An initial analysis of design parameters affecting the interpretation of noise maps: Insights gained in empirical research

Eine erste Analyse der Gestaltungsparameter, die die Interpretation von Lärmkarten beeinflussen: Erkenntnisse aus empirischer Forschung

Beate Weninger, Hamburg

In the course of the development of a colour scheme for representing noise immission in maps the author has conducted a series of analyses and user studies, all to answer concrete research questions. While the author gained pragmatic insights for the general improvement of noise maps and the development of the colour scheme she also observed effects of visual design parameters on map interpretation that were not anticipated. For map interpretation the prior knowledge about the presented phenomenon, the presented content, the visual variable colour and interactions of parameters were determining factors. It became apparent that the individual visual variable colour is only influencing map interpretation for certain tasks. Effects of design parameters therefore are task-dependent as they depend on top-down processing.

■ Keywords: map interpretation, design parameters, noise maps, visual variables, empirical cartography

Im Zuge der Entwicklung eines Farbschemas zur Repräsentation der Lärmimmission in Karten wurden Analysen und Nutzerstudien zur Beantwortung konkreter anwendungsbezogener Forschungsfragen durchgeführt. Es wurden pragmatische Erkenntnisse für die allgemeine Verbesserung sowie für die Entwicklung des Farbschemas erlangt, aber auch Effekte beobachtet, wie Gestaltungsparameter Einfluss auf die Karteninterpretation nehmen können. Das Vorwissen der Nutzer, die Wahl der dargestellten Information, die visuelle Variable Farbe und Interaktionen der Parameter nehmen Einfluss auf die Interpretation. Es zeigte sich, dass Farbe als visuelle Variable nur Einfluss auf bestimmte zielgerichtete Aufgaben (Tasks) hat. Effekte durch Gestaltungsparameter sind daher abhängig von den Tasks der Nutzer und unterliegen der Top-down-Verarbeitung im Wahrnehmungsprozess.

■ *Schlüsselwörter: Karteninterpretation, Gestaltungsparameter, Lärmkarten, visuelle Variablen, empirische Kartographie*

1 Introduction

A map's meaning is dependent on the subjective interpretation of the user – this sociocultural context of maps has been discussed in depth (cf. e. g. Harley, 1989, Wood, 1992). Nevertheless, the geovisual presentation of environmental information, as it is used for decision-making and knowledge transfer, e. g. in planning, is supposed to be objective. Having said this, Papadimitriou et al. (2009, p. 128) state: "Cartography offers the techniques (spatial reference and symbolization) for objective description of geographic features (both qualitative and quantitative), and supports further analysis in combination to other spatial characteristics." This reflects the presumption and ideal situation. In the matter of decision-making, objectivity is a necessary presumption, otherwise decisions based on the underlying geoinformation could not be sustained. In practice and science, nevertheless, examples show that a variety of parameters concerning map design and map content influence interpretation and therefore subsequent steps such as knowledge transfer or decision-making.

An example of environmental information that is presented in maps and is of high relevance in urban planning is noise. Sound in general is an important element of the urban environment. Places are not only characterized by their visual features but also by their sonic identity (Velasco 2000 in Papadimitriou et al. 2009, p. 1269). Physically, there is no difference between sound and noise. Sound is denominated as noise when it is "not wanted, unpleasant or loud" (Cambridge Dictionary, in Stevens, 2012, p. 82), especially if it causes disturbance. Therefore, there is no mathematical description of noise; noise is a psychosocial term and subjective. Therefore annoyance, one effect of noise, is context-dependent. For example "27 % of people are 'highly annoyed' at 55 dB (L_{den}) due to aircraft noise, whereas only 6 % of people are 'highly annoyed' by road noise of the same level" (European Environmental Agency, 2010, cited in Airports Commission, 2013, p. 11). The reason for this is that annoyance is defined by about 15 factors, such as intensity, duration, frequency, time of day, conspicuousness, habitualness for a location, and subjective mental state of the annoyed person (Berkelmann, 2009).

The second major effect of noise is an inherent risk for health. The acoustic environment has generally been associated with well-being (cf. Stockfelt, 1991, Kjellberg et al., 1996, Öhrström, 2006). Even though noise is perceived subjectively, certain sound levels cause „objectively observable harm" (Stevens, 2012, p. 88). By the World Health Organization

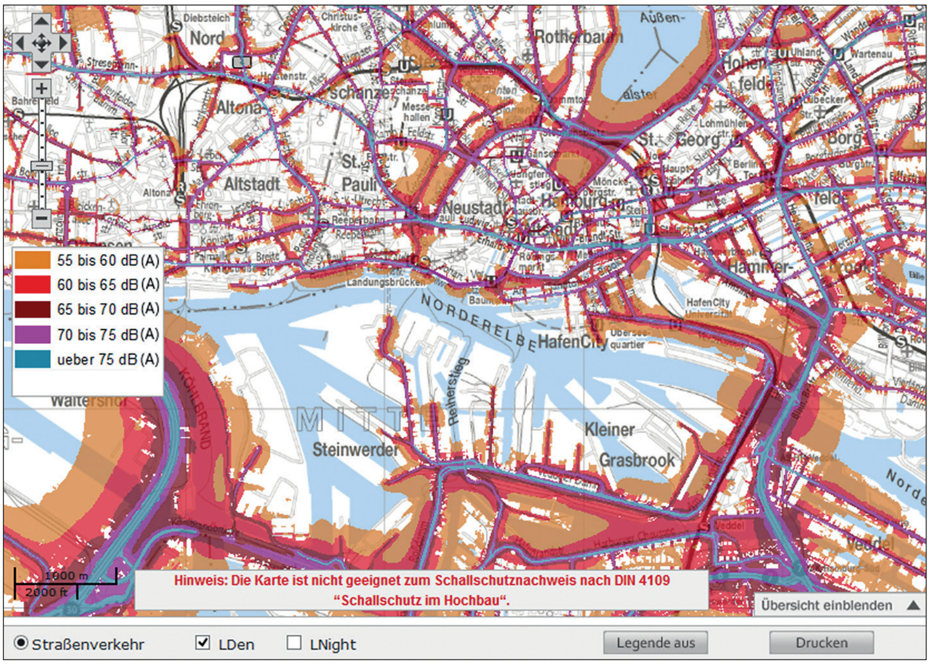

Figure 1: Detail of the END-conform traffic noise map for the City of Hamburg published in an interactive webmap. Colours are according to the German industrial standard DIN 180052:1991 (Landesbetrieb Geoinformation und Vermessung Hamburg, 2015)

(WHO) noise has been identified as the second biggest health risk after air pollution. The European Union has therefore introduced the Environmental Noise Directive (European Parliament and Council, 2002), which includes the development of noise action plans and the mandatory drawing up of noise maps every five years, starting in 2007. The focus is on environmental noise that is defined as "unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity" (European Parliament and Council, 2002, Art. 3a).

Regulations like the END aim at building an objective basis for the abatement of environmental noise. The resulting maps are used for the assessment of noise in European cities, for public participation and for formulating action plans. It is crucial that maps are the major medium that is used for informing the public about noise and that they also serve as a basis for discussion (MacDonald, 2012). It implies a quality suitable for knowledge transfer (Schiewe and Weninger, 2013). However, practical examples throughout Europe indicate that the cartographic presentation is not appropriate for a user- and application-oriented approach that would be needed for a discussion where stakeholders discuss as equals. Already the vague definition of noise provides insights into how challenging the communication of noise situations can be. Additionally, acoustic principles also contribute to this challenge (cf. 3.1 and 3.2). The message that is communicated through the map highly depends on aspects that are presented *in* the map and *how* they are presented, especially since noise is a phenomenon that is invisible.

Therefore, this article aims to outline parameters that influence noise maps' interpretation and presents an initial list. By doing so the author follows a top-down approach und discusses partly unexpected observations. Parameters presented here were gained in empirical research. In the research project at hand German noise maps were analyzed qualitatively and quantitatively to come up with requirements for the cartographic presentation of noise in END-conform noise maps. Colour was identified as the major element for presenting the noise indicators, therefore the research focus was put on developing a new colour scheme. The scheme has been developed in an iterative process, consisting of four empirical user studies and reflects characteristics of noise. Results of the research project showed that colours are important for the interpretation, nevertheless their influence depends on the task. Other elements affected the interpretation as well and indicated that for a thorough study of map interpretation interaction of design parameters has to be considered.

In the following sections the author gives an overview of the representation in strategic noise maps and existing research on noise maps. Influencing design parameters are described in four categories: users' understanding of the represented phenomenon, the importance of what information is presented, the effect of colour, and how design parameters interact with each other. An attempt to explain the observations is made in the last part.

2 Representation of noise in strategic noise maps

In accordance with the Environmental Noise Directive (END), member states are requested to draw up noise maps for major roads, railways, airports and agglomerations, so-called *strategic* noise maps, every five years, starting in 2007 (for a detailed overview of guidelines cf. Weninger, 2015a). Each noise source, such as traffic, railway, airport and industrial noise, has to be presented in an individual map. The maps present the harmonized noise indicators L_{den} (day-evening-night equivalent level) and L_{night} (night equivalent level). The indices are computed or measured according to prescribed ISO standards at an assessment level of 4 m above the ground. Existing national methods can be used if they can be adapted to the indicators set out in the END. Kephalopoulos and Paviotti (2012) discuss noise maps for different national assessment methods in detail.

The indices are presented in 5-dB-classes for equal-noise contours (isophones) of 60, 65, 70 and 75 dB (fig. 1). Visual variables used for the fillings of the contours are colour hue and colour value. The German industrial standard DIN 18005-2: 1991 gives specifications to a predefined colour scheme, however, this is not suitable for an intuitive representation of noise (cf. Weninger, 2015c, forthcoming). Besides these specifications municipalities are free to decide on the base map and on additional map content which leads to heterogeneous map products throughout Germany and Europe.

The scientific community has not approached the cartographic design of noise maps in depth. Engnath and Koch (2001), Jäger and Koch (1996), Müller and Scharlach (2001), and Scharlach (2002) give a general overview of the presentation in noise maps. All addressed the topic before the commencement of the END and therefore did not go into strategic noise maps. A multimedia approach including sound is suggested by Scharlach (2002). Michel (2008) deals with simulation and visualization of outdoor sound and thereby reflects on a variety of representation options, including 3-D representation. Engnath and Koch (2001) also covered the inadequacies of the DIN colour scheme and introduce two variations that use the two visual variables colour hue and value in a systematic manner. Alberts and Alferez (2012) designed another colour scheme for the presentation of L_{den} in strategic noise maps. They defined requirements, but use red and green in combination, colours that cannot be distinguished by about 4 percent of users with colour vision deficiencies (Jenny and Kelso, 2007). In contrast to the proposed colour scheme of the author (cf. Weninger, 2015d), no other colour scheme considers saturation systematically and was evaluated in user studies.

Besides the mentioned research none has a focus on the graphic presentation of *noise* in maps – if we ignore that there has been research about the visualization of sound (e.g. Southworth, 1969, Servigne et al., 1999, Kornfeld et al., 2011). Papadimitriou et al. (2009) examines how cartography can help the comprehension of soundscape and follows an approach from acoustic ecology, where sound is the mediator between the individual and the environment.

Previous work by the author represents a general overview about the visual encoding of acoustic parameters (Schiewe and Weninger, 2013). Results of a qualitative analysis of German official noise maps and recommendations on the presentation are given in Kornfeld et al. (2012) and Schiewe et al. (2012). Weninger (2015c, forthcoming) discusses the suitability of EN-Dconform noise maps for the purpose of informing about environmental noise and the benefits that an integration of crowdsourced noise information would have on noise maps.

One reason why the topic noise maps has not been addressed comprehensively might be that noise maps are only of great interest since 2007, when the first "round" of maps has had to be produced. Additionally, acousticians are in charge of noise modelling and therefore also produce noise maps. Their object of interest is rather the modelling than the visualization. They deal with the presentation in maps and GIS rather on a practical basis, e.g. in the course of noise management (cf. Manvell, 2013) or give examples for the use of GIS for noise mapping (e.g. Farcas and Sivertun, 2009); they do not scrutinize the suitability of the representation for the users. A discussion of the indicators presented in the maps can be found in Berkemann (2009), while McDonald (2012) focuses on noise-relevant communication to the general public.

3 Selected design parameters influencing map interpretation

In the following paragraphs the author exemplifies effects on the interpretation of noise maps describing three selected parameters. All three are considered crucial for the interpretation of maps, yet to varying degree depending on the application and map use tasks. The understanding of the phenomenon might, e.g., not be as important for a simple look-up task as for the definition of criteria for decision-support or for knowledge transfer. The selection of the presented parameters is based on results of empirical studies in the project mentioned above.

3.1 Have the users advanced understanding of the represented phenomenon?

The first and foremost aspect important for map interpretation is the users' understanding and previous knowledge of the represented phenomenon. This is especially of interest in the case of the presentation of environmental issues, such as noise, temperature, or odor that are perceived subjectively and can be emotional.

How noise is perceived depends on a variety of context information that consists of the sound events' characteristics as well as the mental state of a person (Berkemann, 2009). Thus users have a pre-defined concept of noise and add an emotional dimension, especially if they like the sound or if they find it annoying (cf. Botteldooren et al. 2006). Or as Arkette (2004, p. 160) argues "sound, especially within the context of the urban environment, is never a neutral phenomenon". Therefore peoples' perception does not necessarily have to correspond with the scientific, physical description that is used in the form of noise indicators or indices for the presentation in maps. The latter can appear abstract to people with a lack of acoustic knowledge. Especially indices can appear abstract to the general public (cf. e. g. Berkemann, 2009, McDonald 2012). The study described below gives first insights into the background knowledge of potential map users.

A study with 36 students in the fields of urban planning, civil engineering, and architecture at HafenCity University Hamburg (study no. 1) – all programms that deal with maps and plans and even acoustics – showed what is shown in noise maps is not common knowledge (Weninger, 2015a). Asked the question "What do you think is shown in noise maps?" and presented an END-conform traffic noise map, none mentioned a noise indicator, the noise index L_{den}, or sound pressure level, which would have been correct. Three answered that decibel (dB) are shown, ten that noise exposure is shown. Both are general but correct answers, especially if one knows that dB is the unit of sound pressure level. The biggest number, 15 people, thought indicated maps showed loudness, or how loud or quiet it is in an area. Many participants made a connection to traffic density and explained heavily trafficked roads are louder. This is wrong in two respects: the sound pressure level in dB does not *represent* loudness, nevertheless loudness is *dependent* on sound pressure level but also, for example, on the frequency of a sound event. Perceived loudness, presented in the unit *sone*, differs from physical loudness, presented in the unit *phon* and an increase of 10 dB results roughly in a doubling of perceived loudness (cf. Maute, 2006). Menzel and Fastl (2008) and Fastl (2013), for instance, describe how colours of trains or sports cars, respectively, affect the perception of loudness. Red cars and trains are perceived louder than cars and trains in light colours.

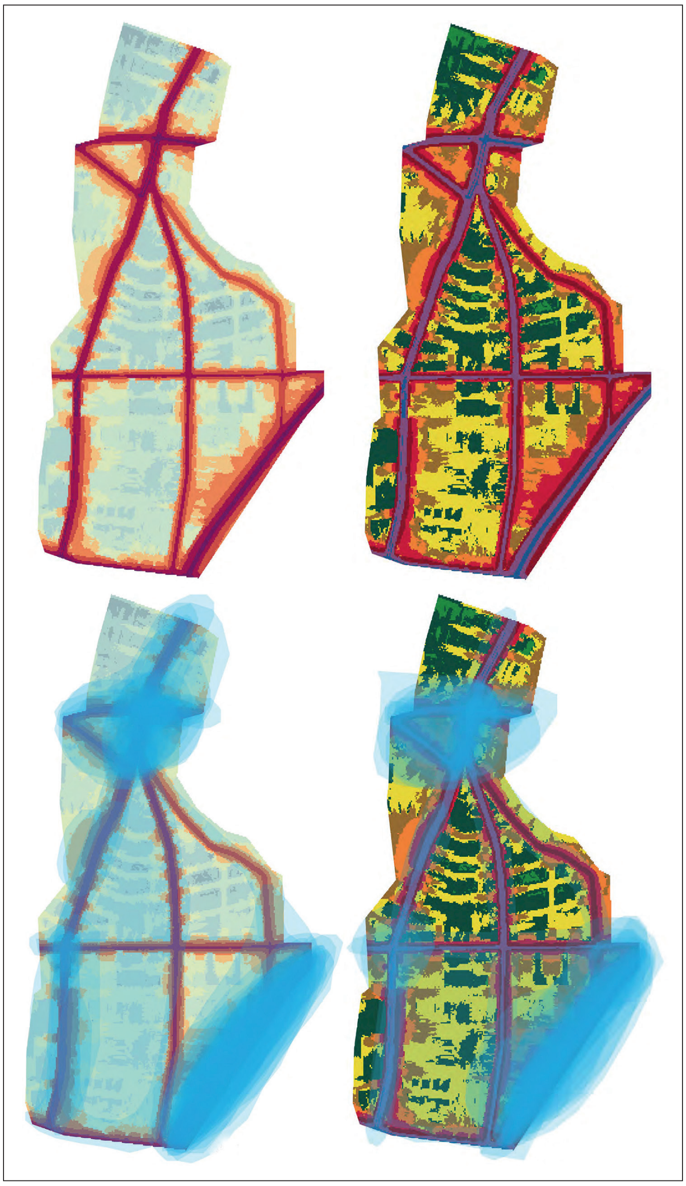

Figure 2: In a study participants had to delineate hotspots, i. e. areas of high noise exposure, in paper maps presenting noise pressure level without any topographic information in the new colour scheme (left) and the DIN-scheme (right). For the analysis the hotspots that were delineated by the users were digitized and presented as transparent layers as in the figures at the bottom ("Silent City" data set, provided by the German Federal Environment Agency and Lärmkontor GmbH)

The second misconception is that the number of cars is linearly connected to the sound pressure level. In fact, a doubling or halving of traffic volume results only in an increase or decrease, respectively, of 3 dB. The reason for this is that sound pressure level is logarithmic. The logarithmic scale was introduced because humans can perceive sound pressure from about 20 µPa (0.00002 Pa) to 200 Pa. To make data more manageable the logarithmic measure sound pressure level (SPL) in the unit dB was introduced. This results in some specialties: Higher values contribute more to a mean value than lower ones. The mean value for 60 and 80 dB is 77 dB – not as many would expect 70 dB. This is not general knowledge and therefore affects interpretation of noise data.

In the user study described above (cf. Weninger, 2015a) participants had to delineate hotspots, i. e. areas of high noise exposure, in paper maps (fig. 2) without any topographic information like roads or buildings. Participants were free to choose the number and size of hotspots. They especially defined wide roads as hotspots. This probably has two reasons: Firstly, they associate a wider band-like area of high noise pressure level with a wider road and

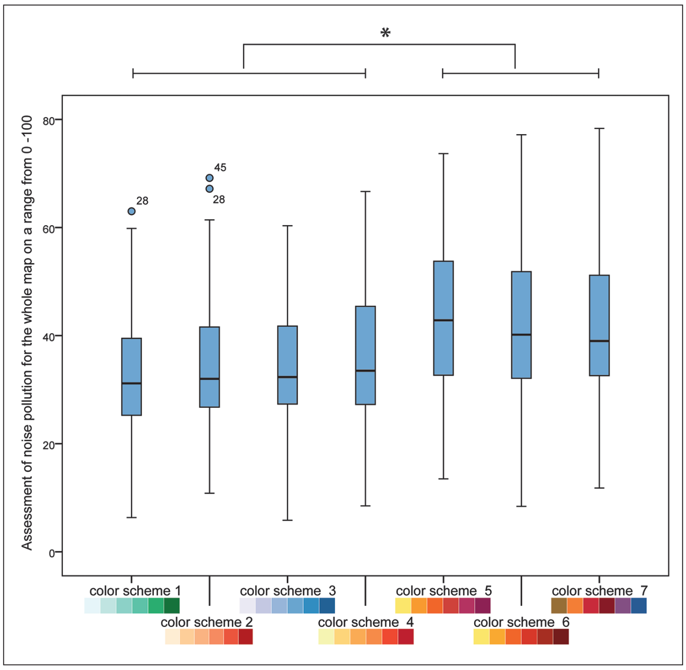

Figure 3: Colour schemes had a significant effect on the interpretation when average noise pollution for the whole map had to be assessed, as this box plot shows. The difference between colour schemes 1 to 4 in contrast to schemes 5 to 7 was significant. * $p < 0, 0001$ (sig.)

they associate the width of the road with heavy traffic, as described above. Thus, bigger areas were associated with higher noise pollution. Secondly, bigger areas in the maps raised more attention because they are more salient and were therefore defined as hotspots although they showed the same dB-values as narrow roads. Critically, it has to be mentioned that the author didn't define what was meant by "areas of high noise pollution" and participants might have anticipated that bigger areas of noise pollution affect a bigger number of people are therefore *real* hotspots (c f. the study by the Fraunhofer Institute for Building Physics described in the next chapter). However, at this point we cannot rule out the fact that results are only due to a representational problem.

We can conclude that acoustic as well as psychoacoustic principles are not known by the general public. Instead, people apply an intuitive and naïve approach of interpretation that leads to the perception that bigger areas of high noise pressure level and wider roads represent higher noise pollution, the latter because more traffic is assumed. The visual dimension that has been used for interpretation here was size in form of the width of the road. One cannot speak of a visual variable because size is not used for the encoding; it is a result of the presentation. The variable colour hue encodes areas of equal sound pressure level, but did not show much effect on the interpretation. Approaching a cognitive approach to visualization can help to represent these characteristics (cf. Fabrikant and Goldsberry, 2005, but no general guidelines are available at this point.

3.2 The influence of represented information on public opinion

The EU directive defines the noise indicator L_{den} to be presented. This is the A-weighted long-term average sound level for individual noise sources, such as traffic, airport noise, and railway noise. This indicator is only one way of representing noise, other indicators can lead to differences of up to 5 dB (European Commission, 2000) which is misleading for non-expert users as all indicators represent the sound pressure level in the unit dB. Although the presentation of L_{den} is predefined, other map layers such as the number of population can be added and would help to make sense of the presentation and to infer consequences.

For the exemplification of the effect of map content on the interpretation of noise maps the author presents results of a study conducted by the Fraunhofer- Institute for Building Physics (FraunhoferInstitut für Bauphysik) on behalf of the GEERS foundation (GEERS-Stiftung) and the subsequent reaction of the media. The Institute for Building Physics did an analysis of the noise maps of the 27 agglomerations with more than 250.000 population and calculated the area that is exposed to a noise level of 55 dB or higher. The result was a ranking of German cities as a basis of noise exposure. The cities with the highest noise exposure, such as Hannover, Frankfurt am Main, and Nuremberg, have up to 70 per cent of total area above 55 dB. The problem of the results is their communication, especially by the media. Spiegel Online, for instance, announced "Scientists declared Hannover to Germany's loudest city" (Spiegel Online, 2011). Other German newspapers and journals, such as Die Welt, Handelsblatt, Focus, and the Süddeutsche Zeitung, also used the phrase "Hannover is the loudest city" in their articles. It is true that Hannover has the highest total area exposed to environmental noise, but this does not necessarily mean that it has the highest amount of people exposed to a high noise level. This could, e. g., be in case of a highway through unpopulated areas of the city. Although it is obvious that map interpretation is dependent on the choice of map layers, this example shows how it influencesopinion-making and therefore public opinion.

3.3 Colour and its effect on the interpretation

While map content and prior knowledge obviously influence the interpretation of noise maps, individual visual variables also have an effect on map interpretation and have a major impact on the communication quality of maps (Fairbairn et al., 2013). In cartography we use 12 visual variables for the encoding of information: Location, size, shape, orientation, colour hue, colour value, texture (Bertin, 1983), colour saturation, arrangement (Morrison, 1874), crispness, resolution, and transparency (MacEachren, 1995). Three of these variables refer to colour and are associated with the perception of colour. Visual variables are the constituent graphic elements of maps. They are "processed preattentively, or in an immediate and preconceptual manner at the sensory level of the human eye" (Roth, forthcoming).

The visual variables therefore rather refer to perception than to cognition.

Below, the author is looking at colour representing sound pressure level and describe the influence of colour on getting an overview of a noise situation, the representation of a range of dB-values, and the influence on look-up tasks and therefore the interpretation of individual values in noise maps.

The results of a user study comparing the effects of seven colour schemes (study no. 2[1]) showed that colour schemes had a significant effect on the interpretation when average noise pollution for the whole map had to be assessed (Weninger, 2013 and 2015a). Colour schemes with less hue transition and lighter colours for lower values significantly resulted in lower values for the estimation of noise pollution, F(4, 1) = 25, 3, p < 0, 0001 (sig.) (fig. 3). However, no significant difference could be found between the effects of warm and cool colours, it was only saturation and the number of hue transitions that showed an effect. Although the effect cannot be quantified and expressed in dB, we can conclude that the interpretation of map content is influenced by the colour scheme if a mean value for the whole map is assessed. This can result in non-effective communication of environmental information and at worst to deliberate manipulation for some map use tasks.

The representation of a range of dB-values by means of colour is discussed on the basis of the results of a study about the associations of colour (study no. 3[2]). Participants were shown pairs of coloured squares and asked if a) both squares represented the same noise level, if the noise level represented by the colour on the right was b) less than twice as high, c) twice as high, or d) more than twice as high as the colour on the left. Results have shown that the highest difference of noise level is associated with colours that have a strong colour contrast, i. e. colour hues differ strongly, such as complementary colours, and/or a very distinct lightness contrast (Weninger, 2015a) (fig. 4). These results are in line with the insights described above and can substantiate them. Sequential schemes with no hue transition and a low contrast between each of the colours are not suitable to represent a big range of values. In contrast, presenting higher values in saturated colours and a higher number of hue transitions is in favor of a big range of values and therefore a logarithmic scale.

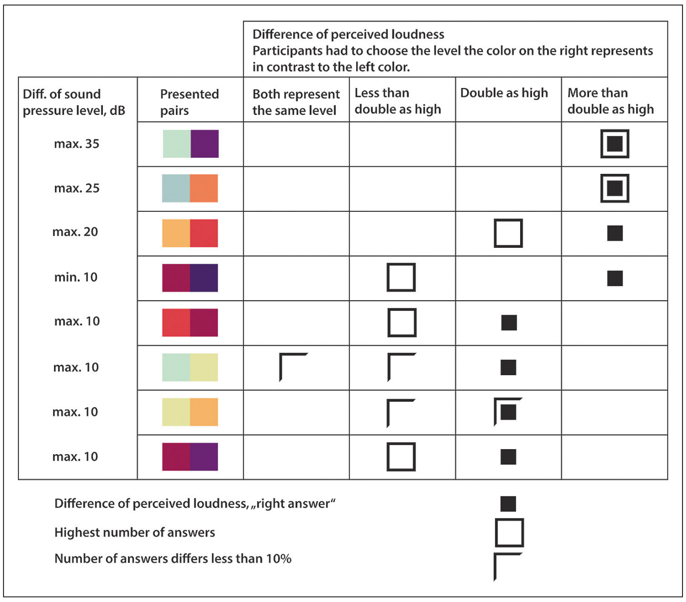

Figure 4: Participants were shown colour-pairs, they had to choose the level of loudness the colour on the right represents in contrast to the left colour. The highest difference of noise level is associated with colours that have a strong colour contrast, i. e. colour hues differ strongly, such as complementary colours, and/or a very distinct lightness contrast.

3.4 Interaction of Parameters

Visual variables and map symbols can be regarded individually, as it was done in the user studies leading to the result presented above. However, for map interpretation the map symbols are perceived in combination and in context of the map use tasks. The influence of the interaction of map symbols is even more intangible than the influence of individual visual parameters. Additionally, the organizational level of design is of relevance. In this respect Fairburn (2013) mentions clarity, hierarchy, and balance and states "these properties of a map image are based on the combinations of decisions made about employing the visual variables at individual symbol level" (p. 311).

While colour had a significant effect on the assessment of average noise pollution in maps (study no. 2, described above), the author did not observe any influence of the colour scheme on delineating hotspots, i. e. areas of high noise pollution, in paper maps (study no. 1). In this between-subjects design participants were shown either three paper maps with L_{den} represented in the colour schemes after DIN 18005-2:1991 or the newly developed scheme in A4 format. The order of maps was randomized. No topographic information, such as buildings or roads, was included. The task was to delineate hotspots by hand. Surprisingly, the qualitative evaluation did not show much effect of the schemes (fig. 2). Only a tendency to mark more red areas in one map was observed. Although there were no map layers for roads, participants were able to recognize the road network and associated it with higher noise pollution according to their experience and prior knowledge. Therefore, they defined nearly the same hotspots on maps with different colour schemes (Weninger, 2015a). Consequently, the prior knowledge about the presented phenomenon (as described above) and the proximity of the point of interest and a potential noise source influences interpretation in noise maps and the respective colour scheme

[1] Study 2 was an online experiment that compared the effects of four Brewer schemes, the DIN 18005-2:1991 scheme and two own schemes on the assessment of the average noise pollution in maps. Each of the seven colour schemes was used in four maps without any topographic information. The 56 users were shown 56 maps in a randomized order, for each they had to assess noise pollution using a range from 0 to 100 and a slider that supported a quick choice.

[2] Study 3, an online study with 125 participants, had the aim to evaluate if colours of the new scheme and respective levels of noise exposure could be associated. Therefore, the author conducted a user study with four parts. The part described here is the second part that aimed at evaluating if colours could represent the difference in represented loudness between two colours.

is subordinate. In contrast, the size of an area was important for the participants' choice, as described above. Therefore, for the task of delineating hotspots in a map colour did not show an effect, but the visual dimension, location and size, did.

There are many more potential interactions of visual parameters that have not been observed nor examined yet: The map symbol for roads seems to be very influential for the perception of high values of sound pressure level, because in traffic noise maps there is a naturally given order by the phenomenon and areas of highest values occluded by the road symbols. The layer of the sound pressure level is sometimes presented transparent above a base map that might have effects on figure-ground perception. Also the influence of different styles of base maps, e. g. monochrome or colour, could be examined in the future.

4 Discussion

In the course of the development of a colour scheme for representing noise immission in maps, analyses and user studies have been conducted, all to answer concrete research questions. While the author gained pragmatic insights for the general improvement of noise maps and the development of the colour scheme, she also observed effects of visual design parameters on map interpretation that were not anticipated. For map interpretation the prior knowledge about the presented phenomenon, the presented content, the visual design parameter colour and interactions of parameters were determining. It is assumed that the following observations are important:

- It is obvious that the choice of map layers and represented information is important for the interpretation of maps. Users will only gain from the information that is actually transferred. However, it is not only about the information that is presented but also about the information that is not presented (cf. Wood, 1992). Insights are gained by combining different layers of information; if a layer, such as data on population, is left out, there will be a major effect on the interpretation.
- For map interpretation, users do not only refer to information presented in the map but inevitably also to their prior knowledge. Especially when complex data is presented users might not have enough expert knowledge, instead they apply an intuitive and naïve approach of interpretation. That for example leads to the perception that bigger, and more salient, areas are more polluted because it is supposed that they represent wider roads and more traffic.
- Our hypothesis was that colour, the visual variable for encoding noise immission, is the major parameter for interpretation. According to our observations, however, the effect of colour is dependent on the tasks users are carrying out. While colour, especially colour value and the number of hue transitions, showed an effect on the assessment of average noise exposure, it did not show an effect on the delineation of hotspots. For the latter task location and area were decisive. It seems like depending on the task, users combine a choice of information to complete the task. In case of delineating areas of high noise exposure they appear to connect a high amount of cars, wider roads and thus bigger areas. Therefore, in some cases a combination of influencing parameters appears that was not predicted.

Our research results have shown that although it was expected to enhance noise maps by applying a more intuitive colour scheme that was tested in user studies, a general enhancement of map interpretation just by improving one parameter cannot be assumed, even if it is seen as a major design parameter. For certain tasks a revised colour scheme might lead to better results in map interpretation, but the results are task-dependent and not generally transferable. These findings are in line with the recommendation that tasks should be considered for the development of a colour scheme (Weninger, 2015b). Pragmatic user studies are helpful to evaluate the suitability of individual map elements or visual variables for specific applications, but for a better understanding how certain maps are interpreted a cognitive approach needs to be applied. This will help to evaluate if effects on the interpretation are due to the representation or to associations and prior-knowledge.

An explanation of what has been observed or a reason for the observations is top-down processing a constructivist approach to perception. Gregory (1970) described that perception is a "hypothesis", an active process, and context, prior-knowledge, or past experiences help us to develop a hypothesis that is mostly correct. "Top-down processes actively seek and extract sensory information and are driven by our knowledge, beliefs, expectations, and goals" (Smith and Kosslyn, 2007, p. 55). Perceptions are interpretations of what we see and involve bottom-up processing, which is driven by sensory information, as well as top-down processing (Smith and Kosslyn, 2007). Also Fabrikant and Goldsberry (2005) state that "our current understanding of visual attention suggests a combination of bottom-up (stimulus driven and pre-attentive) processes and top-down (task/goal dependent, thus cognitive and semantic) components" (Fabrikant and Goldsberry, 2005, p. 4). In this sense the *individual* visual variables, "the basic building blocks" of a map (Roth, forthcoming) after Bertin (1983), Morrison (1974), and MacEachren (1995), as described above, become less important for map interpretation as they are interpreted in connection with a sign, an object, or a task. For carrying-out a task, in turn, users refer to prior-knowledge which leads to top-down processing. Roth (forthcoming) confirms that visual variables are "processed preattentively" and "seen perceptually rather than understood cognitively". However, they gain meaning if a level of organization becomes apparent. Levels of organization are (I) associative perception for presenting related variables, (II) selective perception for showing differences between variables, (III) ordered perception for ranking variables, and (IV) quantitative perception for allowing an estimation of numerical values.

In the introduction the author described the importance of presenting objective cartographic information to facilitate valuable knowledge transfer and decision-making. Based on observations in empirical studies three categories of parameters have been highlighted that influence map interpretation in different ways and therefore might lead to less objective results. Uncontrollable effects on map interpretation are especially a problem for presenting environmental information that is used for decision-making. This information, however, due to its complexity and importance is prone to biased presentation and thus misinterpretation. Comprehensive research is needed that deals with citizens' and decision-makers' information needs and map interpretation under consideration of visual attention (cf. Wolfe and Horowitz, 2004) and map use tasks (cf. Andrienko and Andrienko, 2006).

Acknowledgements

This research project was inspired by outcomes of the project "Evaluation and Optimization of noise action planning according to Environmental Noise Directive 2002/49/EG", funded by the Federal Environment Agency (Umweltbundesamt) of Germany (UFOPLAN FKZ 371055146). The author would like to thank the project partners for their valuable input. Map data for the user studies and figures are based on fictitious data of the project "Silent City", funded by the German Federal Environment Agency and processed by Lärmkontor GmbH.

References

Aarhus-Konvention (1998). Convention in Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters. United Nations Economic Commission for Europe (UNECE).

Airports Commission (2013). Discussion Paper 05: Aviation Noise, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223764/airports-commission-noise.pdf. Accessed June 2015.

Alberts, W. and J. R. Alferez (2012). The Use of Colours in END Noise Mapping for Major Roads. In: Proceedings of Euronoise, Prague 2012.

Andrienko, N. and Andrienko, G. (2006). Exploratory analysis of spatial and temporal data: a systematic approach. Springer, Berlin, Heidelberg, New York

Arkette, S. (2004). Sounds like City. In: Theory, Culture & Society Vol. 21, No. 1, pp. 159–168.

Berkemann, J. (2009). Lärmschutz im Städtebaurecht. V. Vhw: Nordrhein-Westfalen.

Bertin, J. (1983). Semiology of graphics: Diagrams, networks, maps. University of Wisconsin Press: Madison, WI.

Botteldooren, D.; de Coensel, B. and de Muer, T. (2006). The temporal structure of urban soundscapes. In: Journal of Sound Vibration, Vol. 292, pp. 105–123. 18005-2:1991.

Engnath, V. und Koch, W. G. (2001). Lärmkarten. In: Braun, G.; Buzin, R. und Wintges, T. (Hrsg.), GIS und Kartographie im Umweltbereich. Wichmann.

European Commission (2000). Position Paper on EU Noise Indicators. http://ec.europa.eu/environment/noise/pdf/noiseindicators.pdf. Accessed June 2015.

European Environmental Agency (2010). Good practice guide on noise exposure and potential health effects, EEA, Copenhagen.

European Parliament and Council (2002). Directive 2002/49/EC of the European Parliament and of the council of 25 June 2002 relating to the assessment and management of environmental noise (END).

Fabrikant, S. I. and Goldsberry, K. (2005). Thematic r elevance and perceptual salience of dynamic geovisualization displays. In: Proceedings, 22th ICA/ACI International Cartographic Conference, A Coruna, Spain.

Fairbain, D. and Jadidi, M. N. (2013). Influential Visual Design Parameters on TV Weather Maps. In: The Cartographic Journal, Vol. 50, No. 4, pp. 311–323.

Farcas, F. and Sivertun, A. (2009). Road Traffic Noise: GIS Tools for Noise Mapping and a Case Study for Skane Region. In: The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 34, Part XXX.

Fastl, H. (2013). Proceedings of Meetings on Acoustics. In: Proceedings of the International Congress on Acoustics, Vol. 19. Acoustical Society of America.

Fraunhofer-Institut für Bauphysik (2011). Städtelärmranking 2011 – Ein Impuls zum Nachdenken über Hörkultur und urbane Gestaltung. http://www.ibp.fraunhofer.de/de/Presse_und_Medien/Presseinformationen/PM_Laermstudie.html. Accessed June 2015.

Gregory, R. L. (1970). The Intelligent Eye. Weidenfeld and Nicolson: London.

Harley, J. B. (1989). Deconstructing the Map. In: Cartographica, Vol. 26, No. 2, pp. 1–20.

Jäger, V. and Koch, W. G. (1996). Graphische Gestaltung und rechnergestützte Herstellung von Karten des Verkehrslärms. In: Kartographie im Umbruch – neue Herausforderungen, neue Technologien. Beiträge zum Kartographiekongress Interlaken 96, zugleich 45. Deutscher Kartographentag. http://www.kartographie.ch/publikationen/pdf/nr14_interlaken_1996.pdf. Accessed June 2015.

Jenny, B. and Kelso, N. V. (2007). Colour Design for the Colour Vision Impaired. In: Cartographic Perspectives Vol. 58, pp. 61–67.

Kephalopoulos, S. and Paviotti, M. (2012). Noise maps from different national assessment methods. In: Licitra, G. (2012). Noise Mapping in the EU. CRC Press, Taylor & Francis Group: Boca Raton, FL. pp. 311–336.

Kjellberg, A.; Landstrom, U.; Tesarz, M.; Soderberg, L. and Akerlund, E. (1996). The effects of nonphysical noise characteristics, ongoing task and noise sensitivity on annoyance and distraction due to noise at work. In: Journal of Environmental Psychology, Vol. 16, pp. 123–136.

Kornfeld, A.-L.; Schiewe, J. and Dykes, J. (2011). Audio cartography: visual encoding of acoustic parameters. In: Lecture Notes in Geoinformation and Cartography, 1, pp. 13–31.

Kornfeld, A.-L.; Kurz, C.; Hintzsche, M.; Schiewe, J. and Weninger, B. (2012). Weiterentwicklung von Lärmkarten für eine bessere Umweltkommunikation. In: UMID: Umwelt und Mensch – Informationsdienst Vol. 3, pp. 5–10.

Landesbetrieb Geoinfoamtion und Vermessung Hamburg (2015). Lärmkarte Hamburg. http://www.geoportal-hamburg.de/laerm/index.html#. Accessed June 2015.

MacEachren, A. M. (1995). How maps work. The Guilford Press: New York.

Manvell, D. (2012). Maps and geographic information systems in noise management. In: Licitra, G. (2012). Noise Mapping in the EU. CRC Press, Taylor & Francis Group: Boca Raton, FL. pp. 255–267.

Maute, D. (2006). Technische Akustik und Lärmschutz. Carl Hanser Verlag: Wien.

McDonald, P. (2012). Communication to the General Public. In: G. Licitra (eds.). Noise Mapping in the EU. CRC Press, Taylor & Francis Group: Boca Raton, FL. pp. 339–350.

Menzel, D. und Fastl, H. (2008). Influence of Vehicle Colour on Loudness Judgements. In: Journal of the Acoustical Society of America Vol. 123, No. 5, pp. 2477–2479.

Michel, F. (2008). Simulation and visualization of in- and outdoor sounds. PhD thesis. Technical University Kaiserslautern. Kaiserslautern, Germany.

Morrison, J. L. (1974). A theoretical framework for cartographic generalization with the emphasis on the process of symbolization. In: International Yearbook of Cartography, Vol. 14, pp. 115–127.

Müller, J.-C. and Scharlach, H. (2001). Noise Abatement Planning – Using Animated Maps and Sound to Visualise Traffic Flows and Noise Pollution. In: 20th International Cartographic Conference, Vol. 1, pp. 375–385, Beijing, Aug 6–10.

Öhrström, E.; Skanberg, A.; Svensson, H. and Gidlof-Gunnarsson, A. (2006). Effects of road traffic noise and the benefit of access to quietness. In: Journal of Sound Vibration, Vol. 295, pp. 40–59.

Papadimitriou, K. D.; Mazaris A. D.; Kallimanis, A. S. and Pantis, J. D. (2009). Cartographic Representation of the Sonic Environment. In: The Cartographic Journal, Vol. 46, No. 2, pp. 126–135.

Roth, R. E. (forthcoming). Visual variables. In: The International Encyclopedia of Geography: People, The Earth, Environment, and Technology. Available online http://www.geography.wisc.edu/faculty/roth/publications/Roth_2015_EG.pdf. Accessed June 2015.

Scharlach, H. (2002). Lärmkarten – Kartographische Grundlagen und audiovisuelle Realisierung. PhD thesis, Dissertation an der Fakultät für Geowissenschaften der Ruhr-Universität Bochum.

Schiewe, J. and Weninger, B. (2013). Visual Encoding of acoustic parameters – framework and application to noise mapping. In: The Cartographic Journal Vol. 50, No. 4, pp. 332–344.

Schiewe, J.; Weninger, B.; Kornfeld, A.-L.; Kurz, C. and Hintzsche, M. (2012). Gebrauchstauglichkeit von Lärmkarten verbessern. In: Lärmbekämpfung, Zeitschrift für Akustik, Schallschutz und Schwingungstechnik Vol. 5, September 2012, pp. 215–220.

Servigne, S.; Laurini, R.; Kang, M. A. and Li, K. J. (1999). First Specifications of an Information System for Urban Soundscape. In: IEEE International Conference on Multimedia Computing and Systems, Vol. II, pp. 262–266, Florence, June 7–11.

Smith, E. E. and Kosslyn, S. M. (2007). Cognitive Psychology: Mind and Brain. Pearson.

Stevens, M. (2012). Community memories for sustainable societies: The case of environmental noise. VUB-Press: Brussels.

Southworth, M. (1969). The sonic environment of cities. In: Environment and Behaviour, Vol. 1, pp. 49–70.

Stockfelt, T. (1991). Sound as an existential necessity. In: Journal of Sound and Vibration, Vol. 151, pp. 367–370.

Spiegel Online (2011). Forscher erklären Hannover zur lautesten Stadt Deutschlands. Online veröffentlicht am 21.9.2011 unter http://www.spiegel.de/wissenschaft/mensch/0,1518,787329,00.html. Accessed May 2015.

Weninger, B. (2013). The Effects of Colour on the Interpretation of Official Noise Maps. In: Proceedings ICA International Cartographic Conference, Dresden. http://www.icc2013.org/_contxt/_medien/_upload/_proceeding/285_proceeding.pdf. Accessed May, 2015.

Weninger, B. (2015a). Lärmkarten zur Öffentlichkeitsbeteiligung – Analyse und Verbesserung der kartografischen Gestaltung, PhD thesis, HafenCity Universität Hamburg. http://edoc.sub.uni-hamburg.de/hcu/volltexte/2015/219/. Accessed May, 2015.

Weninger, B. (2015b). A Framework for Colour Design of Digital Maps – An Example of Noise Maps. In: Brus, J., Vondrakova, A., and Vozenilek, V. (eds.) (2015) CARTOCON 2014 – Modern Trends in Cartography, Springer: Berlin.

Weninger, B. (2015c, forthcoming). Cartographic Visualisation of Noise and Aspects of Public Understanding of this Information. In: Loreto, V. , Haklay, M., Hotho, A., Servedio, V. D. P., Stumme, G., Theunis, J., and Tria, F. (forthcoming) Participatory sensing, opinions and collective awareness, Springer: Berlin.

Weninger, B. (2015d). A colour scheme for the presentation of sound immission in maps: requirements and principles for design. In: Proceedings EuroNoise 2015, Maastricht, May 2015.

Wolfe, J. M. and Horowitz, T. S. (2004). What attributes guide the deployment of visual attention and how do they do it? In: Nature Reviews Neuroscience, Vol. 5, June 2004, pp. 1–7.

Wood, D. (1992). The Power of Maps. Guilford: New York.

About the author

Since 2009, Dr.-Ing. Beate Weninger has been research fellow at HafenCity University Hamburg (HCU). At present, she works in the Lab for Geoinformatics and Geovisualization. She has a degree in Geography (Universities of Graz and Exeter) and holds a PhD in cartography (HCU). Her research interests include maps for public participation, cartographic presentation of environmental information, such as noise, to the general public, colour for cartographic visualization, and the specification of requirements for a user-centered presentation. Her research methods are user-centered design, empirical user studies and experiments, as well as requirements analyses.

Manuscript submitted: 22.6.2015
after review accepted: 6.7.2015