Evaluating the Effectiveness of different Cartographic Design Variants for influencing Route Choice

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Abstract

This paper addresses the suitability of different cartographic design variants for visually communicating *recommended* routes. We performed a user study, investigating the potential of six different design variants (*color hue*, *distortion*, *length distortion*, *size*, *spacing,* and *symbols*) for influencing route choice using cartographic visualization methods while recommending a longer, but less congested route. The visualizations for all design variants have been prepared in three different levels of intensity of modification (*weak*, *medium,* and *strong*). Although the input data (traffic density) is the same for all representation methods, variations are each visualized using different cartographic design principles. Our results showed that in general, for the majority of routing scenarios, the participants' route choice has been significantly influenced towards choosing the *recommended* route – indicating that the modification of route visualizations does actually lead to a different route choice behavior. Results further revealed that for most variants, willingness to choose the *recommended* route increases with higher intensity of modification. While some of the design variants like *symbols* or *length distortion* have been found effective for recommending routes at all levels of intensity, others like *size* and *spacing* have not been found suitable. A comparison between route choices and estimated route characteristics suggested a close relationship between willingness to choose the *recommended* route and the characteristics participants associate with the representation. In particular, route visualizations that create an impression of *faster*, *more convenient,* or *more fluent* travel experience are more likely to influence route choice behavior.

Keywords: cartographic design; cognitive perception; visual variables; route choice behavior; visual communication; usability

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Introduction

As traffic volumes increase, effective approaches for better distributing road traffic in urban environments are becoming increasingly important. It is of interest for traffic management to inform the road users about temporarily preferable route alternatives. There are different reasons for which a particular route could be recommended by traffic authorities, such as attempting to reduce overall congestion or intensive pollution of particular areas.

To counteract the problems regarding a non-optimal distribution of the road traffic, various approaches from different disciplines have been proposed. From the perspective of transportation planning, traffic management could simply limit the number of vehicles that pass along a road at a certain time. Other approaches for influencing the driver's route choice behavior proactively suggest variable message signs mounted above or beside the road for directly providing traffic information while driving on-route (Wardman et al., 1997), or in general to promote traveler information systems (Abdel-Aty et al., 1995). Different from these methods, in this paper, we describe an approach for influencing a road user's route choice, by visually recommending routes – based on digital, cartographic maps as used for routing services. This is particularly relevant since, in recent years, mobile navigation devices such as car navigation or phones are becoming increasingly important for route planning. Hence, a large number of route decisions are made based on the information provided by routing applications.

Studies regarding route choice behavior show that drivers tend to make a route decision for the individual benefit (Adoko et al., 2013; Ringhand & Vollrath, 2018), whereas drivers are only rarely aware of social aspects for maintaining the efficiency of a traffic system. Researchers discuss a wide range of route choice factors, which have a direct influence on traffic dynamics. These include factors like travel distance or the level of route complexity (Papinski et al., 2009; Ben-Elia & Avineri, 2015), whereas it is widely agreed that the travel time is one of the most important factors (Ben-Elia et al., 2013).

Current routing services usually propose different route options – visualized as colored lines on a metric base map, possibly with additional textual information. However, for successfully conveying the underlying information to the map-reader, maps require a careful and effective design that clearly expresses the map content as well as its message in a cognitively adequate and perceptually salient way (Griffin & Fabrikant, 2012; Otto et al., 2011). Small screen sizes of navigation devices, as well as limited time for decision making in driving situations further clarify the relevance of a distinct map design (Avelar & Hurni, 2006; Kubíček et al., 2017). Also, since traffic-related maps usually intend to address a wide range of user groups, map symbols need to be generally comprehensible.

Visual Communication using Graphical Variables

Cartographers use a large variety of visual means like symbols or colors to highlight relevant parts of a map while obscuring other parts. Bertin (1983) defined a set of fundamental graphical variables: *Position, size, shape, color hue, color value, orientation,* and *texture*. The most commonly used types of visual variables for representing linear features for route-based data are color hue, texture, and size (Bertin, 1983; Kubíček et al., 2017). Stachoň and collaborators (2013) argue that "color can be considered as the most expressive medium" (p. 217) of cartographic representations, however, due to established conventions in the use of color scales, sufficient hue and saturation needs to be selected carefully. The authors further suggest the size of map symbols, which also includes the width of linear features, as the second most important graphical variable. According to the researchers, map symbols with larger size and color that is more intensive are easier to identify in a map. Dong and collaborators (2012) further found that a variable size of linear features outperformed the use of color when communicating traffic maps.

Regarding the width (size) of a road segment, Kubíček and collaborators (2017) propose that a road, which is represented as wider on the map, might be assumed to have a larger road capacity in the actual road network. However, it could also represent a larger number of cars driving along the road (higher traffic volume). Successful decoding of such a visual metaphor is assumed essential for most effectively communicating traffic-related route information.

Goldsberry (2008) further investigated that the use of different visual variables for symbolization affects the perception of traffic maps. Despite violating conventional cartographic visualization rules, the author proposed an approach for using cultural metaphors like traffic lights, for enhancing the intuitiveness of the map representation. Results from this study indicate that the map-readers seemed to easily decode the meaning of the information associated with the symbology, despite the absence of a legend. For visually representing speed and depicting movement dynamics using line features, Lautenschütz (2012) proposed different potential visualizations, such as dot representations using variations in line spacing, line thickness, and color hue as perceptually salient features. The author concluded, “that the dispersion of points along the line and the shape of the representation influence [a map viewer’s interpretation of the presented] objects and their behaviour” (p. 347). Stachoň and collaborators (2013) suggest that using different types of map symbols will have a significant influence on their ability to decode the communicated information. Furthermore, differences in speed and interpretation correctness between people with different map use skills are expected.

Cartographic Generalization for communicating Route Recommendations

In addition to using graphical variables for symbolizing advisability of route options, we further propose that approaches using cartographic generalization techniques may serve as efficient methods for recommending routes. Findings from research in cognitive psychology indicate that people focus on individually perceived relevant information when communicating routes to others, while mentally abstracting the geographic space. Commonly observable characteristics of these *cognitive maps* (Tolman, 1948; Tversky, 1993) relate to cartographic generalization techniques, such as selections, distortions, or simplifications (Agrawala & Stolte, 2001; Downs & Stea, 1973). These characteristics imply that the perceived representation of the route may differ substantially from the actual shape (Skubic et al., 2004). But since for route choice, knowledge about the exact geometry of a road is not essential, an intuitive representation based on abstractions commonly applied in hand-drawn route maps is suggested to enhance overall route map usability (Agrawala & Stolte, 2001).

In practice, these geometric abstractions like the distortion of metric distances (Sadalla & Magel, 1980) are commonly applied in schematic maps such as subway maps to simplify the understanding of complex network structures and to support journey planning (Avelar & Hurni, 2006; Roberts et al., 2013). In the context of a road network, Golledge and Zannaras (1973) discussed that the actual travel time has a direct influence on the perceived traveled distance. In particular, this is suggested to be affected by the traffic dynamics (MacEachren, 1980; Saedi & Khademi, 2019). These findings indicate that preserving metric distances is not essential when visually communicating route information (Tversky & Lee, 1999).

The concepts from cognitive psychology research support our idea of using visual characteristics of different symbol types to communicate traffic dynamics. These types of visualizations are expected to symbolize the recommendation of a route in an intuitive way.

Current studies indicate that a behavior change is possible among road users – to reach a better distribution of road traffic (McCall et al., 2015). As Muehlenhaus (2012) has studied, the design of a map representation while influencing cognition can affect the map-reader's understanding of the map, as well as *persuade* the viewer to accept a specific interpretation of the information.

Previous work dealing with visual communication of spatial information using visual variables (Bertin, 1983; Tufte et al., 1990; Sester, 2002, Garlandini & Fabrikant, 2009) proposes different methods while focusing on investigating their effectiveness and usability for geographic information visualization. However, this work proposes and evaluates the effectiveness of different visual variables specifically for communicating route recommendations based on the current traffic dynamics, as well as their potential for influencing decision-making.

The objective of this work is to investigate the effectiveness of different visual variables for influencing route choice. Among other higher-level reasons, such as reducing air pollution or fuel consumption, congestion reduction is central to maintaining an efficient and safe transport system. In this paper, we exemplarily present an approach for recommending a longer, but less congested route to the map-reader, using cartographic visualization. This *recommended* route is not necessarily always the faster one, but rather the route, which contributes best to a more even distribution of traffic; and therefore benefits the whole traffic system. In our study, we compare a set of design variants, which use different cartographic visualization methods, regarding their effectiveness for visually recommending routes – using traffic density as a criterion to communicate routes to be preferred or to be avoided. The recommendation of particular route options using cartographic design variants is expected to affect route choice behavior. Furthermore, it is assumed that the different design variants contribute to a varying extent to the map-reader's ability to assess the characteristics that led to a route being recommended by the traffic management. The map-reader is expected to intuitively decide for the route that is visually communicated as the *recommended* route.

Method

We designed an experiment for assessing how different types of cartographic design variants of visual variables for recommending routes affect route choice behavior. For that, we created a set of 36 route maps of areas within 18 different German major cities of comparable size. Half of the maps represent the routing scenarios without any modification (*baseline* maps). The *baseline* visualization consists of a map extract showing the two route suggestions of slightly different lengths in a neutral way, as well as a base map for providing a general spatial orientation to the map-reader. Additionally, the start and end points are highlighted using unambiguous icons. To facilitate map-reading, we further use familiar, intuitive visualizations of map background information (like the land use or place names), as commonly used for routing services. For all *baseline* maps, we used a solid, blue-colored (#2800ba) line with a width of 0.8. An example of a *baseline* map is provided in Figure 1.

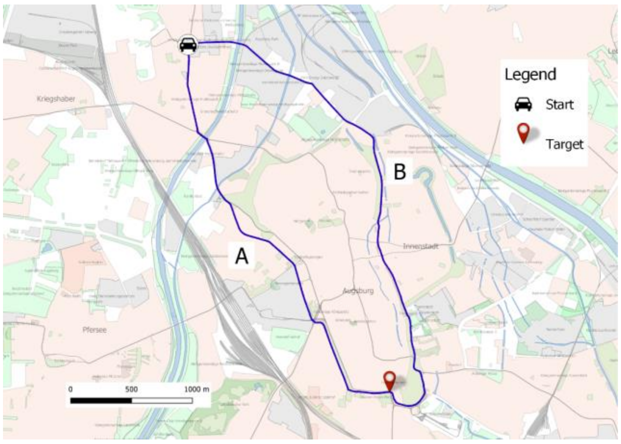

Figure 1. Example of a *baseline* map as used for the experiment (corresponds to the modified map using *distortion* in Figure 2). Route A is slightly shorter than Route B.

The remaining 18 maps represent the same routing scenarios by modifying the visualization using different design variants (*modified* maps). Hence, for each city, there is a *baseline* map and a *modified* map of the same area using one of the cartographic design variants. The modification aims at preferring one route to the other using different cartographic design variants.

Since most of the larger German cities include historically grown, unique urban structures, we allow for differences in the general layout of a city. This larger variety of study areas intends to reduce the influence of familiarity with a city's road network. Additionally, based on the study design, the aim is to direct the focus to the comparison of the two route options, rather than the fact that different visualization techniques have been applied. Each map includes two routes (A and B), which do not intersect each other and both share the same start and end point. One of the routes is always slightly longer than the other route. The percentage of the length of the shorter route in relation to the longer route is always in the range between 80 – 90 %. In the experiment, we focus on a morning-rush-hour scenario, in which the shorter route is affected by a temporary disturbance – resulting in the longer route to be the preferable choice for achieving system-wide traffic efficiency. Therefore, the objective of the modification is to nudge users towards choosing the longer route. While the different design variants visualize this temporary change in traffic density in different ways, the temporarily preferable route is always aimed to be recommended as a result of the modification.

For the 18 *baseline* visualizations (without providing visual information about traffic levels), the majority of map-readers is assumed to decide for the shorter route, since, based on the visualization, there is no explicit hint that the other route might be the more reasonable option. For the *modified* visualizations, however, it is assumed that map-readers are more often willing to decide for the longer route, since, based on the visualization, there are hints that the longer route might be temporarily preferable.

Design Variants

For communicating the traffic-related information to the map-reader, six different design variants are compared exemplarily: a) *color hue*, b) *spacing*, c) *size*, d) graphical *symbols*, e) *length distortion*, and f) line simplification /-distortion *(distortion)*.

While the first four design variants address the symbology level, the design variants *length distortion* and *distortion* have been developed as new approaches for communicating route information, using cartographic generalization techniques (Fuest & Sester, 2019).

The six proposed design variants are informationally equivalent, which means that they visualize the same traffic density information associated with the routes (Fabrikant et al., 2010). However, for each design variant, the visual characteristics for representing temporarily preferable (low traffic density) or non-preferable (high traffic density) route options differ. Table 1 summarizes the visual metaphors for communicating low and high traffic densities for our six different design variants.

Design variant	Visual metaphor	
	Low traffic density	High traffic density
color hue	Green color hue	Red color hue
spacing	Short gaps between dashes	Long gaps between dashes
size	Wide line (much capacity)	Narrow line (little capacity)
symbols	Small amount (car symbols)	Large amount (car symbols)
length distortion	Visually shorter route	Visually longer route
distortion	Simplified line	More complex (distorted) line

Table 1. Visual metaphors for communicating traffic densities using different design variants.

Although the original geometry has been modified for some of the design variants, for all map representations, the topological relations between map elements are retained. Figure 2 shows the map representations of all design variants, using *strong* intensities of modification. For all map representations, Route B is recommended as the temporarily more advisable route option.

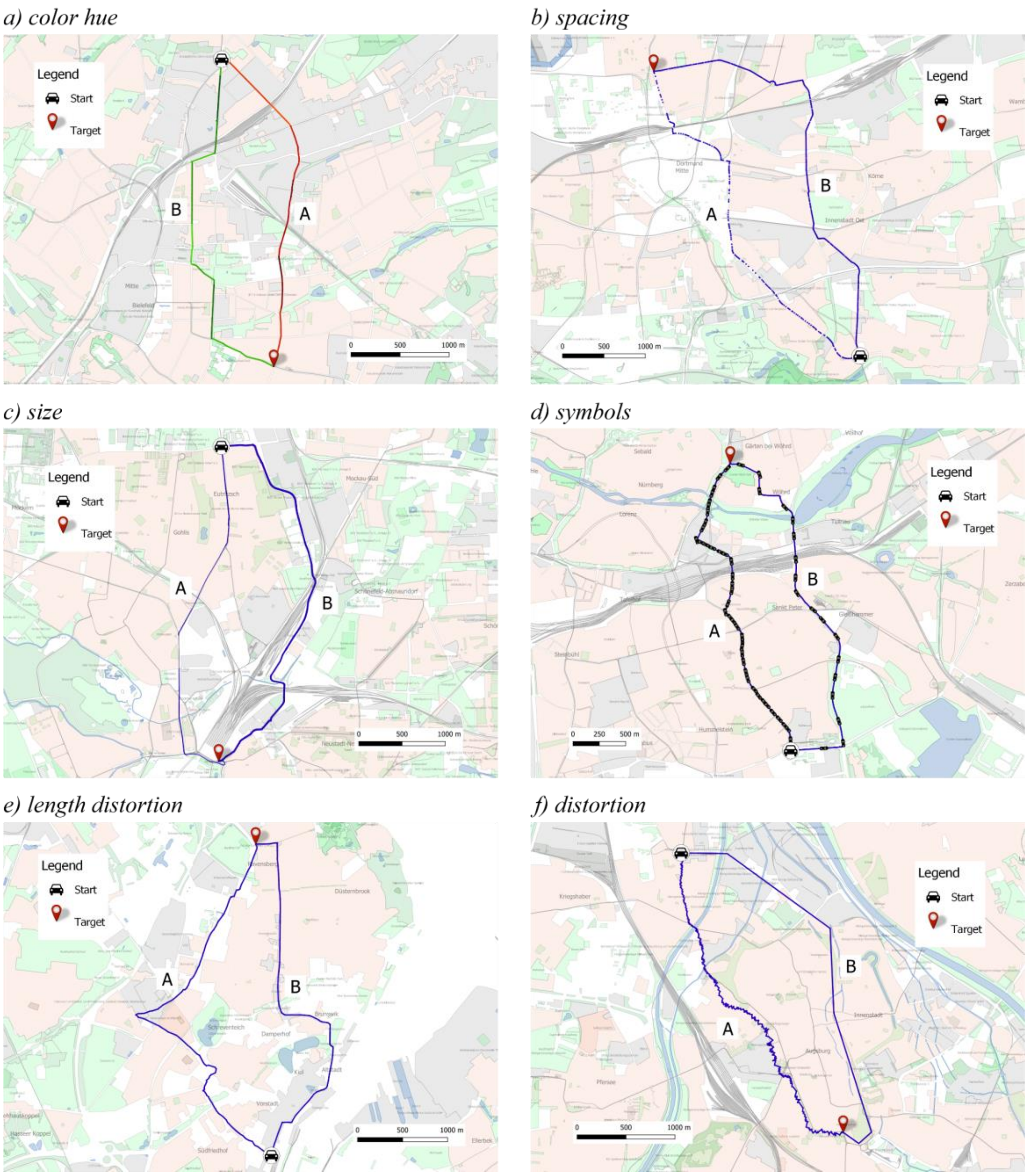

Figure 2. Sample maps showing the six different design variants, as applied to route visualization. a) color hue, b) spacing, c) size, d) symbols, e) length distortion, f) distortion.

While the design variant “color” is commonly classified into the different dimensions “hue”, “lightness” and “saturation”, we decided to only test *color hue* using a red-green color scale as a design variant, since this type of color scale is very commonly and frequently used for communicating traffic in some of the prevalent routing services.

Calculation of Graphical Differences among Design Variants and Modification Intensities

In this paper, we use traffic density as a factor, which serves as a basis for visually communicating route recommendations – represented by visual variations. The visualizations are automatically created based on the traffic density associated with road segments. Since this data can vary over time, it directly affects the visual appearance of the routes based on the visual variable used.

For all routing scenarios in the 18 different cities, we simulated the same distribution pattern of traffic density. For that, we divided the two routes A and B into logical sub-sections (primarily split at important intersections along the route), while allowing variability in length due to differences in the road network structure. For further calculations, we use the ratio *r* of traffic density and average traffic density of a road segment *s*, defined as:

$$r = \frac{dens\ (s)}{ø\ dens\ (s)}$$

The traffic density value ($dens\ (s)$) describes the current, temporary traffic density, while the average traffic density ($ø\ dens\ (s)$) refers to the typical traffic density for the same segment at the corresponding time of day. Figure 3 shows the distribution pattern of the traffic density ratio on a sample pair of routes from our study. All road segments from the left route have a traffic density ratio $r > 1$, relating to an increased traffic density, whereas the segments from the right route correspond to a decreased traffic density ($r < 1$).

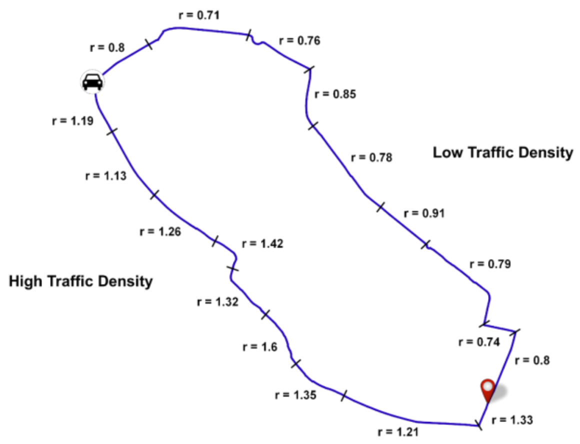

Figure 3. Distribution pattern of the traffic density ratio as used for the user study.

The factors used for the different visualizations all depend on the value *r* and additionally on a weight *w* when using a modification intensity that deviates from the *medium* intensity. The parameters for appropriately calculating the factors have been derived by first determining the visual characteristics for each design variant, which should be varied depending on the traffic density; and subsequently performing visual experiments for determining an appropriate value range.

To determine a suitable way for visualizing traffic information for influencing route choice, we compare the effectiveness of three levels of intensity for the visualization: 1) *weak* (expected lower boundary), 2) *medium* and 3) *strong* (expected upper boundary). Each design variant is represented once using each level of intensity.

For the *medium* intensity, the visualizations are always based on the original traffic density distributions, indicating an objectively perceived, appropriate representation of the traffic-related information. While the *weak* intensity of modification reduces the visualized differences in traffic density distributions to provide a more subtle representation of the information, the *strong* intensity increases these differences towards a more protruding representation. Importantly, these three tested levels of intensity for modification could be extended by an infinite number of intensities between them.

Table 2 provides details regarding the graphical differences concerning the different intensity levels for modifying the maps. As an example, we specify how three different values for the traffic density ratio (*r*) affect the calculation and representation of the visual characteristics of each design variant. In particular, for this study, the calculation of visual characteristics has been adapted to a limited value range: $0 \leq r < 2$.

Design variant	Density ratio (r)	Intensity		
		weak	***medium***	***strong***
color hue	0.5	green - yellow	green	dark green
Variation: Color hue (hex code)	1	yellow	yellow	yellow
	1.5	orange	red	dark red
spacing	0.5	0.75	0.5	0.25
Dash length = 1 mm (fixed)	1	1	1	1
Variation: Length of blank space between dashes (mm)	1.5	1.25	1.5	1.75
size	0.5	1	1.2	1.4
Variation: Width of line (mm)	1	0.8	0.8	0.8
	1.5	0.6	0.4	0.2
symbols	0.5	1 / 125	1 / 150	1 / 175
Variation: Number of symbols to place on the line (symbols/meters)	1	1 / 100	1 / 100	1 / 100
	1.5	1 / 75	1 / 50	1 / 25
length distortion	0.5	0.75	0.5	0.25
Variation: *enlarge* factor for scaling objects	1	1	1	1
	1.5	1.25	1.5	1.75
distortion	0.5	5	10	15
$r < 1$: Removing points from line (line simplification)	1		no change	
Variation: Threshold for simplification (*epsilon*) in meters	1.5	5	10	15
$r > 1$: Adding points to line (line distortion)				
Variation: Distance (d) between line and new point in meters				

Table 2: Graphical differences (values for variation) between the six design variants among the intensity levels *medium*, *weak*, and *strong*.

It is important to note that particularly for the design variants that use geometric distortions (*length distortion* and *distortion*), the parameters for calculating the modifications also depend on the geometry of line segments – such as taking the length of line segments into account as part of the calculation.

Figure 4 depicts the graphical differences between the three different levels of intensity for modification using a sample pair of routes. Route B indicates the *recommended* route.

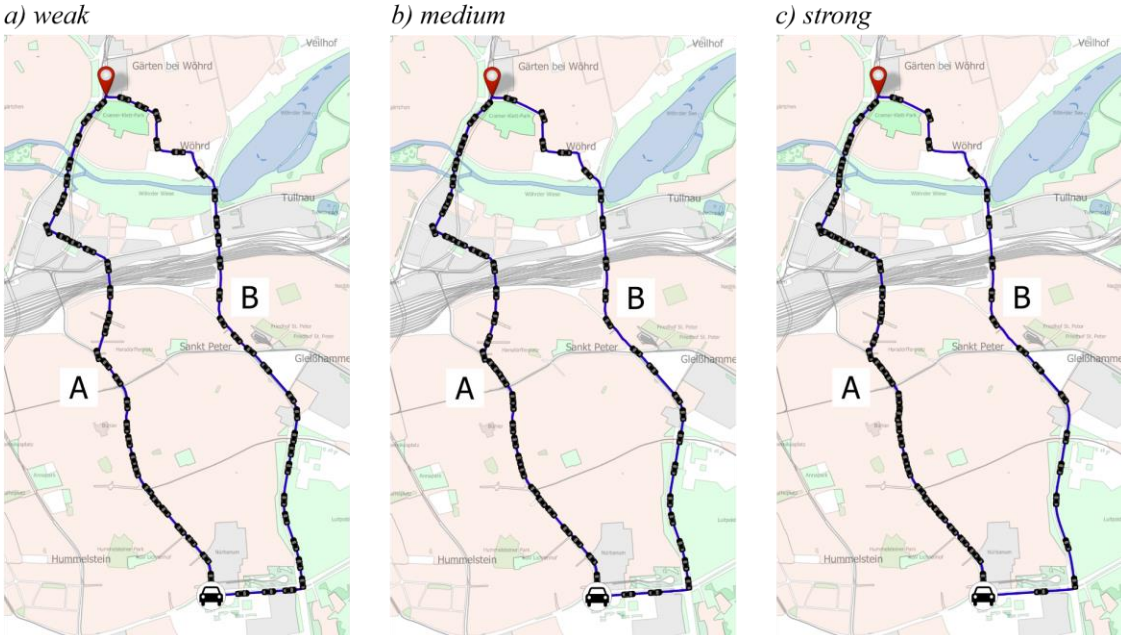

Figure 4. Comparison of the graphical differences between the three levels of intensity (design variant *symbols*): The ratio of the number of car symbols between both routes varies depending on the intensity of modification. Levels of intensity: a) weak, b) medium, c) strong.

Participants

In total, 151 participants completed our study (80 females, 70 males, 1 diverse). The participants range in age from 18 to 57 years (M = 26.20, SD = 6.49). Participants were recruited by inviting students and staff members of different institutes at the authors' universities, as well as persons from various non-scientific backgrounds, to obtain a more diverse sample than would typically be achieved by studying only university students. Since the study has been prepared in German language, all participants were German residents.

In terms of driving experience, 91.4 % of all participants indicated that they own a driver's license, while on average they received the license 9.1 years ago (SD = 6.39).

Furthermore, participants drive on average 5199.15 kilometers per year (*SD* = 6481. 58), ranging from 0 to 30000 kilometers per year.

96.7 % of the test persons had no visual impairment, 46.4 % of them using a visual aid.

Procedure

The user study has been designed as an online experiment. Using a within-subject design, each participant made a route choice decision for each map right after shortly observing it, whereas the time for viewing each map has not been limited. Maps were shown – one after the other – in a randomized order.

For the decision between route A and B, we placed a slider below each map, providing five steps (5-point Likert scale): 1) *Definitely A*, 2) *Rather A*, 3) *No preference*, 4) *Rather B*, and 5) *Definitely B*. That is to not only obtain a route decision in a "yes/no" format but also to obtain information on the degree of approval or disapproval regarding the routes. The route denoted as "Route A" marks the left side of the slider, while "Route B" marks the right side. In 11 of the cases, the longer, but *recommended* route was denoted as "Route B", in seven cases as "Route A". We recoded the resulting values during analysis so that a higher value for route choice always relates to choosing the *recommended* route in the *modified* maps. Maps were presented in full-screen size to ensure better visibility of details.

For the next set of tasks, participants have been presented the *baseline* and the *modified* visualization for the same routing scenario side by side – and were asked to name characteristics of the visually *recommended* route. This task has been prepared once for the six different design variants (presenting the version using the *strong* intensity of modification) and displayed in random order for each participant. The task was defined as follows: "As you see, we have modified the routes. How has the relationship between the routes changed? Route A [or B] now appears to be …" A checklist of six options regarding the characteristics of the route (*faster, more direct, shorter, more comfortable* to drive, *more fluent* to drive or *none of this*) as well as an option for a free text box followed these instructions. The participant was asked to select at least one of the options, however, multiple responses were also allowed.

After completing the tasks, the participants were asked to assess their map use habits and experiences. In particular, they were asked to assign themselves to one of the following five categories (coding scheme in parentheses), as described in Lai and Yeh (2004): “Competent” (0), “comfortable” (1), “occasional” (2) or “inexperienced” (3) map users, as well as “outsiders” (4), who “have not used a map on [their] own” (p. 231). In the experiment task, participants only saw a one-sentence statement for each category, describing the level of expertise in map usage. The experiment concluded with a questionnaire on demographic information with a focus on the driving experience.

Results

The results of this study were analyzed regarding the effectiveness of the six different proposed design variants for visually communicating *recommended* routes.

In the following, we always refer to the *recommended* route as the temporarily preferable route in the *modified* representations. Due to the temporary change in traffic density, we intend to visually communicate this change using the different design variants.

The results for the route choice did not always follow a normal distribution, particularly for the *modified* visualizations. That is because generally very few participants chose the *no preference* option located in the middle of the rating scale, but rather decided for one of the two route options.

Influencing Route Choice

We first observed for each of the design variants the differences between the route choices made for both the *baseline* scenario as well as for the *modified* scenario. Table 3 shows how the mean values for route choice differ for the individual design variants between the *baseline (base.)* visualization and the *modified (mod.)* visualization of the same routing scenario. A routing scenario includes both the *baseline* and the *modified* maps for the same study area.

Design variant	Intensity														
	weak					medium					strong				
	base.	*mod.*	*z*	*p*	*r*	*base.*	*mod.*	*z*	*p*	*r*	*base.*	*mod.*	*z*	*p*	*r*
color hue	2.03	2.97	-7.4	.0*	**.43**	2.6	3.11	-4.22	.0*	**.24**	2.16	2.91	-6.08	.0*	**.35**
distortion	3.87	4.03	-1.96	.05	**.11**	3.29	3.71	-3.88	.0*	**.22**	2.15	3.8	-8.86	.0*	**.51**
length distortion	2.95	3.52	-4.7	.0*	**.27**	1.97	3.71	-9.71	.0*	**.56**	1.81	3.66	-10.13	.0*	**.58**
spacing	3.30	3.23	-0.92	.36	.05	1.82	2.25	-4.09	.0*	**.24**	2.66	3.22	-4.52	.0*	**.26**
size	3.38	3.42	-0.38	.7	.02	2.42	2.56	-1.64	.1	.09	1.98	2.28	-3.61	.0*	**.21**
symbols	2.77	3.34	-4.96	.0*	**.29**	2.6	3.62	-7.05	.0*	**.41**	2.59	4.11	-9.2	.0*	**.53**

Table 3. Mean values for route choice between the groups *baseline (base.)* and *modification (mod.)* and statistics for the Wilcoxon test results (z- score and p), n = 151, $^*p < .05$. Wilcoxon effect size (r) (Cohen, 1988): **small effect**: $0.1 \leq r < 0.3$; **medium effect**: $0.3 \leq r < 0.5$; **large effect**: $r \geq 0.5$.

In general, we can observe that for the majority of routing scenarios there is a shift from choosing the shorter route in the *baseline* maps (lower mean values), towards choosing the *recommended*, but longer route in the *modified* visualizations (higher mean values), indicating that the modification of route visualizations does actually lead to a different route choice behavior.

Using a Wilcoxon test, the difference between the route choices made for the *baseline* and the *modified* visualization has been found significant for most of the routing scenarios (see Table 3), except for *distortion* with *weak* intensity, *size* with *weak* intensity, *size* with *medium* intensity and *spacing* with *weak* intensity. These results indicate that for 14 out of the 18 routing scenarios, the applied visual modifications have a significant effect on route choice behavior (in favor of the *recommended* route). In particular, four of the scenarios (*distortion* with *strong intensity*, *length distortion* with *medium* and *strong* intensity, and *symbols* with *strong intensity*) evoke a large effect for influencing the map-reader's route choice based on the applied visual modifications. The larger the effect, the more likely the map-reader would choose the *recommended* route.

For further analysis, we calculated the differences between the values describing the route choices for the *modified* visualizations and the corresponding *baseline* visualizations as a new variable, by subtracting the values for the *baseline* visualizations from those for the *modified* visualizations. This variable differs from the previously described *route choice* variable (categorical), since it is a metric variable describing the *change* between the route decision made for the *baseline* map and the *modified* map of the same routing scenario. The analysis of this calculated variable also intends to reduce influences caused by some road-network based factors (between the different routing scenarios), which may lead to route choices being always more in favor of the *recommended* or the *non-recommended* route. These *difference* values indicate to which extent the participants changed their route choices in favor of the longer, but visually *recommended* route when presenting the *modified* visualizations. We suggest that the values for this *difference* serve as an indicator for the effect of visualization on route choice behavior – more specifically the willingness to decide for the *recommended* route.

Figure 5 shows for each of the six design variants the mean values of the *difference* variable including error bars for the *standard error*. The visualization illustrates how the willingness to decide for the *recommended* route varies based on the intensity of modification in the visualization. For most of the design variants, we can observe an increase, indicating that participants were more willing to decide for the *recommended* route if the routes have been visualized using a higher intensity of modification. An exception, however, is the design variant *color hue*, for which the *weak* intensity seems most effective. While design variants like *length distortion* or using *symbols* generally seem to influence route choice behavior at different levels of modification intensity, other variants like *size* or *spacing* only have a weak effect on the participants' route decisions. In the case of modifying the routes using *spacing* with *weak* intensity, the route decisions are on average even slightly more in favor of the *non-recommended* route (negative *difference* value).

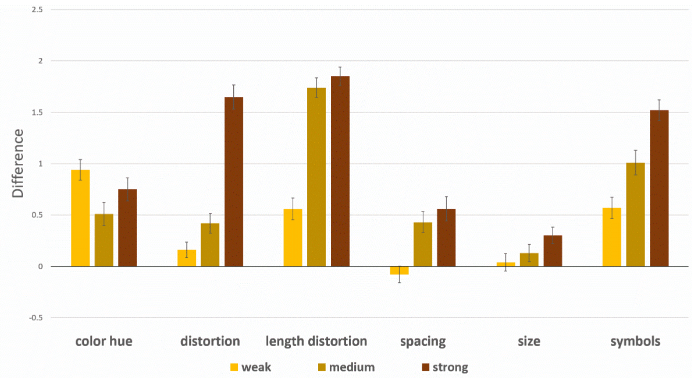

Figure 5. Willingness to decide for the *recommended* route, *difference* values can range from -4 to 4, n = 151.

To investigate the influence of the type of design variant, the intensity of modification, as well as the interaction of both factors, on route choice behavior, we performed a repeated-measures ANOVA. Results reveal a significant main effect for the type of design variant, $F_{(5, 750)} = 50.87$, $p < .001$, $\eta^2 = 0.253$. Similarly, the differences between the three levels of intensity for modifying the visualizations has been found significant: $F_{(2, 300)} = 101.16$, $p < .001$, $\eta^2 = 0.403$. Using a Greenhouse-Geisser correction, we further found a significant interaction effect, indicating that for the different design variants, route choice behavior differs depending on the level of intensity of modification, $F_{(9.06, 1358.54)} = 19.13$, $p < .001$, $\eta^2 = 0.113$. A post-hoc t-test using a Bonferroni correction further emphasizes a different influence of the six design variants on route choice. Table 4 shows that for all pairs of design variants except *color hue* and *distortion*, as well as *spacing* and *size*, the willingness to decide for the *recommended* route differs significantly.

Design variant	*color hue*		*distortion*		*length distortion*		*spacing*		*size*		*symbols*	
	t	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*	*t*	*p*
color hue	-	-	-.09	.93	-6.89	.0*	4.45	.0*	6.31	.0*	-2.95	.0*
distortion	-.09	.93	-	-	-7.58	.0*	5.29	.0*	-7.31	.0*	-3.18	.0*
length distortion	-6.89	.0*	-7.58	.0*	-	-	-12.63	.0*	-15.53	.0*	3.51	.0*
spacing	4.45	.0*	5.29	.0*	-12.63	.0*	-	-	-1.9	.06	-8	.0*
size	6.31	.0*	-7.31	.0*	-15.53	.0*	-1.9	.06	-	-	-9.74	.0*
symbols	-2.95	.0*	-3.18	.0*	3.51	.0*	-8	.0*	-9.74	.0*	-	-

Table 4. Pairwise comparison (Post-hoc t-test) between the six different design variants, $n = 151$, $^{*}p < .05$.

Decision Time

In addition to investigating the participants' route choice preferences, we further measured the time (in seconds) it took the participants to make each of their decisions. Due to the experimental setup, it was not possible to monitor the participants' activities during the experiment. We found a small number of extreme values that are most likely the result of external disruptions or longer interruptions of the experimental procedure by the participant. These arbitrary interruptions are not necessarily related to the concerned route choice scenario. Extreme values larger than 60 (seconds) for a route decision have been defined as outliers and were excluded from further analysis. On average this applies to 3.9 % of all cases for the different routing scenarios.

For investigating the relationship between the time needed to decide for a route when viewing either the *baseline* or the *modified* visualization of the same routing scenario, we conducted paired t-tests. These tests (see Table 5) revealed that for six of the 18 routing scenarios, participants needed significantly more time when viewing a modified visualization. In four of these cases, this applies to the *strong* intensity of modification.

Design variant	Intensity											
	weak				*medium*				*strong*			
	base.	*mod.*	*t*	*p*	*base.*	*mod.*	*t*	*p*	*base.*	*mod.*	*t*	*p*
color hue	11.97	13.84	-2.29	.02*	13.59	15.17	-1.39	.17	12.04	15.03	- 3.21	.0*
distortion	14.54	13.42	.94	.35	13.91	13.42	.82	.41	12.48	14.47	-2.27	.03*
length distortion	14.19	14.6	-.39	.7	14.48	15.93	-1.94	.05	12.39	15.15	-3.57	.0*
spacing	12.54	14.41	-1.84	.07	11.01	13.69	-4.13	.0*	13.25	15.08	-1.9	.06
size	12.76	12.71	-.12	.91	14.39	14.20	-.1	.92	13.15	15	-2.11	.04*
symbols	13.34	13.55	-.67	.5	13.17	14.24	-1.65	.1	13.42	14.43	-1.28	.2

Table 5. Mean values (time in seconds) for the *baseline (base.)* and *modified (mod.)* visualizations and t-test results, n =138, * p < .05.

Similar to our analysis on route choice, we further calculated the difference between the time needed to make the decision when viewing the *baseline* and the *modified* visualizations – by subtracting the time values of the baseline visualizations from those of the modified visualizations. This difference indicates the influence of modification on the time needed to make the decision.

In Figure 6 we can see for each routing scenario the mean value of the difference between the time needed for the route decision (including error bars for the *standard error*) when using the *baseline* or the *modified* map. The illustration further clarifies that for most of the routing scenarios participants needed more time for making their decision when viewing a modified visualization (positive difference value).

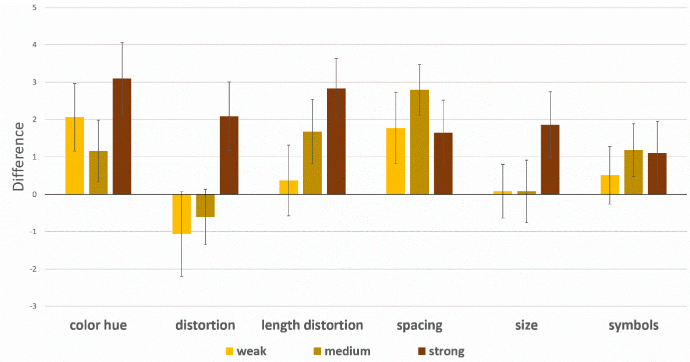

Figure 6: Decision time for route choice: Difference (in seconds) between *baseline* and *modified*, *n* = 138.

We performed a repeated-measures ANOVA to investigate a potential influence of the type of design variant, as well as the intensity of modification, on the time needed to make a route decision. Using a Greenhouse-Geisser correction, results reveal a significant main effect for the intensity of modification, $F_{(1.86,\ 171.21)} = 5.\ 72$, $p < .01$. This indicates that participants needed more time for their route decision (as compared to the corresponding baseline map) if the map has been modified with a higher intensity. However, for the type of design variant, there was no statistically significant difference, $F_{(4.43,\ 407.48)} = 1.63$, $p = .16$. Regarding the effect size, we found that the intensity of modification ($\eta^2 = 0.058$) only has a small effect on the time required for route decisions (Cohen, 1988).

To examine a possible relation between route choice and the time needed for making the decision, we correlated the difference values for both variables for each of the routing scenarios. In most cases, the tested relations have not been found significant – indicating that the route choice in favor of the *recommended* route does not depend on the time required for making the decision. For two of the routing scenarios, however, there was a negative correlation: *Distortion* with *strong* intensity ($r = -.22$, $p < .01$) and *color hue* with *strong* intensity ($r = -.212$, $p < .05$). This indicates that participants who were more willing to decide for the *recommended* route in the modified maps, on average needed less time to make their decision. In contrast, participants who were less willing to decide for the *recommended* route took more time for their decisions.

Route Characteristics

In addition to the results for route choice, we further analyzed the characteristics of the route visualizations, which the participants associate with the different design variants. Although the six different design variants represent the same information about traffic density, the visual variations are assumed to evoke associations with different possible characteristics of the actual route. The associations with the route characteristics are expected to vary among visual variables, due to the use of different visual metaphors.

Table 6 summarizes for each design variant the percentage (%) of how many participants associate the different characteristics with the presented route visualization. For each variant, the characteristic that has the highest percentage has been underlined. Furthermore, all characteristics that have been selected by at least 1/3 of all participants are printed bold. These characteristics can be considered as *important* regarding the visual impression of route maps designed using the specific design variant.

Design variant	Route characteristic						
	faster	*more direct*	*shorter*	*more convenient*	*more fluent*	*none*	*other characteristic*
color hue	<u>**48**</u>	5	4	28	**40**	28	15
distortion	**40**	**38**	17	<u>**57**</u>	**42**	12	8
length distortion	27	**50**	<u>**54**</u>	17	11	14	3
spacing	17	9	2	25	<u>**40**</u>	<u>**40**</u>	10
size	13	6	1	16	18	<u>**60**</u>	15
symbols	**60**	3	4	**42**	<u>**65**</u>	19	9

Table 6. Estimated route characteristics by the participants in percent (100 % = all participants evaluate the characteristic as applicable), n = 151.

Routes, which have been visually recommended using the design variant *color hue*, predominantly seem to be *faster*, *more fluent,* or *more convenient* to drive at. Since we did not make any geometrical changes for this design variant, it makes sense that very few participants judged the routes as being more direct or shorter. Also, a considerable number of participants did not agree with any of the options. This may serve as an indicator, to which extent a visual metaphor has been successfully applied for influencing route choice. For *distortion*, the simplification of the route's geometry for the *recommended* route may have led to the driving experience being expected as *more convenient, more direct, faster,* and *more fluent*. Very similar characteristics (except directness) have been associated with the representation using *symbols*. Obviously, for the design variant *length distortion*, the modified routes are associated as being *shorter* and *more direct*, since due to the geometric modifications resulting from this cartographic generalization method, they actually are.

Interestingly, for the visualization, which uses *size* for recommending routes, in most cases, participants decided for the *none of this* option. A similar pattern is observable for the *spacing* variant. This may indicate (together with the results for route choice) that the decoding of the visual metaphor did not work as expected for these design variants, while their suitability for influencing route choice might be limited.

We further assume that there is a relation between the participant's route choice and the estimations regarding route characteristics for the *recommended* route, indicating that participants who decided for the *recommended* route, on average rather agreed to the route characteristic; and similarly, participants who decided for the *non-recommended* route rather disagreed to the route characteristic. To investigate this relation, we performed chi-squared tests for the relations between the route choice (*strong* intensity of modification as used for the task) and the participant's estimation regarding route characteristics. In particular, an expected relation may occur, if there are high values for route choice (participant decided for the *recommended* route) and a value '1' for the characteristic (approval for the characteristic); similarly, low values for route choice, in combination with the value '0' (disapproval) for the characteristic.

Figure 7 shows a heatmap with the Pearson chi-square values for the relations between the six design variants and the route characteristics. Values marked in dark orange indicate a strong relation, whereas values marked in lighter orange indicate a lower relation.

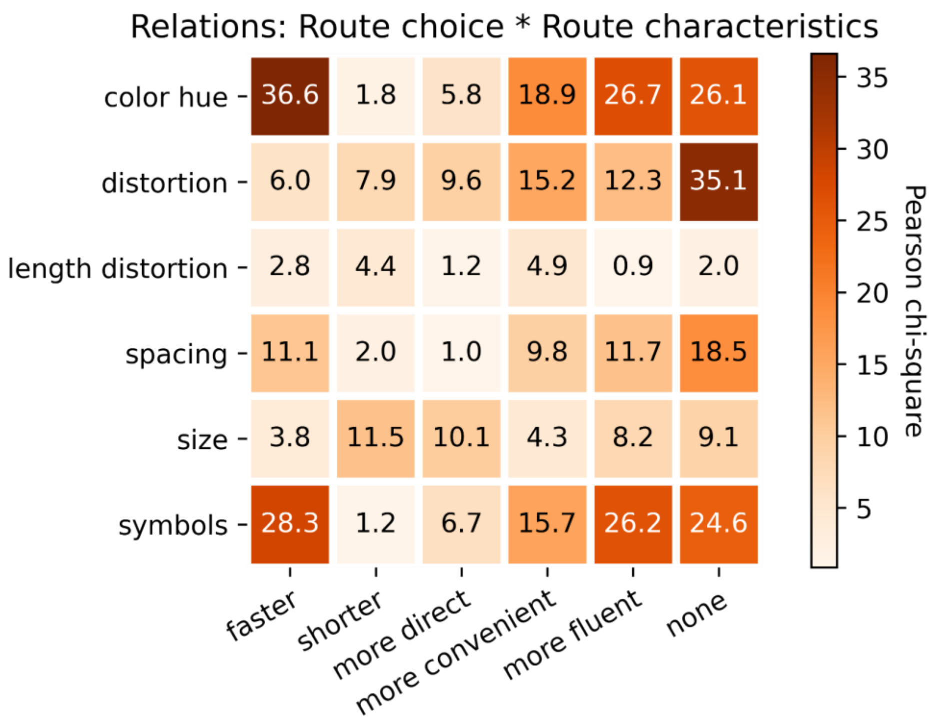

Figure 7. Heatmap showing the relations between the route choices (design variants) and the route characteristics.

Route decisions for the design variant using *color hue* were strongly related to estimating the *recommended* route as *faster*, $\chi^2_{(4)} = 36.62$, $p < .001$, *more convenient*, $\chi^2_{(4)} = 18.92$, $p < .01$, $p < .001$, *more fluent*, $\chi^2_{(4)} = 26.71$, $p < .001$, and *none of this*, $\chi^2_{(4)} = 26.06$, $p < .001$.

Similarly, route decisions for the design variant using *distortion* were strongly related to estimating the *recommended* route as *more convenient*, $\chi^2_{(4)} = 15.18$, $p < .01$, and *none of this*, $\chi^2_{(4)} = 35.14$, $p < .001$. Further significant relations have been found with estimating the *recommended* route as *more direct*, $\chi^2_{(4)} = 9.63$, $p < .05$, and *more fluent*, $\chi^2_{(4)} = 12.28$, $p < .05$. Interestingly, the chi-squared test revealed that route choices for the variant using *length distortion* were not significantly related to any of the route characteristics. Route decisions for the design variant using *spacing* were related to estimating the *recommended* route as *more convenient*, $\chi^2_{(4)} = 9.77$, $p < .05$, *more fluent*, $\chi^2_{(4)} = 11.72$, $p < .05$, and *none of this*, $\chi^2_{(4)} = 18.53$, $p < .01$. Furthermore, there was a relation with the estimation *faster*, $\chi^2_{(4)} = 11.09$, $p < .05$. Route decisions for the design variant using *size* have been found related to estimating the *recommended* route as *more direct*, $\chi^2_{(4)} = 10.09$, $p < .05$., whereas route decisions for the design variant using *symbols* were strongly related to estimating the *recommended* route as *faster*, $\chi^2_{(4)} = 28.34$, $p < .001$, *more convenient*, $\chi^2_{(4)} = 15.71$, $p < .01$, *more fluent*, $\chi^2_{(4)} = 26.23$, $p < .001$, and *none of this*, $\chi^2_{(4)} = 24.56$, $p < .001$.

For design variants for which the *recommended* route has been chosen less often (e.g. *spacing, size*), it was observed that most of the characteristics have not been rated high.

Map Use Habits

For investigating a potential influence of map use habits on route choice behavior when using our map representations, we asked participants to assess their map use habits and experiences. Using the map use habits as a between-subject variable in a repeated-measures ANOVA, there was no significant influence observable, $F_{(4,\,127)} = .51$, $p > .05$. This indicates that the effects, which the different types of route visualizations seem to have on route choice behavior, do not differ significantly based on the level of experience in map reading.

Discussion

This study investigated the effectiveness of different cartographic design variants of visual variables for influencing route choice. In this section, we further discuss the results while focusing on the effectiveness for influencing route choice, the relation between route choice and estimated route characteristics based on the visualizations, as well as the transferability of our findings to real-world applications.

Effectiveness for influencing Route Choice Behavior

The results from our user study reveal that the six different design variants have a significantly different influence on route choice behavior, depending on the level of intensity for modification. In particular, comparing the results for the effectiveness of the different design variants, our findings show that it is possible to influence people's route choice behavior, by visually communicating temporarily preferable route options.

Some of the design variants like *length distortion* or using *symbols* seem to be generally effective for visually communicating *recommended* routes since they influence route choice behavior at different levels of modification intensity. However, other design variants like *size* or *spacing* do not seem to have a significant impact on the participants' route decisions. This is particularly interesting since previous studies (Dong et al., 2012; Goldsberry, 2008; Lautenschütz, 2012; Kubíček et al., 2017) suggest that these representation methods could be efficient for communicating traffic-related information. However, it seems that their potential for influencing route choice behavior is limited.

Modifying the routes using *distortion* further seems to work only if the intensity of modification is applied to a stronger degree. For the design variant *length distortion*, it seems that using the *medium* intensity is already sufficient for influencing the map-reader's route choice because the difference value for *strong* intensity only slightly exceeds the value for *medium* intensity. A reason for this might be the ‘obviousness’ of visual recommendation, due to the path being represented as geometrically shorter. Once the length ratio between the two routes exceeds a certain threshold, the (in the *modified* version) shorter route may already be perceived as the preferable one.

Different from the other design variants, for modifications using the visual variable *color hue*, the willingness to decide for the *recommended* route did not increase with the intensity of modification. In contrast, the representation with *weak* intensity seems most effective. This deviation from the trend suggests that the meaning of the used color scales may not be easy to grasp at first glance. With regard to *color hue* being generally estimated as an efficient visual variable for communicating traffic dynamics (Lautenschütz, 2012; Nelson, 2000), it is assumed that the representation using a continuous color scale (also for the road segments with low traffic density), might have confused some of the participants. That is assumed to be due to their familiarity with prevalent routing applications that show a classed visualization of road congestion, where uncongested roads are assigned only one color hue, which is typically green (Goldsberry, 2008; Lai & Yeh, 2004). Since we did not specifically control for color vision impairments, it might further be possible that individual differences in color vision contributed to some extent to these unusual findings.

Although we expected the *strong* intensity of modification to be representing the upper limit, describing up to which a visualization would be still accepted, while being suitable for visually communicating *recommended* routes, it turned out that there is a trend that the suitability increases with the level of intensity for modification. This raises the question, if even stronger levels of modification (resulting in more extreme use of visual variables) may result in an even higher willingness to choose the *recommended* route. Since we did not investigate the acceptability of these to some extent uncommon visualizations in this study, we intend to address this problem (Muehlenhaus, 2012) in follow-up studies, using different types of cartographic design variants.

While the 18 different routing scenarios in different cities were selected based on similar characteristics of the surrounding road network, it was unavoidable that the environments differ regarding characteristics like the density of the built environment, significant curves in the route layout, the number of crossings or the closeness to the city center. Therefore, we need to assume that the route decision is to some extent also influenced by these additional factors, and not solely based on the modifications applied for the different design variants. This may also be the reason, why for some scenarios, the route decision was for both the *baseline* and the *modified* maps either more in favor of the *recommended* or the *non-recommended* route. However, we were primarily interested in comparing the *difference* values among the different conditions (the difference between route decision for *baseline map* and *modified* map of the same routing scenario) as a measure for the willingness to decide for the *recommended* route, and less in the absolute results for route choice. Therefore, the analyzed data is suggested to be sufficient for measuring the influence of different cartographic design variants on route choice behavior.

The Role of Time during Decision Making

As our results indicate, for most of the routing scenarios, participants needed more time to make their route decision when being presented a modified map representation as compared to the baseline representation. This result is not surprising, since the complexity of information presented, and therefore also the expected cognitive load is higher concerning the modified maps (Bunch & Lloyd, 2006). This additional time could potentially be reduced if users would get more familiar with the different concepts for visualizing traffic density distributions. However, despite the additional information that the map-reader has to decode, the extra time needed for decision-making is estimated to be small.

Relations between Route Choice and Route Characteristics

A closer look at the relations between the route choices and the estimated route characteristics provides some interesting insights. It is suggested that if a characteristic (*faster, shorter, more direct, more convenient* or *more fluent*) is rated high, participants who decided for the *recommended* route are likely to have made this choice due to the association with a route characteristic that has been evoked by the type of visualization. Particularly for design variants for which the *recommended* route has been chosen more frequently, high rated characteristics can provide an important hint regarding *why* the route decision has been made since these characteristics are suggested to be important criteria for route choice.

For the design variants *color hue* and *symbols*, the strongest relations have been found for the route characteristics *faster*, *more convenient* and *more fluent*, indicating that these characteristics might serve as important factors that have influenced route choice behavior when deciding for the *recommended* route. Apparently, participants who preferred the *recommended* route were successfully able to grasp the 'message' to be transferred by the visual metaphor.

As mentioned beforehand, we can assume that (together with the estimated low suitability for visualizing *recommended* routes) for the design variants *size* and *spacing*, a large number of participants did not encode the applied visual metaphors correctly. In most cases, none of the options for route characteristics has been chosen. This is also reflected in the relations between route choice and characteristics. In the case of *size*, a reason for the low effect on route choice behavior could be that the used visual characteristics may have evoked ambiguous interpretations. In contrast to the associations expected for the visual metaphor (wider line = more capacity = faster / low traffic density), it could also be possible to associate the visualization with an opposite scenario (wider line = more traffic = slower / high traffic density). An evaluation of characteristics mentioned by some of the participants as *other characteristics* indicates that a similar number of participants each estimates a wider line as either efficient or inefficient**.** Therefore, we suggest that a representation using a visual metaphor opposite to that (wider line = less efficient) would lead to a similar ambiguity. Due to their apparently low intuitiveness for recommending routes in terms of traffic density, we propose to avoid using the visual variables *size* and *spacing* for influencing a route decision.

Based on our analysis it becomes clear that using visual characteristics that are associated with a *faster*, *more convenient*, or *more fluent* travel experience have been found most important for influencing route choice. This is consistent with the literature in the field of route choice behavior, which indicates that these characteristics also serve as important route choice factors in real-world situations (Papinski et al., 2009). Therefore, it can be assumed that for example in the case of the generally influential design variant *symbols*, participants might have made a direct link to a possible real-world traffic situation - based on the visual representation. This, in turn, would have directly influenced their decision.

Transferability of the Findings to Real World Applications

The results of this study clearly indicate that it is possible to influence the map-reader's route decision solely by using different design variants for modifying the visual map appearance. While communicating the advisability of route options, the use of different intensity levels for modification contributes to the creation of semi-realistic representations that intend to direct the viewers' attention to specific characteristics of the map and trigger a behavior change. This persuasive aspect of visual communication is observable in various types of maps (such as hazard visualizations for promoting public safety) that intend to promote a different view on things or to evoke a behavior change (Stempel & Becker, 2019; Chih & Parker, 2008; Muehlenhaus, 2012). The results of our study support the assumption that this persuasive power of maps can be transferred to visually communicating *recommended* routes by means of cartographic design variants (Hilton et al., 2011).

Our proposed visualizations intend to communicate *recommended* routes primarily during the route selection process prior to navigation. Since at this stage, maps are usually presented as allocentric representations, in this study we focus on investigating the effectiveness of allocentric maps. This type of map facilitates users to compare and make preferences regarding the proposed route options. However, since urban traffic is highly dynamic, route choices may need to be made 'on-the-fly'. Although, during navigation, maps are usually presented as egocentric representations that dynamically update the location, active route decisions (before navigation, as well as updating the route during navigation) are primarily made based on allocentric maps.

Besides, we need to consider that in a real-world setting, the motivations of a driver for choosing a route might differ from those in a laboratory setting. Also, while sitting in a car, drivers might not be able to devote their full attention to the proposed routes, since they could be distracted by additional factors that possibly influence their route choice behavior (Stutts et al., 2005).

Our findings suggest that particularly the visual variables that have been found influential might be suitable for implementation in a real-world routing service. With respect to safety issues caused by a potentially wrong interpretation of the information (e.g. those with geometric modifications), the modified visualizations are intended to be shown as allocentric representations in situations where a route decision has to be made. Possible suitability of some of the design variants for displaying as egocentric representations during navigation could be the subject of further investigation concerning the effectiveness of visual variables in a realistic traffic mapping scenario. Another open question is the transferability of the results to small display sizes (as commonly used for routing purposes), since here, the cognition of symbol variations could require a higher cognitive effort and thus potentially lead to longer map viewing times before making the route decision.

Based on the results of this study, further work on this topic will focus on improving intuitiveness and clarifying the intention of the chosen visualization, e.g. by using dynamic visual variables in animated maps to further emphasize the urgency of choosing the *recommended* route (DiBiase et. al., 1992; Harrower, 2001; Köbben & Yaman, 1995; Mashima et al., 2011). Additionally, we will investigate the generalizability of our proposed approach, by adapting the method to various scenarios in which a route could be recommended by traffic authorities for a particular reason (e.g. reducing overall air pollution). In this context, we will also examine how combinations of several design variants (MacEachren, 1995; Lautenschütz, 2012) may affect route choice behavior.

Conclusion

In this work, we compared a set of six different design variants for visually communicating *recommended* routes using cartographic visualization methods, with a focus on their potential for influencing route choice behavior. Our findings provide evidence that it is possible to influence the map-reader's route choice towards a temporarily preferable route – using cartographic symbolization. We were able to show that most of the applied visual modifications have a significant effect on route choice behavior (in favor of the *recommended* route), while the different design variants each contribute to a different extent to the map-reader’s ability to assess the advisability of route options. While some of the design variants – like the use of *length distortion* or *symbols* for representing temporary changes in traffic density – generally seem suitable for influencing the map-reader's route choice towards a *recommended* route, other design variants like applying variations in *size* or *spacing* only have a weak effect on the map-reader's route choices. For most of the proposed design variants, we observed a significantly higher willingness to decide for the *recommended* route, when the modifications have been visualized with a higher level of intensity.

The results of this study further have shown that route decisions do not depend on the time needed for decision-making for most of the routing scenarios. However, the decision time slightly increases when using a higher intensity of modification.

The willingness to choose the *recommended* route is strongly related to the characteristics, participants associate with a certain representation. In most cases, route decisions in favor of the *recommended* route have been made, if traveling along the route (based on the visualization) has been judged as *faster, more convenient,* or *more fluent*. Therefore, these characteristics are suggested to be important factors for influencing route choice behavior.

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Data Availability Statement

The data that support the findings of this study are openly available in figshare with the identifier http://doi.org/10.6084/m9.figshare.12925589.

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