Evaluating the Memorability of Physical Visualizations

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ABSTRACT
Physical Visualizations are currently mostly used in casual contexts, e.g., as artistic data sculptures. However, their measurable benefits for traditional information visualization are largely unexplored. As a step in this direction, we compared the memorability of physical visualizations to that of digital visualizations. We conducted a user study with 40 participants in which we measured the recall of three types of information immediately after exploration and with a delay of two weeks. The results show that the physical visualization led to significantly less information decay within this time span. Our results build on known effects from cognitive psychology and provide a first indicator for measurable benefits of physical visualizations regarding memorability.

Author Keywords
physical visualization; evaluation; memorability.

ACM Classification Keywords
H.5.2 User Interfaces: Evaluation/Methodology

PHYSICAL VISUALIZATIONS
Information Visualization (InfoVis) helps users to explore and understand large amounts of abstract data. While digital visualizations are well-explored, *physical visualizations* which map data to physical form instead of pixels recently started to attract attention [6, 7, 11]. Reasons for this are the progress in digital fabrication technologies, such as laser cutters and 3D printers [12], as well as recent developments in the field of shape changing displays (e.g., [4]). The fact that such technologies are becoming increasingly commonplace, prompts further research on how digital and physical visualizations can complement one another and to explore areas in which physical visualizations can have benefits.

Jansen et al. [7] compared physical 3D bar charts to their on-screen counterparts and found that physical outperformed on-screen 3D bar charts, but 2D visualizations performed best for all of the tested low-level information retrieval tasks. In their outlook they suggest, that future studies should investigate other factors than pure performance.

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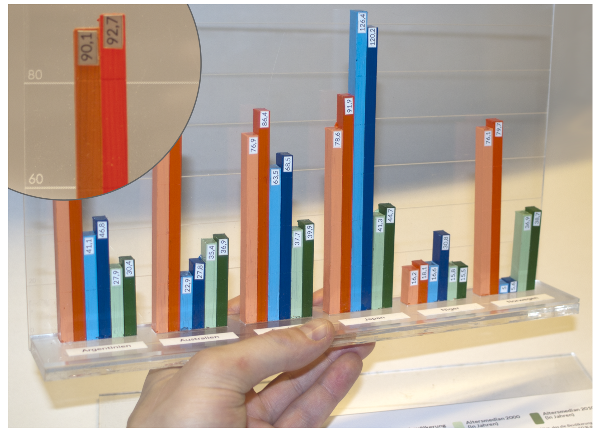

Figure 1. Static physical bar chart which was used in our study and a close-up on the bars' labeling and the background panel.

Visualizations can actually extend human memory [13], and memorability therefore is a frequently discussed topic in InfoVis (e.g., [1, 5]). There are indications that visual and haptic perception are processed dependently [9] and that vision and haptics share common abstract representations of the shape and structure of objects [3]. Furthermore it has been shown that spatial layouts, which were learned through haptic and visual exploration, are stored within a common reference frame: Haptic experiences were able to influence memories that were acquired visually [8]. Previous studies also revealed that physical objects were recalled more frequently than pictures, and pictures more often than words [2].

All of this suggests that a physical representation, for example of a bar chart, could generate a more detailed representation in the subjects' memory and hence be more memorable than its digital on-screen representation.

In a study with 40 participants we compared a physical bar chart (see figure 1) to the same chart displayed on a tablet screen. Memory performance was measured by a questionnaire about the visualizations' content, once immediately after exploration, and again after two weeks. The results show that the modality of the visualization significantly influenced the loss of information during two weeks (see figure 3): Subjects using the physical visualization forgot less information in the category of *extreme values* than those who used the digital visualization.

PRE-STUDY
To discover first tendencies and test the study procedure, we conducted a pre-study with a between-groups design and 3 independent variables: modality (physical, digital), memorization (implicit, explicit) and time (immediately, delayed).

Data Sets

As an abstract data set we chose country indicator data from the Human Development Report (HDR)[1] on the topics of *social integration* and *population trends*. Two data sets were extracted, both consisting of the values for six countries and six different subtopics per country (2x36 values in total). We expected these topics to be interesting to a wide audience, but at the same time not too well known publicly, in order to minimize the effect of previous knowledge. The complexity of the data set was kept on the one hand at a level where the recall of the entire content was rather difficult, but on the other hand not too complicated to avoid a situation in which reading difficulties would distract from the actual content.

Visualization Type

As a visualization, we chose a static vertical bar chart, which is well-known and easily understood by people without experience in InfoVis. It should therefore not influence the experiment's results by either a novelty effect or difficulty in interpretation. A static visualization was chosen in order to investigate just the effects of the modality of the visualization, rather than specific interactions with it.

Visualization Modalities

The final design of the digital bar chart can be seen in figure 2. It was shown on an Apple iPad (2048*1536 px., 264 ppi) in full screen display. We chose a tablet instead of a classic desktop setting in order to create conditions similar to the physical visualization. Both had a similar size and weight and could be held conveniently in one or both hands.

The physical visualization prototype (see figure 1) was built from 8mm acrylic glass using a laser cutter and colored with acrylic paint. The layout and colors of the physical visualization matched those of the digital visualization. Numeric values on the bars, labels for countries as well as the legend were printed on self-adhesive foil. The bars had engraved lines as a reading aid. In addition, a 28*17 cm acrylic panel with engraved numeric values and lines served as a background.

Procedure and Participants

The study took place in an isolated and quiet room. After a questionnaire about demographic data and previous experience with visualizations, subjects started with the *reading phase*: In a counterbalanced order one of the visualizations was presented to each participant. The experimenter encouraged them to read the visualization and think aloud about all content-related issues. Subjects in the *explicit memorization* group were told to memorize the facts because they would be asked about them again later. For the *implicit memorization* group, this ahead warning was not given.

The experimenter checked a list of facts (e.g., all country names and categories) every participant was supposed to speak out loud during the *reading phase*. If items were missing the experimenter asked predefined questions in order to complete the participant's knowledge (e.g., which countries are shown in the visualization?). After the reading phase, subjects filled out a questionnaire collecting qualitative data and another one for subjective memory assessment.

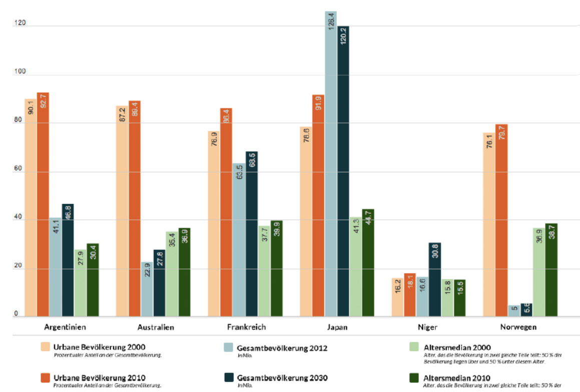

Figure 2. The static digital bar chart which was used in our study.

The *recall phase* started directly after the questionnaires. Subjects were asked to freely recall everything they remembered about the visualizations. When they did not know any more facts, the experimenter asked predefined questions to support the recall process. The *recall phase* was videotaped, transcribed and a recall score was calculated for each participant: One point was given for each correct fact, 0.5 points if facts were only little explicit or too vague.

Out of the 24 participants, eight were female. The average age was 25 (range: 23-27). Participants received a 10 Euro voucher for an online shop.

Results

The pre-study revealed first tendencies and gave us confidence in the general study design. In total, scores for subjects that used the physical visualizations were higher (M=29.58, SE=8.54) than for the digital visualizations (M=22.25, SE=6.42). The results between physical (M=22.58, SE=9.22) and digital (M=19.5, SE=7.96) converged if only the scores of the delayed *recall phase* were taken into account. *Explicit memorization* (M=25.95, SE=3.22) and *implicit memorization* (M=25.875, SE=2.49) led to similar scores overall, independent of the visualization modality. This was contrary to our assumption that subjects would recall more facts when explicitly told to memorize them. We also observed that users did not frequently interact haptically with the physical visualization. While the visualization was often held in both hands, almost nobody traced the bars with their fingers. Users often tilted the visualization in order to have a better perspective and use the guiding lines on the background panel.

MAIN STUDY

The main study was based on the procedure of the pre-study, but parts were modified according to the findings from the pre-study. We kept the between-groups design, but reduced the number of independent variables to one: visualization modality (physical, digital). We only tested *implicit memorization* and measured recall both immediately and after two weeks for all participants. A *memorability score* was defined

[1] http://hdr.undp.org/

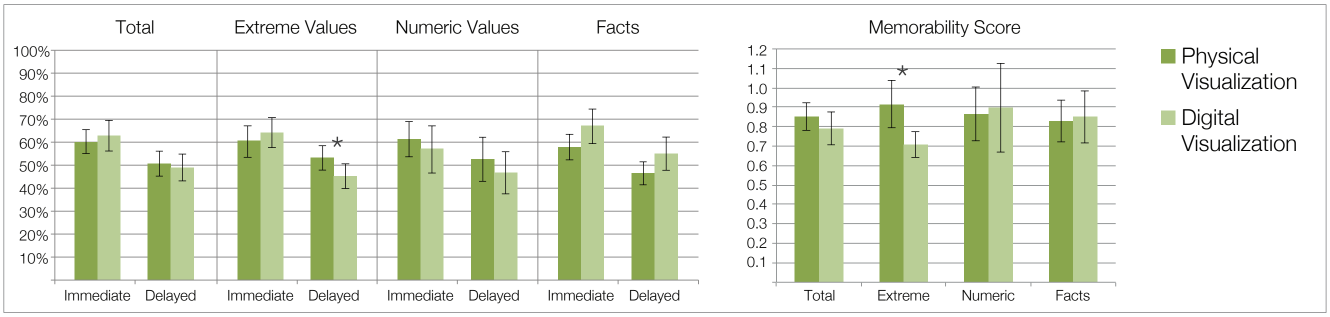

Figure 3. Results of main study: percentage of correct answers for *immediate* and *delayed* recall as well as the calculated *memorability score* (*delayed recall/immediate recall*), with 95% CIs.

as the ratio between the scores for delayed and immediate recall: If, for example, a subject recalled 60% immediately and 45% after 2 weeks, this resulted in a memorability score of 0.75. Using the absolute difference instead of the ratio actually leads to the same overall results.

Data Sets and Visualizations

We used the same data set as in the pre-study. The layout of both the physical and digital visualizations were modified for better readability according to participants' suggestions in the pre-study. We also made changes to the design of the physical visualization to encourage haptic exploration by splitting it into two parts: legend and bars (see figure 1). The latter consisted of a small base which contained all the bars as well as the labels and background panel with the scales. The panel, however, could easily be removed and held in one hand while the other hand could explore the bars.

Procedure and Participants

The questionnaires at the beginning and the end of the study were shortened to reduce study duration. Unclear questions were rephrased. The most important changes were made in the *recall phase*: Instead of asking subjects to recall all remembered facts verbally and transcribing the results, an online quiz assessed each subject's performance in order to gain a more comparable memory score and to exclude possible influences by the experimenter (e.g., differently phrased questions). The quiz consisted of three question categories:

- *extreme values*: Questions which country had the maximum/minimum value were asked for each category, in total 24 questions (e.g., "Which country has the most trust in its government?"). Answers were chosen from a list of the six used countries, as well as "I don't know".
- *numeric values*: Questions about specific numeric values, in total 12 questions (e.g., "In Brazil, only 15% have trust in their government."). Answers were chosen from a dropdown list including "true", "false" and "I don't know".
- *facts*: General questions about the underlying data, in total 14 questions (e.g., "Germany has more trust in its government than Brazil."). Answers were chosen from a dropdown list including "true", "false" and "I don't know".

Participants did not receive any feedback on their performance, nor were they told the correct answers to the quiz. They were informed that they would have to fill out another questionnaire in two weeks, but not that it would be the same. However, some participants suspected there would be another memory test. For the delayed *recall phase* participants received a link to the same quiz via e-mail two weeks later and completed it at home.

For the recall score, we counted all correct answers. We decided against subtracting one point for each wrong answer as only few subjects chose the "neutral" option "I don't know".

Out of the 40 participants, 17 were female. The average age was 23.5 years (range: 18-32). All participants were students of a technical subject. Participants received a 15 Euro voucher for an online shop.

Results

The results of the *immediate* and *delayed* recall score and their ratio, the *memorability* score are depicted in figure 3. The *immediate recall* score for the *digital* modality (M=62.80, SE=3.19) was higher than for the *physical* (M=59.91, SE=2.54) modality. The reverse was true for the *delayed recall*, where the physical visualizations (M=50.68, SE=2.68) performed better than the digital ones (M=48.96, SE=2.85). A breakdown into the three question categories revealed, that the *delayed recall* score for the *physical* modality (M=53.13, SE=2.51) in the category of *extreme values* was higher than for the *digital* (M=45.21, SE=2.55). An independent t-test identified a significant difference, $t(38)=2.21$, $p=0.033$, $r=0.34$. None of the other categories showed any significant differences.

As indicated by the *memorability* score, subjects who used the physical visualizations remembered more information (M=0.85, SE=0.03) than those using the digital visualizations (M=0.79, SE=0.04). Again we found a significant difference for the question category of *extreme values* between *physical* (M=0.91, SE=0.06) and *digital* (M=0.71, SE=0.03), $t(38)=3.092$, $p=0.004$, $r=0.45$.

Participants spent slightly more time in the *reading phase* with the physical visualization (M=19.27m, SE=1.50) than with the digital one (M=17.62m, SE=1.00). The mean score for the subjective memory was higher in the *physical* group (*digital*: M=64.15, SE=2.52 / *physical*: M=66.85, SE=1.92).

After the reading phase, subjects were asked to rate aspects such as memorability or readability on 5-point Likert scales (from 1=*very bad* to 5=*very good*). Those who used the physical visualization found the information significantly more *memorable* (*MODE*=4, *M*=3.85, *SE*=0.17) than those who used the digital visualization (*MODE*=3, *M*=3.10, *SE*=0.14), $t(37.165)=-3.41$, $p=0.002$, $r=0.489$. Participants furthermore had significantly more *fun* reading the physical visualization (*MODE*=4, *M*=3.95, *SE*=0.17) than the users in the digital group (*MODE*=3, *M*=3.25, *SE*=0.16), $t(37.873)=-2.99$, $p=0.005$, $r=0.438$.

CONCLUSION AND FUTURE WORK

We compared the memorability of a physical and a digital 2D bar chart. In a user study with 40 participants and a between-groups design, we tested recall immediately after exploration and again after two weeks. While the number of correct answers did not differ significantly between groups in each single comparison, participants who used the physical visualization forgot significantly less information within the two weeks. Particularly facts about maximum and minimum values could be remembered better, when they were perceived from a physical visualization.

The extreme values in the physical visualizations might have been derived from their visually recalled and imagined shape [8]. The fact that spatial layouts can be memorized better in a physical setting is another plausible explanation: Participants might have remembered where high and low bars were situated, and which country and category was at that position. This would explain why better scores for the physical visualization were achieved in the category of extreme values. Scott [10] argues that pictures are better remembered than object names because they are more distinctive. For physical visualizations this aspect could particularly apply for the extreme values because of the vivid physical height of the bars. As we used a rather simple static bar graph built from acrylic glass, which is for example commonly used in museum installations, we believe that a novelty effect hardly could impact the results.

The slightly longer reading times for the physical visualization cannot be excluded as an explanation for the reduced decay. However, in our opinion it seems unlikely that this causes such a large effect only for the memorability of extreme values and only for delayed recall. As another limiting factor, the study procedure involved optional predefined questions and the verbal expression of all facts the subject saw, in order to ensure that each participant had the same knowledge before the interrogation. This process of verbal expression might have helped some users more to remember the facts than the actual visualization itself. However, this potentially confounding factor should be independent of the modality. A clearer approach for future studies could be to give the subjects certain tasks that induce the same knowledge implicitly.

Furthermore most participants only held the physical visualization in their hands, but did hardly explore it haptically. The use of a more handy physical visualization or tasks that more clearly require haptic interaction could change this in further studies, and we expect that this will even increase the observed effect.

Our results suggest that physicality alone was able to increase the memorability of visualizations for a particular kind of information. Although there are many criteria other than memorability according to which the value of physical visualizations need to be judged (e.g. fabrication costs, interactive exploration, etc.), this is a promising preliminary result for both casual and traditional InfoVis. Physical visualizations could in addition enter areas such as advertisement, journalism or education in general, where it is desirable to present memorable information.

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