DOI: 10.14714/CP76.59

PEER-REVIEWED ARTICLE

Identification of Partially Occluded Map Symbols

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Maps should be legible at all scales, and the information density of a map should be adapted to fulfill this goal. However, there are situations in which overlapping symbols might not be easily avoided. These kinds of cluttered or over-plotted situations often occur today in geovisual analytics and in map mash-ups created using Web 2.0 technologies. In this research project, we examine via a user test the extent to which occluded symbols can still be identifiable. Specifically, we tested how different levels of occlusion affected the accuracy and response time of finding symbols that varied in either color hue, abstract shape, or pictogram. The results of the test show that the efficiency of the symbols decreases when the symbols become partially occluded. Still, even half-occluded complex shapes can be identified quite accurately. Symbols varying in color hue seem to tolerate occlusion the best.

KEYWORDS: map symbols; symbol design; occlusion; overlapping symbols; visual variables; pictograms; map congestion

INTRODUCTION

The digital maps used in modern media consist of data that are created and updated continuously by web users with the help of Web 2.0 technologies (Graham 2010). This mass of data is often presented without cartographic editing, for example in simple map mash-ups, in which all data are displayed on a background map without any control over their overlap. This kind of map publishing easily leads to crowded maps containing numerous overlapping symbols. Some of these symbols cannot be identified at all, cluttering the map without conveying the intended information. This problem is common in maps produced using social networking tools (Field & O'Brien 2010).

Generalization is an essential part of mapmaking. It aims to reduce complexity in order to make the map legible and aesthetically pleasing. The collision or overlap of symbols is one of the conditions which determines *when* generalization is required (McMaster & Shea 1992). In map mash-ups, aggregating map symbols has been found to be a powerful method for solving the problem of overlap (Burigat & Chittaro 2008; Delort 2010). Filtering the data according to the relevance of the thematic objects is also considered important for reducing the visual complexity of map displays (Swienty et al. 2008).

Map displays meant for geovisual analytics tend to be more complex than is cartographically appropriate (Kraak 2010). In exploratory analysis, the user browses large data resources and chooses the items to be shown on the map by querying a database. The user needs to be sure that all of the items fulfilling the query conditions are displayed, especially in cases where individual items are important to the analysis. In these situations, methods such as aggregation or automatic filtering cannot be used, even if the map display is cluttered, because they may hide necessary information and seriously mislead the user during the course of the analysis.

For cases in which methods that remove individual items cannot be used, displacement of the symbols remains one of the few acceptable methods of generalization (Korpi & Ahonen-Rainio 2013). However, it may not be possible to find space for a large number of non-overlapping symbols while keeping them close to their correct locations. In such situations, controlled overlap might be a solution, in which symbols are allowed to overlap slightly, and only heavily overlapping symbols are displaced. One symbol peeking out from behind another symbol can make an important contribution to detecting a pattern during analysis. Allowing symbols to partially overlap on a map would represent a trade-off between the efficiency of identification and not losing the information. Then, an appropriate question would be: *What is a reasonable limit for the degree of occlusion?* For our purposes, a definite limit occurs when the symbols can no longer be efficiently identified, but only serve to clutter the map.

There has been little research on the perception of overlapping or occluded map symbols within the field of cartography. Groop and Cole (1978) have studied how accurately people can judge the sizes of partially occluded circles in proportional symbol maps. However, occluded object recognition has been studied quite extensively in the existing psychological literature. Evidence from such research suggests that early visual processes can handle occlusion information quite well (Rensink & Enns 1995), and this information is then available during the object recognition phase (Wolfe & Horowitz 2004). This suggests that we have mechanisms to recognize occluded objects quite easily. We are also capable of recognizing meaningful objects from very small and low-resolution thumbnail images (Torralba 2009). On the other hand, Rosenholz et al. (2007) claim that human object recognition performance decreases due to occlusion.[1]

However, we did not find that researchers have drawn any conclusions on the effect of the *degree of occlusion* that could help us answer our question about the efficiency of partially occluded map symbols. To bridge this gap, we organized a user test where the task was to search for and *identify* visible and partially occluded symbols on a map. In terms of our question about the reasonable limit of occlusion, the design of the symbols also has relevance because:

1. Some visual variables can be *perceived*, whereas others have to be *inferred* when partially occluded;

2. With regard to visual variable of *shape*, the complexity of the shape affects the symbol identification.

In the next section, we discuss related work on visual variables and occluded shape recognition. After that, we assess the above two claims more thoroughly and form hypotheses based on them. Following the theoretical section, a user test and its results are presented. Finally, we discuss the results in light of theories on occluded object recognition before drawing our final conclusions. The current study aimed at finding practical solutions for visualizing news data on an interactive map. We were especially interested in the capacity of pictograms in map symbols.

1. In cartography, the term *symbol identification* is used and has a meaning similar to *object recognition* in psychology (Keates 1989).

RELATED WORK

VISUAL VARIABLES

Map symbols carry information via visual variables, which were first introduced by Bertin ([1967] 1983). Bertin's seven variables were shape, size, hue, value, orientation, texture, and location. Other cartographers have suggested including additional variables, such as saturation, transparency, crispness, and resolution (MacEachren 1995). Psychologists have also studied the visual variables of objects and introduced slightly different ways of organizing them. For example, Kosslyn and Koenig (1992) categorized the variables as object properties (e.g., color, texture, shape) and spatial properties (e.g., size, orientation).

Different visual variables have different capabilities and serve different purposes when visualizing data. Bertin ([1967] 1983) classified visual variables on the basis of whether they are "selective" or not. For example, color hue is selective because it allows the eye to isolate all elements in one category and disregard other categories. Shape cannot do this and is, therefore, nonselective. Color hue is also the most efficient variable when a uniquely characterized symbol needs to be found on a map (Lloyd 1997). This kind of visual search has been extensively studied in cognitive psychology, and models have been built to describe human visual search mechanisms (e.g., Treisman & Gelade 1980; Wolfe 2007). Based on a number of visual search studies, Wolfe and Horowitz (2004) classified visual attributes according to their ability to guide attention. They included color, size, orientation, and motion in the best, "undoubted" category. They included such variables as shape in the second best, "probable" category. Within Gestalt psychology, color hue is viewed as one of the strongest similarity grouping principles (Quinlan & Wilton 1998).

OCCLUDED SHAPE RECOGNITION

In natural scenes, most of the objects are partially hidden behind other objects. We are used to operating in this kind of an environment, and we can easily recognize objects based on their visible parts. We understand that partially visible objects lie behind other objects, and we do not need to interpret the visible part of the object alone as a whole. This ability is already gained by 2–4 months of age (Valenza et al. 2006). Since the perceptual completion of occluded objects is such an inseparable mechanism in the processes of object recognition, it has been well studied in psychology and neuroscience.

In the psychological literature, two different approaches, *local* and *global*, have been proposed for explaining the processes of recognizing partially occluded objects. Local theories state that people mainly connect the discontinuities between partially occluded contours by finding the simplest continuous function between the points of occlusion (Kellman & Shipley 1991), or on the basis of T-junctions (Rubin 2001). Global approaches suggest that shape regularities, such as symmetries, dominate during the perceptual completion of objects (van Lier 1999; de Wit et al. 2005). Evidence has also been found for the relevance of both influences (van Lier et al. 1995; Tse 1999).

Kellman (2001) separates global and local processes in object recognition. A global process—that is, when the recognition is based on global symmetry or on the familiarity of the object—is a higher level, top-down cognitive process compared to the perceptual local, bottom-up contour interpolation process. A global process requires that the observer have an idea what the occluded object looks like. Also, the gestalt *past experience*[2] *rule states that our visual perception is tuned to search for familiar objects in a particular scene (Wertheimer 1958).* Furthermore, the context can reduce the required visible detail in object recognition. For example, a cat can be recognized from the very tip of its tail peeking out from behind a sofa, if it is already known beforehand that a cat is somewhere in the room (Kosslyn & Koenig 1992).

In a map context, the processes of object recognition can be reviewed by comparing abstract and pictographic symbols. The basic distinction is that a pictographic symbol mimics its object whereas an abstract symbol does not, which means that the identification processes for the two types of symbols differ from each other. Map symbols are identified by matching a symbol on the map against the symbols in the legend or by remembering the meaning of the symbol based on previous experience (Keates 1989). The meaning of an abstract symbol has to be learned beforehand so that the symbol can be correctly identified without using the legend, whereas the meaning of a pictographic symbol can be correctly inferred without previous learning. Because of this advantage, pictographic symbols are usually used in maps designed for novice or occasional users, such as tourists (Kostelnick et al. 2008).

A pictographic symbol loses its advantage of intuitiveness if the conceptual relationship between the symbol and the object it represents is not familiar to the map reader—that is, if the relationship has to be learned similarly to that of abstract symbols (Korpi & Ahonen-Rainio 2010), because it cannot be based on causal reasoning, which is typical of humans (Sloman 2009). Then, a pictogram is nothing more to the reader than a visually complex abstract symbol, and this complexity is the disadvantage of pictographic symbols. Humans can identify simple shapes significantly faster than complex shapes (Alluisi 1960). In a map context, readers can identify pictographic symbols more accurately than abstract symbols, but they can identify abstract symbols more quickly than pictographic symbols (Forrest & Castner 1985).

2. Some sources use the term *familiarity*.

THEORETICAL FRAMEWORK

When considering the efficiency of occluded map symbols, the visual variable used to visualize the symbols and, more specifically, how the visual variables are rendered on the display are important. Such variables as transparency, color hue, value, and saturation do not need contour information; rather, they can be assigned to each pixel, and therefore we refer to them here as *surface-based* variables. Size, shape, orientation, crispness, and resolution cannot be assigned to each pixel but require the contour information in order to be visualized. Therefore, we refer to size, shape, orientation, crispness, and resolution here as *contour-based* variables.

In the case of overlapping symbols, surface-based variables can be *perceived* even when only part of the symbol is visible, but contour-based variables must be *inferred* based on the visible information. The map reader does not need to see the whole symbol in order to see its color. But when the reader tries to identify the shapes of partially occluded symbols, they cannot really be seen; rather, the reader has to rely on cues, such as the fact that a curved line is a part of a circle and that straight angles belong to a square. This suggests that, when they are partially occluded, identifying contour-based variables is more demanding than identifying surface-based variables. However, in practice map symbols are small and the visible areas of partially occluded symbols are obviously even smaller. The human ability to discriminate between color hues weakens when the field size gets smaller than half a degree of visual angle (Ware 2000). Therefore, color variables may not benefit from their perceptible character in the case of heavy occlusion.

When considering the processes of occluded-object recognition, abstract symbols can be identified with local perceptual processes whereas the identification of pictographic symbols requires higher level cognitive processes. In terms of using the symbols on crowded maps, the question is then whether this further slows down the process of identifying pictographic symbols compared to that of identifying partially occluded abstract symbols. When thinking about it intuitively, pictographic symbols lose more of their efficiency when partially occluded. For example, Slocum et al. (2005) state that pictographic symbols might be more difficult to interpret than abstract symbols when the symbols overlap. On the other hand, some studies reveal that global processes are taken into account relatively early in the visual system (Sekuler et al. 1994), which suggests that pictographic symbols might not lose any more of their efficiency when partially occluded than abstract symbols do.

On the basis of the fact that surface-based variables can be *perceived* from partially occluded symbols and that contour-based variables have to be *inferred*, we formed a hypothesis that *surface-based variables cope with symbol overlap better than contour-based variables* (Hypothesis 1). On the basis of the need for cognitive processes to identify partially occluded pictographic symbols, we formed a hypothesis that *abstract symbols cope with symbol overlap better than pictographic symbols* (Hypothesis 2).

USER TEST

We designed a user test to investigate the degree to which occluded symbols are still identifiable. Specifically, we tested *surface-based* versus *contour-based* visual variables and *abstract* versus *pictographic* symbols in the case of occluded symbols. To this end, we tested how effectively (accurately) and efficiently (fast) three symbol types—*color hue* (surface-based variable), *abstract shape*, and *pictogram* (contour-based variables)—could be identified on a map at different occlusion levels. The effectiveness and efficiency of completely visible symbols were compared to the effectiveness and efficiency of partially occluded symbols. The target symbol on a map appeared as either totally visible or as partially occluded by other symbols. The occlusion levels used in the test were chosen on the basis of the hypothetical limits of each case. For the shape-varied symbols (i.e., abstract shapes and pictograms), the tested occlusion levels were 25 and 50 percent; we assumed that in general, more shape information should be visible than missing, although there may be strong individual differences between symbols in this respect (Kosslyn & Koenig 1992). The tested occlusion levels were 50 and 75 percent in the case of color hue, because we hypothesized that the occlusion tolerance would be higher with color hue. Bedford and Wyszecki (1958) found that color discrimination is still quite accurate with field sizes of 12 minutes of visual angle, which is slightly larger than 25 percent of the symbol size used in our test. The task of the subjects was to interpret a map that visualized news items with point symbols representing five different news categories, and to find a unique symbol on the map. The response time and accuracy of the responses were measured.

SUBJECTS

In total, 40 subjects participated in the test. Twenty-seven of the subjects were undergraduate students in geoinformatics, while the rest were graduate students and researchers. The subjects represented a range of nationalities and educational backgrounds. The majority of the subjects were familiar with geographic information systems and spatial data, but their level of experience varied considerably. The age of the subjects ranged from 23 to 58. We tested the red-green color blindness of the subjects using an Ishihara test picture, and none of the subjects proved to have this kind of color deficiency.

TEST MATERIAL

The test maps consisted of a background map and 53 partially occluded or completely visible point symbols. The point symbols represented news items in five different news categories: each category had a different symbol, which varied either in terms of *color hue*, *abstract shape*, or *pictogram*. The five different symbol colors were based on the easily separable color schemes for qualitative data designed by Harrower and Brewer (2003). The abstract shapes and pictograms were designed for the test and drawn using Adobe Illustrator. The symbols used in the test are shown in Figure 1. The diameter of the symbols on the screen was 4 mm, an ordinary symbol size for digital maps and similar tests. The maps and legends used in the test were constructed using Avenza MAPublisher and the test software was implemented in Java. The user interface of the test software is shown in Figure 2.

In each case, one of the categories had only one news item on the map. This was the target symbol that the subject was supposed to find. The test question was: "Which one of the following symbols is presented only once on the map?" This question was used instead of letting the subject search for a given target symbol because in this way the subject had to examine the entire map area and the effect of target location could be minimized. In Figure 2, the target symbol is the orange *economy* symbol (surrounded by a black square). Another news category appeared twice on the map. Below, we use the term "second best guess" for this alternative. The purple *culture* symbol in the figure is the "second best guess" (surrounded by a black ellipse). The other three categories appeared several times on the map (as the *politics*, *sports*, and *accident* symbols), and these were "incorrect alternatives." The background map (Figure 2) was designed so that it would not confuse the subject's perception of the thematic symbols. Water areas, main routes, and urban sprawls were represented with light colors, and no place names were given.

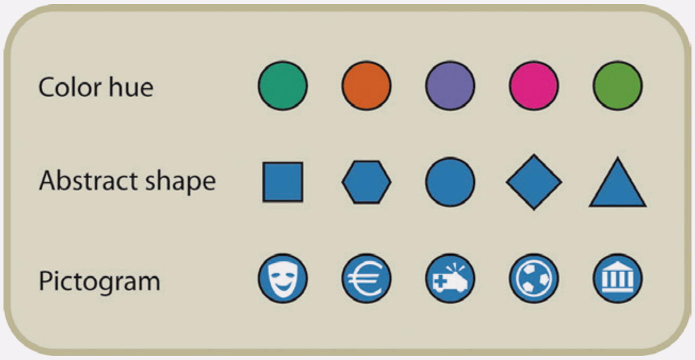

Figure 1: Symbols used on the test.

Since it was assumed that the task could be solved by ruling out symbols that appeared more than once on the map, the target symbol and one of the two symbols used for the "second best guess" were always equally occluded. This was done to ensure that the response was based on identifying the occluded symbols. Since the task was designed so that the subject had to examine the entire map area as a means of ensuring their response, it was assumed that the locations of the symbols on the map would not affect the results. For each occlusion level (0, 25, 50, and 75 percent), there were three alternative locations for the target symbol and the two symbols for the "second best guess." All of the alternative locations were quite close to the center of the map, but the target symbol always appeared in different locations on each test map presented to the subjects in order to prevent them from learning about the locations. The two symbols used for the "second best guess" were always located close to, but not quite next to, each other.

The background map and the spatial distribution of the symbols were constant. This means that a specific location always contained a symbol, but the visual variable, the occlusion level, whether the symbol was a target symbol, and the location of the target symbol varied from map to map. Based on all the possible combinations, a set of 45 maps were constructed. These maps were divided into five subsets of 9 maps each; each set included all nine conditions—that is, they included three symbol types in three different occlusion levels. The test was a within-subjects design, meaning that all of the subjects saw all of the tested conditions. However, not all of the subjects saw the exact same maps, due to the variations in the target locations. Also, the order of the maps varied from set to set. A set size of 9 maps was chosen to keep the overall test short in terms of time since the test session also contained other test tasks that are not presented in this paper.

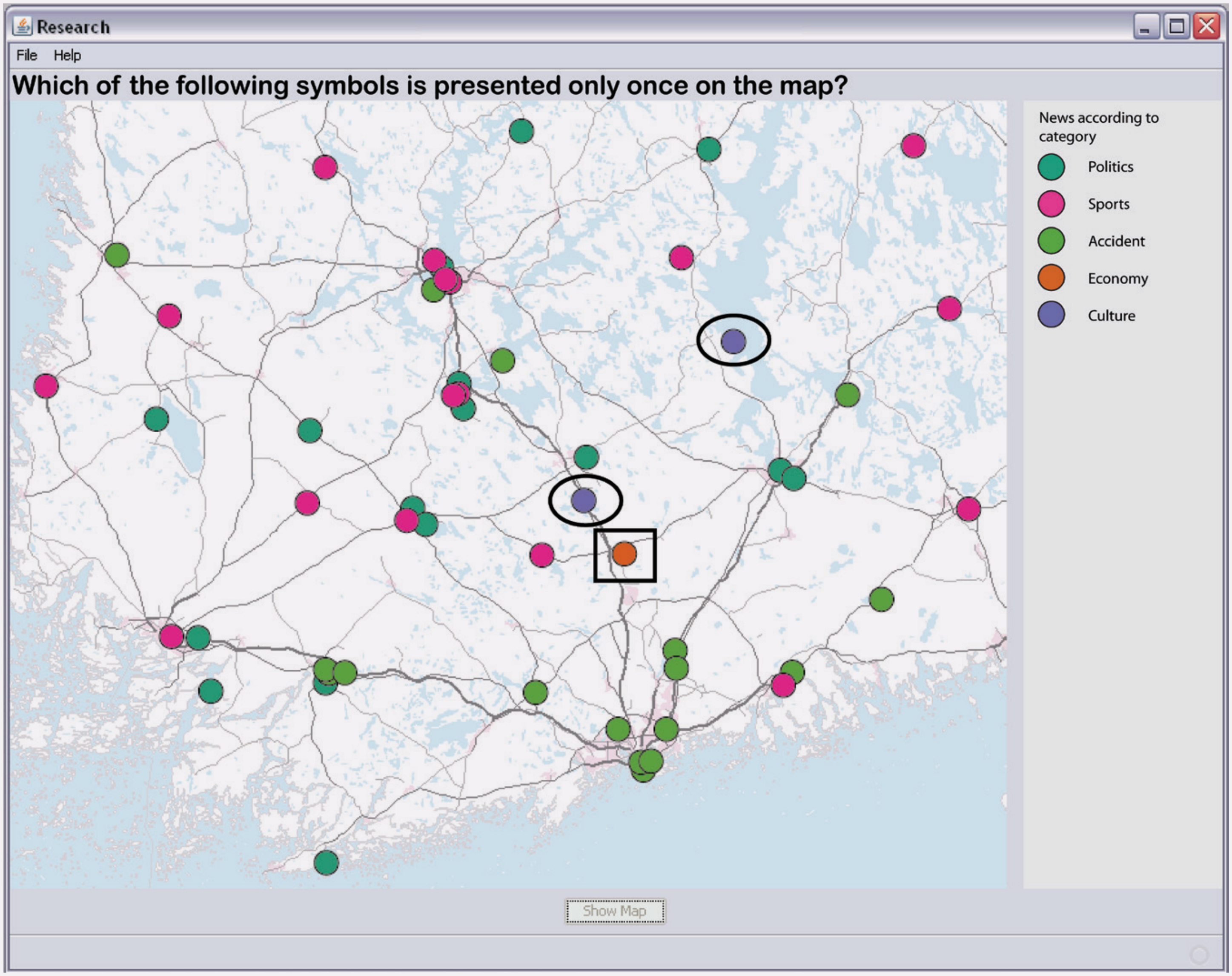

Figure 2: The user interface of the test software. A subject has opened the map and the timing has started. The subject must give a response by clicking on a symbol in the legend. In this case, the target symbol is totally visible. The black square and ellipses were not visible for the subjects.

TEST PROCEDURE

Five subjects at a time took the test with similar laptops in a meeting room. Each of the laptops had a different test set of 9 maps. The theme of the test maps, the task, and the test routine were first introduced to the subjects. The subjects were motivated to respond as quickly and as accurately as possible, since response time and accuracy were being measured. After the short briefing session, the subjects were allowed to start the test at their own pace. During the test routine, the question and the legend showing the possible solutions were first displayed. By clicking a button, the subject rendered the map visible and activated the timer (Figure 2). The timer stopped when the subject clicked a symbol in the legend, which caused a new question with new possible solutions to be shown. The subject was able to rest after answering each question before making the next map visible.

RESULTS

To test the effects of the occlusion levels (0, 25, 50, and 75 percent) on the efficiency of three types of map symbols, we used repeated-measure ANOVAs with IBM-SPSS Statistics version 21. The three symbol types shared two

Symbol (level of occlusion)	Correct			Incorrect
	Mean (ms)	*SD (ms)*	*N (%)*	*N (%)*
Color (0)	6973.55	3523.41	38 (95%)	2 (5%)
Color (50)	9483.59	4071.59	40 (100%)	0 (0%)
Color (75)	11681.18	5754.51	33 (85%)	6 (15%)
Abstract (0)	15580.08	7003.90	36 (92%)	3 (8%)
Abstract (25)	19826.43	8640.99	35 (95%)	2 (5%)
Abstract (50)	23325.32	9724.47	38 (97%)	1 (3%)
Pictogram (0)	25059.64	10705.85	33 (85%)	6 (15%)
Pictogram (25)	26646.07	9913.96	27 (75%)	9 (25%)
Pictogram (50)	33332.56	14781.93	34 (85%)	6 (15%)

Table 1: Descriptive statistics.

common occlusion levels (i.e., 0 and 50 percent); they yielded the main data for comparing the decrease in the efficiency of the different symbol types when they were occluded. We analyzed these occlusion levels using two-way repeated measure ANOVA. Additionally, we tested the color hue when 75 percent of the symbol was occluded in order to assess the theoretical limit of occlusion tolerance, and we tested the shape variables when they were 25 percent occluded in order to analyze the effects of minor occlusion. Therefore, we also performed the analysis with one-way repeated measure ANOVA for each symbol type separately.

Prior to the analysis, we screened and checked the data for any violations with respect to assumptions about the analysis of variance (e.g., independence of cases, normality, and homogeneity of the variances). There were a few outliers in the data, which caused some of the variables to be slightly skewed and marginally violated the assumption of normality. Removing the influential outliers based on a procedure suggested by Tukey (1977) and Hoaglin et al. (1986) provided an acceptable level of normal distribution so that all variables could pass the Kolmogorov-Smirnov test of normality. In addition, we found that the residuals in all variables coincided with the normal line in a P-P Plot and, thus, fit the assumption of normally distributed residuals. The variables also passed Mauchly's sphericity test concerning the two-way repeated measure ANOVA. The results of the analyses are presented in three stages below.

Comparisons	Mean Difference (ms)	Std. Error
Color with Abstract	8622.61*	1080.75
Color with Pictogram	18701.50*	1857.17
Abstract with Pictogram	10078.89*	1822.88

Table 2: Pairwise comparison of the mean at baseline level (totally visible symbols).
*Note: N = 28 for all pairwise comparisons. * $p < 0.001$*

DESCRIPTIVE ANALYSIS

Table 1 and Figure 3 show the results of the comparative analysis done in the study. The results indicate that the majority of the responses were correct: They ranged from 100 percent to 75 percent. The subjects gave slightly more incorrect responses in the case of pictograms than for the other two symbol types, but the difference was not statistically significant. The accuracy of the responses did not seem to drop dramatically for any of the three symbol types at any of the tested occlusion levels. As reaction times of incorrect responses cannot be related to any particular cognitive or perceptual processes, we continued the analysis using only the correct responses.

For all three symbol types, the mean response times for correct responses followed a steady pattern of lengthening as the level of occlusion increased. In the case of color hue, the time difference in the mean response times between totally visible and half-occluded symbols was noticeably smaller (2.5 s) than in the case of abstract shapes (7.7 s) and pictograms (8.3 s). This supports the hypothesis that surface-based variables cope with symbol overlap better than contour-based variables but not the hypothesis that abstract symbols cope with symbol overlap better than pictographic symbols.

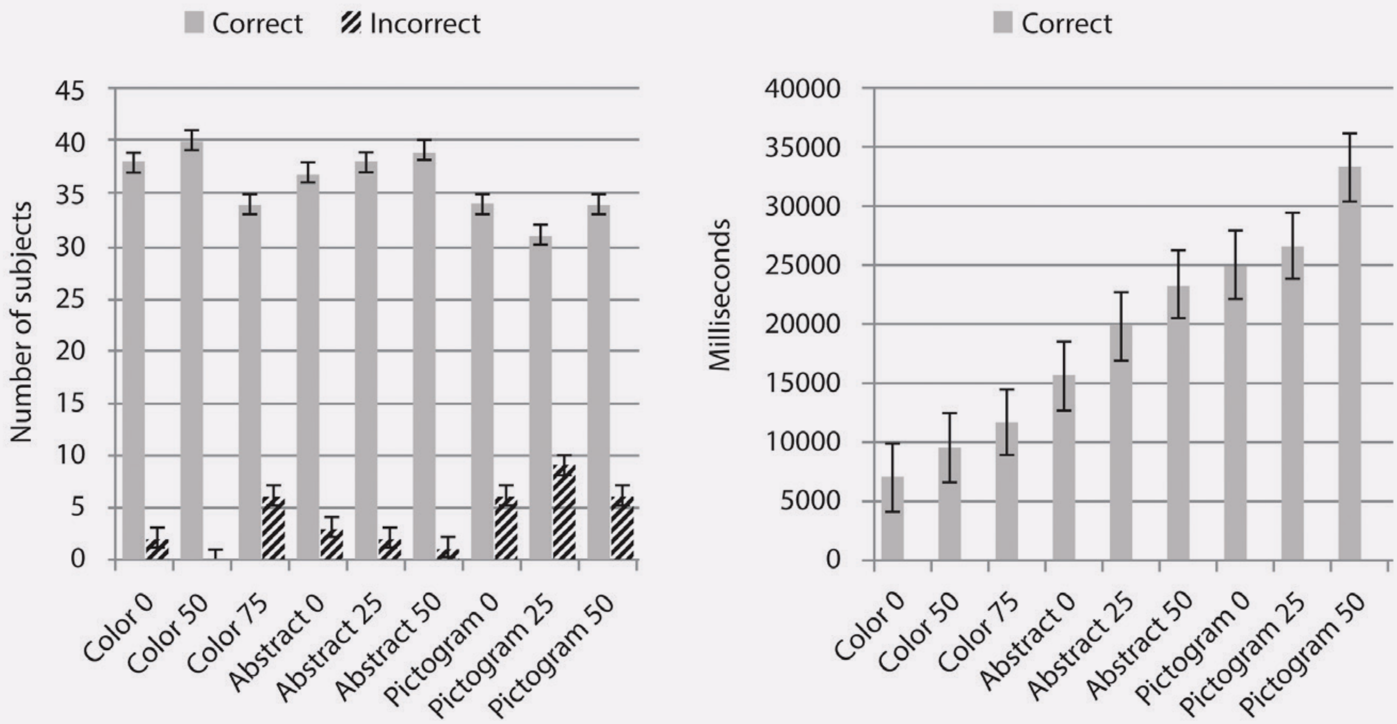

Figure 3: Graph comparison of the frequencies of the correct and incorrect responses (left), and the mean response times of correct responses (right).

EFFICIENCY OF TOTALLY VISIBLE VS. HALF-OCCLUDED SYMBOLS

Using two-way repeated measure ANOVA, we compared the response times at the baseline (i.e., totally visible symbols) between the three types of symbols. The results show significant differences between the three baseline cases for totally visible symbols ($F_{(2, 28)} = 60.86$, $p<0.001$). Table 2 shows that the pairwise comparisons of the means for each of the three baseline cases differed significantly ($p<0.001$). The results therefore denoted that in a totally visible situation, subjects identify color hue more efficiently than they do abstract shapes, and they identify abstract shapes more efficiently than they do pictograms.

In order to test the differences between the response times of the 50 percent occluded cases and the baseline, we implemented a two-way repeated measure analysis, which included two levels of occlusion (i.e., 0 and 50 percent) and the three symbol types. When it came to the levels of occlusion, the means of the response times at 0 and 50 percent occluded levels differed significantly from each other ($F_{(2, 22)} = 137.90$, $p<0.01$). The post-hoc pairwise analysis indicated that the occluded levels (0 and 50 percent) differed significantly from each other for all three symbols types ($p<0.001$). Therefore, the results support the findings of descriptive analysis in that occlusion significantly decreases the efficiency of the map symbols, at least when the symbols are half-occluded. No significant interaction effect between the occlusion levels and symbol types was found ($F_{(2, 22)} = 1.08$, $p=0.35$).

SEPARATE ANALYSES FOR EACH SYMBOL TYPE

Because the tested occlusion levels for color hue were different than for the other symbol types, we used one-way repeated measure ANOVA to perform separate comparisons for each symbol.

Color hue: The result showed that the level of occlusion significantly affected the efficiency with which subjects identified the symbols ($F_{(2, 31)} = 23.58$, $p<0.001$); the means for all three occlusion levels (0, 50 and 75 percent) differed significantly.

Abstract: The result showed that the level of occlusion significantly affected the efficiency with which subjects identified the symbols ($F_{(1.46, 29)} = 8.02$, $p<0.01$)[3]; post-hoc analysis showed that the means for all three occlusion levels (0, 25 and 50 percent) differed significantly from each other

3. In the case of abstract symbols, Mauchly's test indicated a violation of the assumption of sphericity ($\chi^2_{(17)} = 12.48$, $p< 0.01$). Therefore, the degree of freedom was corrected using the Greenhouse-Gesser estimates test.

($p<0.01$). This result suggests that occluding abstract symbols by 25 percent decreases their efficiency significantly compared to totally visible symbols.

Pictogram: In the case of pictograms, we cannot reject the null hypothesis indicating that there are no differences between the three occlusion levels (0, 25 and 50 percent) ($F_{(2, 17)} = 1.29$, $p=0.29$). When repeating the analysis with only two of the levels included in the one-way repeated measure ANOVA, the results indicated a significant difference between baseline and 50 percent occlusion ($F_{(1, 28)} = 23.58$, $p<0.01$). In other words, the mean of the time that participants spent identifying the pictogram at a 50 percent occlusion level (M=30725.47 ms) was significantly greater than the baseline (M=26068.84 ms). This result is in line with the results for the *two-way repeated measure ANOVA*. No significant differences were found between the means of the responses at baseline with 25 percent occluded levels ($F_{(1, 22)} = 1.44$, $p=0.24$) and at 25 percent with 50 percent occluded levels ($F_{(1, 22)} = 3.08$, $p=0.09$). This result suggests that occluding pictographic symbols at a 25 percent level does not decrease their efficiency significantly compared to totally visible symbols. The task of identifying pictograms in a display while visualizing dozens of symbols is difficult, and other factors may have affected the process of identifying pictograms and bedimmed the effect of occlusion. However, it seems that pictograms do not lose any more of their efficiency than abstract symbols when occluded, which is in line with the findings of the descriptive analysis.

We used one-way ANOVA to test whether different subgroups of participants performed differently based on having received different sets of maps. The only (marginally) significant difference was detected in case of totally visible symbols visualized with color hue ($F_{(4, 33)} = 3.48$, $p<0.05$); post-hoc follow-up analysis showed that, in that case, those who saw set 3 were significantly slower than those who saw sets 1, 4, or 5. One-way ANOVA did not indicate other significant differences between the subgroups.

DISCUSSION

SURFACE-BASED VS. CONTOUR-BASED VARIABLES

Our experimental results suggest that the *efficiency* of the symbol decreases when the symbol is partially occluded, regardless of whether the visual variable is *surface-based* or *contour-based*. However, this decrease was not evident until the symbols were half-occluded, since we did not test 25 percent occluded color hue and the results for the 25 percent occluded pictograms lacked statistical significance. The results also show that the symbols can still be identified quite *effectively* (accurately) when half-occluded regardless of the visualization used. This suggests that the human ability to recognize occluded objects applies well to map reading.

On the basis of comparing the lengthening of response times from totally visible symbols to half-occluded symbols, the efficiency of *surface-based* variable color hue (2.5 s mean time) decreased less than the efficiency of *contour-based* shape variables (abstract shape 7.7 s; pictogram 8.3 s). This supports the first hypothesis: *surface-based variables cope with symbol overlap better than contour-based variables*. This means that while all symbols seem to tolerate occlusion, the visual variable used in the symbols indeed affects the symbols' ability to maintain its efficiency while occluded. Furthermore, our categorization of *surface-based* and *contour-based* variables seems to be valid when assessing the visual variables' ability to tolerate occlusion, and there is a difference in efficiency between *perceiving* and *inferring* occluded map symbols in practice.

ABSTRACT VS. PICTOGRAPHIC SYMBOLS

The subjects located abstract symbols faster and slightly more accurately than pictographic symbols on the test maps, but no drop in accuracy occurred when the abstract or pictographic target symbols were occluded. In these two cases, the response times lengthened in similar fashion (abstract shape 7.7 s; pictogram 8.3 s) when the symbols were half-occluded. This suggests that the need for global processes when identifying partially occluded pictograms does not lengthen the response times any more than identifying partially occluded abstract shapes that only require local processes during the identification process; hence, the second hypothesis—*abstract symbols cope with symbol overlap better than pictographic symbols*—is not supported by the results. Therefore, in practice pictographic symbols can tolerate symbol overlap as well as abstract symbols. Our results support the studies claiming that global processes dominate in object recognition, whereas the dominance of the local processes is not supported, at least when object recognition is applied to a complex map reading task. Another explanation for the efficiency of the pictograms when occluded is that the context facilitates the search because the process of identifying complex pictograms on a map is facilitated by the user's familiarity with a limited set of possible map symbols.

When designing the pictograms, the possibility of overlap means that it is at least as important to design the pictograms separate from one another as to make them characteristically recognizable. The pictograms used in our test were designed first of all to be separable from one another. It is obvious that if pictograms resemble one another, then users might not correctly discriminate between them and other symbols that are partially occluded. Five different pictograms appeared on the test maps, but in practice the number may be considerably higher. For example, the symbol sets used in crisis management include dozens of symbols (ANSI 2006; GICHD 2005). When the number of different pictograms increases, the task of designing the pictograms easily separable from one another becomes more complicated.

VISUAL VARIABLES IN MAPS USED FOR GEOVISUAL ANALYTICS

The results also support the findings of visual search studies on the sovereign efficiency of color hue (e.g., Wolfe & Horowitz 2004; Lloyd 1997). In our test, subjects were able to even identify a 75 percent occluded color hue more quickly than they could completely visible shapes. Similarly, our results support the findings of studies that subjects identify simple shapes more quickly than they do complex shapes (e.g., Alluisi 1960; Forrest & Castner 1985). In our test, subjects identified a 50 percent occluded abstract shape as quickly as they did a completely visible pictogram. However, our results differ from those of Forrest and Castner (1995) who found that subjects identified the pictographic symbols *more accurately* than they did abstract symbols. In our study, only five different symbols appeared on the map, whereas the maps used by Forrest and Castner had several different symbols, which reduced the possibility of mistakes in our case.

In practice, our results stress the fact that efficient variables should be used on maps intended for geovisual analytics. However, efficient variables cannot be varied to represent many different values. Subjects can only discriminate between relatively few different color hues or abstract shapes, as shown in the difference in accuracy for the abstract symbols when comparing the results of this study to those of the study by Forrest and Castner (1995). In this respect, pictograms have no equal. For example, more than just a few different symbols are needed when using map symbols to represent news topics or news content. Therefore, the strengths of different visual variables should be used in the case of geovisual analytics. Our suggestion is to use the attention-guiding and selective variable of color hue in combination with an illustrative pictogram, so that the color hue represents the higher level category and the pictogram represents a specific sub-level category. In this way, the color will help guide the search (Wolfe 2007) and the map reader can more easily access the information represented by pictograms.

NEEDS FOR FURTHER STUDY

The number of test maps presented for each subject was relatively small because of time constraints imposed by other experiments in the test session. Therefore, the number of factors that we were able to test was limited, and two issues should be studied further. First, more occlusion levels would need to be tested to better determine the level of occlusion at which the loss of efficiency reaches a critical point. For example, we assume that the abstract and pictographic shapes would no longer be effectively identifiable at the level of 75 percent occlusion, but to be sure it would need to be tested. Furthermore, we could fully compare the performance of different visual variables with each other if we tested the same occlusion levels for all types of symbols. Second, we used color hue to represent a *surface-based* variable and shape to represent a *contour-based* variable. Although color hue outperformed shape when they were partially occluded, more variables need to be tested to categorically state whether this superiority of color hue extends to other surface-based variables.

CONCLUSIONS

The results of our test give evidence for decreased *efficiency* of map symbols that are partially occluded. Therefore, overlapping symbols should generally be avoided in cartography. On the other hand, our results suggest that symbols can be identified quite accurately when partially occluded. This means that valuable observations can be made on the basis of partially occluded symbols on maps intended for *geovisual analytics*. Therefore, instead of excluding some symbols from a map due to a lack of space, symbols in crowded locations can be arranged so that they partially overlap with one another.

The question of the *reasonable limit* for occlusion cannot be answered unambiguously on the basis of our test, since we did not reach an occlusion level where the effectiveness of the symbols dropped dramatically. Also, the map symbols' ability to tolerate occlusion depends on the visual variable used. *Surface-based* variables seem to outperform *contour-based* variables because the efficiency of color drops less than the efficiency of the shape variables when the symbols are half-occluded. Therefore, the maximum level of occlusion is also likely to be higher with surface-based variables than with contour-based variables. In our test, the symbols were identifiable at all tested occlusion levels. The most occluded level was 75 percent with color hue and 50 percent with abstract and pictographic shapes. These percentages are likely close to the usable maximums for each case with a symbol size of 4 mm. This result underpins the capacity of color as an efficient visual variable and suggests that it should be used in maps for geovisual analytics, where the map display tends to become crowded.

While the visual variable used seems to affect the efficiency of a map symbol when partially occluded, the complexity of the shape does not. Readers can identify an abstract shape more efficiently than a pictogram on a map containing several symbols regardless of whether or not the symbols are partially overlapping or totally visible; however, partial occlusion does not further weaken the efficiency of pictograms compared to abstract shapes. The efficient visual variable of color hue should be used in combination with pictograms to help readers access the information represented by the pictograms.

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