmap).

### Visual Cues

Prior works have defined two categories of visual cues: integral cues and separable cues [1, 5, 18]. Integral cues highlight the focus point by modifying the pre-existing integral properties of the visualization (i.e. making the area that is not the focus point transparent). Separable cues augment the existing image with additional components, such as arrows, to emphasize the focus point. Although researchers have also used the terms "internal" and "external" in existing literature,

**Figure 2: An outline of the study procedures: the box with a dotted border shows the main section, the recall quiz, and the comprehension quiz for the first visualization. These sections were repeated for each of the four visualizations.**




we use the terms "integral" and "separable" as they are more descriptive and follow the classical works of Garner in the cognitive science literature [11].

We evaluated four integral and four separable visual cues in our study based on the ten visual cues for presentations in Kong et al's taxonomy [18]: contour, glow, shape, bracket, arrow, brightness, desaturation, transparency, loupe, and depth of field (See Table 1). We combined shape and contour into one category since these two cues were visually similar for most of the chart types. We removed loupe that enlarged the highlighted region since it distorted the proportions and location of data and was not applicable for most of the scenarios. When we applied the separable cues, we selected a color that was not used in any of the four charts to ensure that the cue was noticeable by creating a contrast. We evaluated all eight cues in the in-lab study and had an uncued condition resulting in nine conditions in total.

## 4 IN-LAB EXPERIMENT

### Participants and the study setup

We conducted an in-lab study with 30 participants (15 females) from a university in the Midwest. The mean age was 28.4 years with a standard deviation of 11.2 years. Their mean visual literacy score was 6.2 out of 8 ($\sigma = 1.27$).

Participants sat in front of a 22 inch monitor with a 1680 x 1050 resolution, and a stereo speaker was placed on both sides of the monitor. We calibrated the eye-tracker after each participant signed the consent form and turned on the eye-tracker at the beginning of the main section. The participants' eye movements for these sections were recorded by a Tobii Eye Tracker 4C. The eye-tracker was placed underneath the monitor and operated at a sampling rate of 90 Hz. All the study materials were presented on a web browser, and the participants worked through the study at their own pace. The setting resembled watching an online video but without the full control settings for the video.

### Pre-study survey

We began the study by obtaining the users' consent. The participants filled out a brief demographic survey with questions about age, gender, occupations, and their level of knowledge about each of the chart topics. We measured their knowledge on the topics since it might influence their quiz scores.

After the participants completed the survey, we conducted a short visualization literacy quiz to measure their familiarity and literacy of the presented chart types. During the visual literacy quiz, participants saw four charts, one of each chart type in our study, and answered two questions per chart. We wrote the questions based on Lee et al,'s work on Visualization Literacy Assessment Test (VLAT) [20]. The participants could omit the question if they were unsure of the answer. We added a time limit in order to prevent people taking the time to learn how to read the charts and to ensure that we were measuring their current visualization literacy level. We had a strict time limit of 2 minutes per chart. The full questionnaire can be found in the Supplementary Materials.

### Main study procedures

The participants started by reading the instruction of the overall structure of the study. The study consisted of three sections: a visual cue section, a quiz section, and a preference section. The visual cue section and the quiz section was repeated for each visualization. Refer to Figure 2 for the general study flow. Each participant saw four visualizations in total, one visualization without a visual cue, and three visualizations with different visual cues. We randomly ordered the visual cue conditions so that each participant saw a subset of three out of the eight visual cues that contained at least one integral cue and at least one separable cue. We counterbalanced the order of the cues to avoid order effects.

*Visual cue section.* The visual cue section (ex. first box in Fig 2-1) consisted of an explanation phase where we explained the general layout of the visualization and a fact phase where we described three to five selected parts of the visualization in more detail . Each page consisted of a visualization with selected sections visually cued, and an accompanying audio narration that automatically started playing when the page loaded.

During the explanation phase, we highlighted different components of the chart (e.g., legends, axes, labels, colors, etc.), one at a time. For example, a verbal explanation "Red represents a negative impact" accompanied the SNS heatmap where all the red cells were highlighted (See Table 1d). During the selected facts (i.e. storytelling) phase, different sections of the visualization were highlighted with a verbal account of the corresponding story. For example, we narrated "Facebook has a negative impact on sleep" while highlighting the relevant information in the visualization. On each page, the participants could click on the "replay the audio" button or click on the right arrow button to proceed. No option was provided for going back to the previous page to maintain the narrative flow. We recorded the number of times they replayed the audio and the time they spent on each page.

*Quiz section.* The quiz section consisted of a recall quiz and a comprehension quiz as shown in the second and third boxes in Fig 2-1. In the recall quiz, the participants answered three multiple choice questions that involved recalling information from the visualization (e.g., "Which of the following categories of well-being is reported as the most negative for Facebook users?"). The visualization was not present on the page during the recall quiz. Then the participants answered three multiple choice comprehension questions (e.g., "Which social network site has a positive impact in real-world relationship and a negative impact on access to health advice?") while the visualization was visible at the top of the page. We used the results from the quiz section to measure learning outcomes including whether the participants understood the chart correctly and were able to obtain and recall the narrated and cued information. We repeated the visual cue section and the quiz section for each of the four visualizations. We chose the recall questions based on the regions that were visually cued and mentioned in the narration in the previous section. The comprehension questions were chosen to cover diverse visualization tasks including retrieving a value, finding an extremum, and comparing values [20].

*Preference section.* After having seen all four of the visualizations, the participants evaluated all eight cues for each visualization based on their 1) perceived effectiveness level and 2) perceived aesthetics level. We showed them a row of eight visual cues applied to the same visualization and asked them to categorize each cue as "Very effective," "Somewhat effective," and "Not effective" by dragging and dropping the cue into the group they found most appropriate. A short video of this process is included in the Supplementary Materials. We repeated the process for each of the four visualizations. Then they rated the aesthetics of visual cues in a similar manner by placing each cue into one of "Very pleasant-looking," "Somewhat pleasant-looking," and "Not pleasant-looking" bins. Each cue was rated eight times in total – once for effectiveness and once for aesthetics for each of the four visualizations.

*Semi-structured interview.* After the main study procedures described in the last section, the in-lab study concluded with a fifteen minutes interview on the participants' perceptions of visual cues. We asked whether they found the cues useful for understanding the chart and whether they found them useful for recalling information. They rated the usefulness from 1 (Not useful at all) to 5 (Very useful) and elaborated on their answers. We then asked about whether they relied on the memory of the audio, the visualization, or both for the recall quiz. Then we asked which cues they found the most and the least useful and prompted for an explanation. Lastly, we asked for which visualization the visual cues would be most/least useful.

### Independent and dependent variables

This study had three independent variables: the visualization, cue, and visual literacy. The dependent variables were recall and comprehension quiz scores, first fixation time (in milliseconds), fixation duration (as a %), and the section duration (in seconds). We define the first fixation time as the time from the beginning of the section until the respective regions of interest (ROIs) were first fixated upon. Fixation duration is the total amount of duration the participant fixated on the ROIs in the fact section divided by the total duration of the fact section. We chose to only analyze fixation during the fact section because explanation sections contained more general instructions where the ROIs were hard to define. For example, the ROI for the instruction "Blue lines show male-dominated occupations" in the middle-class slope graph is hard to define since the blue lines distributed across the whole visualization (See Figure 1k). For the section duration, we report the total duration (fact duration + explanation duration) since the total amount of time spent looking at a visualization may influence the person's familiarity with the visualization.

### Results

Table 1 contains a summary of the in-lab study results. In this section we present the results for the eye gaze data and the quizzes, supported by the findings from the interviews.

*Cues significantly reduce the first fixation time.* We first analyzed whether there is a significant difference in eye gaze patterns between cued and uncued conditions. The results of Welch two sample t-tests shows that there was a significant difference between the conditions ($t(43.61)=-4.465$, $p=.001$) for the first fixation, but not for the fixation duration ($t(60.56)=1.1531$, $p=0.253$). In other words, while cues help people find the region of interest (ROI) faster, we did not find a statistically significant influence of the cues on the duration spent attending to those regions. This disparity between the first fixation time and fixation duration can be seen in the respective rows in Table 1. The fixation duration for the integral

**Table 1: In-lab study results show that visual cues did not have a significant influence on people's recall and comprehension scores, but significantly reduced the first fixation time. The maximum score is 3 for recall and 3 for comprehension.**

| | | Africa choropleth map | | Graduates arrow plot | | Middle class slope graph | | SNS heatmap | | Summary | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Avg | Std | Avg | Std | Avg | Std | Avg | Std | Avg | Std |
| Recall Score | Uncued | 2.25 | 0.71 | 1.14 | 1.07 | 2.75 | 0.46 | 2.57 | 0.79 | 2.2 | 0.96 |
| | Separable Cue | 2.36 | 0.5 | 1.3 | 1.16 | 2.45 | 0.93 | 2.87 | 0.35 | 2.32 | 0.93 |
| | Integral Cue | 2.18 | 1.08 | 1.54 | 0.97 | 2.55 | 0.69 | 2.88 | 0.35 | 2.21 | 0.97 |
| Comprehension Score | Uncued | 2.75 | 0.46 | 2.86 | 0.38 | 2.5 | 0.53 | 3 | 0 | 2.77 | 0.43 |
| | Separable Cue | 2.9 | 0.3 | 3 | 0 | 2.72 | 0.47 | 2.93 | 0.26 | 2.89 | 0.31 |
| | Integral Cue | 2.91 | 0.3 | 2.62 | 0.51 | 2.73 | 0.47 | 2.88 | 0.35 | 2.77 | 0.43 |
| First fixation time Fact (ms) | Uncued | 2.25 | 0.71 | 3.22 | 1.54 | 3.91 | 1.63 | 1.97 | 0.74 | 2.86 | 1.41 |
| | Separable Cue | 1.36 | 0.66 | 1.77 | 1.01 | 1.39 | 0.47 | 1.42 | 0.26 | 1.47 | 0.78 |
| | Integral Cue | 1.68 | 1.71 | 2.07 | 1.95 | 1.73 | 1.19 | 1.02 | 0.65 | 1.69 | 1.52 |
| Fixation duration Fact (%) | Uncued | 54% | 19% | 15% | 11% | 30% | 10% | 46% | 21% | 36% | 21% |
| | Separable Cue | 50% | 19% | 22% | 12% | 50% | 18% | 46% | 30% | 43% | 24% |
| | Integral Cue | 47% | 18% | 22% | 15% | 50% | 21% | 57% | 33% | 42% | 24% |
| Section duration Total (s) | Uncued | 131.66 | 25.77 | 177.2 | 55.43 | 178.73 | 21.92 | 114.31 | 47.41 | 150.79 | 46.72 |
| | Separable Cue | 139.89 | 20.75 | 154.47 | 19.99 | 242.72 | 144.9 | 103.52 | 23.01 | 155.45 | 87.5 |
| | Integral Cue | 129.13 | 18.68 | 175.42 | 58.8 | 182.26 | 29.63 | 95.29 | 16.34 | 150.42 | 49.81 |

cue and separable cue conditions were higher than that for the uncued condition in general, but for the Africa choropleth map, people in the uncued condition spent more time in the ROI than those in the cued conditions.

We examined the eye gaze heatmaps for the three conditions to gain a better understanding of people's eye gaze patterns when viewing a narrative visualizations with and without cues. In Figure 3, we show an aggregated eye gaze pattern for all participants who were in the separable cue condition, integral cue condition, and uncued condition. The audio script for that particular slide was: "In terms of self expression, all social networks are positive. Twitter and Instagram even more so than Snapchat and Facebook." Heatmaps for the separable and integral cue conditions show that people mainly focused on the self-expression row at the bottom part of the visualizations and the labels at the top of the page when the relevant region was cued (Figures 3a and b). On the other hand, the vertical search patterns in Figure 3c shows that participants in the uncued condition spent a significant amount of time along the list of well-being categories, searching for the self-expression row.

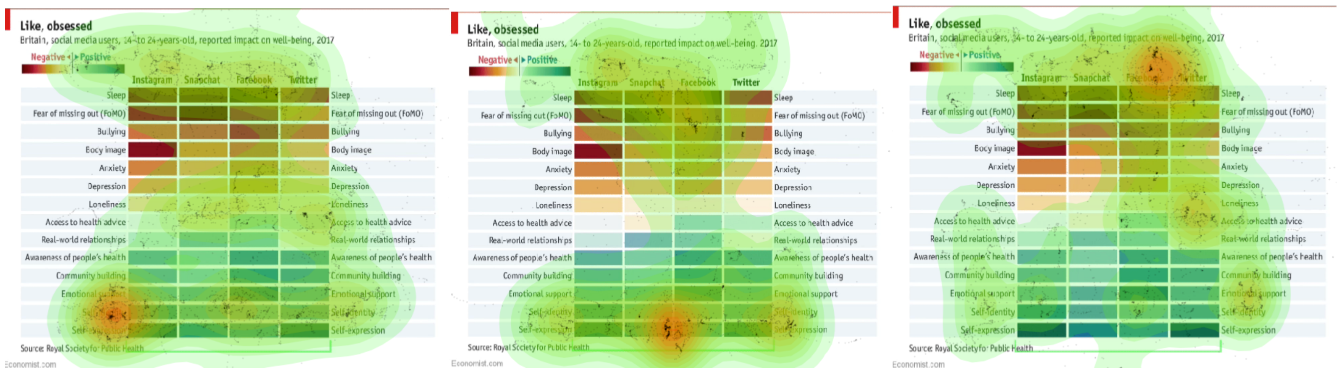
**Table 2: In-lab quiz scores with cues ordered by the recall score. Four cues had a higher recall score than the uncued condition, but none of the differences were statistically significant. Glow had a significantly higher comprehension score compared to the uncued condition.**

In-lab: Average quiz scores by cue (s.d.)

| Integral / Separable | | recall | | comprehension | |
|---|---|---|---|---|---|
| S | Shape | 2.58 | (0.51) | 2.83 | (0.39) |
| S | Bracket | 2.57 | (1.13) | 2.86 | (0.38) |
| I | *Transparency* | 2.42 | (0.67) | 2.67 | (0.49) |
| S | Glow | 2.33 | (0.72) | 3.00 | - |
| | Uncued | 2.20 | (0.96) | 2.77 | (0.43) |
| I | *Desaturation* | 2.18 | (1.08) | 2.91 | (0.30) |
| I | *Depth of field* | 2.13 | (1.13) | 2.75 | (0.46) |
| I | *Brightness* | 2.08 | (1.08) | 2.75 | (0.45) |
| S | Arrow | 1.92 | (1.26) | 2.85 | (0.38) |

*Cues do not improve the learning outcomes in general.* A three (separable, integral, uncued) × two (quiz scores) MANOVA on the recall and comprehension scores revealed that viewing a presentation of a visualization with an integral cue or a separable cue did not lead to better a recall nor comprehension performance (Pillai's trace = 0.027, $F(4,234) = 0.81$, $p = 0.52$) than viewing the presentation without a visual cue. Although cues increased the average recall scores for SNS and graduates visualizations, the differences were not significant for both the SNS heatmap ($F(1, 28) = 2.112$, $p=0.157$) and the graduates arrow plot ($F(1, 28) = 0.4197$, $p = 0.522$). Similarly, although an increase was seen for comprehension in Africa and middle-class visualizations, the differences were not significant (Africa: $F(1, 28) = 1.253$, $p = 0.273$) (middle-class: $F(1, 28) = 1.333$, $p = 0.258$).

*The glow cue leads to an improvement in comprehension.* More insights can be gained by looking at individual cues in Table 2 although caution must be taken in over-interpreting the data since there are only around ten data points per cue. The average recall quiz score for half of the cue conditions (e.g. glow, shape, bracket, and transparency) was higher than that for the uncued condition. The comprehension quiz score was higher overall for cued conditions as well. However, the recall score of arrow condition was very low, which brought down the average score for cues. When we performed a t-test comparing each cue to the uncued condition, we found that glow had a significant impact on comprehension compared to the uncued condition ($t(43) = 2.93$, $p = 0.007$, $d = 0.66$). Although shape was the best performing cue for recall, we did not find a statistically significant difference to the uncued condition in recall scores ($t(40)= 1.66$, $p = 0.11$, $d = 0.16$).




**(a) Separable Cue Condition** **(b) Integral Cue Condition** **(c) Uncued condition**

**Figure 3: The aggregated eye gaze heatmaps show that visual cues help people find and focus on the narrated region faster. The audio narration for this slide emphasized self-expression, the last row of the visualization.**

**Table 3: In-lab preference survey ordered by the perceived effectiveness: people indicated brightness and transparency (integral cues) as the most effective cues, while they reported shape and glow (separable cues) as the most aesthetically pleasing.**

| Integral / Separable | (N=120) | Perceived effectivenss: very effective | somewhat effective | not effective | Perceived aesthetics: very pleasant | somewhat pleasant | not pleasant |
|---|---|---|---|---|---|---|---|
| I | *Brightness* | 91 | 18 | 11 | 51 | 32 | 37 |
| I | *Transparency* | 71 | 35 | 14 | 61 | 43 | 16 |
| S | Shape | 52 | 63 | 5 | 67 | 45 | 8 |
| S | Glow | 49 | 64 | 7 | 65 | 45 | 10 |
| I | *Desaturation* | 27 | 40 | 53 | 32 | 34 | 54 |
| I | *Depth of field* | 12 | 40 | 68 | 13 | 28 | 79 |
| S | Arrow | 9 | 48 | 63 | 15 | 59 | 46 |
| S | Bracket | 8 | 55 | 57 | 13 | 68 | 39 |

*The influence of the audio narration.* We found that participants rarely replayed the audio - only 7 participants replayed audio at all. When we used a simple linear regression to fit the recall scores based on the audio replay times, a significant regression equation was found ($F(1,118)=4.185$, $p = 0.043$). Interestingly, audio replay times was associated with a lower score (-0.27) while we had predicted that replaying the audio would result in a higher score. One explanation is that people only replayed the audio when they were completely lost and did not follow the explanation at all. Thus even though they replayed the audio, they were still not able to fully comprehend the selected facts. When asked whether they relied more on the audio narration or the visualization for the quiz sections, 13 participants answered that they relied more on the visual component, 11 answered that they relied more on the audio, and 4 reported that they relied on both modalities equally. We did not obtain a specific answer from two of the participants.

*The perceived effectiveness and aesthetics of cues differ.* One of the most interesting findings during the study was the difference between the cues that people found the most pleasant looking versus the cues that they found to be the most effective. As prior research showed an overwhelming preference of integral cues over separable cues [18], we had hypothesized that people would find integrals cues more aesthetically pleasing compared to the separable cues and that the perceived effectiveness would be higher for integral cues. However, although people indicated brightness and transparency (integral cues) as the most effective cues, they reported shape and glow (separable cues) as more aesthetically pleasing as shown in Table 2. Many of the participants (N=17) also chose glow and shape when asked to choose the most effective cue during the interviews. One of participants explained that “All the map is still there. Nothing is being taken away while it is precisely calling what is important.” While participants perceived brightness to be very effective, the aesthetic level of brightness was controversial as it was rated 51 times as “very pleasant-looking,” 32 times as “somewhat pleasant-looking,” and 37 times as “not pleasant looking.” Some participants commented that brightness was “dark and ugly” (P9) but “really draws your eyes to the correct parts” (P18) and made “the relevant sections popped out” (P12).

## 5 ONLINE EXPERIMENT

Although half of the cues had a higher average recall score compared to the uncued condition, the differences were not statistically significant. This might be due to the small sample size in the in-lab study since each cue was only seen by around eleven participants. Thus, we selected the best performing cues based on the average recall scores and re-examined them with a bigger sample size through an online experiment. We evaluated one separable and one integral cue, and added a combined cue condition to test whether a combination of those cues would bring out the best of both or cancel out the strengths of each other.

### Participants

We recruited a hundred participants from Amazon Mechanical Turk (52 female). Age ranged between 22 and 63 years old ($\mu$ = 35.97, $\sigma$ = 9.38). The experiment lasted around 30 minutes, and the participants was paid $4.15 upon the acceptance of their submissions. Their occupations ranged from nurses and social workers to a farmer, and 35 of them stated that they incorporate visuals/graphics in their work. All of them were familiar with bar graphs, and most were familiar with line graphs (N=97) and pie charts (N=87). Around a third (N=29) were familiar with stacked graphs. Their mean visual literacy score out of 8 was 5.62 ($\sigma$ = 1.5).

**Online study: quiz scores by cue**

| **Africa** | recall | comprehension | total |
|---|---|---|---|
| uncued | 2.52 | 2.56 | 5.08 |
| shape | 2.24 | 2.44 | 4.68 |
| transparency | 2.88 | 2.56 | 5.38 |
| combined | 2.36 | 2.24 | 4.6 |
| **Graduates** | recall | comprehension | total |
| uncued | 1.76 | 2.4 | 4.16 |
| shape | 2.16 | 2.36 | 4.5 |
| transparency | 1.92 | 2.16 | 4.08 |
| combined | 1.96 | 2.28 | 4.24 |
| **Middle class** | recall | comprehension | total |
| uncued | 2.76 | 2.52 | 5.25 |
| shape | 2.28 | 2.52 | 4.8 |
| transparency | 2.48 | 2.6 | 5.08 |
| combined | 2.72 | 2.6 | 5.32 |
| **SNS** | recall | comprehension | total |
| uncued | 2.76 | 2.36 | 5.12 |
| shape | 2.8 | 2.72 | 5.52 |
| transparency | 2.56 | 2.8 | 5.36 |
| combined | 3.16 | 2.8 | 5.96 |

**Table 4: Online study average quiz scores by cue and by visualization. The maximum score is 4 for recall, 3 for comprehension, and 7 in total. The cues significantly improved the comprehension scores for the SNS heatmap.**

### Changes based on the in-lab study

For the online experiment, we reduced the number of cues to three. We chose one cue from each category – shape for separable and transparency for integral – that resulted in the highest recall scores out of their categories. These cues were also the most preferred cues from each category based on results of the preference survey. We added a combined cue condition (see Figure 1h) where both transparency and shape were applied to cue a region. In the combined cue condition for the Africa choropleth map, we replaced the shape cue with the contour cue since the rectangles clashed with regions cued with transparency (see Figure 1i). In the single cue condition, the contour cue was barely noticeable on the Africa choropleth map. However, we found that the cue was more appropriate in the combined cue condition as it could work as an extra emphasis although it was not strong enough to work effectively on its own. Since we had four visualizations and four conditions (three cued and one uncued) in the online study, each participant saw all possible cues. The same three cues were evaluated in the preference survey. Thus each cue was seen and evaluated by a hundred participants.

Based on the results from the interview of in-lab study that some people solely relied on the audio information to answer the recall questions, we added a recall question for each visualization that required visual memory. Information tested in these questions was relevant to the verbally mentioned facts, but not directly mentioned in the audio. For example, one of the added question was "In which part of Africa is Kenya located?" We also added one short answer question as an attention check question (e.g., 'What else do you recall from the presentation? Please describe the contents in a few bullet points or simple sentences. For this time only, write "read africa" at the end of your answer to indicate you've read this.'). Two of the authors read through all of the open-ended answers and filtered data points based on whether a participant's answers for all four questions only contained gibberish answers or text for passing the attention check question (e.g., answers that only said "read africa" without any additional information on the visualization).

### Results

*Cues have no effect on recall and comprehension in general.* We found no significant effect of cues on the recall ($F(1,398) = 0.00543$, $p = 0.941$) or comprehension quiz scores ($F(1,398) = 0.2602$, $p = 0.610$).

*Cues significantly aid comprehension for the SNS heatmap.* However, when we analyzed the effect on each visualization, we found that SNS comprehension score increased significantly with cues ($F(1, 98) = 6.419$, $p = 0.0129$, $R^2 = 0.06$; estimate = -0.413 for the uncued condition). Also, with the

**Table 5: Online study preference survey: the perceived effectiveness of cues were not aligned with their actual effectiveness. For example, people perceived shape as the most effective cue for the middle-class slope graph, but people in the shape condition received the lowest quiz scores.**

| | | Perceived effectiveness | | | Perceived aesthetics | | |
|---|---|---|---|---|---|---|---|
| | (N=98) | very effective | somewhat effective | not effective | very pleasant | somewhat pleasant | not pleasant |
| Africa | shape | 37 | 55 | 6 | 19 | 51 | 28 |
| | transparency | 45 | 46 | 7 | 31 | 55 | 12 |
| | combined | 59 | 31 | 8 | 42 | 45 | 11 |
| Graduates | shape | 33 | 48 | 17 | 19 | 52 | 27 |
| | transparency | 9 | 52 | 37 | 9 | 35 | 54 |
| | combined | 30 | 52 | 16 | 15 | 59 | 24 |
| Middle class | shape | 48 | 40 | 10 | 35 | 30 | 33 |
| | transparency | 24 | 53 | 21 | 22 | 45 | 31 |
| | combined | 44 | 40 | 14 | 28 | 43 | 27 |
| SNS | shape | 26 | 35 | 37 | 22 | 25 | 51 |
| | transparency | 46 | 40 | 12 | 36 | 48 | 14 |
| | combined | 58 | 31 | 9 | 43 | 47 | 8 |

exception of comprehension quiz scores for the Africa choropleth map, the cues generally increased the scores for recall and comprehension as can be seen in Table 4 although the differences were not statistically significant.

The visualization that benefited the most from visual cues was the SNS heatmap, where the recall score was increased by 0.41 points with the combined, cue and comprehension scores was increased by 0.44 points with the transparency cue. This result is interesting given that the SNS heatmap was often rated as the visualization where visual cues would be the least useful (N = 18) in the interviews.

*Inconsistency between the perceived and actual effectiveness.* We found that people's perceived effectiveness and the actual effectiveness of visual cues were often inconsistent. For the Africa choropleth map, participants in the transparency condition had the highest quiz scores, but people considered the combined cue as the most effective cue. For the middle-class slope graph, people in the shape condition received the lowest quiz scores, but people perceived shape as the most effective cue. The only instance where the perceived effectiveness matched the actual effectiveness is the graduates arrow plot; most people rated the transparency cue as the least effective, and the transparency cue performed the worst. This prediction that the transparency is not effective for the graduates arrow plot is interesting since transparency was usually rated highly in effectiveness both in the in-lab study and in the online study. One possible explanation is that the graduates arrow plot shows how the earnings of graduates in each major change in relations to earnings of other majors. Since the transparency cue de-emphasized all other majors that were not the focus of the story, the cue made it difficult to compare the earning of the cued major with the earnings of other majors. The necessity of the context for the comprehensive understanding of the visualization might have led people to find transparency ineffective in this case. Another interesting preference outlier is shape for the SNS heatmap; while shape was usually deemed as effective and pleasant-looking, the majority of the people rated shape as not effective and not pleasant-looking when it was applied for the SNS heatmap. The shape cue involved green colored rectangles, which blended in with the colorful rectangular cells on the heatmap. As a result, the cue was not as noticeable as it was in other visualizations, which might have led to the decreased preference.

## 6 DISCUSSION

Through the in-lab study and the online study, we found that visual cues help guide the audience's eye to a region, but in general, does not influence the learning of the material that the region covered. Our in-lab study results further showed that the *type* of the cue influences its effectiveness, with glow performing better than the other cues. However, rather than suggesting glow for all situations, we encourage people to consider three additional factors when deciding on a visual cue based on the study results: the role of the cue, the visual characteristics of the region that is highlighted, and the visual complexity of the chart type.

### The role of visual cues

Two main expectations for visual cues emerged during the interviews: to highlight the important material and to obscure the distractions. Eye-tracker data analysis showed that both integral and separable visual cues are effective in guiding the audience to the region of interest. In contrast, the category of the cue determines how well it can serve the second role. This was clearly shown by the diverging preference between integral and separable cues depending on the intended role of the visual cues. Some participants specifically stated that the visual cue should only serve the first role by emphasizing the regions of interest while leaving the context intact. Others thought the cue needed to serve a secondary role of removing distractions and preferred integral cues. P17 elaborated "I liked transparency because it removes the background so that I got a bit more focus, and the relevant material stands out to me." One instance where the second role of removing distractions is necessary is when visual cues are serving as a visual tactic of "Transition Guidance" [24]. For example, a person may want to introduce one element of the visualization at a time to achieve a staged transition. Using integral cues, audience's attention can be guided to the highlighted section for each stage of the transition while maintaining the integrity of the chart.

As for the primary role of visual cues, we have studied visualizations with well-paced audio narratives with one to two seconds of pauses between the slides, and thus the immediate focus may not have been imperative in understanding the material. The role of the visual cue as a swift guidance may be more essential in situations when the visualization is narrated at a faster pace. Such scenarios include when a student is listening to an online course at a higher speed, or when a presenter is quickly pacing through the key results. For these instances, separable cues may be more appropriate as they further reduce the first fixation time compared to the integral cues (See Figure 1), potentially because separable cues guide the audience in a quick sequence without requiring them to adjust to the changing context.

### Visual properties of the highlighted region

Besides the role of the cues, another factor to consider while selecting a cue is the visual property of the region that is selected. Oelke et al.'s work on visual cues for such pixel-based visualization [22] showed that cue effectiveness is bounded by factors such as sparsity of the dataset and "the boosting task (boosting of pixel, passages, or a trend)." We found that even though arrows, bracket, shape, and glow are all separable cues, shape and glow have an advantage over the others when boosting passages or an *area* of the visualization as mentioned in our interviews, "When I are trying to follow along the arrow, I got lost. Where is the arrow is pointing to? So I looked again." (P22). Since shapes and glow are as easily applicable to visualizations using existing graphic tools, we present them as a feasible alternatives to integral cues that are on par in both the perceived effectiveness and aesthetics when highlighting regions that cover rows or columns of information. To note, the visualizations used in our study cover a very specific domain space due to the limited data size and dimension. The effectiveness of glow could easily drop significantly with a different data granularity or task. Thus current results are not sufficient to support a definitive conclusion. In fact, arrows might be more useful for dense datasets or highlighting a single pixel due to its preciseness. Future work is needed to further investigate the effectiveness of cues given different data granularity and tasks.

### The type and the complexity of the chart

People determined the usefulness of the visual cues depending on the perceived complexity of the chart. The reported order of the perceived visual complexity (from the most complex to the least) during the interviews were the middle class slope graph, the graduates arrow plot, the Africa choropleth map, and the SNS heatmap. Although the SNS heatmap was considered as the most simple chart by 19 out of 30 participants, the SNS visualization was the only visualization where there was a significant difference in quiz scores with and without cues.

This improvement in comprehension scores for the SNS visualization when accompanied by visual cues contrasts people's general perception that the visualization is relatively simple and in consequence, visual cues would be least useful for it. A possible explanation of this disparity is that the SNS heatmap may not be as simple as people perceive it to be. The SNS heatmap is conceptually simple with four social networks clearly listed above and fourteen well-being criteria listed on each side of the heatmap. But when accounting for the number of potential regions of interest (ROI) and the number of distinguishable colors, the chart is quite complex for visual processing. Each cell in the heatmap is a potential ROI resulting in 56 ROIs within the heatmap alone, and the chart uses a continuous color scale, which adds numerous possibilities for each ROI. In other words, the viewer has to distinguish the shade of a color while being aware of which specific cell they are decoding. Altogether, these different components of the visualization add to the cognitive load of the viewers, and thus guiding the viewers to a specific ROI through visual cues in SNS heatmap may have been more helpful than people realize.

Similar advantage of visual cues may also apply to other charts involving a large number of potential ROIs and those that require a higher cognitive load. Examples of such charts that involve the combination of columns and row are tables and correlation matrices.

### The audio narrative

Our results differ from prior results presented in our related works section, where the majority of the work [3, 4, 6, 14] found a significant effect of visual cues on learning. One potential reason is the presence of audio narrations. In our study, all of the conditions included an audio narrative along with a visualization. Since information was presented in multiple modalities (visual and audio), the influence of visual cues on learning outcomes might have been overshadowed by the influence of the audio narration. There is a wide range of situations starting from where audio narration is an integral part of conveying the information (e.g., listening to an online seminar) to where conveying information through audio is not an option (e.g., using visual notifications for deaf students as in Cavender et al.'s study). Thus although our work adequately addresses situations where the audio narration plays an integral role, our findings may not generalize to settings where no audio is present. Future work including a no-audio condition will help distinguish the main effects and the interaction effect between the audio and visual cues on understanding and learning of a visualization.

## 7 LIMITATIONS

Our work studied four complex chart types, and a future study involving a larger range of the chart complexity and chart characteristics should be conducted to generalize the results to different chart types. We omitted loupe in both the in-lab and the online study since the cue was not applicable for all four charts covered in our study. We omitted contour for the in-lab study as the cue was very similar to another cue (i.e., shape), and the difference between the two cues was barely noticeable for most of the visualizations.

## 8 CONCLUSION

We studied visual cues' effectiveness and user preference by in-lab and online studies. The results show that visual cues may not lead to a significant improvement on people's recall and comprehension of the visualizations with audio narration, but can help people focus on the relevant regions faster. We also found an inconsistency between the perceived effectiveness and the actual effectiveness of visual cues showing that people's intuition on visual cues may not be accurate. Based on the results of our study, we propose different factors presenters should consider when choosing a visual cue including the role of the cue, the visual characteristics of the cued region, and the visual characteristics and the type of the visualization.

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