The Effects of Colour on the Interpretation of Traffic Noise in Strategic Noise Maps

Beate Weninger

Lab for Geoinformatics and Geovisualization, HafenCity University Hamburg

Abstract. An experiment shows that colours have an influence on the interpretation of noise maps. We compared the effects of seven colour scales, four with a transition from light to bright colours and three consisting only of bright colours. According to the results bright scales cause that noise pollution is assessed higher while we did not find any effects of cool, warm or signal colours like red. The outcomes give crucial insights for further research on the development of colour scales for specific scenarios like the presentation of environmental information and public participation.

Keywords: colour, colour design, colour scale, colour scheme, perception, environmental information, public participation

1. Introduction

Noise mapping has been obligatory in Europe since the year 2002, when the European Union adopted the Environmental Noise Directive (END). Since then noise maps have to be drawn up every five years by the member states.

Noise maps are the main source for informing the public about environmental noise and are also the basis for noise action plans. According to the END the information on noise should be "clear, comprehensible and accessible" for the public (2002/49/EC, article 9/2). Anyhow, examples throughout Europe lack appropriate and satisfactory cartographic presentation. Especially the colour scale representing noise pressure level is object of discussion (e.g. Alberts & Alférez 2012, Schiewe & Weninger 2013). It is based on the ISO 1996:2 from 1987. Although the description of colours is not part of the second version (2007), variations of the original scale are still in use in many countries such as e.g. Germany, Austria, Switzerland, Scotland, Northern Ireland, Malta. The problem with the scale is that the colours cannot be intuitively put in order because as *Figure 1* shows, seven different hues are used that differ strongly in lightness. Different hues should rather be used for qualitative scales instead (Brewer 1994) *unless* there is a clear and systematic change in lightness that indicates an order.

Because colour is the major graphical variable for displaying noise pressure levels as isophones (equal loudness contours) in maps, our research aims at creating and testing an alternative colour scale. Our approach is to test principle requirements and alternative scales in user studies. Therefore, we conducted an experiment to explore the effects of colour on the interpretation of noise maps. Results will deliver insights for the further development of the scale.

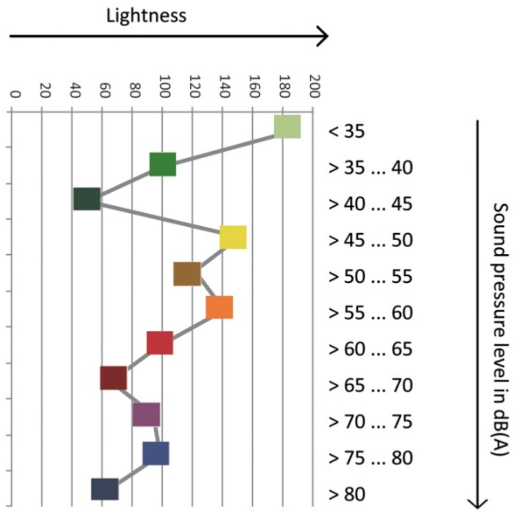

Figure 1. Colour scale as proposed by ISO 1996:2 (1987): colours cannot be intuitively ranked (Schiewe & Weninger 2013)

2. Background and Objectives

Principles in colour design for maps have been defined for instance by MacEachren (1995) and Brewer (e.g. 1992, 1994). Levkowitz defines that colours of a scale should (1) „preserve the order of the original values“; (2) “convey uniformity among values they are representing, and representative distances between them; and (3) create no artificial boundaries that do not exist in the original data”. (1996: 97) The principles order and separation are also specified by Trumbo (1981).

However, practical experiences show that “color is a cartographic quagmire” (Monmonier 1996). Reasons for this are e.g.:

- Brewer palettes are finite (Wijffelaars et al. 2008);
- nature of data varies strongly for different use cases and can be e.g. logarithmic, sequential, diverging, or qualitative (Harrower et al. 2003);
- different output devices lead to different presentations of colours.
- „The more complex the spatial pattern of the maps, the harder it will be to distinguish slightly different colours” (Harrower et al. 2003: 32).

Consequently “colour specifications in ColorBrewer should never be treated as ironclad guarantees since colour reproduction (weather on screen or in print) is an inexact science“ (Harrower et al. 2003: 33). Colour schemes have to be adapted to the use case and respective data. Our requirements for the colour scale representing noise pressure level, put in three groups, hence are:

1. Individual colours of the scale should be distinguishable in different scales and object size;
2. the colours of the scale should be easily assignable to the legend, and
3. the colours should be intuitively assigned to the values they represent and to their referring qualities. They should not lead to an under- or overestimation of the presented traffic noise situation.

The third requirement is subject to this paper.

Generally it is agreed that hue is used to express qualitative information and value and saturation to express quantitative information. Colour hue discriminability, according to Luria et al. (1996, cited in MacEachren 1995), is “truly astronomical” for up to around ten colours, but drops rapidly as the number of colours rises. According to this fact we decided to develop and test not a sequential scale but a multi-hue scale to enhance discriminability (requirement 1).

Challenges are that perception of colours is influenced by surrounding colours. This phenomenon is called simultaneous contrast (Albers 1970, Monmonier 1996, Lyons et al. 2000). For instance, orange adjacent to red will seem more yellow while it seems more red adjacent to yellow (Lyons 2000). Simultaneous contrast can also cause problems to assign object colours to the map legend, especially if dark areas surround light areas. The colours of the light areas are thus difficult to discriminate (Brewer et al. 1997). Therefore, scales were developed that do only consist of bright colours. But (how) does the use of bright colours effect the interpretation of map content in contrast to light colours?

Cleveland et al. (1983) conducted experiments on color-caused optical illusions and evaluated the effect of color on the perceived size of objects. He compared maps in light colors (light yellow and green) with maps in bright colors (red and dark green). The results showed that red objects were judged bigger than green regions "even though the regions were the same size" (Cleveland et al. 1983: 104). "No such consistent distortion occurred when the low-saturation brighter colors were used" (1983: 104). According to his study there are clear effects of colour on the interpretation of e.g. size. However, to our knowledge there are no other studies that examine these effects in depth for thematic mapping. Nevertheless, it is crucial to further explore and consider such effects when developing a colour scale representing environmental information, otherwise this can result in misinterpretation or over- or underestimation of the presented phenomena.

3. Experimental Set-Up

3.1. Research Questions

To explore the effects of colour on the interpretation of noise maps our research questions were:

1. *Does the colour representing noise pressure level influence the assessment of noise pollution?*
2. *Does the colouring of the first class of the represented noise pressure level (colour/ no colour) influence the assessment of noise pollution?*

Based on observations from related work and own experience we hypothesized that:

H1 Noise pollution is assessed higher if brighter colours are used, while it is assessed lower with pastel colours.

H2 Noise pollution is assessed higher if reddish colours are used to present high values because red is a signal colour.

H3 Noise pollution is assessed lower if blue and green shades are used for the presentation of the sound pressure level.

H4 Noise pollution is assessed lower if the first class of noise pressure level is uncoloured, because users tend to assume that the absence of a graphic variable, i.e. colour, represents the class "no value".

3.2. Study Design

The experiment was set-up as a within-subjects field experiment with the general public as user group. Although we are aware of the fact that graphics are displayed differently on different screens, which has to be considered in the experiment's results, we decided to gain results that could be used for an application-oriented development of a colour scale. As noise maps are usually examined under manifold conditions on the internet, a field experiment seemed more appropriate.

Answers were not mandatory for every question thus data sets were counted as complete if participants have seen all questions not only if they answered all. The option “no answer” was given to avoid arbitrary answers.

3.3. Tasks

The tasks in the experiment were consistent with a realistic user scenario. Participants had to assess the noise pollution of each of the 56 map sections on a scale from 0 to 100 with the help of a slider.

Attention should be paid that the unit dB(A) that is used to describe sound pressure level is logarithmic. Hence, no arithmetic mean of the displayed sound pressure level should be calculated. This complicates the assessment of noise pollution in a map section, because laymen are usually not aware of this fact and are unable to estimate the value without knowing the formula. Therefore, we decided not to ask for the mean sound pressure level in dB(A) but for an estimation of the noise pollution on a scale from 0-100. Thus we also changed the labelling in the legend and specified only the lowest and highest classes. To counteract a learning effect the maps were randomized.

Participants were introduced to the tasks by the graphic shown in *Figure 2*. It describes how certain levels of noise pollution (0, 50, and 100) look like and how the scale should be used.

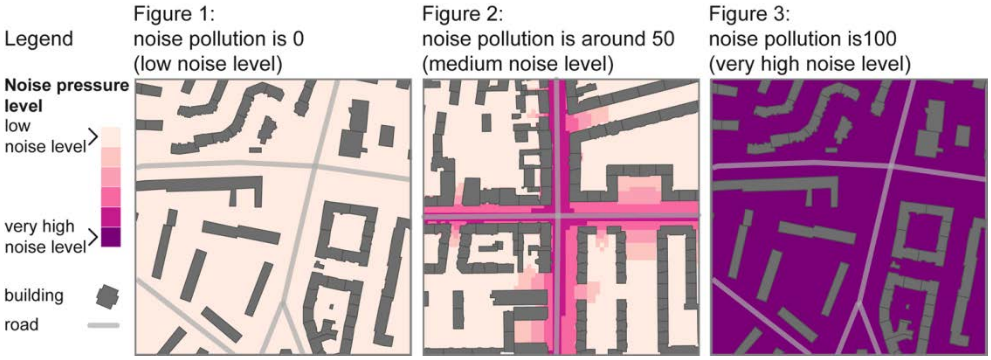

Figure 2. Introduction to the tasks

3.4. Stimuli

The dependent variable was the effect of different colour scales on the assessment of noise pollution. The following three independent variables, referred to as factors, were assigned: colour scale, map section and the colouring of the first class of the displayed noise pressure level *(Table 1)*. Because of the 7x4x2 factorial design 56 runs were required, i.e. every participant got to see 56 test maps.

Factor	Factor levels
colour scale	seven scales *(Figure 3)*
map sections	four different variations (*Figure 4*)
colouring of noise pressure level's first class	colour according to the scale or no colour
	56 variations in total

Table 1. Overview of factors and factor levels.

To gain reliable results, four of the seven used **colour scales** (*Figure 3*) were by Brewer (Brewer 2005). These scales follow a similar pattern: they are sequential, start with very light colours and are not designed for a certain use case. Therefore, we also tested two scales that were designed for the purpose of noise mapping (scale 5 and 6, Schiewe et al. 2012). They are also sequential, but consist of brighter colours as described in *Section 2*. The seventh non-sequential scale is based on the ISO 1996:2 from 1987, is still proposed by the German DIN 18005-part 2 and has to be used for strategic noise maps in Germany. All scales are multiple-hue scales, i.e. there are at least two hues involved. For interpretation the scales can be grouped as introduced below:

- Four scales (1-4) start with very light pastel colours,
- two consist of cool colours and two of warm colours,
- three scales (5-7) consist of bright colours only.

.

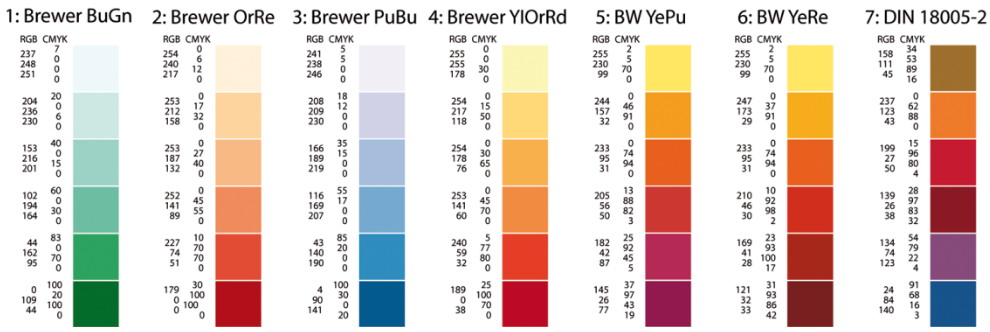

Figure 3. The colour scales used in the experiment with colour codes for RGB and CMYK

Four different **map sections** were used (*Figure 4*, *Figure 5*) that are based on data of a model city and thus unknown to the participants. They show sound pressure level for traffic and were chosen according to the difference of their equivalent continuous sound pressure level to facilitate a ranking of the maps from low to high. During the experiment the sections were rotated randomly to counteract recognition.

The classes to display noise pollution are in accordance with German law (34. BImSchV) to construct a realistic user scenario: six classes with a size of 5 dB(A).

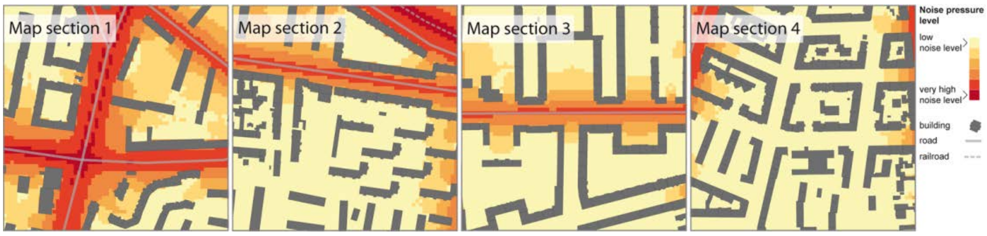

Figure 4. The map sections (reduced size) in the Brewer colour scale *YlOrRd*

As third factor we varied the **colouring of the first class** of the presented noise pressure level (*Figure 5*). In practice there is big variation, around 70% of German's official noise maps show an uncoloured first class. Depending on the information in the legend this may lead to misconceptions. Thus it was of our interest to gain insights if this has any effects on the interpretation.

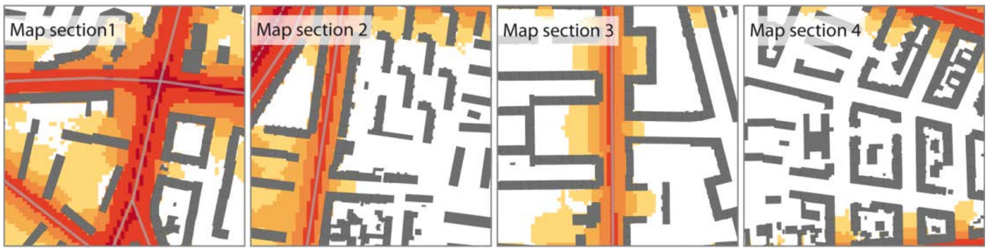

Figure 5. The map sections (reduced size) in the Brewer colour scale *YlOrRd* with uncoloured first class

3.5. Participants

We recruited 81 unpaid participants through personal e-mails, mailing lists and social network posts. 56 completed the experiment entirely (25 female, 30 male, 1 no answer).

Predominantly users were in the 21-40 year age group (72%), but also all other age groups were represented: 41-50 years with 6, 51-60 years and 61-70 with respectively 3 and over 71 years with 4 participants.

96% of users live in the German language area. The remaining 4% of the participants - though not from German language area - were able to take part the experiment in German language and therefore their answers were also considered.

13.3% male participants indicated that they had some kind of colour vision deficiency (CVD) that was diagnosed by a doctor, which was not the case with any female participants. This means that participants with CVD are a little overrepresented, because generally 8% of the male and 0.4% of the female population have some kind of colour vision deficiency (Jenny & Kelso 2007). Besides the question concerning CVD we showed two Ishihara (pseudoisochromatic) plates between the map reading tasks. Additionally to the four persons who already mentioned a CVD one other male participant was unable to identify both plates and 8 more participants were unable to identify one plate. Altogether 23% percent of the participants had problems to identify numbers in red and green under the conditions they conducted the experiment. Consequently, we have to consider that even more users than the 8% male users might have problems distinguishing content presented in red and green due to different problems.

4. Results

The aim was to analyse the influence of different colour scales on the assessment of noise pollution and thus the interpretation of noise maps. We explored two research questions related to our objectives.

1. *Does the colour scale representing noise pressure level influence the assessment of noise pollution?*

The error bars in *Figure 6* indicate that participants assessed a higher level of noise pollution if noise pressure level was presented in bright colours (scales 1-4).

For the statistical analysis we used a non-parametric Kruskal-Wallis one-way analysis of variance that does not assume normal distribution, identical distribution and equal size of examined groups (Eckstein 2008). The test showed a significant effect of colour scales on the assessment of noise pollution: $H(6) = 81.918$, $p < .000$; i.e. at least one of the scales leads to different effects than the other scales. Post-hoc pairwise comparison by means of Games-Howell-Test (for a lack of equal variances) showed that colour scales 1 to 4 lead significantly to a lower estimation of noise pollution in the map sections than scales 5 to 7 ($p < .000$).

Consequently, our hypothesis H1 saying that noise pollution is assessed to be higher if brighter colours are used, while it is assessed lower if noise pressure level is presented in pastel colours is met. Whereas our results do not support our hypothesis H2 that noise pollution is assessed higher if red is used to present high values. The reddish scales 2 and 4 lead to a lower estimation in contrast to the bright reddish scales 5 and 6. Moreover, the cool scales with blue and green shades also did not show any effects in contrast to reddish scales. Thus, the hypothesis (H3) that blue and green shades effect in a lower assessment was rejected in the experiment.

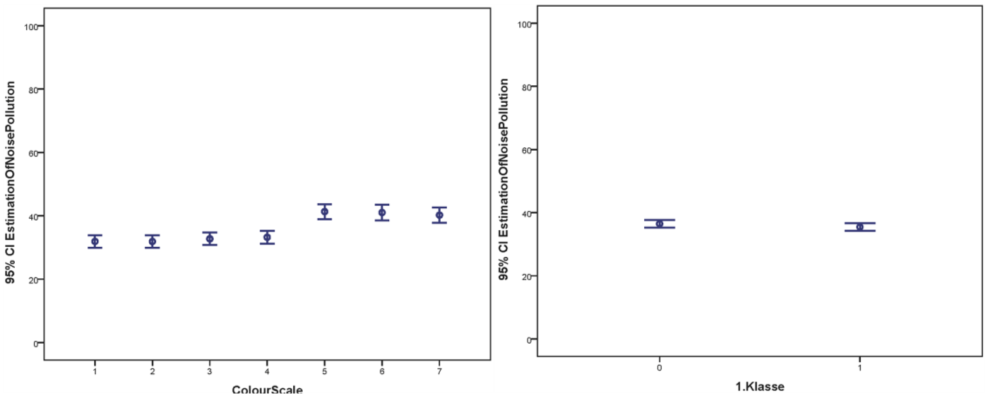

Figure 6. Error bars with a 95% confidence interval for the mean of the estimation of noise pollution on the basis of seven colour scales (left) and for the effect of the colouring of noise pressure level's first class (right)

2. *Does the colouring of the first class of the represented noise pressure level (colour/ no colour) influence the assessment of noise pollution?*

According to error bars in *Figure 6* there is no difference in the two groups. We found no evidence that the colouring of the first class influences the assessment of noise pollution. An independent samples t-test did not show any effects and rejected the null hypothesis: $t(3001) = 1.199$, $p = .231$. Hence our hypothesis H4 that a coloured first class leads to a higher assessment of noise pollution is not supported by the results.

5. Discussion and Future Work

This within-subjects experiment showed an effect of colour scales for assessing noise maps. We examined a statistically significant difference between light and bright scales, the latter lead to an estimated higher level of noise pollution that corresponds rather to the presented information. However, colour shades like the signal colour red, or cool shades like green and blue did not show any effects. Unexpectedly also a variation in the colouring of the noise pressure level's first class did not show any effects on the interpretation. Obviously, the information in the legend was well understood.

The experiment showed that noise pollution was underestimated, especially when scales 1-4 were used that start with light colours. This could be counteracted if the colour scale would display the logarithmic nature of the data. Therefore, the distances between the colours should not be equal but increasing.

The use of Ishihara plates showed that more participants than expected according to prevalent statistics had problems to distinguish red and green in at least one of the two presented plates. This does not necessarily indicate medical problems, but can also allude to “device-specific colour reproduction and environmental conditions (dark room or sunlight)” (Steinrücken & Plümer 2013: 20) which affected interpretation. Thus, if almost 25% of participants had “spontaneous CVD” this has to be considered in colour design for maps.

Due to the set-up as a field experiment the results are applicable to the further development of colour scales. They are essential because they show how users can be influenced and maybe even manipulated with an inappropriate choice of colour. Especially for the purpose of public participation and presentation of environmental information such a manipulation should be excluded.

In a next step we will refine the colour scales on the basis of the above mentioned results and conduct further experiments and studies to examine the suitability for the specific use case noise mapping. We put the focus on the suitability of multi-hue scales that are supposed to increase discriminability and the adaptation to the data’s logarithmic nature.

References

Albers J (1970) Interaction of Color, Grundlegung einer Didaktik des Sehens. DuMont Schauberg, Köln

Alberts W, Alferéz JR (2012) The use of colours in END noise mapping for major roads. In: European Acoustic Association, EURONOISE 2012

Brewer CA (1992) Reviewing of Terms and Simultaneous Contrast Research for Cartography. Cartographica 29(3&4):20-30

Brewer CA (1994) Color Use Guidelines for mapping and visualization. MacEachren, A.M. & Taylor, D.R.F (Hrsg.) Visualization in modern Cartography, S. 123-147.

Brewer CA, MacEachren AM, Pickle LW, Herrmann D (1997) Mapping Mortality: Evaluating Color Schemes for Choropleth Maps. Annals of the Association of American Geographers 87(3):411–438Brewer, C.A. (2005). Designing better Maps

Cleveland WS, McGill R (1983) A Color-Cuased Optical Illusion on a Statistical Graph. The American Statistician 37(2):101-105

DIN Deutsches Institut für Normung e.V. (1991) DIN 18005-part 2, Noise abatement in town planning; noise maps; graphical representation of noise pollution. Beuth, Berlin

Eckstein PP (2008) Angewandte Statistik mit SPSS. Gabler Wiesbaden

Environmental Noise Directive 2002/49/EC, 25 June 2002, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:189:0012:0025:EN:PDF

Harrower M, Brewer CA (2003) ColorBrewer.org: An Online Tool for Selecting Colour Schemes for Maps. The Cartographic Journal 40(1): 27–37

International Organization for Standardization (1987) ISO 1996: 2, Acoustics – Description and measurement of environmental noise, Part 2: Acquisition of data pertinent to land use

International Organization for Standardization (2007) ISO 1996: 2, Acoustics – Description, measurement and assessment of environmental noise, Part 2: Determination of environmental noise levels

Jenny B, Kelso NV (2007) Color Design for the Color Vision Impaired. Cartographic perspectives 58:61-67

Levkowitz H (1996) Perceptual Steps along Color Scales. International Journal of Imaging Systems and Technology 7:97-101

Lyons P, Moretti G, Wilson M (2000) Colour group selection for computer interfaces. Rogowitz BE Pappas TB (eds.) Human Vision and Electronic Imaging V 3959:302–313

MacEachren AM (1995) How Maps Work. The Guilford Press New York

Monmonier M (1996) How to Lie with Maps. The University of Chicago Press

Schiewe J, Weninger B (2013, accepted) Visual Encoding of acoustic parameters – framework and application to noise mapping. The Cartographic Journal

Schiewe, J, Weninger B, Kornfeld AL, Kurz C, Hintzsche M (2012) Gebrauchstauglichkeit von Lärmkarten verbessern. Lärmbekämpfung, Zeitschrift für Akustik, Schallschutz und Schwingungstechnik 5:215-220

Steinrücken J, Plümer L (2013) Identification of Optimal Colours for Maps from the Web. The Cartographic Journal 50(1):19–32

Trumbo BE (1981) A Theory for Coloring Bivariate Statistical Maps. The American Statistician 35(4):220-226

Wijffelaars M, Vliegen R, van Wijk JJ, van der Linden EJ (2008) Generating color palettes using intuitive parameters. EuroVis'08 Proceedings of the 10th Joint Eurographics / IEEE - VGTC conference on Visualization:743-750