Drieling [eds.], Räumliche Orientierung, Karten und Geoinformation im Unterricht (Geographiedidaktische Forschungen 49; Braunschweig), pp. 10–21.

Schiewe, J. & M.K.W. Schweer (2013): Vertrauen im Rahmen der Nutzung von Karten. Kartographische Nachrichten, 63(2/3): 59–66.

Schulze, U, I. Gryl & D. Kanwischer (2014): Spatial Citizenship: Creating a Curriculum for Teacher Education.-In: Vogler, R., A. Car, J. Strobl & G. Griesebner [eds.]: GI_Forum 2014 – Geospatial Innovation for Society (Berlin), pp. 230–241.

Stachoň, Z., Šašinka, Č., Štěrba, Z., Zbořil, J., Březinová, Š., Švancara, J. (2013): Influence of Graphic Design of Cartographic Symbols on Perception Structure. Kartographische Nachrichten, 63(4): 216–220.

Vetter, M. & F. Barnikel (2014): Veränderung der Raumorientierungsqualität durch digitale Karten versus analoge Karten – Implikationen für die Kartographie. Tagungsband zur Gemeinsamen Jahrestagung der DGfK, DGPF, GfGI und des GiN in Hamburg 2014 (DGPF Tagungsband 23/2014), 8 pp.

Vetter, M., F. Barnikel, M. Pingold & R. Plötz (2012): Untersuchung zur Verwendung digitaler und analoger Karten im Erdkundeunterricht unter besonderer Berücksichtigung der Raumorientierung.-In: Hüttermann, A., P. Kirchner, S. Schuler & K. Drieling [eds.], Räumliche Orientierung, Karten und Geoinformation im Unterricht (Geographiedidaktische Forschungen 49; Braunschweig), pp. 227–241.

Willis, K.S., C. Hölscher & G. Wilbertz (2009): Understanding Mobile Spatial Interaction in

Urban Environments.-In: Minker, W., M. Weber, H. Hagras, V. Callagan & A. Kameas. [eds.]: Advanced Intelligent Environments (Heidelberg), pp. 119–138.

Wolbers, T. & M. Hegarty (2010): What determines our navigational abilities?, Trends in Cognitive Sciences, 14/3, pp. 138–146.

Zobl, F., Henning, S., Neuschmidt, J. & W.W. Wasserburger (2013): Barrierefreie Karten: Entwicklung einer webbasierten Desktop- und mobilen Anwendung für sehbeeinträchtigte und blinde Personen Kartographische Nachrichten, 63(6): 319–327 und blinde Personen. Kartographische Nachrichten, 63(6): 319–327.

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Mixed Research Design in Cartography: A Combination of Qualitative and Quantitative Approaches

Gemischtes Forschungsdesign in der Kartographie: Eine Kombination qualitativer und quantitativer Ansätze

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The contribution deals with methodological issues connected with the evaluation of cartographic materials. A new research design for map evaluation comes from an extensive cooperation between cartographers and psychologists. Contrary to strictly quantitative approaches, we propose a mixed research design, combining the quantitative and qualitative methods, because also the qualitative exploration of the corresponding cognitive strategies is in some cases necessary for an in-depth interpretation of the results. Proposed research design is demonstrated by a sample experiment concerning comparison and evaluation of suitability of two different cartographic approaches to avalanche hazard visualization. The quantitative analysis enables to detect potential differences in the compared visualization methods in the sense of their effectiveness and efficiency, and the qualitative analysis of the eye-movement data might improve our understanding of the ways different cognitive strategies are applied. The experiment was carried on the newly developed interactive assessment tool MUTEP, which substantially increases the reliability of experiments in cognitive cartography. MUTEP enables easy data collection and effective evaluation of the results which could be subsequently analyzed.

■ Keywords: evaluation, mixed research design, MUTEP, eye-tracking, cognitive cartography

Der Beitrag behandelt methodologische Aspekte bei der Evaluierung kartographischen Materials. Basierend auf der engen Zusammenarbeit von Kartographen und Psychologen ist ein neuer Forschungsansatz zur Kartenevaluierung entwickelt worden. Im Gegensatz zu rein quantitativen Ansätzen wird hier ein Forschungsansatz vorgeschlagen, der qualitative und quantitative Methoden vereint, da für eine vertiefte Interpretation der Ergebnisse in einigen Fällen eine qualitative Untersuchung der entsprechenden kognitiven Strategien notwendig ist. Der vorgeschlagene Forschungsansatz wird beispielhaft anhand einer Untersuchung demonstriert, bei der zwei kartographische Ansätze zur Visualisierung des Lawinenrisikos verglichen werden. Die quantitative Analyse deckt dabei potentielle Unterschiede der Visualisierungsmethoden im Hinblick auf ihre Tauglichkeit und Effizienz auf, während die qualitative Analyse der Blickbewegungsdaten unser Verständnis über die verschiedenen angewandten kognitiven Strategien erweitern kann. Die Untersuchung wurde mit Hilfe des neu entwickelten interaktiven Bewertungstools MUTEP durchgeführt, das die Zuverlässigkeit von Experimenten zur kognitiven Kartographie beträchtlich erhöht. MUTEP erleichtert die Datensammlung sowie die effektive Auswertung der Ergebnisse.

■ *Schlüsselwörter: Evaluation, Forschungsdesign, MUTEP, eye-tracking, kognitive Kartographie*

1 Introduction

The objective evaluation of cartographic products, or even elementary visualization methods, is often problematic due to the very nature of the stimulus material. Complex stimuli, like cartographic visualizations, apparently require specific evaluation procedures. The present paper reviews existing evaluation procedures and employs an interdisciplinary approach to propose general outlines of compound procedures for the evaluation of cartographic visualization. The importance of the evaluation issue is also supported by legislative demands (Řezník 2013).

The methods and design used in the evaluation process significantly affect the results obtained, as well as the validity of the evaluation (Olson 2009; Wolfe et al. 2004). Mixed research design (see Creswell 2003), by combining quantitative and qualitative approaches, might help to increase the reliability and objectivity of collected data. While the former enables analysis of a large amount of data, the latter might shed some light on the actual processes involved. According to Johnson and Christensen (2010, p. 33), quantitative research employs the "deductive or confirmatory or top-down method", which is fundamentally used for description and explanation. These methods are based on quantitative data, specifically on the statistical analysis of variables. This analysis subsequently leads to the generalizing of the results and final interpretation or trends prediction. In contrast, qualitative research employs the "bottom-up or inductive exploratory method", which is used primarily for exploration and observation of how people think and experience some specific situations or their lives. Qualitative methods presume the use of qualitative data that is explored for the presence of any particular patterns, themes or holistic features.

Štěrba et al. (2014) compare the quantitative and qualitative approaches in more detail and they introduce the theoretical basis of both approaches in a historical perspective. They argue that the quantitative approach has dominated in science for a long time and its principles are well known. The qualitative approach in psychology, in contrast, was widely spread in the second half of the 20th century, inspired by other methodologies, for example, in ethnography. Wilson (1977) points out that the methodology of the qualitative approach was based on two basic principles: the qualitative-phenomenological hypothesis and the naturalistic-ecological hypothesis. The first hypothesis stresses the fundamental unavailability of objectivity in research in social sciences where the final scientific findings are influenced by the participants as well as the researcher. In contrast, the second hypothesis reflects the limited capability of the researcher to deal with a complex environment, including the determining and verification of universal rules. Considering that the experimental design enables the achievement of objective and measurable data, the second hypothesis plays a more important role in the definition of the qualitative approach in the context of our study. Thus, we use the term 'qualitative' in a narrower sense here, and the term could be understood to be "exploratory data analysis" (see Leinhardt and Leinhardt 1980). In other words, the qualitative research covers the methods that require neither any set hypotheses prior to data collection nor the conducting of a statistical test of the assumed relationships. The researcher, in contrast, employs appropriate methods and instruments facilitating an in-depth analysis and exploration.

In our study, we employed a combination of the two research techniques, namely via the administration of stimulus material with MUTEP (MUltivariate TEsting Programme) software and with the use of an eye-tracking system. MUTEP software enables the effective observation of usability metrics (response time and error-rate) and subsequent statistical analysis of the results. This quantitative analysis shows the main significant differences in perception of the studied stimuli (i.e. cartographic visualizations) that could be adequately used for the final interpretation (see Stachoň et al. 2013, Štěrba et al. 2011). In some cases, however, additional qualitative analysis, regarding the elementary cognitive strategies employed by users, is needed for an in-depth exploration of the results and the confronting of the set hypothesis. An exploratory analysis of eye-movement data (acquired from a small sample size of users) might improve, for these purposes, our understanding of how the different cognitive strategies are applied (Li et al. 2010, Broedersen 2002).

Each of these approaches offers a different type of objective data processing, and we believe that an adequate combination of both might result in a better understanding of cognitive strategies used by the respondents and the quality of observed and evaluated cartographic representations.

2 Evaluation in cartography

The complex issue of cartographic product evaluation is already dealt with during the process of map creation. Evaluation data provides crucial feedback on the extent to which a map serves the purpose it was designed for. If the determinants of successfully working designs (with regard to a pre-defined criterion) were not known, efficient production of practical, usable maps would be more difficult. An evaluation can be conducted at different stages or throughout the whole cartographic process. The objective is to ensure optimal quality of maps or other cartographic products (cartographic applications, GIS, etc.). As a key prerequisite of appropriate evaluation, the primary function of each specific map must be clearly defined. As mentioned above, a map is only considered usable when it serves its intended purpose in a given context and for a particular type of user. Users therefore, logically, have to play a major part in the evaluation process.

Multiple ways of cartographic product evaluation exist which can provide meaningful feedback about usability, and the topic has been addressed by several authors (e.g. Nivala et al. 2008; Sedlák et al. 2011; Elzakker 2004). Most of these approaches tackle the problem of outcome objectification, which becomes more difficult as the complexity and the number of criteria involved in the evaluation process increase. With highly specialized maps intended for a narrow group of users it is possible to focus on a specific set of criteria which are crucial for the purpose of the product. In most cases, however, it is necessary to factor in many different variables which may directly or indirectly impact the product's usability.

In general, three types of evaluation can be distinguished: expert evaluation, user evaluation, and combined evaluation (e.g. Kaňok et al. 2000). The subjective expert and user types of evaluation, although easily obtainable and accessible, are disadvantageous precisely because of their inherent subjectivity (e.g. Miklošík 2002). The use of this type of evaluation is generally recommended only as a preliminary step taken prior to a more complex assessment, as it can assist in the selection of further procedures and more adequate evaluation methods. These subsequent evaluation methods are based on users' performance in map-based decision making, i.e. the completion of a set of pre-selected tasks. The methods come from an interdisciplinary collaboration of psychologists and cartographers and combine approaches focused on an objective measurement of variables related to the user's performance on a particular map-reading task with qualitative data obtained through observation and/or self-report measures (see Rubin 2008; Tullis et al. 2008; Wilkening and Fabrikant 2011). The main advantage of this approach is in the fact that the evaluation process itself is supervised by experts but all data is provided by the users. The combined approach seems especially promising in the fields of human activity which target specific demands on maps, such as crisis management, military operations, etc. Evaluation of this kind was employed, for example, by Štěrba et al. (2011) and Kubíček et al. (2014), and will be further discussed in the following chapters.

3 Mixed research in cartography

Improved map designs are only achieved through the improvement of map development processes. Evaluation and analysis of maps play an essential part in this improvement by providing valuable feedback which helps to enhance the usability of cartographic products. However, purely quantitative (through statistical analysis) or purely qualitative evaluation (with the help of exploratory data analysis) frameworks are sometimes insufficient to achieve this goal. In such cases, it is appropriate to employ a combination of these two frameworks, which potentially results in greater validity of results and enables more suitable interpretations through mutual complementarity of the two approaches. Thus, mixed-research designs are widely applicable in cartographic usability research. Despite this fact, as noted by Olson (2009), combinations of quantitative and qualitative designs are often neglected in cartography. One of the first authors who stressed the importance of mixed research designs in experiments was Buttenfield (1999), who used several supplementary methods in her study, representing both quantitative and qualitative approaches.

Griffin (2012) and Hegarty et al. (2010) point out that cartographic stimuli are so complex that highly elaborate experimental designs must sometimes be developed to test them, preceded by appropriate pilot studies. Each evaluation process essentially starts with the precise definition of the examined area as well as the target user group and the key characteristics of the evaluated cartographic product (Slocum et al. 2001). Mixed research designs of interdisciplinary methodological origins attempt to deal with the complexity issue in cartographic materials (Jabine et al. 1984). Results obtained by combined methods are generally more easily interpretable. In cartographic experiments, relatively large amounts of data needs to be collected and analyzed before confronting the original hypotheses. Valid results can only be achieved with sufficiently large samples and adequately designed tasks. Great emphasis is also placed on the structure of the test (Olson 2009). In this respect, the administration software used in the present study – MUTEP – proves to be a valuable tool for quantitative data collection because it provides a fast and flexible platform for the reliable measurement of both effectiveness and efficiency of response in a given test battery (see below).

Even though quantitative data collection procedures provide information on important variables such as response time (Wolfe et al. 2004), it is sometimes necessary to conduct a parallel qualitative exploration, for example to determine cognitive strategies employed by the participants which would correspond to the scores and results obtained through quantitative measurements. This might lead to more accurate interpretations and further potential applications. In cartography, a specific type of data can be supplied by an eye-tracking system and this data can be analyzed in the qualitative way. Some indicators derived from eye-tracking may inform us about the actual actions and strategies of different groups of participants distinguished by scoring patterns (Popelka and Brychtová 2013, Popelka and Voženilek 2012; Garlandini and Fabrikant 2009). Such approaches can also help cartographers to comprehend different ways in which given visualization can be perceived.

3.1 MUTEP: quantitative data collection tool

In virtually all experiments, substantial effort should be invested into maximizing the objectivity of data collection. This can be achieved through exact quantification of the variables observed. MUTEP is one of the software tools providing this type of benefit. The application is an interactive testing environment offering new possibilities of combining quantitative and qualitative research methods. Designed primarily for the assessment of map usability, the tool is a result of extensive collaboration between cartographers and psychologists.

MUTEP application allows the researcher to test basic component actions of the user during a map-reading task, such as remembering individual symbols or locating them on the map (Stachoň et al. 2013; Kubíček et al. 2011). The performance on complex tasks is typically assessed by instructing the respondent to summarize certain types of information provided by the map (e.g. finding the shortest route between two landmarks, suggesting an escape route, looking up data according to the given attributes, etc.). The system does not only record the number of correct/incorrect responses (including accuracy) and response time, but creates a database of all user actions, such as displaying map legends. Psychological tests and surveys can also be administered through the MUTEP platform. A profound advantage of the system is the possibility to conduct different tests on a large number of respondents at the same time, which considerably improves the efficiency of the experiment. In addition, data export works independently of the on-going processes within the application (see Figure 1). Thanks to all of these qualities, administration via MUTEP substantially increases the reliability of experimental methods used in cognitive cartography.

3.2 Qualitative analysis of eye-movement data

The successful completion of map-reading tasks places particularly high demands on the participant's visual attention system. Using eye-tracking techniques, it is possible to provide the researcher with information on where the participant is looking at any given time and the sequence in which their eyes are shifting from one location to another (Poole and Ball 2006). Utilizing the strong relationship between gaze direction and visual attention, the task-related interplay between fast eye movements (saccades)

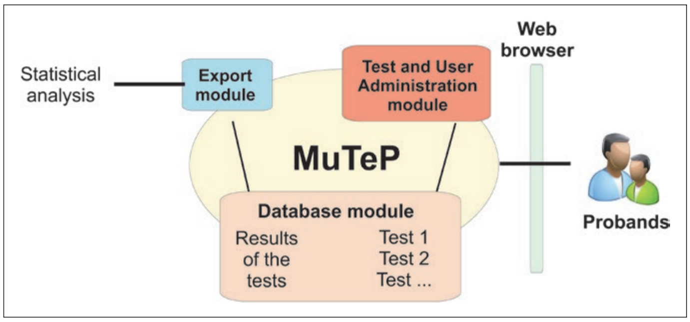

Fig. 1: A functional schema of MUTEP application for usability evaluation

and fixations provides researchers with additional information on how participants solve a given task, which cannot be derived from reaction time measurements or self-reports alone (for an overview on fixation- and saccade-based metrics and its interpretations, see, e.g., Poole and Ball 2006).

There are two general cases in which eye-tracking can be used for qualitative data collection. The first option is to employ eye-tracking as a preliminary study piloting a new experimental design. In this first step, the researcher examines the performance on various parts of the test, as well as the progress of the respondents on the individual tasks, including problem-solving strategies, understanding of instructions, intuitive control of the software's functions, etc. By means of administration of this kind consecutively several times, the experiment can be modified and finalized into the most suitable form used in the main data collection via MUTEP (or similar application). Similarly, qualitative pilot studies can assist in formulating final hypotheses. A primary advantage of this procedure is that it helps to improve research designs without being overly time-consuming.

The second option is to perform qualitative analysis after sufficient amount of quantitative data has already been collected. This approach is especially applicable when interpretation of overall (test-related) or partial (task-related) results cannot be adequately interpreted without additional information on participants' task-solving strategies. Quantitative data does not usually reveal much about the nature of the participant's responding to the test, which remains a 'black box', concealing virtually all information on causes and structure of the observed effects. Qualitative analysis of the participant's behavior, however, can point to potential regularities in approaching certain types of tasks, such as cognitive processes involved in successful task completion or factors leading to errors and inaccurate responses. As well as clearer interpretation and deeper examination of the original hypotheses, eye-tracking based qualitative analysis can also be used in enhancing the accuracy of specific findings through subsequent administration of adjusted tasks in a smaller sample (Manson et al. 2012).

4 Demonstration of mixed research design

The proposed mixed research design and its possible advantages are demonstrated by a sample experiment focused on the comparison and evaluation of suitability of two different cartographic approaches to avalanche hazard visualization, namely intrinsic and extrinsic cartographic visualization methods. The experiment outlined below only serves as an illustration of the procedure and the main aim of the study is to describe the proposed methodology in more detail.

The experiment was designed in order to demonstrate the potential gain of using MUTEP software in conjunction with eye-tracking devices. We conducted a pilot study using an EyeLink 1000 remote eye-tracking system (SR Research). A simple MUTEP-experiment was emulated using Experiment Builder, the visual experiment creation tool by SR Research. This enabled us to focus on our research question and ignore, for the time being, details of hardware integration and the eye-tracking data was recorded in a format ready to use for exploratory data analysis using the EyeLink Data Viewer (Andrienko and Andrienko 2005).

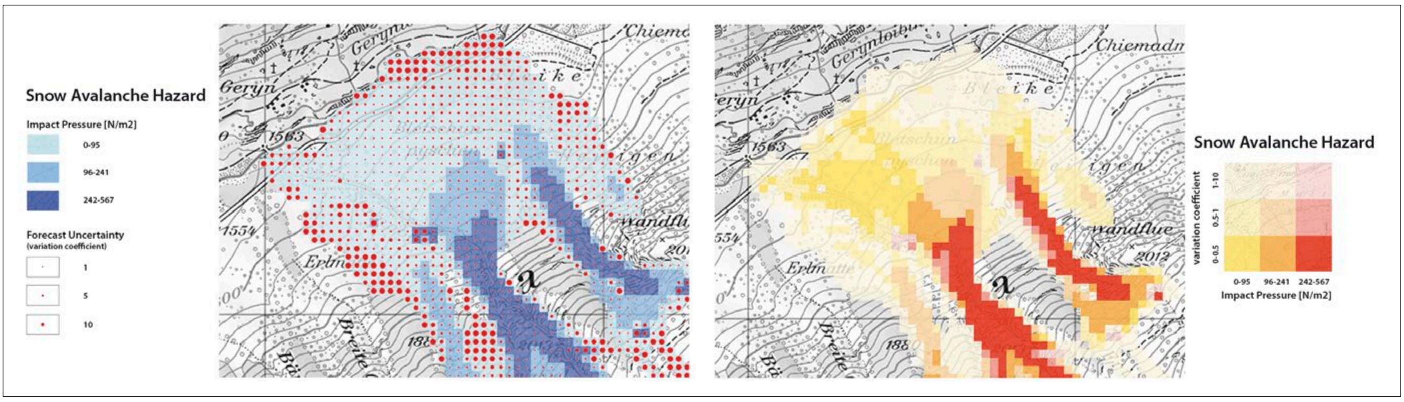

Fig. 2: Examples of uncertainty visualizations used in the test. Extrinsic variables – proportional circles (left); intrinsic variables – changes in saturation (right)

This tool provides ready-to-use solutions for basic eye-tracking metrics as well as advanced tools for analyzing gaze-shift between areas of interest (AOIs) and the calculation of different types of attention maps, e. g., fixation based heat maps (Wooding 2002).

The study focused on differences in intelligibility of intrinsic and extrinsic cartographic displays used for uncertainty visualization. The topic of the study – snow avalanche hazard and its uncertainty – was chosen for its practicality. Kunz (2011) distinguishes between univariate displays, where the avalanche hazard data and uncertainty are displayed in separate maps which have to be compared, and bivariate displays, where thematic data and inherent uncertainty are displayed in one single map. Bivariate displays are further subdivided into extrinsic display techniques, in which additional geometry is added to the symbolization, and intrinsic techniques, in which a visual variable of the symbolization is modified to indicate uncertainty. In the present study, two different bivariate uncertainty visualizations were applied: Proportional circles on top of the assessment result visualizations were used as extrinsic displays, and changes in saturation of the assessment results were used as intrinsic displays (see Figure 2).

Both visualizations were tested separately on two (randomly divided) groups of geography students, equalized in terms of age and gender (intrinsic N=36, extrinsic N=37). The whole test battery consisted of several subsequent tasks regarding the determination of the area with the defined avalanche hazard (see an example on Figure 3). During the experiment, both response correctness and response time were measured. Among other things, we tested three basic user abilities with increasing level of complexity:

- simple decoding of the predicted value (rate of avalanche hazard)
- uncertainty level decoding (avalanche presence uncertainty)
- comparison of combined values (both avalanche hazard and uncertainty)

The experiment was designed and conducted via the MUTEP platform. The battery completed by the respondents also included an adapted version of Navon's Compound Letter Test (CLT, see Navon 1977). The test measures the cognitive style of the respondent on the analytic-wholistic dimension and was constructed with regard to the options and limits of online administration (see Kveˇ ton et al. 2004). Kozhevnikov (2007) describes cognitive styles as heuristics used by the individual when processing information about the environment. These heuristics can be detected on elementary and automated, as well as complex and conscious levels of perception. For instance, an individual with analytic (as opposed to global) orientation will automatically attend to details in a presented scene, and will try to resolve problematic situations by focusing on elementary aspects and relationships and rely primarily on these elements when making his/her decisions.

4.1 Quantitative part of the study: Data collection via MUTEP

Quantitative analysis of the data obtained in our sample experiment using the MUTEP software did not reveal unambiguous differences between both test versions. Thus, none of the two visualization methods proved clearly a higher efficiency or effectiveness in all items than the other one. However, according to Lobben (2004), different people might employ different strategies on the same map tasks. One of our objectives was therefore to test whether the two visualization versions engaged different cognitive strategies/processes. Moderate correlations emerged between the performance on specific cartographic visualizations and the CLT scores. Those users who were more analytically oriented showed better performance (i.e. shorter response times) on intrinsic visualizations ($r=0{,}512$, $p<0{,}01$), whereas 'wholists' performed better on the extrinsic version of the test ($r=0{,}397$, $p<0{,}01$). These findings directed our attention even more closely to the concrete ways in which individual tasks were solved, or more precisely, cognitive strategies which could potentially explain the observed effects.

To explore the possibility that the above mentioned correlations actually indicated the employment of different cognitive strategies in each task, the parallel cartographic tests were in the next step of the experiment adapted for the environment of the EyeLink eye-tracking system. We hoped that qualitative analysis of the eye-movement data would improve our understanding of the way different cognitive strategies were applied.

4.2 Qualitative part of the study: Data collection using E-T

In the first stage, we conducted a semi-structured inquiry among the respondents who participated in the previous study as well as new respondents who had not previously completed the test. The second group received test instructions and was familiarized with both versions of cartographic visualization. The interviews were mainly focused on the intelligibility of instructions and the degree of understanding of the target phenomena depicted on the maps, i.e. avalanche hazard and uncertainty. On top of that, we were interested in subjective comprehensibility and intuitive decoding of the two visualization methods (i.e. the map legends). The semi-structured interviews indicated that while one part of the respondents perceived the intrinsic method as more intuitive, another part preferred the extrinsic method of visualization. Moreover, one group of respondents, among those who had no previous experience with the test, did not fully comprehend the principle of the given visualization method at all, which happened especially in the case of the intrinsic method.

For this reason, we decided to design an eye-tracking experiment to analyze these observations more deeply. Two parallel test versions were prepared on the Experiment Builder platform (see SR Research website). The tests were analogous to those previously administered through MUTEP, but were partly modified and extended by the inclusion of several additional tasks. Our main research questions, reflecting – in our opinion – the differences in cognitive strategies employed in task completion, concerned the means of legend decoding and the subsequent phase of required area location in the provided map field.

The following example presents one possibility of analyzing data obtained from one of the test items (see Figure 3). The instruction was to indicate which of the four fields marked on the map represented a medium level of avalanche hazard. Neither the video recording analysis nor heat map comparisons yielded any significant differences on this task. In the next step, several areas of interest were defined, two of which were analyzed in more depth. The first area of interest (AOI) was represented by the legend alone, the second by the map field. The following variables were compared for the two versions: total response time, total number of fixations during the trial, total number of fixations in the legend, including durations, total number of fixations in the map field, including durations, the numbers of saccades within the legend and within the map field, and the number of saccades between the map field and the legend, and vice versa.

On average, respondents who worked with intrinsic visualization completed this task in 9.9 seconds, while those working with extrinsic took 7.4 seconds. The former group thus needed about 34 % more time to solve the task. At the same time, however, the 'extrinsic' group kept their gaze on the legend for 1.37 seconds on average, while the 'intrinsic' group took only 0.66 seconds. This suggests that the 'extrinsic' group needed about twice as much time to decode the legend. Also in this group, there were three times as many fixations (5.4) on the legend than in the 'intrinsic' group (1.7). All of these results indicate that the extrinsic visualization method might require more time as well as more gaze fixations for successful legend decoding than the intrinsic method does. In contrast, the 'intrinsic' group spent 41 % more time searching the map field itself and comparing the target areas, and also fixated their gaze 36.6 % more in this AOI than the 'extrinsic' group did. Surprisingly enough, the number of saccades between the legend and the map field was extremely low in both cases (1.0 in extrinsic visualization and 0.7 in intrinsic visualization in the legend – map field direction; 1.3 in extrinsic visualization and 0.4 in intrinsic visualization in the opposite direction). We can explain this phenomenon in two ways. Firstly, the legend did not change for successive trials, so the participants did not need to read it again as long as they still could recall the given information from memory. And the second explanation is based on the fact that we only followed direct saccades between legend and map field, and so indirect patterns (e.g. from legend over the instruction to the map field) were not included in the analysis.

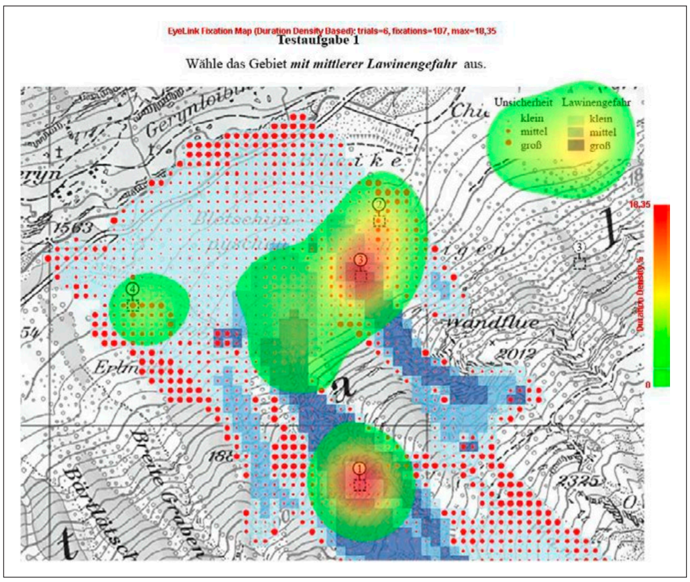

Fig. 3: Heat map – example analysis of one of the tasks in the test. The instruction was to determine the area of medium avalanche hazard

Based on the analysis of this task, we might conclude that the whole task-solving process should be divided into at least two different phases, i.e. legend decoding and visual search and comparison of the target areas in the map field. The extrinsic method, although it requires more time in the legend-decoding phase, seems to compensate for this time loss through a subsequently much briefer visual search period. This is a demonstration of how an in-depth analysis of a single test item can shed more light on the results obtained from purely quantitative data.

5 Conclusion and outlook

The objective of the presented paper was to provide an illustration of how mixed research design can be applied in cartographic product evaluation. Although there are certain barriers between the quantitative and qualitative approaches, which are caused by crucial methodological differences (Trafimow 2014), based on our findings we assume that a combination of these approaches can still work effectively when key target qualities of specific cartographic visualizations need to be established. For this reason, we provided a brief summary of the existing evaluation methods and made use of an interdisciplinary context to discuss possible ways of achieving objective evaluations of usability of cartographic products by means of combining several different methodological approaches. General conclusions derived from quantitative data analyses (such as average response time comparisons) can be substantially enhanced through employing a complementary qualitative approach, which is able to specify the reasons why the given time differences occurred from the perspective of the map user (time needed for task comprehension, visualization decoding, and task solution itself).

In our study, mixed research design use was demonstrated by an experiment involving the comparison and evaluation of two different visualizations of avalanche hazard – using intrinsic and extrinsic cartographic methods. Although the quantitative analysis of the correctness and response times, tested in the first step with MUTEP application, showed generally similar results for many parallel items, significant correlations emerged between respondents' performance on the two parallel task versions and the cognitive style scores. This fact shows a possible relationship between the achievement in the cartographic tasks and specific personality traits. To explore the possibility that these correlations actually indicated employment of different cognitive strategies, a part of the cartographic tests was subsequently adapted for an eye-tracking system environment. Exploratory data analysis of the eye-movement data provided more clues for understanding the ways different cognitive strategies could be applied.

In conclusion, based on our research experience, mixed research designs seem to represent an effective way of studying users' cognitive strategies, which was demonstrated in our example study.

Therefore, we argue that combinations of various methods in usability research may provide a good means of achieving greater objectivity in cartographic product evaluation, especially when qualitative approaches are employed, which can potentially help to clarify some of the constituent processes involved in map perception.

Note

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References

Andrienko, N., Andrienko, G. (2005). Exploratory Analysis of Spatial and Temporal Data. A Systematic Approach, Springer Verlag, Germany.

Broedersen, L., Andersens, H. K., Weber, S. (2002). Applying eye-movement tracking for the study of map perception and map design. Kort und Matrikelstyrelsen, Denmark, 98 p.

Brunswik, E. (1955). Representative design and probabilistic theory in a functional psychology. *Psychological Review*, 62, 193–217.

Buttenfield, B.P. (1999). Usability Evaluation of Digital Libraries. Science and Technology Libraries, 17(3/4), 39-59.

Creswell, J. W. (2003). Research design: Qualitative, quantitative, and mixed methods approaches (2nd ed.). Thousand Oaks, CA: Sage.

Dobešová, Z. (2009). Hodnocení kartografické fukcionality GIS, UP Olomouc.

Elzakker, C. (2004). The use of maps in the exploration of geographic data. *Netherlands geographical studies* 326, Utrecht/Enschede, 139 p.

Garlandini, S., Fabrikant, S. (2009). Evaluating the Effectiveness and Efficiency of Visual Variables for Geographic Information Visualization. *In*: K. S. Hornsby, ed. *COSIT 2009*, Springer-Verlag, 195–211.

Hegarty, M., Canham, M. S. and Fabrikant, S. I. (2010). Thinking About the Weather: How Display Salience and Knowledge Affect Performance in a Graphic Inference Task. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 36(1), 37–53.

Li, X., Coltekin, A. A., Kraak, M. J. (2010). Visual Exploration of Eye Movement Data Using the Space-Time-Cube. *Geographic Information Science, Lecture Notes in Computer Science*, 6292, 295–309.

Jabine T.B.; Straf, M.L.; Tanur, J.M.& Tourangeau, R (1984). Cognitive Aspects of Survey Methodology: Building a Bridge between Disciplines (73–101). Washington, DC: NacionalAcademy Press.

Johnson, R. B., Christensen, L. B. (2010). Educational Research: Quantitative, Qualitative, and Mixed Approaches, (4nd ed.). Sage Publications, 621 p.

Kaňok, J., Voženílek, V., Dušek, R., Drápela, M. V., Novák, S., Mikšovský, M., Friedmannová, L., Klečková, K. (2000). Kartografické hodnocení Školního atlasu České republiky, Kartografie Praha, a.s., Proceedings of ČGS conference 2001, Česká geografická společnost.

Kozhevnikov, M. (2007). Cognitive styles in the context of modern psychology: Toward an integrated framework. *Psychological Bulletin*, 133, 464–481.

Kubíček, P., Šašinka, Č. (2011). Thematic uncertainty visualization usability – Comparison of basic methods, *Annals of GIS*, 17 (4), 253–263.

Kubíček, P., Šašinka, Č. , Stachoň, Z. (2014). Vybrané kognitivní aspekty vizualizace polohové nejistoty v geografických datech. *Geografie*, 119, 1, 67–90.

Kunz, M. (2011). Interactive visualizations of natural hazards data and associated uncertainties. PhD Thesis, ETH Curych, 103 p.

Květon, P., Jelínek, M., Vobořil, D. and Klimusová, H. (2004). Computer-based tests: the impact of test design and problem of equivalency, *Computers in Human Behavior*, 23(2007), 32–51.

Leinhardt, G., Leinhardt, S. (1980). Exploratory Data Analysis: New Tools for the Analysis of Empirical Data, *Review of Research in Education*, 8, 85–157.

Lobben, A. K. (2004). Tasks, Strategies, and Cognitive Processes Associated With Navigational Map Reading: A Review Perspective. *The Professional Geographer*, 56(2), 270–281.

Manson, S. M., L. Kne, K. Dyke, J. Shannon, and S. Eria (2012). Using eye tracking and mouse metrics to test usability of web mapping navigation, *Cartography and Geographic Information Science* 39 (1).

Miklošík, F. (2002). Objektivizace hodnocení map a mapových děl, Vojenská akademie v Brně, S-619, Brno, 90 p.

Navon, D. (1977). Forest Before Trees: The Precedence of Global Features in Visual Perception. *Cognitive psychology*, 9, 353–383.

Nivala, A.M., S.A. Brewster, and L.T. Sarjakoski. (2008). Usability evaluation of web mapping sites. *Special Issue on Use and User Issues of The Cartographic Journal* 45(2): 130-40. ISSN: 1743-2774

Olson, J.M. (2009). Issues in human subject testing in cartography and GIS, *Proceedings of the International Cartographic Conference 2009*.

Poole, A., Ball, L. J. (2006). Eye tracking in HCI and usability research, *Encyclopedia of human computer interaction*, 211–219.

Popelka, S., Vozenilek, V. (2012). Specifying of Requirements for Spatio-Temporal Data in Map by Eye-Tracking and Space-Time-Cube, *Proceedings of International Conference on Graphic and Image Processing (ICGIP 2012)*, Singapore, doi:10.1117/12.2011438.

Popelka, S., Brychtová, A. (2013). Eye-tracking Study on Different Perception of 2D and 3D Terrain Visualisation, *The Cartographic Journal* Vol. 50 No. 3 Maney Publishing, 240–24. ISSN: 1743-2774.

Rubin, J. (2008). Handbook of usability testing: How to Plan, Design and Conduct Effective Tests, 2. vyd., Indianapolis: Wiley Publishing Inc., 2008, 348 p., ISBN 978-0471594031.

Řezník, T. (2013). Geographic information in the age of the INSPIRE Directive: discovery, download and use for geographical research. Geografie, 118, No. 1, 77–93.

Sedlák, P., Hub, M., J., K., Komárková, J. (2011). Preference uživatelů internetových mapových aplikací zjištěné na základě hodnocení použitelnosti. 19. *Kartografická konferencia Kartografia a geoinformatika vo svetle dneška*. Kartografická společnost' Slovenskej republiky, Bratislava, 131–139. ISBN 978-80-89060-19-1.

Slocum, T. A. , Blok C. , Jiang B. , Koussoulakou A. , Montello D. R., Fuhrmann S. , Hedley N. R. (2001). Cognitive and usability issues in geovisualization, *Cartography and Geographic Information Science* 28, p61-75.

SR Research. Retrieved on December 10, 2013 from http://www.sr-research.com/eb.html.

Stachoň, Z., Šašinka, Č., Štěrba, Z., Zbořil, J., Březinová, Š., Švancara, J. (2013). Influence of Graphic Design of Cartographic Symbols on Perception Structure, *Kartographische Nachrichten*, 4/2013, 216–220.

Štěrba, Z., Stachoň, Z., Šašinka, Č., Zbořil, J., Březinová, Š. Talhofer, V. (2011). Evaluace kartografických znakových sad v kontextu osobnosti uživatele, *Geodetický a kartografický obzor*. 99/57, vol. 8, pp 6.

Štěrba, Z., Šašinka, Č. Stachoň, Z. (2014). Usability testing of cartographic visualizations: principles and research methods. *5th International Conference on Cartography and GIS*, 2014. 7 p. ISSN 1314-0604.

Sturm, T. (2006). Is there a problem with mathematical psychology in the eighteenth century? A fresh look at Kant's old argument, *Journal of the History of the Behavioral Sciences*, 42(4), 353-377.

Trafimow, D. (2014) Considering Quantitative and Qualitative Issues Together, *Qualitative Research in Psychology*, 11:1, 15-24.

Tullis, T., Albert, B. (2008). Measuring the user experience: collecting, analyzing and presenting usability metrics, 1. vyd., Burlington: Morgan Kaufmann publications, 2008, 316 p., ISBN 978-0123735584.

Wilkening, J. and Fabrikant, S. I. (2011). The Effect of Gender and Spatial Abilities on Map Use Preferences and Performance in Road Selection Tasks, Proceedings of the *25th International Cartographic Conference, Paris, France*, July 2011.

Wilson, S. (1977). The Use of Ethnographic Techniques in Educational Research, *Review of Educational Research*, 47(2), 245–265.

Wooding, D. S. (2002). Eye movements of large populations: II. Deriving regions of interest, coverage, and similarity using fixation maps. *Behavior Research Methods, Instruments, & Computers*, 34(4), 518–528.

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

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Mapping Techniques of Spatiotemporal Relationships for a Centric Road Network Model

Kartographische Techniken raum-zeitlicher Beziehungen für ein zentrisches Straßennetzmodell

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The aim of the study is to determine the effectiveness of cartographic representation methods based on the proportion of correct decisions for each map, as well as users' perceived effectiveness and their subjective evaluation of the graphical attractiveness of the mapping techniques used to convey information about spatio temporal accessibility. Several visualisations (both traditional and less conventional) are used to show distances between points in an hypothetical centric road network model. The relationships between the starting point and the destination points are considered in three ways: the Euclidean distance, the topographic distance measured along the roads, and the temporal distance. Fifty students were asked to estimate shortest, longest and matching distances and to pick out from the options the most effective and the most graphically attractive method of portrayal. The best result was achieved for two-dimensional mapping techniques with information about accessibility level labelled directly on the map. Students also performed better when seeking the shortest distances between central and destination point, and the best estimation results were achieved for the Euclidean distance.

■ Keywords: mapping techniques, spatial and temporal accessibility, attractiveness of cartographic presentation, map effectiveness

Das Ziel der diesem Beitrag zugrunde liegenden Studie besteht darin, die Leistungsfähigkeit kartographischer Darstellungsmethoden zu ermitteln. Hierzu wurden die fachlichen Entscheidungen für jede einzelne Karte und die von den Benutzern subjektiv empfundene graphischen Attraktivität der Kartentechniken miteinander verglichen. Bei den Informationen geht es um die Vermittlung raum-zeitlicher Erreichbarkeit. In der Studie wurden verschiedene, sowohl traditionelle wie auch weniger übliche Veranschaulichungen benutzt, um Entfernungen zwischen Punkten in einem hypothetischen zentrischen Straßennetzmodell aufzuzeigen. Die Beziehungen zwischen Start- und Zielpunkt wurden auf drei verschiedenen Wegen betrachtet: der euklidischen Distanz, der topographischen, entlang einer Straße gemessenen Distanz und der zeitlichen Distanz. Bei dem Versuch wurden fünfzig Studenten gebeten, kürzeste, längste und vermittelnde Entfernungen zu schätzen und aus den gegebenen Optionen die effektivste und graphisch attraktivste Veranschaulichungsmethode herauszusuchen. Das beste Ergebnis erzielten zweidimensionale Kartentechniken mit Informationen über das Erreichbarkeitsniveau, die direkt auf der Karte angezeigt worden waren. Auch agierten die Studenten besser, wenn sie die kürzesten Verbindungen zwischen Zentral- und Zielpunkt suchen sollten, wobei das beste Schätzungsergebnis für die Euklidische Distanz ermittelt wurde.

■ *Schlüsselwörter: Kartentechniken, räumliche und zeitliche Erreichbarkeit, Attraktivität kartographischer Darstellungen, Leistungsfähigkeit von Karten*