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Nudging travellers to societally favourable routes: The impact of visual communication and emotional responses on decision making

Stefan Fuest [a,*], Monika Sester [a], Amy L. Griffin [b]

[a] Institute of Cartography and Geoinformatics, Leibniz University, Hannover, Germany
[b] School of Science, RMIT University, Melbourne, Australia

A R T I C L E I N F O

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A B S T R A C T

As urbanisation increases, in many places, the transport system is suffering from problems that may affect large parts of the urban population, such as traffic congestion or increased air pollution. In both cases, a better distribution of traffic flows could contribute to establishing a more sustainable transport system, and to improve the situation from a societal point of view. In this paper, we use cartographic symbolisation for communicating favourability of route options for achieving a societal benefit. Since map symbols can evoke different emotional responses in the viewer, we investigate to which extent map symbols evoke positive and negative emotions and whether these influence route choice decision making. We created different cartographic visualisations and designed a user study that investigates the effectiveness and suitability of these different visualisation variants for influencing route choice based on two scenarios: *traffic* and *air quality*. Fourteen route maps were prepared using different map symbols to symbolise *societally favourable* and *non-favourable* route options. The results of this study show that map symbols can be used effectively for influencing route choice towards choosing the *favourable* route for the two tested scenarios. While visualisations that modify only *lines* were more effective in the *traffic* scenario, *area* symbol modifications were more effective for the *air quality* scenario. The symbolisation evoked a wide range of emotions in participants. While non-favourable routes mainly evoke *negative* emotions (particularly *fear*), favourable routes mainly evoked *positive* emotions (particularly *contentment*) or no emotions. The results further demonstrate that for some of the visualisation variants, emotions felt in response to the map visualisations contributed significantly to changing the route choice decisions in favour of the *societally favourable* route option. The findings of this research demonstrate the relationship between route choice behaviour and emotional responses elicited by map symbols.

Introduction

As urbanisation increases, so does the demand for efficient forms of mobility. In particular, a high proportion of motorised individual transport can cause far-reaching problems for the transport system. Suboptimal distributions of traffic flows can overload the existing transport infrastructure, and lead to problems that may affect large parts of the urban population, such as traffic congestion at bottlenecks, or increased air pollution at critical locations. In both cases, a better distribution of traffic flows could contribute to improving the situation from a societal point of view.

To counteract these situations, traffic authorities impose various measures, focusing primarily on direct intervention in the traffic infrastructure, such as speed limits, low emission zones, or variable message signs. However, particularly in unfamiliar environments, most route decisions are made prior to the start of the trip, using route maps as provided by routing service applications or navigation systems. While the majority of these display the most travel-time-efficient route options for the individual traveller, some recent approaches guide drivers to a *societally favourable* route that temporarily improves the performance of the entire traffic system. A *societally favourable* route is expected to help improve the traffic or environmental situation in a particular geographic area so that it benefits everyone affected by that situation. Examples of this are collaborative routing approaches like one developed by Graphmasters (2020), which aims to optimise traffic dynamics by reducing traffic jams and thus saving emissions. Similarly, a recent release of Google Maps intends to nudge travellers to eco-friendly route alternatives by default, instead of suggesting time-efficient routes

* Corresponding author.
E-mail addresses: stefan.fuest@ikg.uni-hannover.de (S. Fuest), monika.sester@ikg.uni-hannover.de (M. Sester), amy.griffin@rmit.edu.au (A.L. Griffin).

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(Glasgow, 2021). Another approach, introduced by Quercia et al. (2014), suggests the shortest path that is also emotionally pleasant.

While the described approaches can optimize system-wide traffic, the resulting route recommendations may not necessarily match the individual preferences of the traveller. Regarding factors that influence a driver's route choice, most researchers agree that the time required to reach the destination can be considered as the most relevant factor for choosing a route, where minimising travel time is often preferred over minimising travel distance (Papinski et al., 2009; Abdel-Aty et al., 1995). Further factors relevant to a driver's route choice are the complexity of the path to be traversed (Bailenson et al., 1998), or the number of traffic lights or stop signs along the route (Papinski et al., 2009), which could impede an experience of a smooth, continuous movement. If the recommended route, for example, clearly deviates from the most efficient route in terms of travel time or distance, then the traveller might perceive this route option as less reasonable in terms of individual effort. Therefore, for effectively communicating the benefit of choosing a *societally favourable* route, route maps should attempt to convey the (negative) *feeling* that the traveller might get when being exposed to societally sub-optimal traffic.

Our approach to address this problem is to use cartographic symbolisation for communicating *favourable*, as well as *non-favourable* route options to the traveller. Visual variables are an intuitive way of communicating spatial variations in map objects. Bertin's visual variable set (Bertin, 1983) has been elaborated over time – for example adding variables such as transparency or blurring / fuzziness (Kinkeldey et al., 2014). Like any other type of visual representation, map symbols can evoke different emotional responses in the viewer (Caquard & Griffin, 2018). Therefore, it is important to investigate to which extent map symbols evoke positive or negative emotions and whether these then influence route choice decision making.

Related work

Research on emotions related to driving behaviour has shown that aggressive driving behaviour can be influenced by strong emotions felt by the driver, while *anxiety* and *contempt* showed the same negative and dangerous driving pattern as did *anger* (Roidl et al., 2014). Jing et al. (2018) further suggest that the feeling of *regret* (or not wanting to experience regret) may contribute to provoking a behaviour change. Previous research has shown that it is important to address people's emotions (Roeser, 2012) for understanding the moral impact of the risks related to environmental phenomena. Hence, emotions are suggested to be essential for making rational decisions (Lakoff, 2010). We expect that providing intuitive visualisations that evoke anticipated emotions that might be experienced in a situation will make the experience of the mapped phenomenon more tangible to the map-reader.

The challenge here is to use map symbols in a way that the symbolisation adequately communicates the emotions that are expected to be associated with the scenario.

Framing environmental communication

For effectively communicating environmental information, it is important to apply a suitable *framing* of the information, since the way information is framed makes a difference regarding how people think about a problem, make decisions, and take actions (Scheufele & Iyengar, 2012). Framing of environmental information is suggested to be most effective when appealing to empathy as well as personal and social responsibility (Lakoff, 2010). While in the literature framing effects are discussed primarily in the context of verbal or textual descriptions or statements, the concept of framing can also be transferred to visual communication, such as graphical illustrations, visual imagery, or maps (Lakoff, 2010).

Framing effects are commonly related to either *gain framing* or *loss framing*. While gain framing describes the case of emphasising the benefits of the communicated situation, loss framing emphasises a potential negative outcome of the situation. Gain framing is suggested to be generally more suitable for communicating the severity of environmental impacts. Further research in this field (Myers et al., 2012) showed that a public health focus for framing environmental hazards is likely to elicit emotional responses that increase willingness for solving environmental issues. Banks et al. (1995) found that loss frames are more effective in changing behaviours that are considered risky, while gain frames are more effective in changing behaviours that are considered safe. Previous research in the field of framing also indicates that negatively framed information generally has a stronger impact on decision making than positively framed information (Spence & Pidgeon, 2010).

A special case of a loss frame is *fear framing*, which describes a negatively focused loss frame that intends to evoke a more extreme, negative emotional response. Despite its assumed effectiveness for motivating people to make a behaviour change, it is advisable to use fear framing carefully, since it could lead to a complete avoidance of the communicated situation.

For a large part of the global population, environmental problems such as climate change or air pollution are a psychologically distant issue because people may not feel directly affected by their consequences. Hence, emotional responses related to these topics might be relatively weak for some people (Pirani et al., 2020). To make environmental issues more tangible, framing can be used to present them as a more prominent, local, closer issue (Spence & Pidgeon, 2010).

Emotions and mapping

Some researchers have attempted to transfer the concept of framing to cartographic language. For instance, Pearce (2008) translated written descriptions of space into visual characteristics using cartographic symbols. For mapping the space according to individual experience, she suggested replacing cartographic conventions with other expressive forms that directly capture the emotions associated with a place but that may not preserve geometrical correctness. She used variations in colour hue to visually encode emotions such as the perception of danger. Colour is commonly used as a variable for expressing emotions, since different colours are associated with certain sentiments or emotions (Kushkin, 2022). However, the decoding of colour schemes depends highly on cultural colour conventions. According to Kelly (2019) and Anderson and Robinson (2021), darker colour values may be used for showing fear, danger, or sadness of the communicated information, while bright colours may relate to happier situations. Besides the use of colours, visual cues such as shapes or lines are also frequently used in arts for expressing emotions and thus influencing the sentiment of the observer. While round shapes and soft lines and colours usually intend to evoke peaceful, positive feelings, jagged, sharp lines or shapes are commonly used for communicating negative feelings or energy.

Alternative approaches for mapping emotions apply visual variables other than colour, such as contour lines or spike shapes for symbolising the level of emotional arousal (Nold, 2009). Klettner (2019) evaluated the effects of different map symbol shapes on emotional responses by defining bipolar items for emotions based on the *circumplex model of affect*. She found asymmetric shapes lead to strong and highly negative emotions, while symmetric shapes evoke mild and primarily positive emotional responses. Another study conducted by Carroll and collaborators (2020) investigates the effectiveness of different visual variables to trigger feelings of uncertainty, with the aim to emotionally influence map readers in their path choice. For allowing more intuitive decisions, they used different cartographic design principles, such as colour, noise, blur, sketchiness, and scribble. They reported that wider lines and brighter colours evoked a feeling of faster movement, while a solid line evoked a feeling of safety, and adding scribble to the map was associated with a higher level of stress. Among others, they found that scribble, blur, and noise were particularly effective for influencing path choice.

Regarding line size, however, Kelly (2019) found that wider lines in combination with darker colour value were associated with fear and dangerous situations, which confirms that the interpretation of line size as a visual variable is to some extent ambiguous and highly context-specific (Fuest et al., 2021). Pirani and collaborators (2020) further found that although choropleth maps are easy to use and familiar to many users, they were not effective for evoking emotions, since they have been evaluated as *boring, neutral*, or *traditional*. Instead, unusual map types using conspicuous pictographs or symbols that depict the seriousness of a situation were effective for evoking emotional responses. The authors pointed out that design choices can influence emotions, but they may be incongruent with the topic or data represented (Anderson & Robinson, 2021). Therefore, it is important to relate the mapped emotions to the topic that should be communicated.

For mapping emotions related to an environmental phenomenon, Pearce (2008) suggested applying symbolisation not only to a travelled path, but also to the surrounding area for adequately mapping emotions experienced in a situation. Examples for symbolising areal information are variations in colour applied to a choropleth or isoline map (Słomska-Przech & Gołębiowska, 2021).

For successfully evoking an emotional response, the used visual variable needs to be congruent with the communicated phenomenon. Additionally, a higher level of experienced arousal is suggested to lead to a higher level of motivation, and increase the likelihood of a behaviour change (Roeser, 2012).

User study

Based on the reviewed research in the fields of framing environmental communication and mapping emotions, we used visual variables to develop symbols we thought would be suggestive of how encountering one of two environmental phenomena along a route, *traffic* congestion or poor *air quality*, would be experienced. Since according to the concept of loss framing, communicating negative emotions is expected to be more effective for decision-making than communicating positive emotions, we applied visual modifications to non-favourable route alternatives (Spence & Pidgeon, 2010). In this way, we transfer the concept of framing to visual map communication (Lakoff, 2010).

In our user study, we investigated which emotions were evoked by the map symbols and whether these emotions lead to choosing a *societally favourable* route. We used the same visual variables for representing two different environmental phenomena to test the generalisability of the visualisation methods.

Route maps

We created a set of 14 route maps showing parts of different real-world urban road networks. Each of the route maps includes two route options, yet both routes share the same start- and end-points. The maps always include one non-favourable route and one slightly longer route that is favourable based on the current traffic situation or air quality conditions. Importantly, because of the geographical distribution of the underlying data, some smaller parts of the favourable route may contain segments that are defined as slightly non-favourable, and vice versa. For all route maps, both route options differ clearly regarding the visual communication of their favourability. In all cases, the shorter, non-favourable route ranges between 80% and 90% of the length of the longer, favourable route. In particular, larger differences in length between the two routes have been avoided, since with long detours, the emissions of cars also add a considerable amount of further pollution to the atmosphere, which would contradict the concept of promoting *societally favourable* routes. Across the 14 different route maps, the route length ranges between 3.5 km and 7.5 km. This range of distances is typical of inner-city driving distances for running errands (Neumeier, 2014). We did not expect the differences in path length between the different maps to have a large influence on decision-making. That is, because despite the differences in length across the maps we used in the experiment, the urban structure of the areas to be crossed is similar among the different selected areas.

Since we aimed to test realistic route choice scenarios, we created all route maps based on real environments within four different major cities in Germany, while taking care to avoid including recognisable structures in the road network to reduce the impact of participants' familiarity with specific locations. Due to potential differences in the structural characteristics of the different real-world road networks, we identified several potentially confounding factors that should be controlled in order to minimise their likelihood of influencing route choice.

We selected route pairs that 1) have the same number of turns for both route options (Venigalla et al., 2017; Parthasarathi et al., 2013); 2) use roads of similar road classes (Vreeswijk et al., 2014); 3) use the same travelling direction (Brunyé et al., 2015); 4) and have a similar road network density (Parthasarathi et al., 2013). According to Brunyé et al. (2010), map users tend to choose southern rather than northern routes. To ensure that all routes that we used in the experiment run from north to south, some maps have been rotated from their real-world orientation. We initially planned to select route pairs that had the same number of left- and right-turns for each route option. This was difficult to achieve from a geometric point of view, so we compromised by having three real turns per route (not counting turn-like bends), including either two right turns and one left turn, or one right turn and two left turns.

Fig. 1 shows the geometries of two example route pairs that fulfil these requirements. Route pairs always consist of one shorter, but temporarily non-favourable route (due to current traffic conditions or air quality), and one longer route that is temporarily favourable from a societal point of view. We rotated each map (if not already in the desired orientation) so that the start and end point could be connected by an imaginary vertical line. Furthermore, for most of the route pairs, we produced an additional version of the map by rotating it 180 degrees. We did this to reduce variations in road network structures across the stimuli, while assuming participants would not identify that some images were rotated versions of other images. The road lanes selected as part of a route were adapted to the driving direction (according to right-hand driving traffic). This further reinforces the impression that all presented road networks were distinct from each other. These route pairs were used (as described below) to generate both *non-modified* maps, where both routes were depicted using the same map symbols, and *modified* maps, where a different symbol was applied to the non-favourable routes.

To construct the *modified* maps, the graphical differences in the map symbols that indicated varying levels of traffic congestion or air quality along the unfavourable route were generated from an input data set. For defining graphical differences, we used a set of observed values whose data source depends on the scenario and a threshold value (Fuest et al., 2022). The observed values comprise traffic density measurements or particulate matter concentrations associated with a road segment. For both scenarios, we used a set of 56 observed values ranging between *0* and *100* (28 below and 28 above the threshold), while defining a threshold value of *50*.

Values above the threshold relate to societally non-favourable parts of the road network, while values below the threshold relate to favourable parts. The ratio of the observed value and the threshold is mapped to communicate route favourability. To make the different maps comparable, we always created a similar distribution pattern – with small adjustments of the point distribution to capture the shape of the routes to achieve a more realistic distribution.

Fig. 2 shows an example point distribution for one of the route pairs as used in the user study. The observed values were then interpolated using inverse distance weighting (IDW), before assigning the resulting raster values to the road network shapefiles. In the *traffic* scenario, although traffic congestion would normally be thought of as a linear phenomenon, the idea was to indicate congested areas where small deviations from the route to avoid congestion on a single road segment

Fig. 1. Two examples of route pair geometries that meet the route design requirements, each displaying one non-favourable and one favourable route.

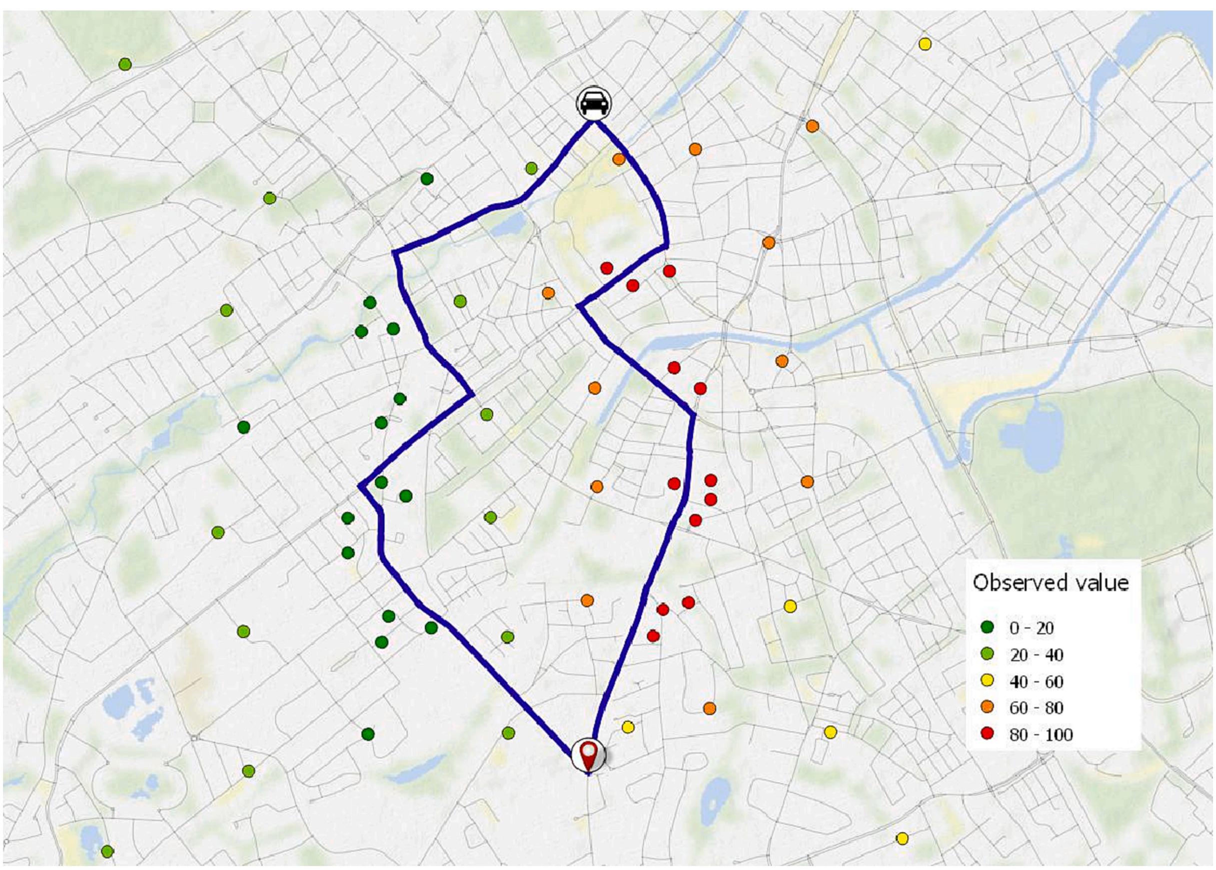

Fig. 2. Sample route pair with point distribution of observed values.

would not make the trip quicker.

Fig. 3 provides an example of a *non-modified map* where both route choices are shown with the same symbols, as compared to a corresponding *modified map* of the same area. Both map types share several common features. For representing the two route options, A and B, we use a blue line (except for the one visualisation variant that used

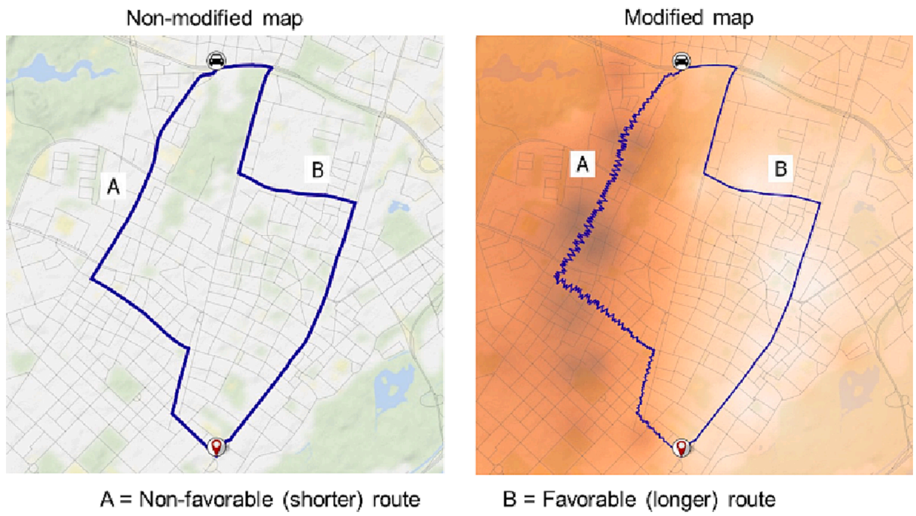

Fig. 3. Non-modified map representation as compared to a modified map of the same route pair.

variations in colour hue). The start and end point of the routes are marked by distinctive icons. The car icon represents the start of the route, while the pin icon indicates the end of the route. The surrounding road network is displayed in the background using a light grey colour and thinner lines. The base map shows land use categories symbolised with colours that reflect their real-world appearances (e.g., green for open space and parklands, blue for water, etc.).

Since the *non-modified* map does not show any visual modification between the routes, and no further information was provided, we expected that participants would choose the slightly shorter route (here: Option A) when working with these maps. In the *modified* version of the map, the shorter route is communicated as societally not favourable and the symbolisation (here: line distortion and orange-brown-coloured background) intends to make the route look less attractive and potentially evoke negative emotions. Therefore, the modified map tries to nudge the map-reader towards taking the longer, favourable route (here: Option B). Across the different route maps, we varied which route option (A or B) shows the favourable route and which option shows the non-favourable route. The left-hand route is always labelled as route option A, while route option B is always shown on the right.

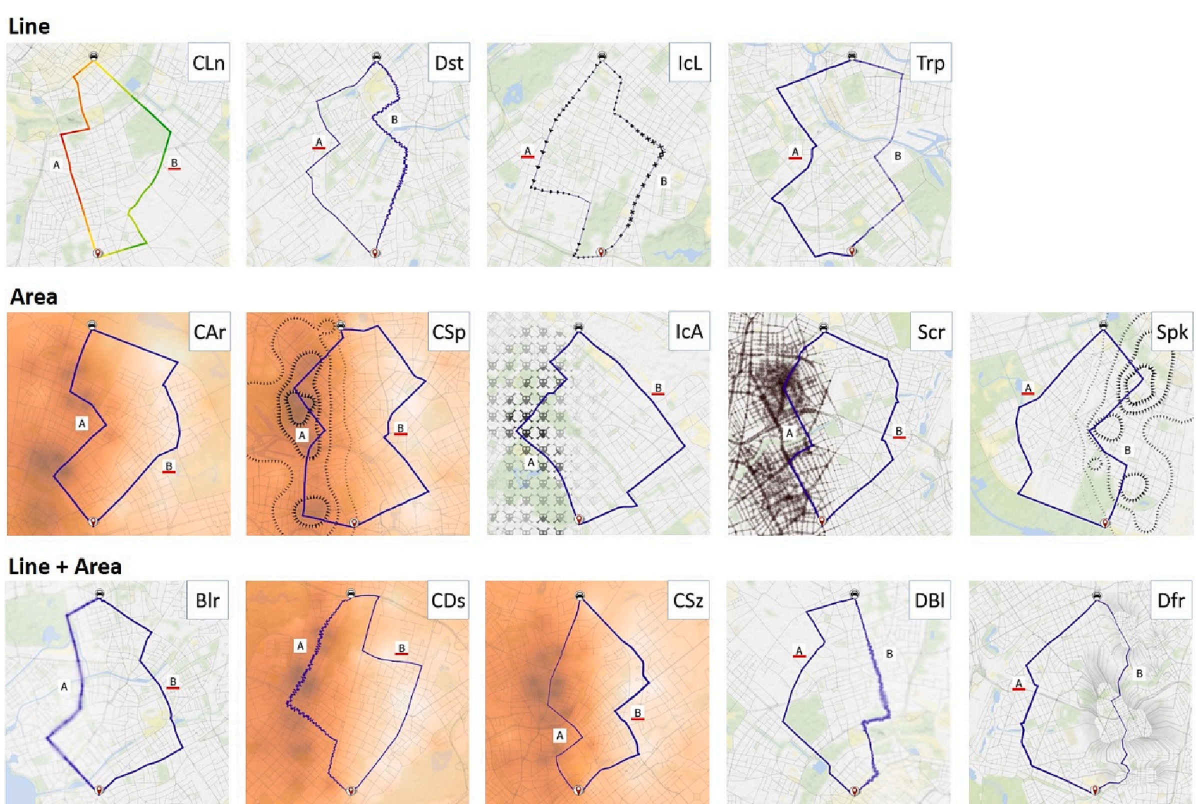

Fig. 4. The 14 visualisation variants as used for the user study. The route option communicated as societally favourable (*A* or *B*) is underlined in red. The visualisations modify line, area or line + area geometries. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Visualisation variants

Fig. 4 provides an overview of the 14 different visualisation variants used in the study. Importantly, in some of the maps shown in this figure, the societally favourable route is shown on the left side, while in other maps it is shown on the right side. For all maps, the route option that is visually communicated as favourable is marked in the figure by underlining the label *A* or *B* in red (note that in the maps as shown in the user study, this additional information was not provided). The symbol set included line, area, and line + area geometries for symbolising temporarily favourable and non-favourable parts of the road network. We tested some traditional visual-variable-based approaches, such as variations in colour hue, colour value, size, transparency or blurring, as well as some experimental approaches for visual communication using more complex symbolisation – such as line distortion, geometric deformation of areas, adding scribble to roads, or spike shapes.

In the further course of the paper, we use the following abbreviations, when referring to the different visualisation variants:

Blur = *Blr*, Colour Area = *CAr*, Colour Distortion = *CDs*, Colour Line = *CLn*, Colour Spikes = *CSp*, Colour Size = *CSz*, Distortion Blur = *DBl*, Deformation = *Dfr*, Distortion = *Dst*, Icons Area = *IcA*, Icons Line = *IcL*, Scribble = *Scr*, Spikes = *Spk*, Transparency = *Trp*.

A separate file with a detailed description of the design characteristics of the 14 different visualisation variants for visualising route favourability is provided in the supplementary materials of this paper (document B). In general, we chose symbols that we believed could be applied to multiple scenarios and that therefore could potentially communicate information related to both scenarios (*traffic* and *air quality*). To ensure that participants could sufficiently see the graphical differences between the map visualisations, they saw full size images of the maps during the study.

Study design

The study was deployed as an online survey using the German language and is based on a mixed design (see Fig. 5). Participants were assigned randomly to one of the two scenarios: 1) *traffic*, or 2) *air quality*. Within each of these two groups, participants were asked to complete the same set of four tasks.

In the first task, participants are asked to make a route choice decision for each non-modified map, followed by each of the modified maps. For both sets of maps, the individual maps are shown in randomised order. By asking participants to examine the unmodified maps first, it was possible to investigate if the difference in length between the two visualised routes has an effect on route choice (independent of knowing how the route map will look like when using symbolisation). This information is important as a ground truth for comparison with the results for the modified maps to measure the effect of applying symbolisation. The route choice was made by selecting the participant's preferred option based on a 5-point Likert scale. The options were *Definitely A*, *Rather A*, *No preference*, *Rather B*, or *Definitely B*. Option *A* always referred to the route visualised on the left, option *B* to the route visualised on the right.

For the second task, participants were asked to provide free text descriptions. In the first part of the task, they were asked to describe their general strategy (or strategies) for making route choice decisions based on the non-modified and modified maps. In the second part of the task, they were required to identify which single map was most helpful and least helpful for making the route choice decision and describe the reasons for this in full sentences. Our intention was to apply different methods for analysing emotions, such as sentiment analysis using emotion lexicons (Mohammad & Turney, 2013; Hölzer et al., 1997; Vo et al., 2009). However, due to relatively short descriptions provided by most of the participants, the results were not sufficiently informative and are not reported here.

In the third task, participants viewed all modified maps one-by-one in randomised order, and they were asked to select the emotions they felt when viewing the societally favourable and non-favourable route in the map. For classifying emotions, models typically either define emotions as discrete categories (Harmon-Jones et al., 2016), or describe them based using different dimensions. A prominent example of a dimensional model is the *circumplex model of affect* as proposed by Russell (1980), which suggests emotions can be distributed in a two-dimensional circular space, consisting of the two dimensions *arousal* and *valence*. Valence refers to the level of pleasure, describing how positively or negatively a situation or event is experienced, while arousal indicates the level of activation in terms of how exciting or calming a situation or event is experienced to be. Hence, emotions can be specified at any level of arousal or valence, or at a neutral level. Studies that classify emotions as discrete categories propose several basic emotions. Accordingly, additional emotions can be assigned to these discrete emotions based on their similarity.

Based on these common classifications, several tools or instruments have been implemented to *measure* emotional responses of humans to situations, events, or objects. Examples of these tools are *Plutchik's wheel of emotions* based on eight primary bipolar emotions, or the *Geneva Emotion Wheel (GEW)* (Scherer, 2005), which consists of 20 basic emotions aligned on a circle that is organised using two dimensions: valence (negative to positive) and control (high to low) (Sacharin et al., 2012). In addition to the arrangement of emotion terms on a circle, this tool allows further differentiation of emotion intensities. To help participants describe their emotions, we used the German version of the Geneva

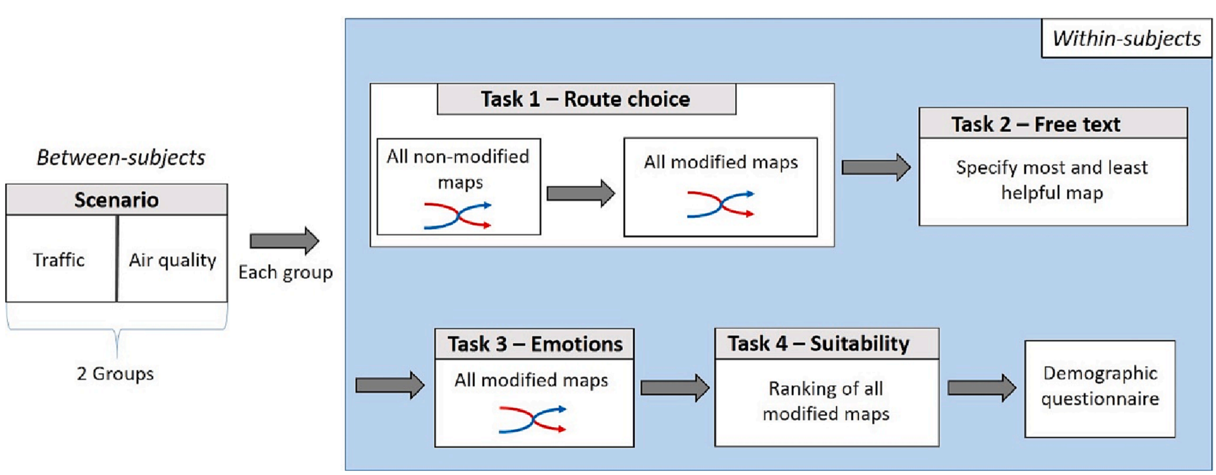

Fig. 5. Study design.

Emotion Wheel, which lists 20 emotions (ten positive and ten negative emotions), with the option to select different intensities for each emotion. Participants also have the option to choose *no* emotion or *other* emotion, in case none of the provided emotions matches their response to the map. This instrument was suitable for the purpose of our project, since it comprises most of the expected emotions related to the communicated scenarios and has been validated for German-language studies (Scherer et al., 2013).

We instructed participants to select the emotions in the corresponding intensity that best describes the feeling they have when they follow route option *A* and route option *B*. Fig. 6 shows how this was presented in the user study, with the map on the left and the German language version of the *Geneva Emotion Wheel* on the right. The blue points indicate the positions in the wheel that one particular participant has selected. For each emotion, there are five circles that can be selected, with a larger circle that is further away from the centre of the wheel representing a higher intensity of emotion. Very small circles close to the centre, however, relate to a very low intensity of the selected emotion. For an illustration of the English language version of the Geneva Emotion Wheel, please refer to Fig. 10.

In the fourth task, we asked participants to rate the suitability of the visualisations. Here, we instructed participants to rate how suitable they found the maps for the presentation of the visualised information (either traffic information or air quality information) by ranking them from most to least suitable. The experiment concluded with a demographic questionnaire focusing on travel behaviour and map usage.

The study was developed using the *Lime Survey* platform and was made accessible to potential participants by distributing the access link. All participants were informed about the aim of the study and the study procedures and agreed to specifications regarding data anonymisation and data analysis. In particular, the collected data does not include information that reveals a person's identity.

Hypotheses

Before conducting the experiment, we developed five hypotheses:

H1:"We expect a general shift towards choosing the longer, but *societally favourable* route when showing the modified maps as compared to route choice for non-modified maps.".

This expectation is based on previous work showing that map symbolisation can be effective for influencing route choice (Fuest et al., 2021).

H2:"We expect a higher willingness for adapting route choice behaviour (showing pro-social behaviour) in the *traffic* condition scenario, compared to the *air quality* scenario.".

This expectation is based on previous research suggesting that people feel personally unaffected by environmental impacts, and therefore also less responsible to act in a more altruistic way (Roeser, 2012).

H3:"We expect that line modifications will be more effective for the *traffic* scenario while area modifications will be more effective for the *air quality* scenario.".

This expectation is based on commonly applied types of visualisations for the two different scenarios of *traffic* (Kubíček et al., 2017) and *air quality* (Lahr & Kooistra, 2010). Furthermore, a traffic jam is typically considered a linear phenomenon, whereas air quality is a continuous areal phenomenon.

H4:"We expect that routes communicated as favourable will primarily evoke positive emotions, while routes communicated as non-favourable will primarily evoke negative emotions.".

This expectation is based on the types of emotions commonly suggested to be evoked by the symbolisation we applied in the maps (Carroll et al., 2020; Kelly, 2019; Nold, 2009).

H5:"We expect that emotional responses to map symbols in the modified maps contribute to changing the route choice decision towards choosing the societally favourable route.".

Assuming correctness of *H1*, this expectation is based on previous research indicating the importance of appealing to people's emotions related to the communicated situation for achieving route choice behaviour change (Roeser, 2012).

Results

The results of the study were analysed with a focus on testing the hypotheses, including the influence of the visualisation variants on route choice and the role emotions play when making a route choice decision.

Participants

Most of the participants were either students or staff members at the authors' university or German-speaking participants from other

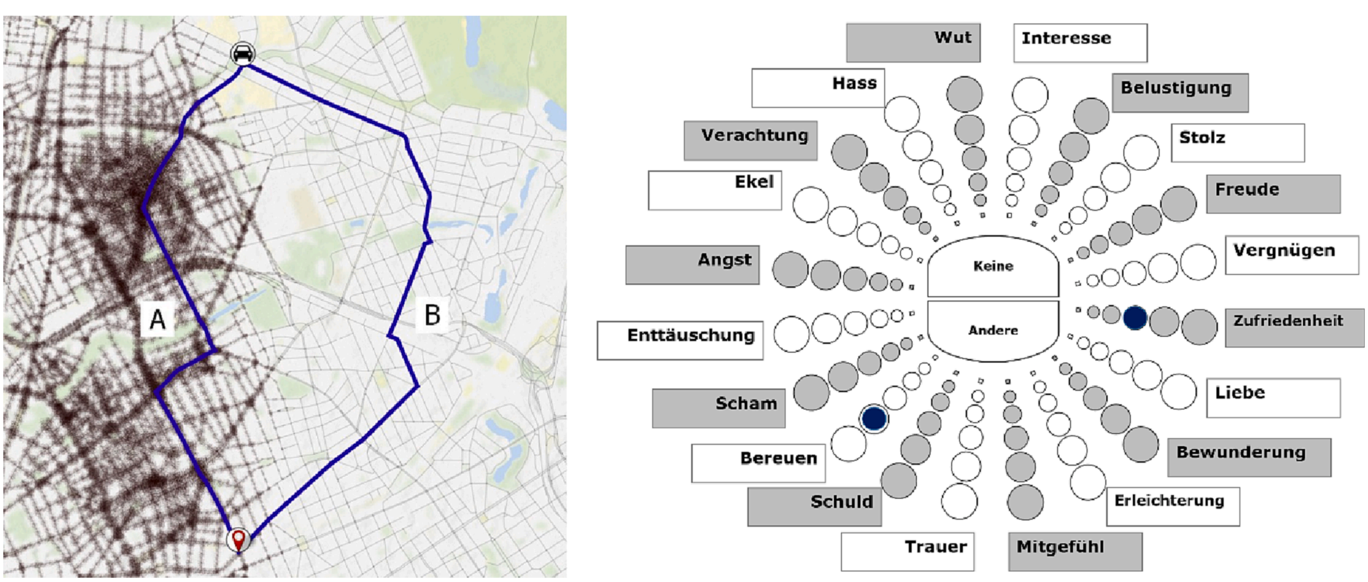

Fig. 6. Sample visualisation as used in the user study showing the Scribble variant, with a modified map on the left and the *Geneva Emotion Wheel* on the right. The task looked the same for both scenarios. Clockwise translations of the emotion terms from German language: Interest, amusement, pride, joy, pleasure, contentment, love, admiration, relief, compassion, sadness, guilt, regret, shame, disappointment, fear, disgust, contempt, hate, anger.

universities or research institutes in Germany, Austria, and Switzerland.

A dataset consisting of 126 complete responses (*traffic* scenario: $n = 73$, *air quality* scenario: $n = 53$) has been used for analysis. The noticeable difference in sample size for the two different scenarios is due to the fact that participants in the *air quality* scenario dropped out of the survey more frequently than did participants in the *traffic* scenario. The reason for participants dropping out more frequently in the air quality scenario may have been that some people thought the topic was not relevant to them, or due to difficulties with expressing emotions related to air pollution. An evaluation of the point in time when participants frequently dropped out of the survey revealed that the majority of participants dropped out at a relatively early stage, during the route choice task. This observation is similar for both the traffic and air quality scenario groups, however, in the air quality scenario, comparatively more participants dropped out when the modified maps (and along with that the air quality topic) were introduced. A second, less distinct peak is observable when introducing the emotion-related task. Participants in the *traffic* scenario (34 female, 38 male, 1 not specified) ranged in age from 19 to 67 years ($M = 28.85$, $SD = 11.42$), while participants in the *air quality* scenario (27 female, 22 male, 2 diverse, 2 not specified) ranged in age from 18 to 64 years ($M = 30.49$, $SD = 13.25$). Two participants indicated they had a red-green visual impairment. Therefore, we removed these responses from the analysis.

The majority of participants (91.3 %) indicated having driving experience, while the remaining participants (8.7 %) never drove a car.

Since many of the participants have a cartography-related background, experience in map usage is relatively high: 25.4 % experts, 49.2 % frequent users, 21.4 % occasional users, while only 4 % reported they had no experience in map usage. Similarly, most participants are familiar with common map visualisations: 10.3 % estimate themselves as experts, 46.8 % reported they had a good overview, 37.3 % have a general overview, while 2.4 % report having no overview of map visualisations. Additionally, 3.2 % reported that they were not sure how to answer this question.

H1: Shift towards choosing the societally favourable route

Results regarding route choice preferences for the non-modified maps support our hypothesis that most would choose the shorter route option – the route which is communicated as non-favourable in the modified maps: 70.7 % of all responses for the non-modified maps indicated the participant would *rather* or *definitely* prefer the shorter route option.

Fig. 7 provides a first impression regarding the users' route choice preferences for the modified maps. For each visualisation variant, the figure shows the percentage of route choice preferences based on the 5-point Likert scale as used in the survey for the two different scenarios, *traffic* and *air quality*. In both scenarios, users tended to choose the route that was communicated as favourable. However, there are distinct differences observable between the scenarios, as well as among the different visualisation variants.

In the *traffic* scenario, people are more likely to *definitely* choose the societally favourable route. In the *air quality* scenario, however, users predominantly selected they would *rather* choose the favourable route. This suggests that the visual communication may have been less effective for the *air quality* scenario.

When comparing route choice preferences for the different visualisation variants, we can observe that for most of the variants such as *Colour Line* (*CLn*), *Colour Distortion* (*CDs*), or *Icons Line* (*IcL*), most participants chose *rather* or *definitely* the favourable route.

In case of the *Transparency* (*Trp*, both scenarios) and *Colour Area* (*CAr*, *traffic* scenario) variants, however, a relatively large percentage of participants chose *rather* the non-favourable route, indicating that for these variants, visual communication did not have the desired effect.

To test whether participants' responses were affected by the map modifications, we examined whether there was a shift to choosing the societally favourable route in the modified maps as compared to the non-modified maps. Fig. 8 illustrates the route choice results for the modified maps and the corresponding non-modified maps for the 14 different visualisation variants, considering the two scenarios separately. The route choice results for the different visualisation variants

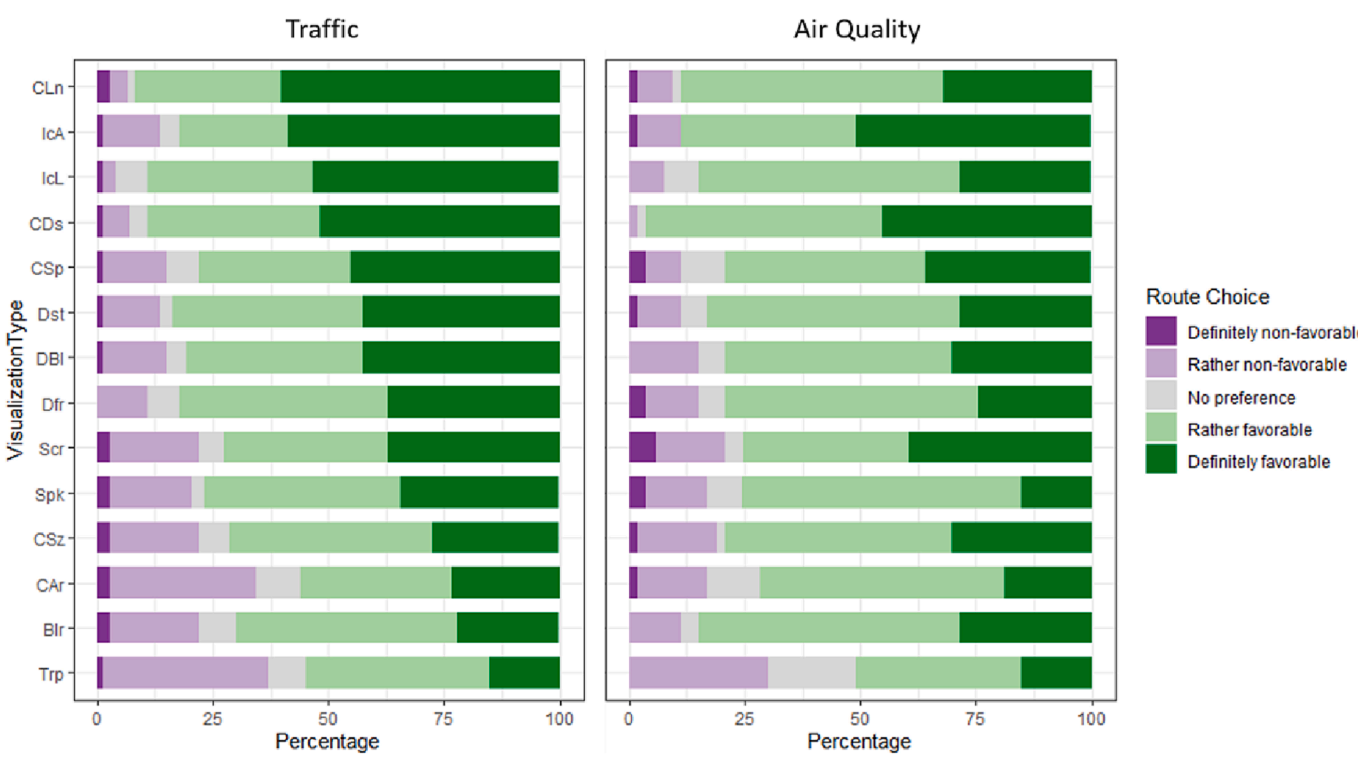

Fig. 7. Route choice preference percentages for the *modified* maps, based on the 5-point Likert scale.

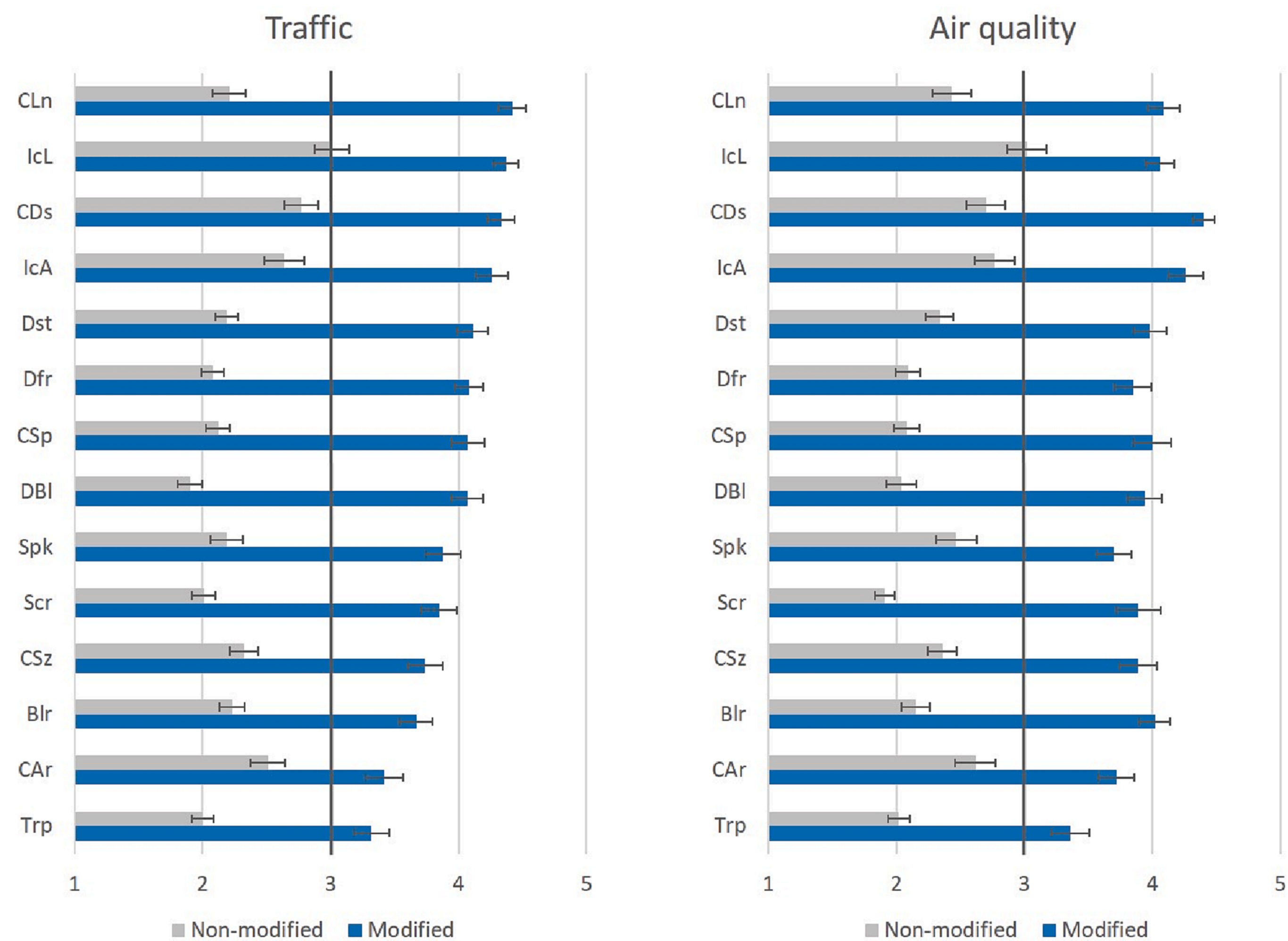

Fig. 8. Mean route choice results for the non-modified and modified maps based on the 5-point Likert scale (1 = *definitely non-favourable*, 2 = *rather non-favourable*, 3 = *no preference*, 4 = *rather favourable*, 5 = *definitely favourable*). The error bars indicate the standard error.

are shown in descending order based on the results for the *traffic* scenario. The vertical line depicting the option *no preference* (value 3 at the x-axis) as a threshold between favoured and non-favoured maps has been visually highlighted to facilitate estimating trends in the data.

As shown by the mean values being less than three, unsurprisingly, in most cases participants chose the shorter route option (i.e., the unfavourable route) when viewing the non-modified maps. In the modified maps, we can observe a clear shift towards choosing the longer, favourable route for all visualisation variants in both scenarios. In other words, visual communication for influencing route choice generally seems to have worked as we predicted in hypothesis *H1*. However, there are some interesting differences between the variants. Unsurprisingly, the widely used and generally well-known *Colour Line* (*CLn*) variant was effective, and participants' preference for the societally favourable route was higher for the *traffic* scenario than the *air quality* scenario. Other variants such as *Transparency* (*Trp*) or *Colour Area* (*CAr*) seem to be less effective. The efficacy also seems to increase when combining the *CAr* variant with other visual variables – for example for the variants *CDs*, *CSz*, and *CSp*. In general, we can also observe that visualisations that only modify lines were more effective in the *traffic* scenario, while areal modifications were more effective for the *air quality* scenario, as we predicted in hypothesis *H3*.

To assess whether the variables *modification, visualisation variant* and *scenario* have an influence on participants' route choice, we performed ordinal regression by defining a *Cumulative Link Mixed Model (CLMM)*, using the *ordinal* and *emmeans* packages in *R*.

To verify that our sample size was appropriate for performing ordinal regression, we performed a post-hoc power analysis using the R package "popower" (Whitehead, 1993). Since our primary aim in this study was to compare modified vs. non-modified maps, the power analysis was done based on the factor *modification*. Because the analysis has been done as a post-hoc power analysis, we used the actual proportions to calculate the odds ratio rather than the expected proportions. Since the proportions of choosing the favourable route differ considerably between modified and non-modified maps, a very high odds ratio (OR) of 17.31 could be obtained.

Consequently, considering the sample sizes for both scenarios, we achieved a power of one in both cases. Hence, we can conclude that the sample data was appropriate for performing the regression analysis.

The first ordinal regression model tested the influence of map *modification* (*modified* or *non-modified*) and *visualisation variant* on route choice, while considering the data from the two scenarios in separate analyses (*traffic* scenario: $R^2_{Nagelkerke} = 0.48$; *air quality* scenario: ($R^2_{Nagelkerke} = 0.51$)). For both scenarios, ANOVA results reveal a significant main effect of *modification* (*traffic* scenario: X^2 $(1, N = 73) = 1016.14$, $p < 2.2\text{e-}16$; *air quality* scenario: X^2 $(1, N = 53) = 807.01$, $p < 2.2\text{e-}16$), and *visualisation variant* (*traffic* scenario: X^2 $(13, N = 73) = 138.43$, $p < 2.2\text{e-}16$; *air quality* scenario: X^2 $(13, N = 53) = 107.05$, $p < 2.2\text{e-}16$). We further found a significant interaction effect for *modification* and *visualisation variant* (*traffic* scenario: X^2 $(13, N = 73) = 68.56$, $p = 1.476\text{e-}09$; *air quality* scenario: X^2 $(13, N = 53) = 35.78$, $p < .001$), indicating that for different visualisation variants, route choice behaviour differs depending on the modification type.

Pairwise comparisons among estimated marginal means (EMMs) further confirm a significant difference of route choice between *non-modified* and *modified* maps for all visualisation variants. Table 1 summarises the mean route choice values (for *non-modified* and *modified*), the difference between the non-modified and modified preferences (*shift*) and test statistics (*estimate, z*-score and *p*-value), as well as the effect size (Cohen's *d*) for the *traffic* and *air quality* scenarios. Except for the variant *CAr* (*medium effect* for both scenarios), we found a *large effect* for all visualisation variants in both scenarios regarding the difference between route choice for the non-modified and corresponding modified map. Taking the visualisation variant *Distortion Blur (DBl)* in the *traffic* scenario as an example, we can draw the following conclusions from the table: While users on average chose rather the shorter, non-favourable route in the non-modified maps (value for *n.-mod* close to 2), route choice has been influenced considerably when showing the modified map, towards on average choosing rather the longer, but societally favourable route (value for *mod.* that was close to 4).

For further analysis, we calculated the difference between the mean route choice values for the modified maps and those for the non-modified maps as a new variable. We applied ordinal regression to test for a possible difference regarding the scenario and the visualisation variant. The regression model provided results that are very similar to those for route choice for the modified maps. The similarity of results confirms the adequateness of the route pair selection. The analysis using the *shift* as the dependent variable is provided in the supplementary materials.

H2: Scenario-dependent willingness to adapt route choice behaviour

We next tested the influence of the scenario (*traffic* or *air quality*) and visualisation variant (14 visualisation variants of route maps) on route choice for the modified maps. For that, we applied two-way repeated-measures ordinal regression with *CLMM*. The regression model was defined by using *route choice* as the dependent variable, and *scenario* and *visualisation variant* as independent variables (fixed effects), and *participant* as a random effect.

The results for the regression model ($R^2_{Nagelkerke} = 0.41$) showed a significant main effect for the *visualisation variant* (X^2 (13, $N = 126$) = 201.59, $p <$ 2e-16), but not for *scenario* (X^2 (1, $N = 126$) = 0.73, p =.39). This indicates that the type of visualisation used in the modified maps has a significant influence on route choice. Different than we predicted in hypothesis *H2*, the main effect for *scenario* was not significant. However, we found a significant interaction effect for *scenario* and *visualisation variant* (X^2 (13, $N = 126$) = 32.04, p =.002), indicating that for different visualisation variants, route choice behaviour differs depending on the scenario.

Post-hoc comparisons comparing different visualisation variants revealed that route choice behaviour differs significantly between many visualisation pairs (see Table D in the supplementary materials). In particular, *Transparency (Trp)* differs from most of the other visualisation variants in terms of its effectiveness. Participants were significantly less likely to choose the societally favourable route when viewing the *Trp* variant as compared to other visualisation variants; ten visualisation pairs were significantly different in the *traffic* scenario, six pairs in the *air quality* scenario. For the *traffic* scenario, the smallest significant difference was for the pair *Trp, Scr* (*estimate* = -1.3), while the largest difference is reached by the pair *Trp, CLn* (*estimate* = -2.97). Similarly, for the *air quality* scenario, the smallest significant difference is observed for the pair *Trp, Blr* (*estimate* = -1.52), while the largest difference is reached by the pair *Trp, CDs* (*estimate* = -2.62).

H3: Scenario-dependent effectiveness of symbolisation dimensions

To examine whether the effectiveness of different symbolisation dimensions (line, area, line + area) depends on the scenario (*H3*), we constructed an ordinal regression model with *scenario* and *symbolisation dimension* as independent variables, *route choice* as the dependent variable and *participant* as a random effect. Results for the regression model ($R^2_{Nagelkerke} = 0.31$) reveal that the *symbolisation dimension* did not have an effect on route choice (X^2 (2, $N = 126$) = 1.4, p =.5), but the interaction between *scenario* and *symbolisation dimension* was significant (X^2 (2, $N = 126$) = 7.67, p =.02). This indicates that for the different symbolisation dimensions, route choice behaviour differs depending on the scenario – supporting our assumption of line type modifications would be more effective for the *traffic* scenario and area type modifications would be more effective for the *air quality* scenario.

However, pairwise comparisons did not show any significant relationships between scenarios and dimensions. This can be explained by the relationship between the ANOVA and the (Tukey) post-hoc test not being one-to-one. Thus, non-significant post-hoc results might be due to pairwise comparisons not considering the distribution of all tested group means as a whole. Hence, the distribution of means (clustered or even) could lead to different results for the ANOVA. In summary, it seems that hypothesis *H3* is to some extent supported, but as post-hoc results have shown, a scenario-dependent difference in effectiveness of symbolisation dimensions could not be statistically verified.

H4: Emotional responses to map symbols

In the following section, we describe the results related to the participants' felt emotions based on the data collected using the *Geneva*

Table 1
Mean route choice values (non-modified (n.-mod.), modified (mod.)), shift variable and statistics for EMM pairwise comparisons (estimate (est.), z-score and p-value), n = 73 (traffic), n = 53 (air quality), *** p <.001. P-value adjustment using the Tukey method. Effect size (Cohen's d): small effect: 0.2 ≤ d < 0.5; medium effect: 0.5 ≤ d < 0.8; large effect: d ≥ 0.8 (Cohen, 1988).

Variant	Traffic							Air quality						
	n.-mod.	*mod.*	*shift*	*est.*	*z*	*p*	*d*	*n.-mod.*	*mod.*	*shift*	*est.*	*z*	*p*	*d*
Blr	2.23	3.67	1.44	−2.41	−7.79	**<0.001*** **	1.11	2.15	4.02	1.87	−3.85	−9.78	**<0.001*** **	1.47
CAr	2.51	3.42	0.91	−1.69	−5.34	**<0.001*** **	0.59	2.62	3.72	1.1	−2.24	−5.79	**<0.001*** **	0.75
CDs	2.77	4.33	1.56	−2.87	−8.79	**<0.001*** **	1.01	2.7	4.4	1.7	−3.66	−9.25	**<0.001*** **	1.41
CLn	2.21	4.42	2.21	−4.41	−12.59	**<0.001*** **	1.57	2.43	4.09	1.66	−3.5	−8.78	**<0.001*** **	1.26
CSp	2.12	4.07	1.95	−3.54	−10.85	**<0.001*** **	1.5	2.08	4	1.92	−4.01	−10.2	**<0.001*** **	1.66
CSz	2.32	3.74	1.42	−2.52	−8.06	**<0.001*** **	1.01	2.36	3.89	1.53	−3.15	−8.18	**<0.001*** **	1.09
DBl	1.9	4.07	2.17	−4.12	−12.43	**<0.001*** **	1.62	2.04	3.94	1.9	−4.11	−10.3	**<0.001*** **	1.77
Dfr	2.08	4.08	2	−3.54	−11.05	**<0.001*** **	1.7	2.09	3.85	1.76	−3.61	−9.34	**<0.001*** **	1.51
Dst	2.19	4.11	1.92	−3.37	−10.47	**<0.001*** **	1.5	2.34	3.98	1.64	−3.27	−8.51	**<0.001*** **	1.22
IcA	2.64	4.26	1.62	−3.26	−9.41	**<0.001*** **	0.98	2.77	4.26	1.49	−3.42	−8.44	**<0.001*** **	0.98
IcL	3.01	4.37	1.36	−2.53	−7.8	**<0.001*** **	0.93	3.02	4.06	1.04	−2.15	−5.66	**<0.001*** **	0.84
Scr	2.01	3.85	1.84	−3.36	−10.35	**<0.001*** **	1.35	1.91	3.89	1.98	−4.4	−10.84	**<0.001*** **	1.59
Spk	2.19	3.88	1.69	−3.18	−9.64	**<0.001*** **	1.09	2.47	3.7	1.23	−2.54	−6.63	**<0.001*** **	0.98
Trp	2	3.32	1.32	−2.36	−7.45	**<0.001*** **	0.92	2.02	3.36	1.34	−2.67	−6.94	**<0.001*** **	1.04

Emotion Wheel.

Following the common categorization of emotions into positive and negative valence as proposed in the circumplex model of emotions (Russell, 1980), we categorized the emotion terms into negative and positive emotions. Fig. 9 provides an overview of the percentages of participants who felt *positive, negative, no* emotion, or *other* emotions related to the *societally favourable* and the *non-favourable* route for the 14 different visualisation variants, separately for the *traffic* and *air quality* scenarios. As hypothesized in *H4*, favourable routes have been mainly associated with positive or no emotions, while non-favourable routes have been mainly associated with negative emotions. However, there are some interesting differences between the visualisation variants, as well as between the scenarios. For example, we can observe that for most of the variants the non-favourable route has evoked negative emotions among a higher percentage of participants in the *air quality* scenario – particularly for those visualisation variants that visualise areal features. This might be related to negative emotions associated with air pollution (Böhm & Pfister, 2008). For positive emotions, the differences between the scenarios were smaller. However, visualisation variants involving a colour area background (*Colour Area* (*CAr*), *Colour Size* (*CSz*), *Colour Spikes* (*CSp*), *Colour Distortion* (*CDs*)) generally evoked a higher proportion of negative emotions even among the favourable routes. This, again, is particularly observable for the *air quality* scenario.

In Fig. 10, we show the variety of emotions that have been felt for the visualisation variant *Scribble (Scr)* in the *traffic* scenario as an example. It is clear that participants felt mostly positive emotions (or no emotions) about the societally favourable route, while they felt mostly negative emotions for the non-favourable route. The corresponding figures for all other visualisation variants are provided as supplementary material (Figure E). For another detailed illustration of the percentages of felt emotions (related to the 20 different emotion terms) for each visualisation variant, refer to a set of radar charts (Figure F) in the supplementary materials.

The results regarding the percentages of felt emotions show some interesting patterns. While societally favourable routes mainly evoke either no emotions or positive emotions such as *contentment* or *relief*, the emotions felt for non-favourable routes are more diverse. For many of the visualisation variants, the non-favourable route seems to have evoked the emotion *fear*. This is particularly the case for the variants *Scr, IcA, Dfr*, and the colour-based variants *CAr, CSz, CSp* and *CDs*. But other negative emotions such as *anger*, *disappointment*, *regret*, or *disgust* have also been felt relatively often. While the emotion *anger* has been felt by a particularly high percentage of participants for the *Colour Line* (*CLn*) variant in the *traffic* scenario, the emotion *disgust* has mostly been felt when looking at the colour-based variants in the *air quality* scenario and the *Scribble* (*Scr*) variant. In several cases, the positive emotion *interest* has been selected for the non-favourable route. This might be due to interest in what the visualisation intends to communicate, and therefore could be a potential sign of ambiguity of the symbolisation.

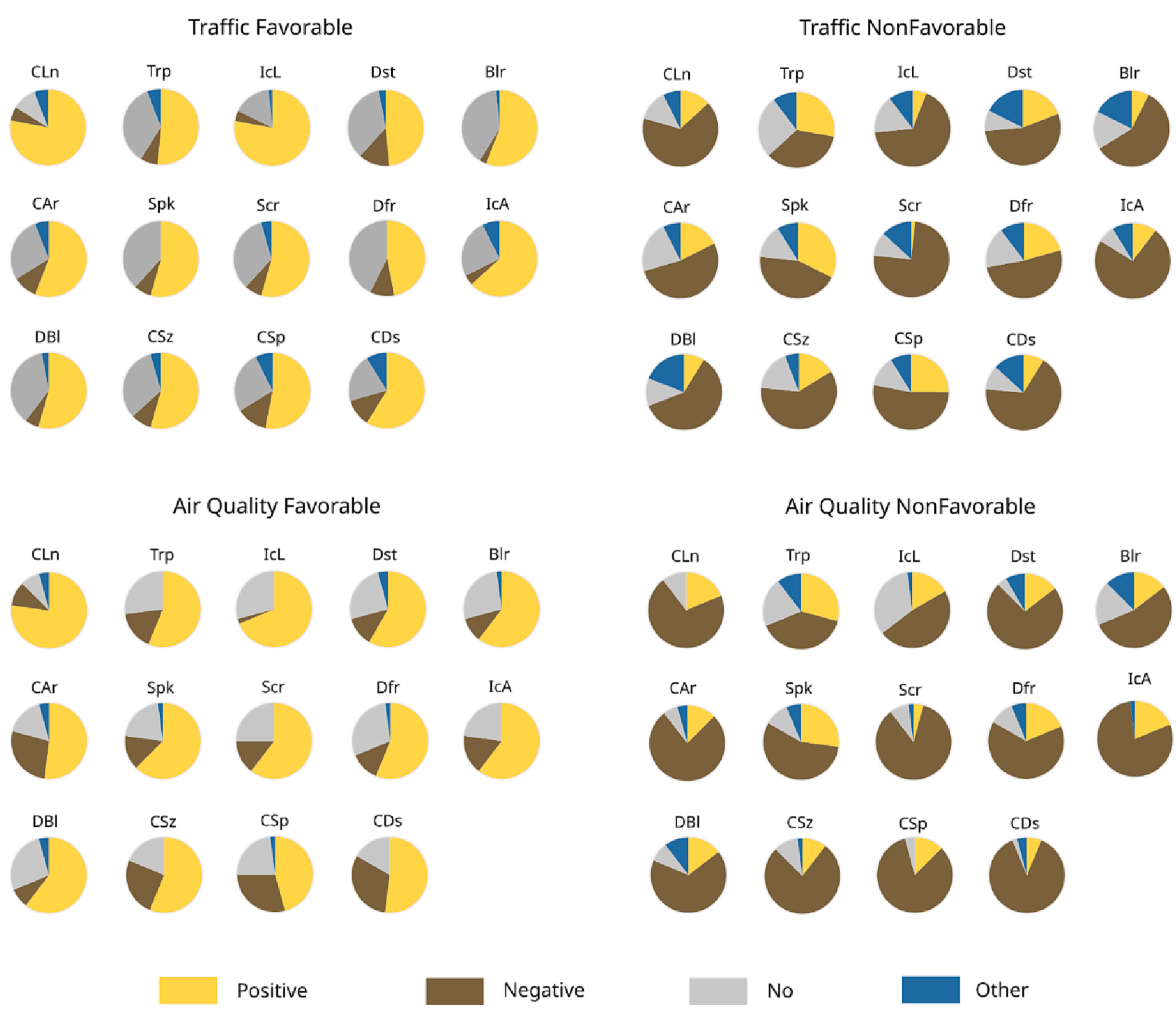

Fig. 9. Percentages of emotions felt related to the different visualisation variants for the societally favourable and non-favourable route in the two different scenarios *traffic* and *air quality*. Emotions have been classified into *positive*, *negative*, *no* (emotion), and *other* (emotion).

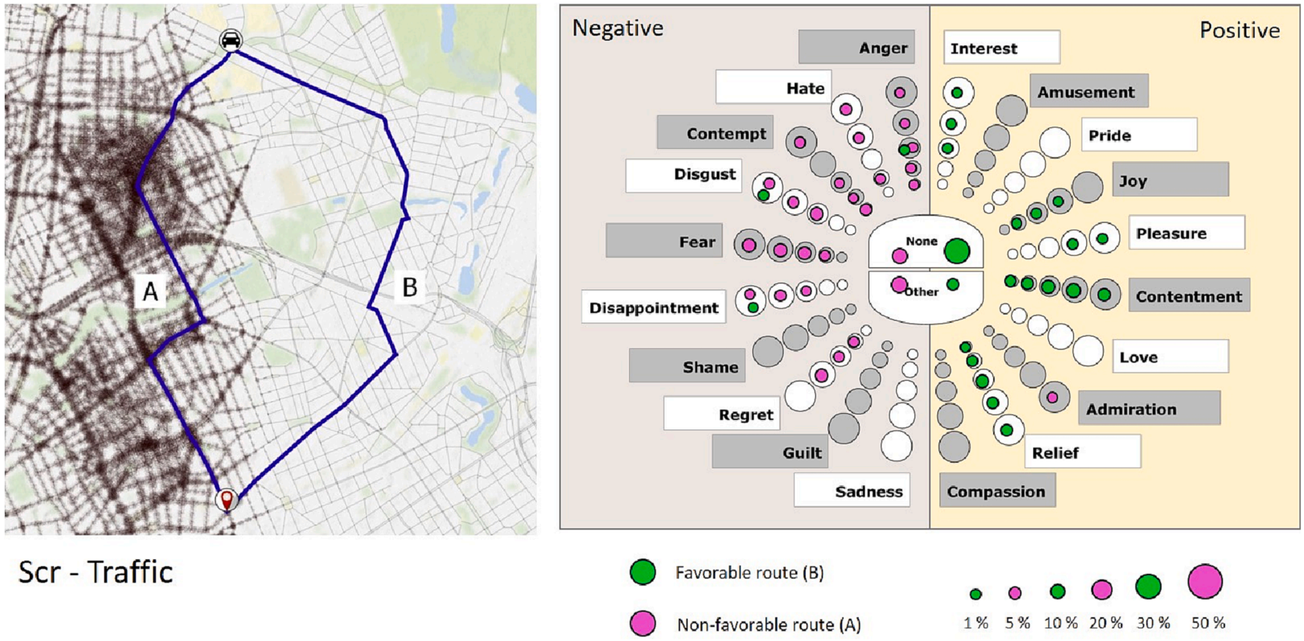

Fig. 10. Percentages of felt emotions, visualised for the *Scribble (Scr)* variant in the *traffic* scenario. See similar figures for the other visualisation variants in the supplementary materials (Figure D).

H5: Effect of emotions on route choice decision making

We hypothesized there might be a relationship between participants' felt emotions and their route choice decisions (*H5*). We performed binary logistic regression to assess whether the felt emotions related to the modified map visualisations significantly predict a route choice decision in favour of the societally favourable route.

We recoded route choice values from the 1–5 scale to binary format, with value 1 indicating route choice in favour of the favourable route (original values 4 and 5) and the value 0 indicating route choice in favour of the non-favourable route or no preference (original values 1, 2 and 3). Additionally, the nominally scaled emotion variable with the characteristics *positive, negative, no* emotion, and *other* emotion has been coded as follows: While responses for no emotion have been coded as 0, negative emotions have been coded as values ranging from -1 to -5. For this, the value -1 has been multiplied with the value for the corresponding intensity of the emotion as indicated by the participant in the Geneva Emotion Wheel (ordinal values between 1 and 5). The same principle has been applied for positive emotions, resulting in values that range from 1 to 5, with the value 1 being multiplied with the intensity value of the emotion. Due to its limited informative value, responses for the option *other* emotion have not been considered as part of the model.

For most of the visualisation variants, the model suggests that the emotions evoked by viewing the map representations have an impact on participants' route choice behaviour. Table 2 summarises the regression coefficients and odds ratios for the binary logistic regression model. For each visualisation variant, the results are provided separately for the two scenarios and within each scenario, we distinguish between emotions related to the societally favourable route (*Fav*) and emotions related to the societally non-favourable route (*N_Fav*).

We can observe that for the emotions related to the favourable route, in most cases, a route decision in favour of the favourable route is more likely if a positive emotion has been felt regarding the visualisation of the favourable route (odds ratio > 1), while for the non-favourable route, this is more likely to occur in the case of a felt negative emotion (odds ratio < 1). However, there are some deviations from this pattern. While for the non-favourable route, in all cases, negative emotions are more likely to influence route choice in favour of the favourable route, there are some cases in which negative emotions for the favourable route influence route choice. This pattern is for example observable for the *Colour Distortion* (*CDs*) variant in the *traffic* scenario (odds ratio $= 0.939$) and the *Colour Size* (*CSz*) variant (odds ratio $=$ 0.902) in the *air quality* scenario. Many of these cases relate to area modifications such as variants using a colour background. As the analysis on emotions has shown, these types of visualisations evoke a variety of emotions and due to their areal nature, negative emotions may not only be associated with the non-favourable route but to some extent also with the favourable route.

In the *traffic* scenario, three relations have been found significant, while for the *air quality* scenario, six relations are significant. This indicates a slightly higher importance of emotions for making a route choice decision in the *air quality* scenario. Furthermore, significant relations have been primarily found for emotions related to the non-favourable route (seven relations), while for the favourable route, only two significant relations have been found. Supporting hypothesis *H5*, this finding indicates that both positive and negative emotional responses to map visualisations can influence route choice. However, negative emotions related to non-favourable routes are more likely to influence route choice behaviour than positive emotions related to favourable routes.

Suitability of visualisations

Fig. 11 provides the results for the suitability ranking of the different visualisation variants based on the percentages of assigned ranks. Results for the suitability of visualisation variants are shown in descending order, based on ranks 1 and 2 in the *traffic* scenario.

In general, the pattern is consistent with the route choice results. The *Colour Line* (*CLn*) variant, for example, is rated as suitable for the *traffic* scenario, but comparatively less suitable for visualising *air quality* information. The *Icons Line* (*IcL*) variant is another line type modification that has been found relatively suitable for visually communicating *traffic* information. While there is a clear favourite for the *traffic* scenario, the most suitable representation for *air quality* is less clear. Although the *CLn* variant was on average also rated as most suitable for visually communicating *air quality*, there is a tendency for variants using areal modifications being rated as more suitable for communicating the *air quality* scenario than line type modifications – such as the colour-based

Table 2
Test statistics for the binary logistic regression model including the regression coefficient (*Reg Coef*), the *Odds Ratio* (Exp(B)) and the *p*-value, * $p < .05$, ** $p < .01$. For each variant, statistics are provided for emotions related to the societally favourable route (*Fav*) and the societally non-favourable route (*N_Fav*).

Variant	Traffic *Emotion_Route*	*Reg Coef*	*Odds Ratio*	*p*	Air Quality *Emotion_Route*	*Reg Coef*	*Odds Ratio*	*p*
Blr	Fav	0.152	1.164	0.289	Fav	-0.13	0.878	0.505
	N_Fav	-0.279	0.757	0.051	N_Fav	-0.14	0.869	0.412
CAr	Fav	0.139	1.149	0.295	Fav	0.103	1.108	0.408
	N_Fav	-0.264	0.768	**0.009****	N_Fav	-0.174	0.84	0.147
CDs	Fav	-0.063	0.939	0.717	Fav	0.343	1.409	0.365
	N_Fav	-0.177	0.838	0.229	N_Fav	-0.653	0.52	**0.042***
CLn	Fav	-0.023	0.977	0.895	Fav	0.023	1.023	0.911
	N_Fav	-0.231	0.794	0.105	N_Fav	-0.357	0.7	**0.036***
CSp	Fav	0.041	1.042	0.768	Fav	0.221	1.247	0.165
	N_Fav	-0.181	0.834	0.059	N_Fav	-0.29	0.748	**0.035***
CSz	Fav	-0.032	0.968	0.8	Fav	-0.103	0.902	0.505
	N_Fav	-0.269	0.764	**0.01***	N_Fav	-0.186	0.831	0.156
DBl	Fav	-0.1	0.905	0.606	Fav	-0.038	0.962	0.837
	N_Fav	-0.241	0.786	0.184	N_Fav	-0.176	0.839	0.251
Dfr	Fav	0.105	1.111	0.513	Fav	0.418	1.518	**0.041***
	N_Fav	-0.032	0.968	0.779	N_Fav	-0.427	0.652	**0.013***
Dst	Fav	0.005	1.005	0.97	Fav	-0.01	0.99	0.963
	N_Fav	-0.063	0.939	0.611	N_Fav	-0.316	0.729	0.067
IcA	Fav	-0.011	0.989	0.954	Fav	-0.048	0.953	0.816
	N_Fav	-0.294	0.746	**0.019***	N_Fav	-0.292	0.747	0.058
IcL	Fav	0.108	1.114	0.563	Fav	0.502	1.652	0.082
	N_Fav	-0.216	0.805	0.244	N_Fav	-0.309	0.734	0.222
Scr	Fav	0.168	1.183	0.178	Fav	0.182	1.2	0.211
	N_Fav	-0.261	0.771	0.125	N_Fav	-0.311	0.733	0.06
Spk	Fav	0.222	1.249	0.083	Fav	-0.01	0.99	0.943
	N_Fav	-0.152	0.859	0.15	N_Fav	-0.225	0.799	0.065
Trp	Fav	0.241	1.273	0.065	Fav	0.27	1.311	**0.047***
	N_Fav	-0.127	0.88	0.271	N_Fav	-0.096	0.909	0.466

variants (*CAr*, *CSz*, *CSp* and *CDs*) and the *Scribble* (*Scr*) variant.

Further factors influencing route choice

To conclude the analysis of the user study results, we examined a possible influence of gender on route choice. We performed ordinal regression to test whether gender has an influence on route choice, with *gender* and *visualisation variant* as independent variables, and *route choice* as the dependent variable.

While *visualisation variant* has a significant effect on route choice (X^2 (13, $N = 126$) = 196.16, $p = < 2e\text{-}16$), the influence of *gender* was not significant (X^2 (1, $N = 126$) = 0.001, $p = .97$). Similarly, the interaction between *visualisation variant* and *gender* was not significant (X^2 (13, $N = 126$) = 13.27, $p = .43$). This indicates that the differences in route choice behaviour among the different visualisation variants do not depend on gender. A further tested interaction between *scenario* (X^2 (1, $N = 126$) = 0.81, $p = .37$) and *gender* (X^2 (1, $N = 126$) = 0.02, $p = .89$) when making route choice decisions also was not significant (X^2 (1, $N = 126$) = 1.99, $p = .16$).

We did include age as an independent variable, since a look at the age distribution of participants revealed that the majority of participants was aged 30 years or younger (74 % in the *traffic* scenario and 64.2 % in the *air quality* scenario), and therefore a comparison between age groups would not have provided meaningful information.

Discussion

The results of the user study have shown that the most appropriate design decision for nudging a traveller's route choice towards a *societally favourable* route varies depending on the phenomenon that is communicated. Furthermore, different types of symbolisation evoke different emotions that in some cases seem to contribute to decision making. Our findings demonstrate the importance of appealing to people's emotions related to the communicated situation for achieving a behaviour change in route choice (Roeser, 2012), by applying suitable map symbolisation.

We discuss our findings with a focus on the influence of different visualisation variants on route choice and the effects of emotions on route choice. In this context, we discuss to which extent the five

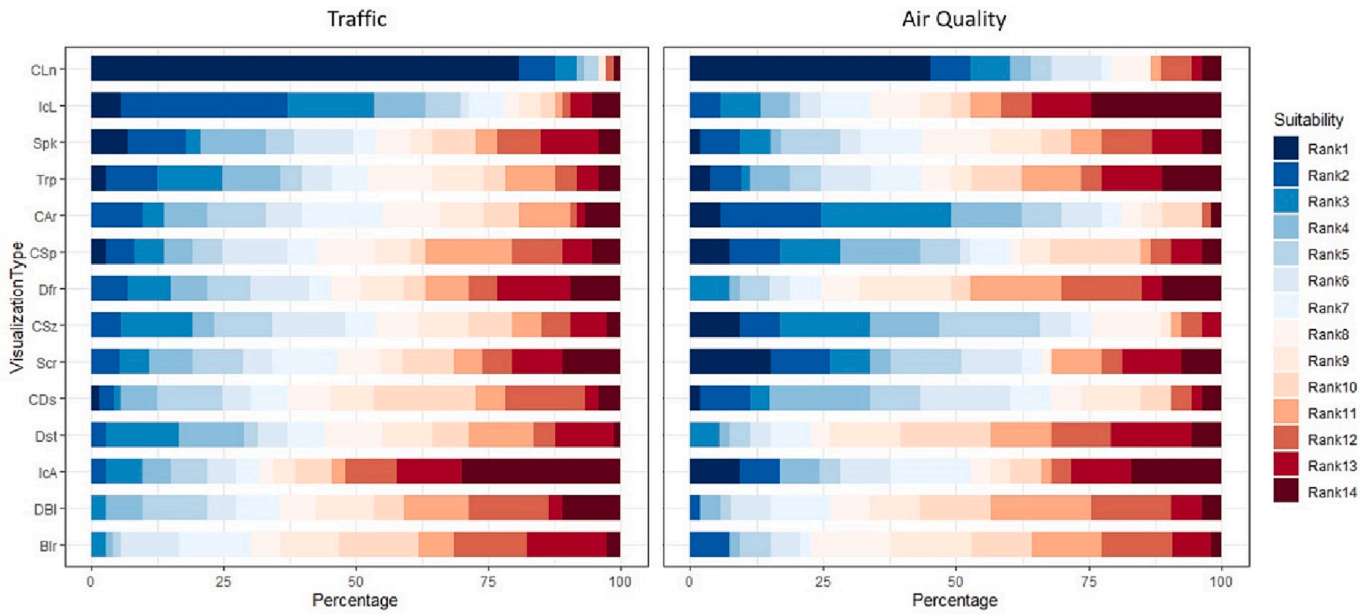

Fig. 11. Stacked bar charts illustrating the percentages of ranks assigned to visualisation variants for estimating suitability of visualisations for communicating the scenarios *traffic* or *air quality*. Rank 1 indicates the highest suitability, Rank 14 the lowest.

hypotheses could be supported by the results of our user study. Based on this discussion, we propose *successful* visualisation variants for visually communicating *societally favourable* routes. We conclude with some limitations of the study design and an outlook for future research directions.

Influence of different visualisation variants on route choice

The route choice models supported our hypothesis (*H1*) that the map-reader's route choice decision can be influenced towards choosing a *societally favourable* route for all visualisation variants (Fuest et al., 2021). The fact that *scenario* was not a significant factor in this model leads us to reject our hypothesis (*H2*) that participants would exhibit a higher willingness for showing pro-social behaviour in the *traffic* scenario than in the *air quality* scenario. Different than suggested by Roeser (2012), participants seemed to feel affected by the introduced environmental impact, since our study has shown that environmental issues such as air pollution motivated people to a similar extent to choose a *societally favourable* route as did disruptions in traffic conditions. As Banks and collaborators (1995) suggest, these results further verify the effectiveness of the applied loss framing for evoking a behaviour change, related to scenarios that are considered risky or potentially hazardous for the population. The emotions evoked by the map symbolisation may also have motivated a change in environmental behaviour (Roeser, 2012).

Rather, the results suggest that participants' willingness to follow the route recommendation depends more heavily on the visualisation chosen for the particular scenario. In the following, we discuss the performance of several visualisation variants that yielded particularly interesting or surprising results.

As hypothesized in *H3*, the results of the user study have shown that line type visualisations were most effective for the *traffic* scenario, while in the *air quality* scenario, areal symbols were more effective. In the *air quality* scenario, we also found that variants using a colour area background are effective for symbolising emissions. Hence, results verified that choosing commonly applied types of visualisation for the two scenarios (Kubíček et al., 2017; Lahr & Kooistra, 2010) also leads to a higher effectiveness for influencing route choice.

The results also showed that the *Colour Line* (*CLn*) variant, which is widely known and used for depicting traffic data, has performed well for influencing route choice in the *traffic* scenario. Although this variant also performed reasonably well in the *air quality* scenario, there are clear differences in its effectiveness, but particularly in its suitability between the scenarios. The still relatively good performance of the *CLn* variant for the *air quality* scenario could be explained by the fact that symbolisation using coloured lines is a very common type of visualisation in route maps that might still be reasonable and understandable to some extent, despite its atypical application to an 'areal' scenario.

The results for the *Icons Area* (*IcA*) variant are somewhat surprising. Despite the low suitability rating of this variant for communicating favourability of routes, this variant was in fact effective for influencing route choice. Additionally, this variant evoked strong emotions such as fear for the societally non-favourable route, indicating it is a very emotive symbolisation method. The effectiveness of icons for conveying the seriousness of the communicated situation has also been verified by Pirani and collaborators (2020). This clear contradiction between effectiveness and rated suitability suggests this type of visualisation might be very controversial, which therefore may not make it appropriate for universal usage. The effectiveness and suitability of this visualisation variant may vary depending on the choice of the icon. As reported by participants in their free text comments, using skull icons may be too drastic; others had difficulties taking the visualisation seriously. Therefore, a different icon choice may lead to markedly different results.

The results based on pairwise comparisons between the different visualisation variants further suggest that the variant *Transparency* (*Trp*) performs differently from most other variants. In particular, its effectiveness was low for both scenarios. The felt emotions results further indicate that due to the high percentage of participants selecting the emotion *interest* for the societally non-favourable route, the symbolisation might be ambiguous for some map users. Given its relatively low suitability rating, we can conclude that the variant *Trp*, at least as we operationalized it, was not successful for influencing route choice. Interestingly, the *Trp* variant as used in this study visually resembles the *noise* variant as presented in Carroll et al. (2020), which they found to be effective for emotionally influencing the user's choice of the optimal path. The low effectiveness of using transparency for symbolising route options in our study might be related to difficulties in associating the symbolisation with the two scenarios.

The effect of emotions on route choice

The emotions that participants felt were consistent with our hypothesis (*H4*). Routes communicated as favourable primarily evoked positive emotions, while routes communicated as non-favourable primarily evoked negative emotions. Consistent with previous research (Kelly, 2019), our findings indicated that colour in general has a great impact on emotional responses, particularly in the *air quality* scenario. Similar to their effectiveness for influencing route choice, we can particularly observe that the variants that use a colour area background evoke negative emotions among a high percentage of participants, which also influenced the emotions felt concerning the societally favourable route in the map towards a more negative emotion. Furthermore, in the *air quality* scenario, negative emotions have generally been evoked more frequently than in the *traffic* scenario, which indicates that negative consequences related to this type of environmental information seem to play a more important role in decision-making than for the *traffic* scenario.

Surprisingly, for some visualisation variants (particularly *Transparency* (*Trp*) and *Spikes* (*Spk*)), participants felt positive emotions for the route that was visually communicated as non-favourable. Taking a closer look at the specific emotions felt for these variants, it becomes apparent that the positive emotion *interest* was felt by many participants for the non-favourable route. Considering the relatively low effectiveness of the visualisation variants *Spk* and particularly *Trp*, this further raises the question, whether interest in the route visualisation might be related to uncertainty about the information that is communicated by the visualisation.

Negative emotions towards the societally non-favourable route are more likely to affect route choice behaviour than positive emotions towards the favourable route (*H5*). This pattern was observed to a greater degree in the *air quality* scenario. Considering the higher level of negative emotions felt for the maps depicting *air quality*, negative emotions associated with environmental issues such as air pollution indeed seem to have evoked a behaviour change towards a more *societally favourable* route choice decision. Hence, different than suggested by Pirani and collaborators (2020), participants reported relatively strong emotional responses to a seemingly distant topic such as air pollution. In particular, the application of framing in the context of map symbolisation might have helped presenting this kind of topic as an emotionally closer issue (Spence & Pidgeon, 2010). However, the larger impact of negative emotions towards the non-favourable route on choosing the favourable route might be biased due to our decision to primarily visually modify non-favourable routes, while the favourable route remained unmodified, except in cases where there are symbols in close proximity to the favourable route.

Successful visualisation variants for nudging travellers to societally favourable routes

The preceding analysis of the results has shown that there is no single visualisation variant that is ideal in terms of its effectiveness for influencing route choice towards choosing the societally favourable route, as well as its suitability for visually communicating the relevant information. Moreover, the most effective use of symbolisation differs depending on the scenario. In this section, we evaluate and propose *successful* visualisation variants based on different criteria and provide suggestions for potential applications.

For the *traffic* scenario, the *Colour Line* (*CLn*) variant, which is widely used for visualising traffic information, was successful based on several factors such as effectiveness and suitability. Due to their familiarity with this type of representation, map users may have felt comfortable making decisions based on the symbolisation.

Another variant that we suggest could be successful for communicating traffic information is the variant *Icons Line* (*IcL*), which uses symbols for communicating societally favourable and non-favourable parts of the route. Like the *CLn* variant, the *IcL* variant evoked positive emotions for the favourable route among a particularly high percentage of participants, which indicates that the symbolisation successfully communicated the sentiment that should be associated with the route. Since we did not compare the performance of the selected icons with other possible options, its effectiveness might be altered (either positively or negatively) by choosing a different icon.

Although the *Colour Line* (*CLn*) variant also performed reasonably well for the *air quality* scenario in terms of effectiveness and suitability, we here propose a different type of visualisation as successful. The variants using a colour area background (*CAr, CSp, CSz* and *CDs*) were clearly effective for communicating air quality. This effectiveness seems to have been influenced by the emotions evoked by the map representations. For the variants *Colour Spikes* (*CSp*) and *Colour Distortion* (*CDs*), there was a significant relationship between a negative emotion related to the non-favourable route and a route choice decision in favour of the *societally favourable* route. Hence, map users seem to have successfully interpreted the symbols as an environmental hazard that should be avoided. Considering its high effectiveness for influencing route choice, we propose the *CDs* variant to be successful for nudging travellers to a *societally favourable* route that would help to improve air quality. However, since other colour area-based representations have also been found effective, further combinations with other visual variables are likely to turn out to be successful, too.

Limitations of the study design

The routes that we selected for our user study had a length between 3.5 and 7.5 km, which correspond to typical inner-city traffic (e.g. for running errands). Therefore, we did not consider longer route lengths. However, it is likely that people make different choices depending on the length of a route. For example, for longer, between-city routes, it is likely that there are fewer possible route options available, which, however, involve more different road types (such as highways or country roads). Also, driver behaviour may differ for different travel purposes, such as commutes or running errands, since factors such as time pressure might be of different importance.

Although the user study was prepared carefully to try to reduce potential sources of bias, based on comments collected from the participants regarding the study, we noticed a few issues that may have influenced the results to some extent. For example, some participants mentioned being unsure about interpreting some of the symbolisation types, while others indicated they had difficulties expressing emotions related to a map in general. This difficulty might have arisen because we asked for their *anticipated emotions*, instead of measuring actual emotions felt while exposing participants to the traffic or air quality situation.

A further limitation relates to the free text descriptions provided by participants for describing their route choice strategies and the reasons why a map symbol has been judged as helpful for making a decision or not. We intended to perform sentiment analysis using emotion lexicons for analysing the number of emotion words included in a textual description, which requires a sufficiently long text as an input, in order to provide meaningful results. However, since most participants provided rather short descriptions, we found that the data in general was not sufficient for performing this type of analysis. Examples of such descriptions are sentences like "*The symbols on the map clearly and unmistakably indicate a danger, so that you decide against this route*", but also quite short descriptions like "*Very clear representation of the traffic load*". We assume that, due to the impersonal, online setup, it is difficult to capture participants' felt emotions, and because of the length of the survey, participants may have felt less motivated to provide detailed descriptions. Therefore, we suggest that online surveys are only conditionally suitable for collecting textual or verbal descriptions for analysing emotions, while a personal interview between the experimenter and the participant might yield more useful results. Another option for possibly obtaining more useful results could be to design a similar user study that focuses only on collecting textual descriptions, which might help the participant putting more effort in providing such descriptions. Yet another possibility would be to more directly ask participants to describe emotions that they felt.

A further potential issue might be that the *Geneva Emotion Wheel* may not contain all relevant emotion terms related to this task. Participants suggested that some of the emotion terms such as *love* or *sadness* may not be appropriate in the context of route choice. They also mentioned that emotions such as *confusion, uncertainty, annoyance, stress*, or *boredom* could be considered when measuring emotions related to route maps. Furthermore, some participants mentioned that they felt multiple or mixed emotions, which may have impeded choosing one specific emotion term on the wheel.

Outlook

Since we found that emotions related to route maps played an important role in route choice decision-making, we plan to conduct further research that investigates the effectiveness of other means of evoking emotions in route maps. In this context, textual descriptions, sonification (Edsall, 2010), or animations are potential approaches that could enhance effectiveness for influencing route choice by intensifying emotional responses.

Furthermore, since the results showed that visualisation variants differed in their effectiveness for influencing route choice and felt emotions depending on the scenario, additional scenarios could be studied with the aim to recommend *societally favourable* routes. This may also involve the generation of further visualisation variants.

Conclusion

In this study, we investigated how emotional responses to cartographic symbols can influence a traveller's route choice decision towards choosing a route option that is favourable from a societal point of view. The results of the user study verify the effectiveness of visual communication for influencing route choice using map symbols for the two tested scenarios *traffic* and *air quality*. Visualisations that only modify lines were more effective in the *traffic* scenario, while areal modifications were more effective for the *air quality* scenario.

We have shown that the different visualisation variants have evoked a wide range of emotions in participants. While non-favourable routes mainly evoke negative emotions (particularly *fear*), societally favourable routes mainly evoke positive emotions (particularly *contentment*) or no emotions. If the *air quality* scenario is introduced, the visualisations evoke a higher percentage of negative emotions as compared to the *traffic* scenario. Using binary logistic regression, we have further shown that for some of the visualisation variants, positive or negative emotions as a response to the map visualisations contributed significantly to changing the route choice decision in favour of the *societally favourable* route option. The map design rated by participants as *most suitable* seems very clear for the *traffic* scenario (*Colour Line* variant), but less clear for the *air quality* scenario. In general, it was observed that areal modifications seem more suitable for the *air quality* scenario, while line modifications seem more suitable for the *traffic* scenario.

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CRediT authorship contribution statement

Stefan Fuest: Conceptualization, Methodology, Formal analysis, Resources, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Monika Sester:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision. **Amy L. Griffin:** Conceptualization, Methodology, Formal analysis, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2023.100829.

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