Influence of Graphic Design of Cartographic Symbols on Perception Structure

Einfluss des graphischen Designs kartographischer Signaturen auf die Wahrnehmungsstruktur

Zdeněk Stachoň, Čeněk Šašinka, Zbyněk Štěrba, Jiří Zbořil, Šárka Březinová, Josef Švancara; Brno (Czechia)

This paper presents a research that was established by interdisciplinary cooperation of psychologists and cartographers. The research is focused on influence of graphic design of map symbols on perceptual structure. Two different sets of map symbols were presented on identical topographic background. Each of the symbol sets was created by different authors and particular symbols vary in size, structure or color shades. An influence of cognitive style of respondents was observed too.

■ Keywords: Gestalt factors, perceptual structure, map, cognitive style

Dieser Artikel stellt ein Forschungsprojekt vor, das in interdisziplinärer Kooperation von Psychologen und Kartographen eingerichtet wurde. Der Forschungsfokus ist auf den Einfluss des graphischen Designs von Kartensignaturen auf die Wahrnehmungsstruktur gerichtet. Dabei wurden zwei verschiedene Sätze von Kartensignaturen auf einem identischen topographischen Hintergrund präsentiert. Jeder der Signaturensätze war von verschiedenen Autoren erstellt worden. Einzelne Signaturen variierten in Größe, Struktur oder Farbschattierung. Auch wurde der Einfluss des kognitiven Stils der befragten Personen beachtet.

■ *Schlüsselwörter: Gestaltfaktor, Wahrnehmungsstruktur, Karte, Wahrnehmungsstil*

1 Introduction

Research on effective map design becomes one of the crucial task of cartography (Griffin, Fabrikant 2012 or Brychtova et al. 2012) and can be also demanded legislatively (Řezník 2013). Map design consists of subsequent tasks from used color schemes to overall map composition. One of the most complex tasks is design of map symbols. Design of map symbols should comply with many requirements depending on the map purpose. Mainly, map symbols have to be generally comprehensible, i.e. their dependence on personal characteristics of users and other variables which influence map reading should be as small as possible. Individual symbols in the set must be distinguishable and it is also necessary to minimize size of map symbols in order to reduce total amount of graphic content of maps (Staněk et al. 2010).

The aim of this study is an experimental verification of the process of perceptual discrimination in complex stimulation material, which will be in accordance with the requirement of high ecological validity of the research, with regard to user's cognitive style. From the cartographic point of view, the possibility of evaluation of symbol sets was also investigated; this evaluation is seen as a necessary step in the process of creating a suitable general methodology, according to which maps could be evaluated in the future.

The searching technique obtains two processes: foveal identification of target content and the selection of extrafoveally identified elements for subsequent fixation. This selection is based on peripherally perceived information on potential targets. The irrelevant objects, which are not similar to the potential targets, have to be ignored, the similar objects have to be fixed, analyzed and compared with the target. This selection takes place already on the level of pre-attention mechanisms, which are global, non-differentiated and parallel. They divide the global visual field before conscious segmentation on background components and potential target components. After this segmentation, focal attention is focused on incoming target objects. According to Neisser (1964, 1967), the tasks of pre-attention mechanisms of the visual searching is to activate possible targets from the peripheral field – these possible targets direct focal attention to relevant targets. This expectation relates to the expectation of perceptual structuring hypothesis (see Williams, 1967) –differentiated perception of searched field is determined by the main characteristics of the target, then the perceptual structuring is based on these characteristics. If a person is searching for a red object, then they perceive a symbol composed of red figures on a background made of other colors.

According to the Gestalt theory, one of the basic principles in the process of perception organization is grouping, which is directed for example by principles of similarity or proximity (Koffka 1935). Many experiments have been carried out used various stimulation material; these experiments have confirmed the above-mentioned principles. Currently, the Gestalt theory is verified also by computer modellmodellinging (see Zhu, Weng 1999) or used in research of neurological correlates of psychological phenomena (see Qiu, von der Heydt 2005). The aim of the presented research was to verify validity of these phenomena in special stimulation material: maps.

Desolneux et al. (2003) claim, that it is necessary to distinguish between global and partial gestalt. Global gestalt is the result of simultaneous influence of partial gestalt principles. Furthermore, the authors presume that in order to identify gestalt, the point of view of probability also has to be taken into account; this approach is called the "Helmholtz principle". If attributes (e.g. color, orientation, location etc.) of each object within the picture are examined and the degree of their mutual similarity corresponds with the probability of random distribution, then gestalt is not present, i.e. Gestalt perception is not evoked. In the opposite case, visual sensations are organized into a complex perception, i.e. gestalt takes place.

Another frequently investigated topic in psychology is also the bi-stability, or multi-stability in perception of phenomena (see Attneave 1971). An example of bi-stable (reversible) figure is the Necker cube (Einhäuser et al., 2004), or the Rubin chalice (Hasson 2001). The dynamics of perceived phenomena was studied among others by Merk and Schnakenberg (2002), or Suzuki and Grabowecky (2002). Accordingly, we assume that division of the perception field into figure and ground takes place also during perception of maps, and also that in case of a thematic map reader's attention can be consciously focused either on the thematic content or on the topographic background. The more different is the character of both these map components, the easier it is to switch between figure and ground. On the other hand, the mechanism which can negatively interfere during the perception and information searching from the topographical background is the unintended attention initiated during perception of remarkable symbols. These remarkable symbols spontaneously draw attention and therefore symbols of thematic content act in the given moment as distractors. These processes are in mutual competition.

2 Properties of map symbol

Some cartographic theories (see Pravda 2003) describe the possibility of decomposition of a particular map into small entities, which are described as map symbols. A map symbol can be defined as a graphic entity with meaning represented on the map. Therefore, a map symbol contains simultaneously spatial and semantic information. Map symbols can be categorized (Robinson (1984), in MacEachren 2004) as geometric (e.g. triangle for camping), associative (cross for church) or pictorial (bike for bicycle path). Meaning of particular map symbols can be found in the map legend. The necessity of legend usage can be minimized by utilization of motivated map symbols, which can be understood without map legend. We can assume that using different types of map symbols will have significant influence on their processing and perception. There are expected differences in speed and interpretation correctness between people with different map use skills.

During map production, design of map symbols is the main outcome of cartographer's work. The appearance of a symbol is usually composed of basic graphical variables. J. Bertin (1974) defined six fundamental variables – size, shape, orientation, color, intensity and structure (see Fig. 1). Some authors (e.g. Drápela 1983) extended the above-mentioned list with position. Influence of position on appearance of map symbol lies in interaction with surrounding map symbols.

Color can be considered as the most expressive medium of cartography; therefore, it is usually used for the most important parts of map content. However, proper hue and saturation has to be carefully selected. For example in thematic maps, more intensive colors are used for expression of presented topic; on the other hand, moderate colors are used for topographic background.

In the presented experiment, there are two symbol sets displayed on the same topographic background.

Size of map symbols is the second most important graphical variable. Size influences speed of particular map symbol identification; on the other hand, there is significant influence on increase of graphical saturation and readability of the map.

There is a need for objective evaluation of map symbol sets which needs to come from fundamentals of map symbols (graphical variables). In our study we have

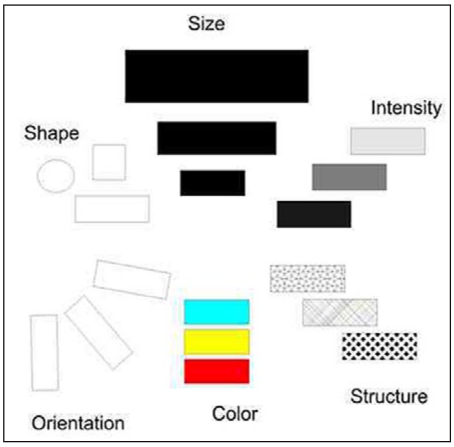

Fig. 1: Graphical variables of map symbol (Bertin 1974)

parameterized size (millimeters) and color (HSV color model) of evaluated symbols. In the presented experiment, the hypothesis was that map symbols with larger size and more intensive colors will be better readable and findable. The above-mentioned characteristics were specified for all evaluated map symbols and supported with qualitative evaluation of rate of abstraction of map symbols. Rate of abstraction parameterized efficiency of spatial information communication in the sense of isomorphic aspects of map language as defined by Drápela (1983).

3 Dependence of map reading performance on cognitive style

Cognitive style is one of the psychological concepts, which is concerned with inter-individual differences in perception and cognition. Sternberg and Zhang (2001) argue that cognitive style is a developmentally stabilized form of cognitive control which is relatively similar in different contexts. The concept of cognitive style describes variability in the way how various people process information and which form of information they prefer. This psychological topology has considerable potential application in the field of cartography. Modern contextual geographical information systems enable visualization of geographic data in a way that allows their rapid adaptation to the needs and preferences of specific users, i.e. to their cognitive styles. Riding and Cheema (1991) compared contemporary concepts of cognitive styles and argue that two main general and measurable dimensions can be detected in all explored concepts. One of them is the global-analytical dimension, which indicates concentration of the individual on the whole or on detail. The other is the verbal-visual dimension, which reflects preferences of individuals to use and to process either verbally or pictorially coded information. Blazhenkova and Kozhevnikov (2009) distinguish between object-visual cognitive style (object imagery) and spatial-visual cognitive style (spatial imagery). They based their conception on evidence concerning functional and anatomical

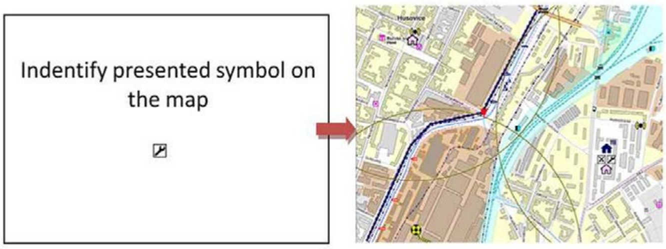

Fig. 2: Example of task focused on perception (2 subsequent slides).

specialization of the human brain. They developed a psychological diagnostic test called Object-Spatial Imagery Questionnaire (OSIQ) for measurement of the preferences. Vidláková (2010) constructed a Czech adaptation of the test and currently works on its standardization for the Czech population. Kozhevnikova et al. (2005) argue that object imagers process and remember images (or scenes) in detail, vividly and holistic as compact perceptual entities; on the other hand, spatial imagers process information more analytically and schematically, they are focused more on spatial relationships between objects and they perform more spatial transformations. Therefore, we assumed that performance during work with both compared symbol sets would also vary depending on cognitive styles of participants.

4 Research method

4.1 Participants

A total of 68 participants took part in the research. They were students of the 2nd and 3rd years of the Institute of Geography, Faculty of Science, Masaryk University. The group included 27 females and 41 males aged 20–26. Several participants didn't finish all parts of the test; therefore, their results were removed from evaluation. Participants were randomly divided into experimental group and control group. For experimental group, map symbol set A was used; for control group, map symbol set B was used.

4.2 Procedure and stimuli

The entire test battery consisted of three separate parts: cognitive style questionnaire, tasks focusing on perception and tasks focusing on associativeness of map symbols. Perception tasks were divided into two subtests. In the first subtest, participants were asked to find successively 38 specified map symbols that were placed in various parts of individual map segments. Each target symbols was at first presented individually in an instruction screen, where it was examined by participants. After that, testing screen was presented, in which participants were required to locate the previously shown symbol and mark it with a mouse click (see Fig. 2). In the second subtest consisting of 10 tasks, participants were asked to locate objects represented in the map background (e.g. crossing of two specified streets). For all tasks and both groups, a uniform topographic background developed specifically for emergency management maps was used.

Thematic map symbols designed for the used topographic background represent in this experiment the independent variable. Two map symbol sets with varying graphical design were created independently by two authors (Drápela et al. 2009; Friedmannová 2010); however, both sets representing the same phenomena and objects were tested independently in fixed order.

Fig. 3: Examples of map symbols from both sets used in the experiment

Individual symbols in set A are on the average almost twice as large as symbols in set B (average area of symbols in set A is 64 mm^2, whereas in set B it is 34 mm^2). Symbols in set A use almost always more distinct color hue than symbols in set B. Other parameters of HSB color model have similar values for symbols in sets A and B (average saturation is 89 % in set A and 84 % in set B; brightness is 84 % in set A and 84 % in set B).

From a qualitative point of view, it was determined, that symbols in set A are more iconic, whereas symbols in set B are more schematic. In set A, colors are used in a more contrasting way, and also affixes are more robust. In set B, use of colors in individual symbols and in also in the entire set is more balanced and conservative. Set B also more often uses numbers for expressing quantity and letters for increasing associativeness of symbols (e.g. „V" for armed forces, "vojsko" in Czech). On the other hand, in set A pictorial or associative clues are used (e.g. crossed swords for armed forces). Overall, set A gives the impression of being more noticeable and plastic (see Fig. 3).

Data collection took place in an air-conditioned study room on LCDs with a resolution of 1280 x 1024. All workplaces were equipped with the same type of mouse. Tasks were solved in map segments with the size 900 x 675 pixels. The experiment was carried out on-line on software platform MuTeP (Multi-variant Testing Program), which allows presentation of various graphical materials and also records and automatically evaluates various types of user actions. More detailed information about MuTeP can be found in Kubíček, Kozel (2010) or Konečný et al (2011).

Experiment design reflects possibilities and limitations of computer-based testing, as described e.g. by Květon and Klimusová (2002). In the subtest focused on perception two types of screens were used. For each task, there was a screen with instructions. After the user reads the instructions, they proceeded to the next screen by pressing „Next" button. On the screen where the actual task is solved (symbols were marked by a mouse click), shift to next task instruction screen takes place automatically after the mouse click. There was only one correct solution of each task and after answering, no subsequent correction was allowed. Before the start of the test, all participants were trained in basic operation of the software.

Examination of map perception was divided into two subtests. In the first subtest, participants were asked to identify a map symbol in the displayed map segment. The map symbol was shown in the previous screen, but the graphical presentation was not accompanied by its verbal naming. Used symbols differed in their levels of associativeness; therefore, the map symbol was not to be perceived as unconditionally meaningless.

In the second subtest, participants were required to identify and mark locations displayed in a topographic background. Locations such as street intersections or confluences were selected. Participants at first read instructions (e.g. „Where do Filipinského and Veleckého streets intersect?") and subsequently marked the described location in the displayed map segment.

Participants also completed a cognitive style questionnaire (OSIQ – Object-Spatial Imagery Questionaire), which monitored preferences in their ways of thinking and cognitive processing of stimuli. Correlation of OSIQ scores and performance in map tests was determined to verify whether various graphical character of map symbol sets may influence (i.e. facilitate or hinder) perception of visual stimuli depending on cognitive styles of individuals.

5 Results

5.1 Sub-test 1

The first sub-test was focused on identifying the required cartographic symbol within a map field. This part consisted of 38 pairs of symbols in total. The average measured time in this sub-test was significantly lower in the experimental group (M=3.06 s, SD=0.70); in contrast, the average result in the control group was 4.49 s (SD=1.50), see Figure 4. Only correct answers were evaluated. The difference between corresponding parallel symbols was also observed, and the experimental group reached lower reaction time in 35 symbols (16 of them were statistically significant). The control group had better result only in 3 cases, but none of them was significant. The difference between the two groups was tested with the independent t-test (($t = -4.95$, $p < .001$)). Power of the statistical test was 98 %.

5.2 Sub-test 2

In the second sub-test, participants were supposed to search the required objects within the background information (on the topographic map layer). This part consisted of 9 pairs of equivalent tasks. The average reaction time in this sub-test was also significantly lower in the experimental group (M = 7.00 s, SD = 1.83). The average time in the control group was, in contrast, 8.47 s (SD = 2.23), see Figure 5. The difference between both parallel symbol sets was again observed with even more convincing result: the experimental group reached lower reaction time in all of the tasks (3 of them were statistically significant). The difference between the two groups was tested with the independent t-test (($t= -2.98$, $p < .01$)). Only correct answers were evaluated. Power of the statistical test was 80 %.

Eventually, we also measured sex differences in the results of both tests. Males reached lower reaction times than females in both sub-tests of set A and in the first sub-test in set B. However, none of the result was statistically significant.

5.3 Relation between the test performance and the user's cognitive style

The results of the last part (OSIQ questionnaire) were finally used to assess the relation between the task performance and the user's cognitive style. Pearson's correlation coefficient was used to measure the relation. The correlation measure proved that spatial visualizers (schematically-oriented persons) reached higher reaction times in the set A ($r = 0.37$ for sub-test 1 and $r = 0.40$ for sub-test 2; $p < .05$).

6 Discussion and outlook

Digital cartography enables user centered map design. During the experiment we

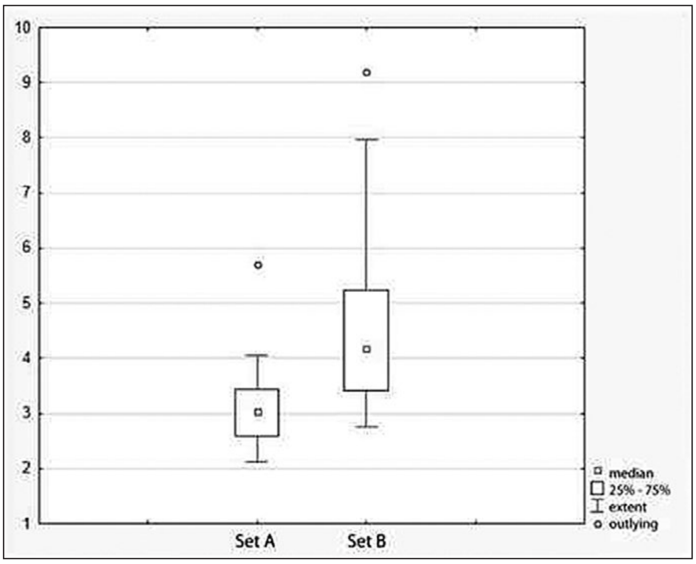

Fig. 4: Average reaction times for identifying cartographic symbols

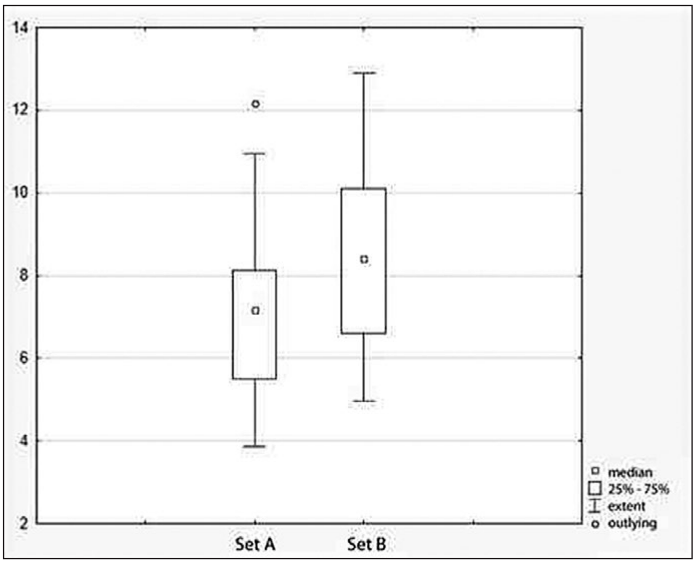

Fig. 5: Average reaction times for identifying objects in the map background

tried to prove the gestalt rules with a relatively specific stimulus – a cartographic symbol. We assumed that if the particular thematic symbols were perceived as a figure layer, it would be much easier for the user to distinguish and localize these symbols from the background topographic map. It was confirmed that performance of participants working with set A was significantly better. Generally, symbols in this set consist of distinct features and affixes. This is assumed to be the decisive reason for perceiving the symbols as the figure layer. Objectiveness of the test was increased by placing the symbols to varying parts of the map.

In the second subtest, it was discovered that the use of more noticeable symbols also facilitates easier perception of the background information. These results document the processes observed in the case of bistable reversible figures. These processes enable the user to actively choose elements both in figure and in background layer. We presume that these processes are more significant than the power of unintentional attention caused by other symbols (distractors). The design of the experiment could not show exactly how the two phenomena interact, but this was not the objective of the study. In any case, we expect that if the distinctiveness of the symbols increases, the figure-background reorganization will be disrupted, because the impact of the unintentional attention will become more decisive. To get more precise information about the influence of the two phenomena, a more suitable experiment needs to be designed, in which the elementary graphic entities of the symbols will be changed one by one. However, design of such experiment for cartographic symbols is very complex.

Relatively tight relation between the cognitive style of spatial imagery and the user's performance in the set A was found. The results show some negative impacts on the performance of the schematically-oriented users with the symbol set A, where the symbols that are more contrasted and iconic. On the contrary, no similar impact of the symbol set B (which is more schematic) on object visualizers was observed.

In this study, all the symbols were used and exposed without explanation of their meaning. We believe that the next extension of the study could cover also exploration of the influence of the symbol meaning to its perception within the map. The hypothesis of such an experiment would be the following: if the user works with meaningful cartographic symbols in the map, the observed efficiency of identifying both figure and background objects will be higher.

Note

This work was supported by the program of "Employment of Best Young Scientists for International Cooperation Empowerment" (grant number CZ 1.07/2.3.00/30.0037) co-financed from European Social Fund and the statebudget of the Czech Republic.

References

Attneave, F. (1971): Multistability in perception. Scientific American 225, 62–71.

Bertin, J. (1974): Graphische Semiologi.e. Diagramme, Netze, Karten. Berlin, Walter de Gruyter.

Blazhenkova, O., Kozhevnikov, M. (2009): The new object-spatial-verbal cognitive style model: theory and measurement. Applied Cognitive Psychology 23, 638–663.

Brychtova, A.,Popelka, S., Dobesova Z. (2012): Eye-tracking methods for investigation of cartographic principles. SGEM 2012 Conference Proceedings Volume II STEF92 Technology Ltd., Sofia, Bulgaria, 1041-1048 p. ISSN 1341-2704

Desolneux, A., Moisan, L., Morel, J.M. (2003): Computational gestalts and perception thresholds. Journal of Physiology-Paris 97, 311-324.

Drápela, M. V. (1983): Vybrané kapitoly z kartografi.e. Praha, SPN.

Drápela, M. V., Rybanský, M., Salvetová, Š.,Tajovská, K. (2009): Project of map symbology creation for emergency events and natural disasters. In Konečný, M., Zlatanova, S., Bandrova, T. (Eds.), Cartography and geoinformatics for early warning and emergency management: towards better solutions.Brno, Masaryk University, 150–156.

Einhäuser, W., Martin, K. A., König, P. (2004): Are switches in perception of the Neckercuberelated to eye position? European Journal of Neuroscience 20, 2811–2818.

Friedmannová, L. (2010): Designing map keys for crisis management on the regional operational and information centre level: monitoring transport of dangerous goods via contextual visualization. In Konečný, M., Zlatanova, S., Bandrova, T., (Eds.), Geographic information and cartography for risk and crisis management. Berlin - Heidelberg, Springer-Verlag, 425–437.

Griffin, A.L., Fabrikant, S. I. (2012): More Maps, More Users, More Devices Means More Cartographic Challenges, Cartographic Journal, Vol. 49,Â No. 4: 298-301.

Hasson, U., Hendler, T., Bashat, D.B., Malach, R. (2001): Vaseor face? A neural correlates of shape-selective grouping processes in the human brain. Journal of Cognitive Neuroscience 13, 744–753.

Koffka, K. (1935): Principles of Gestalt Psychology. New York, Harcourt and Brace.

Kozhevnikov, M., Kosslyn, S., Shephard, J. (2005): Spatial versus object visualizers: a new characterization of visual cognitive style. Memory & cognition 33, 710–726.

Konečný, M., Kubíček, P., Šašinka, Č. & Stachoň, Z. (2011): Usability of Selected Base Maps for Crises Management – Users Perspectives. Applied geomatics, 3(4), 189–198.

Kubíček, P. Kozel, J. (2010): Cartographic Techniques for Adaptive Emergency Mapping. In Kremers, H., Susini, A. (eds.): Risk Models and Applications. Berlin: CODATA-Germany e.V., 49 - 62, 13 s. ISBN 978-3-00-030278-7.

Květon, P., Klimusová, H. (2002): Metodologické aspekty počítačové administrace psychodiagnostických metod. Československá psychologie 46, 251–264.

MacEachren, A. M. (2004): How maps work: representation, visualisation, and design. New York, The Guilford Press.

Merk, I., Schnakenberg, J. (2002): A stochastic model of multistable visual perception. Biological cyberbetics 86, 111–116.

Neisser, U. (1964): Visual search. Scientific American 210, 94–102.

Neisser, U. (1967): Cognitive psychology. New York, Appleton-Century-Crofts

Pravda, J. (2003): Mapový jazyk. Bratislava,UniverzitaKomenského Bratislava.

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

Riding, R., Cheema, I (1991): Cognitive Styles – an over view and integration. Educational Psychology 11, 193–215.

Qiu, F.T., Heydt, R. von der (2005): Figure and Ground in the Visual Cortex: V2 Combines Stereoscopic Cues with Gestalt Rule. Neuron 47, 155-166.

Staněk, K., Friedmannová, L., Kubíček, P., Konečný, M. (2010): Selected issues of cartographic communication optimization for emergency centers, International Journal of Digital Earth, vol. 3, No. 4, 316–339.

Sternberg, R. J.,Grigorenko, E. L. (1997): Are cognitive styles still in style? American Psychologist 52, 700–712.

Sternberg, R. J., Zhang, LF. (Eds.) (2001): Perspectives on thinking. Learning and cognitive styles. Mahwah, Lawrence Erlbaum Associates.

Suzuki, S., Grabowecky, M. (2002): Evidence for perceptual 'trapping' and adaptation in multistable binocularrivalry. Neuron 36, 143–157.

Vidláková, I. (2010): Object – Spatial Imagery Questionnaire (OSIQ). Annales Psychologici P14, 67–76.

Zhu, S. Ch., Wu, Y.N. (1999): From local features to global perception – A perspective of Gestalt psychology from Markov random field theory. Neurocomputing 26–27, 939–945.

About the authors

Zdeněk Stachoň, Zbyněk Štěrba, Šárka Březinová, and Jiří Zbořil: Department of Geography

Čeněk Šašinka and Josef Švancara: Department of Psychology

Masaryk University, Brno (Czechia); http://www.geogr.muni.cz/