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EMPIRICAL STUDY OF CARTOGRAMS

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ABSTRACT
We report on an empirical study investigating the effectiveness and efficiency of spatial inference making with contiguous (value-by-area) cartograms, compared to informational equivalent choropleth maps, combined with graduated circles. We find significant differences in people's inference-making performance dependent on the map type. Overall, results suggest that the choropleth map with graduated circles is more effective and more efficient than the cartogram for the analysis of population census data. However, map effectiveness and efficiency also significantly depends on the inference task complexity, and more surprisingly, on the shape characteristics of the depicted enumeration units. For simple tasks, cartograms seem as effective and efficient as the more traditional mapping method. For complex inference questions, inference performance with cartograms is significantly dependent on whether regular or irregular zones are distorted. As we know still very little about the perception and cognition of cartograms, we hope to shed new light for this intriguing mapping method with this empirical study.

INTRODUCTION
The task of a cartographer is to graphically communicate thematically relevant geographic information in a perceptually salient way to a map reader. To accomplish this goal the cartographer chooses the appropriate mapping method, considering the map theme, the map purpose, and the target audience. From this point of view, often a guiding question for a cartographer is: What happens if the cartographer loses control about his/her own depicted data, and how can this be avoided? One may lose control if the user needs specific background knowledge or training to effectively and efficiently interpret the map content. Less trained map readers may make wrong inferences with complex or unusual map depictions, and this might be especially true in the case of multivariate statistical maps. For example, the boundaries of choropleth maps showing population census data are not data driven, but refer to pre-defined political enumeration units. This requires the data to be standardized if areas of unequal sizes are to be compared, as population is rarely evenly distributed over the land. Typically, shades of colors are used to communicate the thematic information. However, if it is important to also depict absolute values for better understanding, then choropleth maps are commonly complemented by graduated symbols. Value-by-area cartograms, on the other hand, depict the same information in enumeration areas that are resized in proportion to chosen (absolute) attribute values. In the case of a cartogram showing population census data, the spatial distribution of a social phenomenon becomes arguably readily apparent at first glance. There is no need to standardize the

data, because the resized areas represent the absolute values of the chosen attribute. Cartograms can also include relative information of an attribute, for example by shading the scaled enumeration areas in choropleth manner. In this empirical study, we investigate, if and to what extent (in terms of levels of complexity) people are able to make sense of contiguous (value-by-area) cartograms, compared to choropleth maps, combined with graduated circle maps.

RELATED WORK

Previous empirical research by Dent (1975), Griffin (1983) and Aschwanden (1998) on cartograms has shown how differently people may interpret the depicted information. Dent (1975) and Griffin (1983) suggest that a cartogram can only be understood in combination with a geographically un-distorted map (e.g., an inset map) to be able to judge the magnitude and location of distortion. Dent (1975) further suggests that irrespective of the map type, map symbols and labels (including the information in the legend) need to have the appropriate level of detail to make sense of the depicted information. Griffin (1983) found that people were able to correctly identify respective identical areas in a reference map and a value-by-area cartogram. Aschwanden (1998) suggests that participants are able to comprehend a complex theme well when displayed in more than one cartogram. Finally, Sun and Li (2010) examined the effectiveness of cartograms in a preference study. Their results show, that for qualitative themes (e.g., US election) cartograms seem to be more effective and more preferred than traditional thematic maps. In summary, prior research shows that while cartograms appear unusual or even provocative, they also seem readable, understandable, and accepted by map readers. However, still very little is known about the effectiveness and efficiency of visuo-spatial inference-making with cartograms, compared to more traditional thematic map forms (Bollmann and Koch, 2002).

EXPERIMENT

To empirically evaluate our research question, if and up to which inference complexity people are able to make sense of contiguous cartograms, we designed a controlled within–subject experiment.

Participants: Fifty participants were recruited from a cartography class at the University of Applied Science in Karlsruhe. On average, participants were 24.2 years old, and no one reported having a viewing deficiency (i.e., acuity or color blindness).

Design and Materials: We constructed two informational equivalent map stimuli using two different depiction methods: a choropleth map overlaid with graduated circles (choro/symbol) and a contiguous value-by-area-cartogram (cartogram) (i.e., first independent factor: map type). For both map types we used two characteristically different geographic regions: one version with regularly shaped enumeration units (i.e., Counties in Kansas), and a second with irregularly shaped enumeration units (i.e., Communes in the Canton of Basel) (i.e., second independent factor: shape). We designed test questions of varying difficulty based on Bertin's (1974) map reading levels (i.e., third independent factor: question type). The simple questions are based on the elementary and medium reading levels, where map readers have to analyze one map element or a group of elements. The complex questions relate to the overall map reading level where a map pattern or an overall trend needs to be investigated. For each condition, we generated multiple versions of the stimuli by systematically rotating the maps, by placing the response labels in different enumeration units, and by varying the spatial distance between the units to be assessed. Participants were not informed about the true data source and the map locations. The presentation order of the stimuli was systematically varied and rotated to avoid potential learning biases. We measured participants' accuracy and response times while solving the tasks (i.e., dependent variables).

For locational reference all stimuli included a labeled inset map (on the left side in Figures 1 and 2) of the same size as the test map (right hand side in Figures 1 and 2), and a meaningful legend. Two visual variables were utilized to communicate the identical statistical information, namely 1) absolute number of the available workforce (i.e., employed and unemployed workers) varied by size, and 2) percentage of unemployed people varied by color value. The color-scheme was selected with ColorBrewer (http://www.colorbrewer2.org) considering color deficient users. The value-by-area cartograms were constructed using the Gastner & Newman diffusion algorithm included in the ScapeToad software (http://scapetoad.choros.ch/).

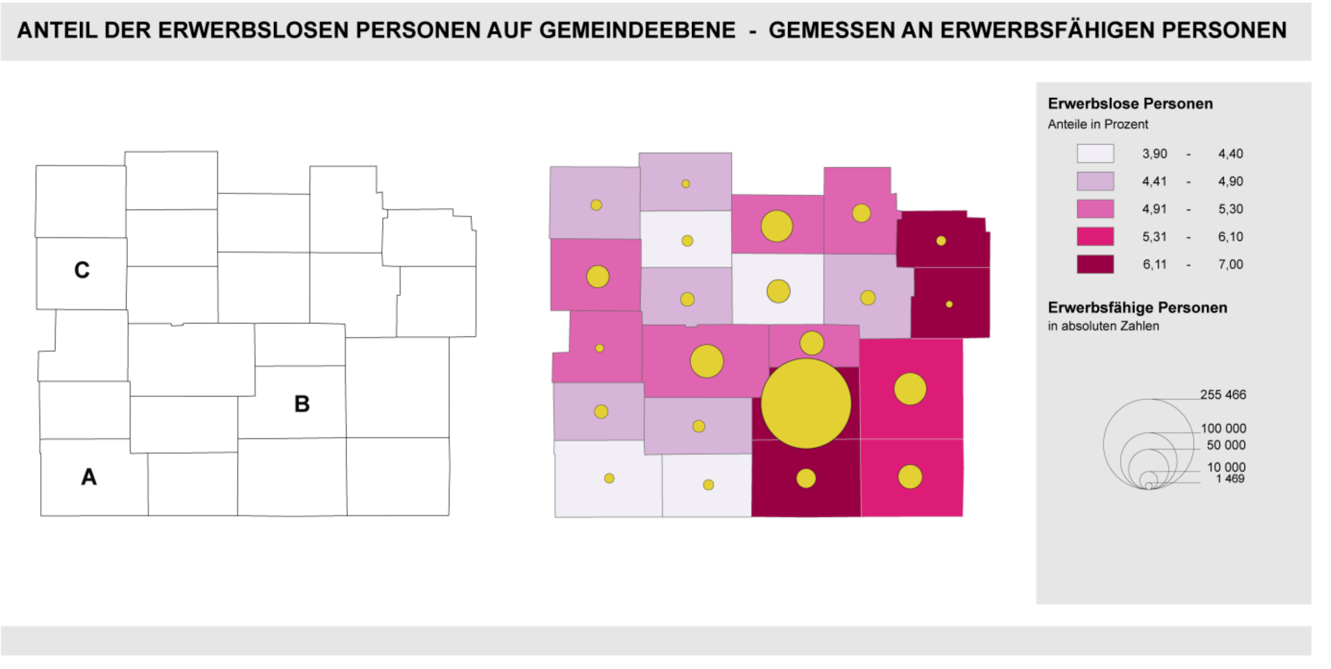

Figure 1: choropleth sample test stimulus (regular region)

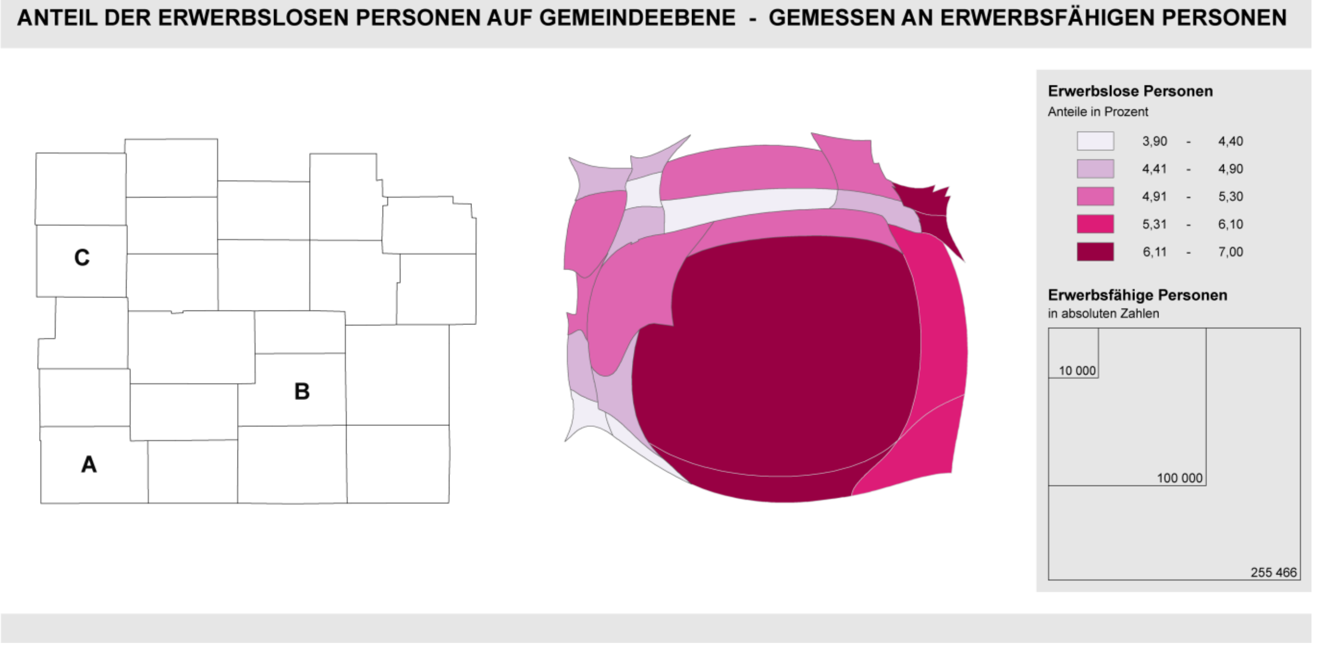

Figure 2: cartogram sample test stimulus (regular region)

In summary, the test design included a two (choropleth / cartogram) by two (easy / difficult) by two (regular / irregular) within-subject factorial experiment.

Procedure: The experiments took place in a lab equipped with standard personal computers connected to the Internet at the University of Applied Science in Karlsruhe. The experiment was carried out with a standard web browser displayed in full-screen mode on a 19-inch color display set to 1280x1024 pixel screen resolution. First, participants were asked to match labeled polygons in the inset map with corresponding ones in the test map (this part of the experiment is called pre-test in the remainder of this paper). This pre-test allows us to know whether participants are indeed able to correctly identify relevant enumeration units in the test maps, especially when dealing with distorted cartograms. Next, each participant was asked to answer four easy and three complex questions in random viewing order, in all conditions. Participants were asked to select their answers from a list with three choices, one of which was the correct answer.

RESULTS

We first analyzed participants' pre-test performance by means of an ANOVA with Bonferroni correction, to investigate whether participants are able to correctly identify relevant polygons in the test maps using the labeled inset map; this being a pre-requisite for answering all subsequent test questions. Overall, the choropleth map yielded 100% correct responses and the cartogram 96%, respectively, as shown in Figure 3.

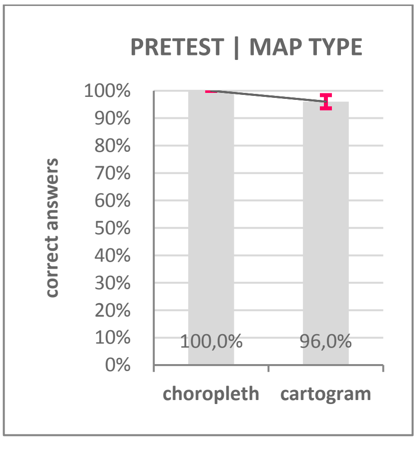

Figure 3: response accuracy for the pretest | map type

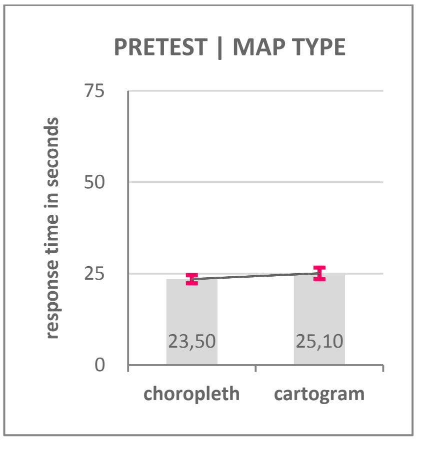

Figure 4: response time for the pretest | map type

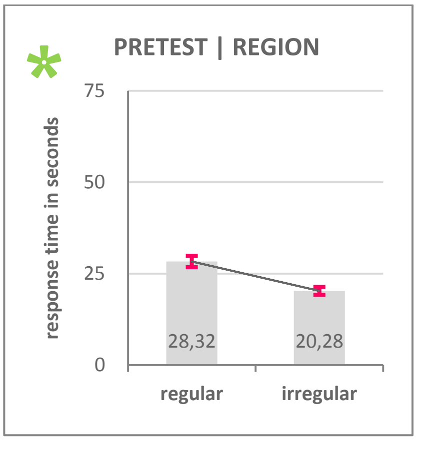

Figure 5: response time for the pretest | region

We find no significant difference in polygon identification across map types (F=2.761, p>.01, Power= .370). Overall, it took participants on average less than 30 seconds to respond (see Figure 4). The slight response speed difference between map types is also not statistically significant (F=1.757, p>.05, Power= .255). However, if we further distinguish the shape of the enumeration units, as shown in Figure 5, we find that participants on average need 28.32 seconds to respond for regular shapes, while for the irregularly shaped enumeration units they only take 20.28 seconds. This difference in response speed is indeed significant (F=52.969, p<.01, Power=1.000). In other words, the regularly shaped enumeration units are more efficiently identified (i.e., in speed), but not necessarily more effectively (i.e., accuracy).
We further analyzed participant responses with respect to the independent variables discussed earlier and results are shown in Figures 6, 7 and 8 below.

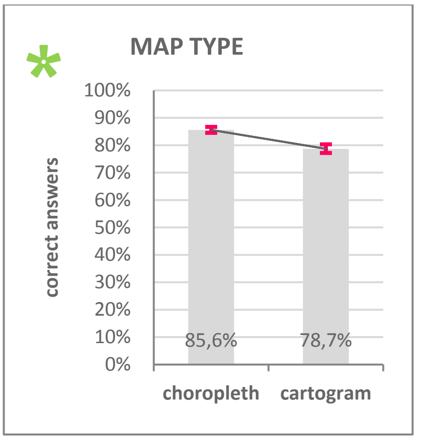

Figure 6: response accuracy for the map type

Figure 7: response accuracy for the region

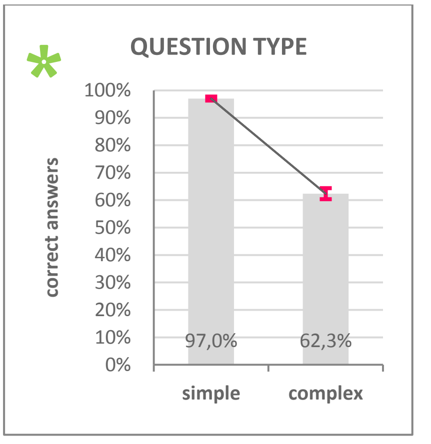

Figure 8: response accuracy for the question type

Participant accuracy overall (Figure 6) is on average higher for the choropleth maps (M=85.57%) compared to the cartograms (M=78.71%). A repeated measures ANOVA (with Bonferroni correction) suggests a statistically significant difference between the map types (F=16.137, p<.01, Power=1.000). When further distinguishing the maps with respect to polygon shape, as shown in Figure 7, we find that our participants give more correct answers with the irregularly shaped regions (M=85.43%) compared to the regularly shaped regions (M=78.86%). This accuracy difference is statistically significant (F=27.401, p<.01, Power=1.000). Irrespective of the map type, participants have an almost perfect accuracy score for the easy questions (M=97.00%), but are on average less than 70% correct for the complex questions (M=62.33%) as can be seen in Figure 8. These differences in question type are again significant (F=318.000, p<.01, Power=1.000).

Investigating this result in more detail for the simple questions, we find a significant difference in response accuracy between map types (choropleth: M=98.75%, cartogram: M=95.25%). However, participants' response accuracy for the two tested map types are on average well above 95% correct. In other words, while there is a difference across map type, people are able to interpret cartograms very effectively and efficiently, if the map reading task level is simple. This is contrasted by the results for the complex test questions which included trend detection in a specific region of the map, or the visual integration of two shown statistical variables. Overall, the accuracy of response for the complex questions (M=62%) is significantly lower for both map types compared to the simple questions (M=97%). In other words, regardless which map type, participants had great difficulty answering more complex test questions. Furthermore, on average, participants' accuracy with the cartogram is significantly lower (56% correct) compared to the choro/symbol map (68% correct) for the complex questions. This is particularly due to a region shape effect, which we did not anticipate. Surprisingly, participants performed significantly better with the irregularly shaped enumeration units, compared to the regularly shaped enumeration units. Why?

To accurately answer a complex question, participants needed to integrate the patterns of two shown variables. While they were never asked to identify an exact data value, or estimate magnitudes, they needed to relatively compare magnitudes in regions, i.e., whether one region had more or less employed/unemployed people than another region. One reason for the low accuracy score of the choropleth map for the regularly shaped units (64.47% correct) could be that the regular polygons are all small and more or less of the same size, but represent high data magnitudes. Hence, slight misinterpretations of relative size difference in the map could have meant large differences in true data values. In contrast, the variation in polygon size for the irregularly shaped maps is larger, but the range of depicted data values is smaller. Thus misinterpretation of relative size differences in the map has a much smaller impact on the data value range, compared to the regularly shaped units. This could be one reason that the irregular shaped choropleth map yielded on average 71.33% correct answers.

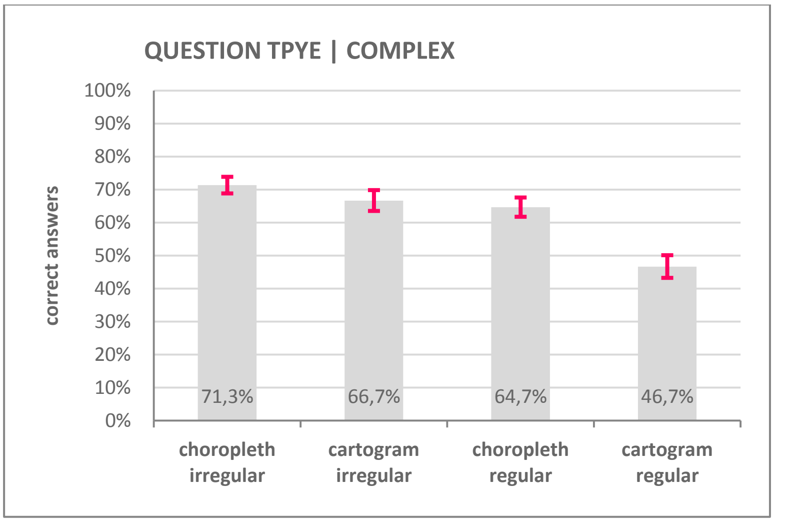

Figure 9: Participants´ response accuracy for the complex questions

DISCUSSION

While the overall results suggests that participants on average perform better with the choropleth map compared to the cartogram, we are still left with the question why there is so much difference between the two different cartogram map types (see Figure 9), and why this is particularly so for the complex questions? One possible explanation for this effect might be the quality and magnitude of the shape transformation when comparing polygons in the non-distorted inset map with the cartogram. For the easy questions, this transformation was not relevant for an accurate response. Participants needed to locate the labeled polygons and then assess the respective ones in the map by consulting the legend. However, for the complex questions, participants needed to specifically compare original polygons in an inset map with respective distorted polygons in a cartogram, and assess size changes in combination with color value changes. This was generally hard for participants, as regardless of the map type, the accuracy of these questions is generally below 30% correct.

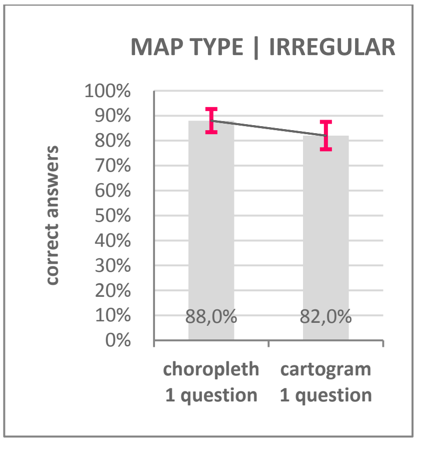

Figure 10: response accuracy for one complex question

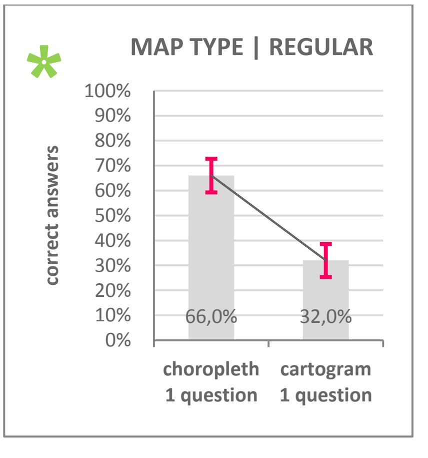

Figure 11: response accuracy for one complex question

Specifically, for the last of the complex questions, it was necessary to make an inference between two size variables. In the choropleth map condition, participants needed to compare the size of a graduated circle with the polygon size of its respective enumeration unit. For the cartogram, they needed to compare the size of the original polygon with the size of the distorted polygon. The results for this last question only (see Figure 10), suggests that it is indeed possible to answer this kind of question correctly. In fact, with irregularly shaped polygons the response accuracy is high for both, the choropleth map (88% correct) and the cartogram (82% correct), and this difference is not significant

(F=0.815, p<.01, Power= .143). However, the response pattern looks differently for the regularly shaped polygons, where participants' answers, on average, were significantly lower for both, the choropleth map (66% correct), and the cartogram (32% correct). The difference between map types for regularly shaped polygons is now significant (F=16.447, p<.01, Power= .978). One possible reason for this result is shown in Figure 12 below. While the shape characteristics for the irregular units do not change much after transformation (i.e., Basel), the shapes of the regularly shaped units (i.e., Kansas) change dramatically.

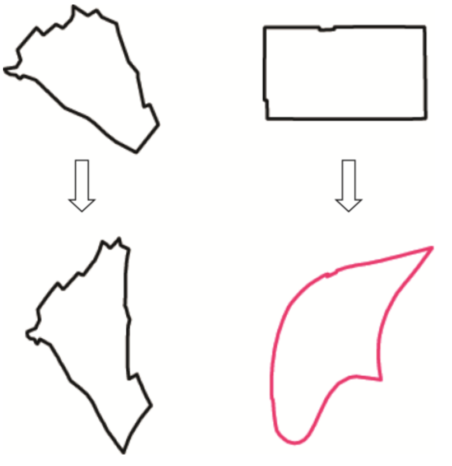

Figure 12: Transformation effect of polygon shapes

It is not clear at this point if and how this particular problem relates to the chosen cartogram algorithm. It may simply be that great care needs to be applied when using the Gastner & Newman cartogram algorithm with regularly shaped enumeration units that also have high data values, as to reduce perceptual complexity when solving harder inference questions. However, to mitigate the transformation effects from a regular to an irregular shape (i.e., with the mostly square counties in Kansas), a cartographer might choose another transformation algorithm, or depiction method. For example, in Kansas, were the original polygons have nearly the same size and shape a non-contiguous cartogram might be a perceptually more salient fit.

CONCLUSIONS AND OUTLOOK

This study set out to investigate how people make sense of population data depicted in contiguous (value-by-area) cartograms, compared to informational equivalent choropleth maps, combined with graduated circle maps. The overall results show that the more commonly used choropleth/graduated circle map combination yields more effective (accurate) and more efficient (faster) responses than the cartogram maps. However, we also find that effectiveness and efficiency of spatial inference making also depends on the task complexity, and more surprisingly, on the shapes of the enumeration units. Irrespective of map type and unit shape, participants had great difficulty to answer more complex inference questions correctly, especially if it involved the integration of two visual variables; color value and size. For simple questions, cartograms seem almost as effective and efficient for inference making as choropleth/graduated circle maps. Similarly, participants perform equally well with choropleth maps and cartograms for complex questions, but only when the shape of the units are irregular. In other words, effectiveness and efficiency of cartograms depend on the enumeration shape transformation and the complexity of the question.

In summary, our results show that shape characteristics of the enumeration units before and after the cartogram transformation are important to consider when using cartograms. In other words, for optimal cartogram choice a cartographer has not only to consider the statistical data relationships, but also the shape characteristics of the enumeration units, and how these characteristics are handled by the various existing cartogram algorithms.

Our study provides rare empirical evidence for the contention that the more unfamiliar cartogram can be as effective and efficient than traditional statistical mapping techniques, including choropleth maps and graduated circle diagrams, specifically when considering task complexity and enumeration unit characteristics. However, we know still very little about why this is the case. Further research is needed to investigate the potential effect of employed cartogram algorithms, and their respective transformation parameters. We also believe that legend design might be another important factor to consider for effective cartogram use. Cartograms are intriguing visual displays, and allow depicting population data in unusual ways. We believe that this mapping method deserves greater attention by cartographers, and hope to have provided a first stepping-stone with this contribution.

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