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The Impact of Global/Local Bias on Task-solving in Map-related Tasks Employing Extrinsic and Intrinsic Visualization of Risk Uncertainty Maps

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Abstract:	The form of visual representation affects both the way in which the visual representation is processed and the effectiveness of this processing. Different forms of visual representation may require the employment of different cognitive strategies in order to solve a particular task; at the same time, the different representations vary as to the extent to which they correspond with an individual's preferred cognitive style. The present study employed a Navon-type task to learn about the occurrence of global/local bias. The research was based on close interdisciplinary cooperation between the domains of both psychology and cartography. Several different types of tasks were made involving avalanche hazard maps with intrinsic/extrinsic visual representations, each of them employing different types of graphic variables representing the level of avalanche hazard and avalanche hazard uncertainty. The research sample consisted of two groups of participants, each of which was provided with a different form of visual representation of identical geographical data, such that the representations could be regarded as "informationally equivalent". The first phase of the research consisted of two correlation studies, the first involving subjects with a high degree of map literacy (students of cartography) (intrinsic method: N = 35; extrinsic method: N = 37). The second study was performed after the results of the first study were analyzed. The second group of participants consisted of subjects with a low expected degree of map literacy (students of psychology; intrinsic method: N = 35; extrinsic method: N = 27).The first study revealed a statistically significant moderate correlation between the students' response times in extrinsic visualization tasks and their response times in a global subtest (r=0.384, p<0.05); likewise, a statistically

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Figure 1. Triarchic structural model of performance when solving map-related task

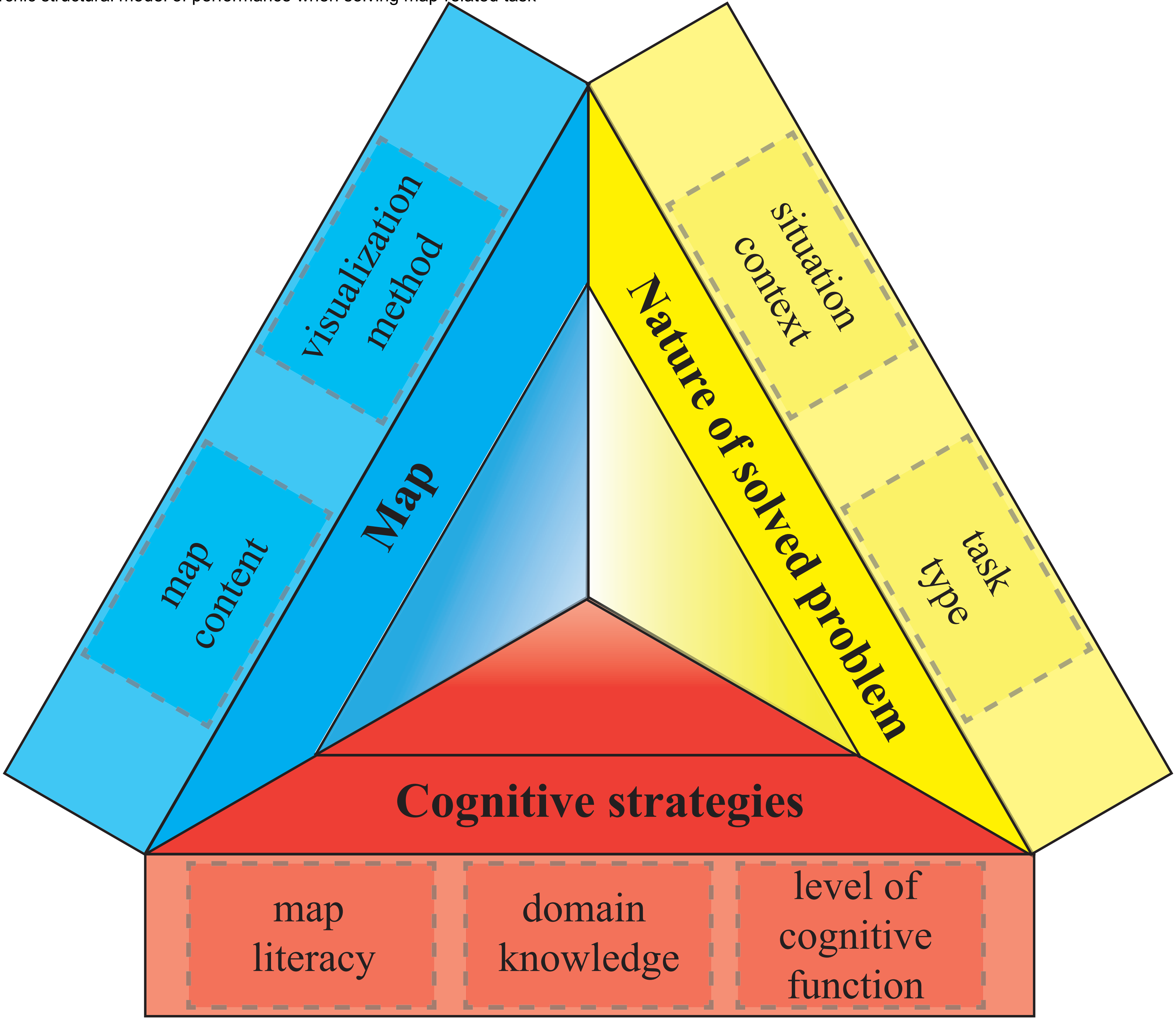


Figure 2. Snow avalanche hazard and hazard uncertainty map: left - extrinsic visual representation; right - intrinsic visual representation

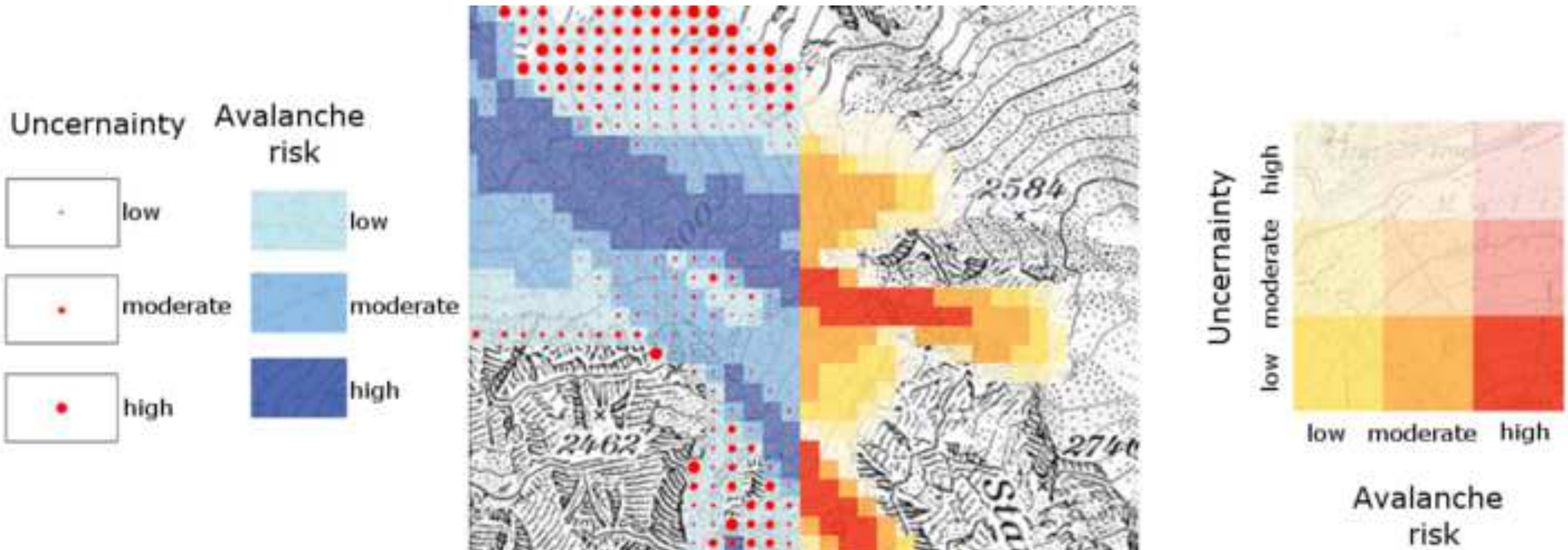


Figure 3. Differences in the encoding of variables between the extrinsic (first column) and intrinsic (second column) form of visualization; third column shows the difference

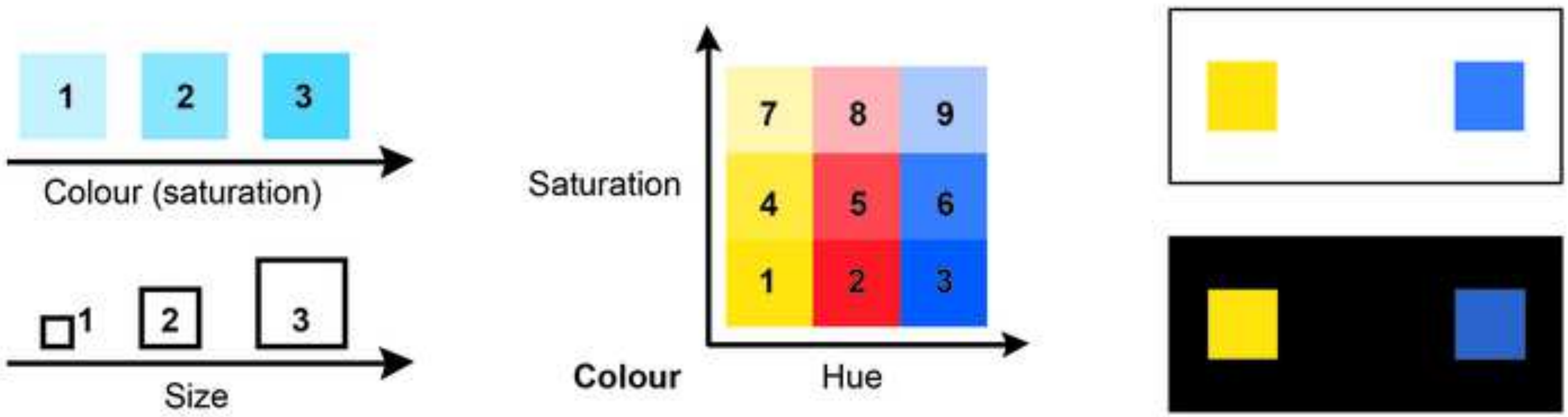
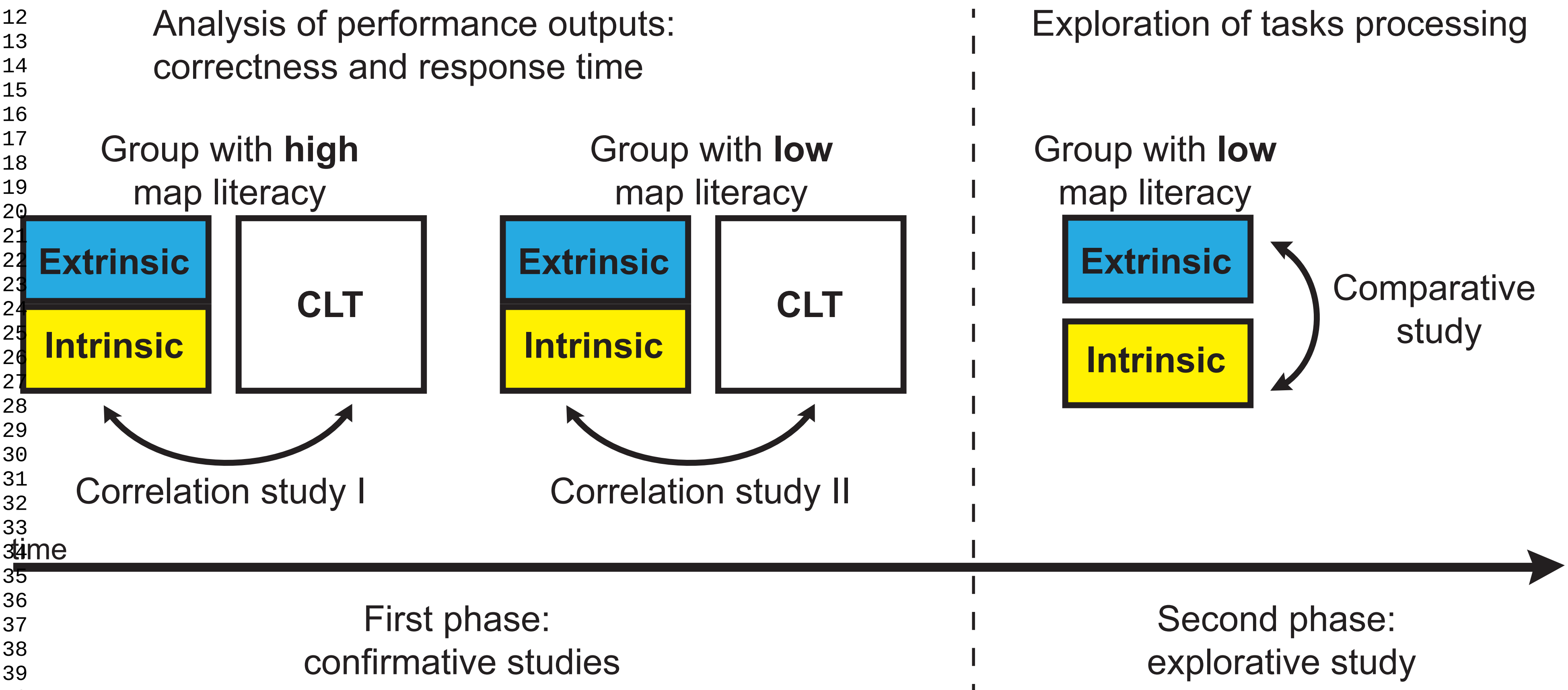


Figure 4. Structure of used combined extensive-intensive research design



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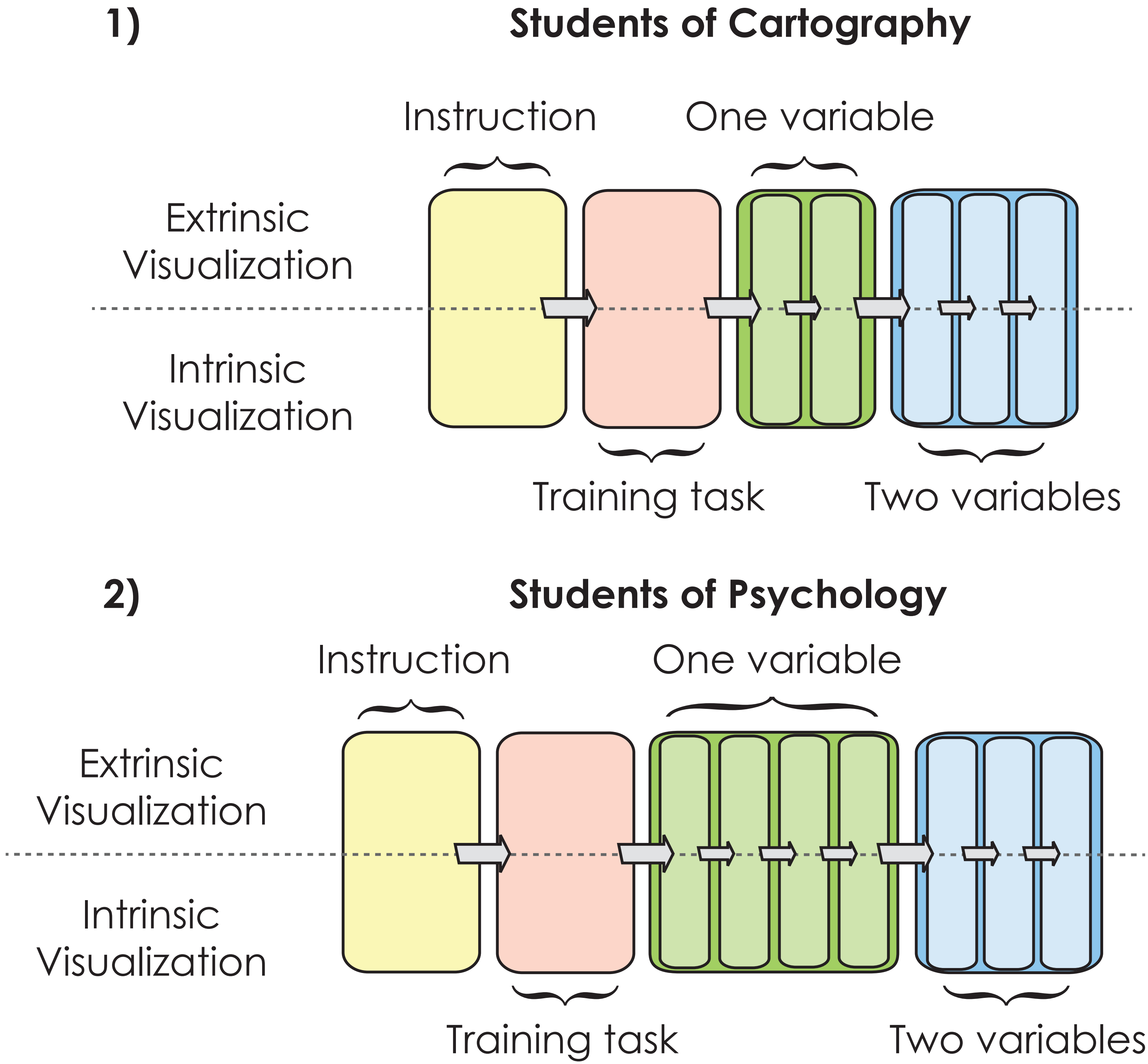

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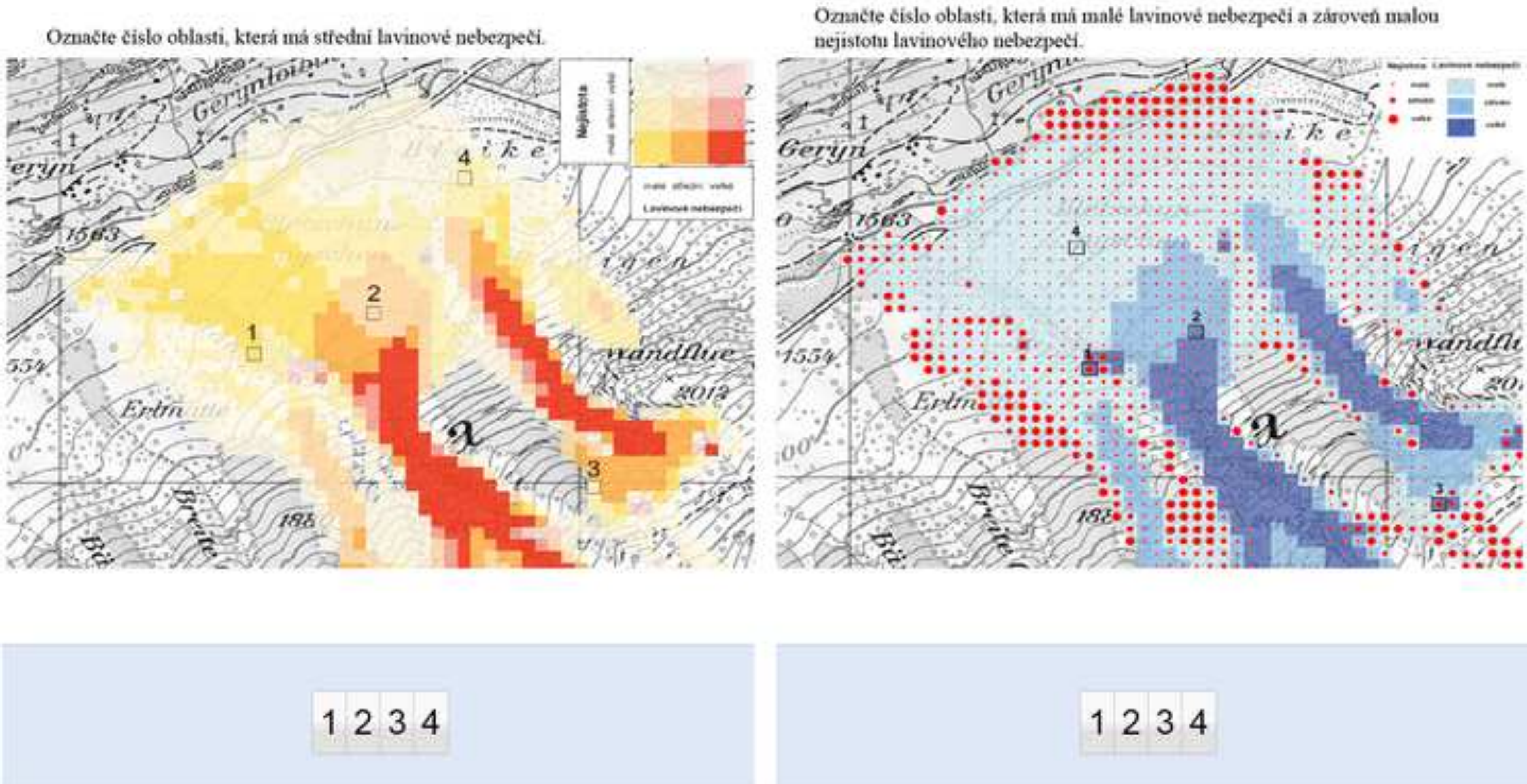
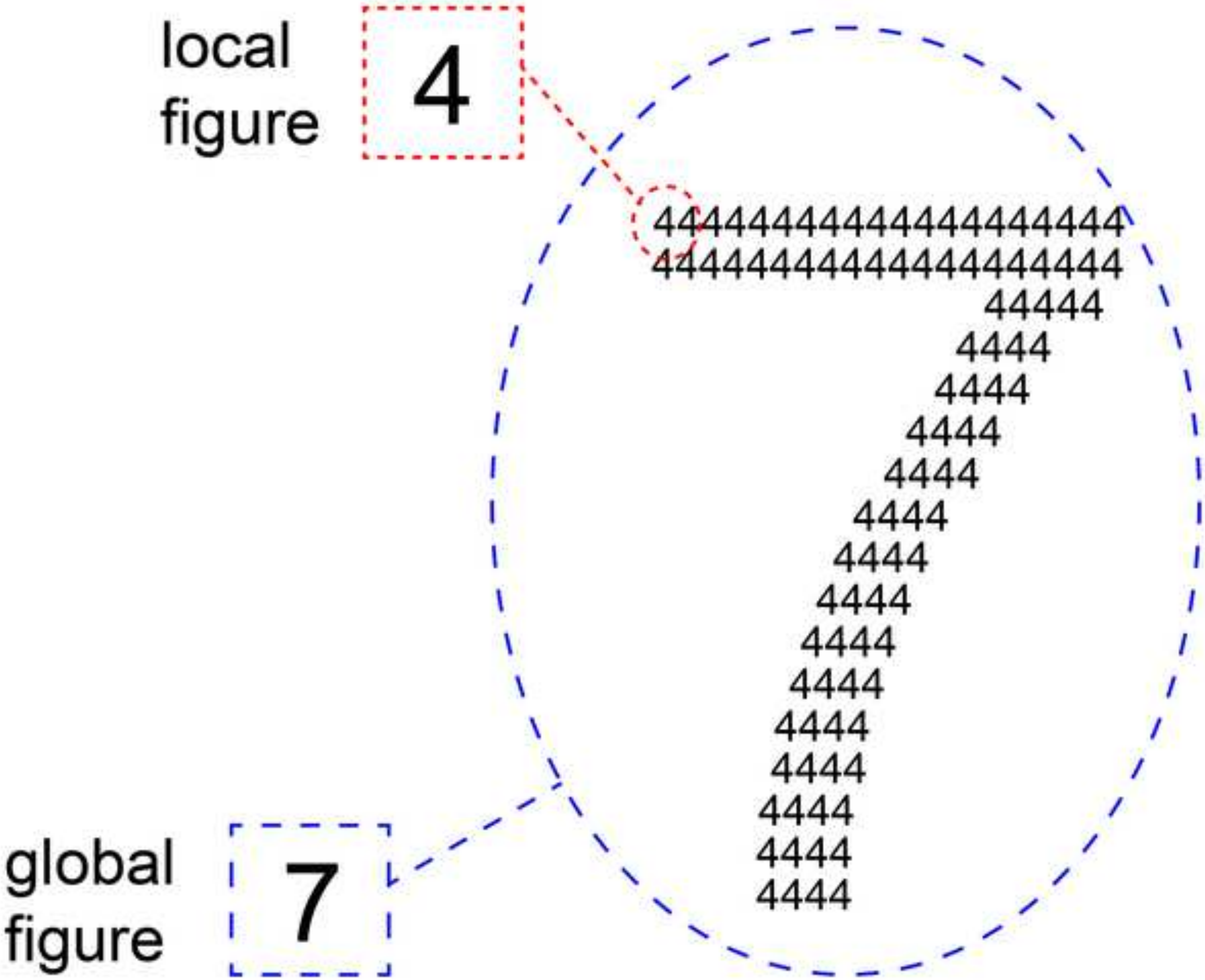


Figure 7. A compound stimulus (left)



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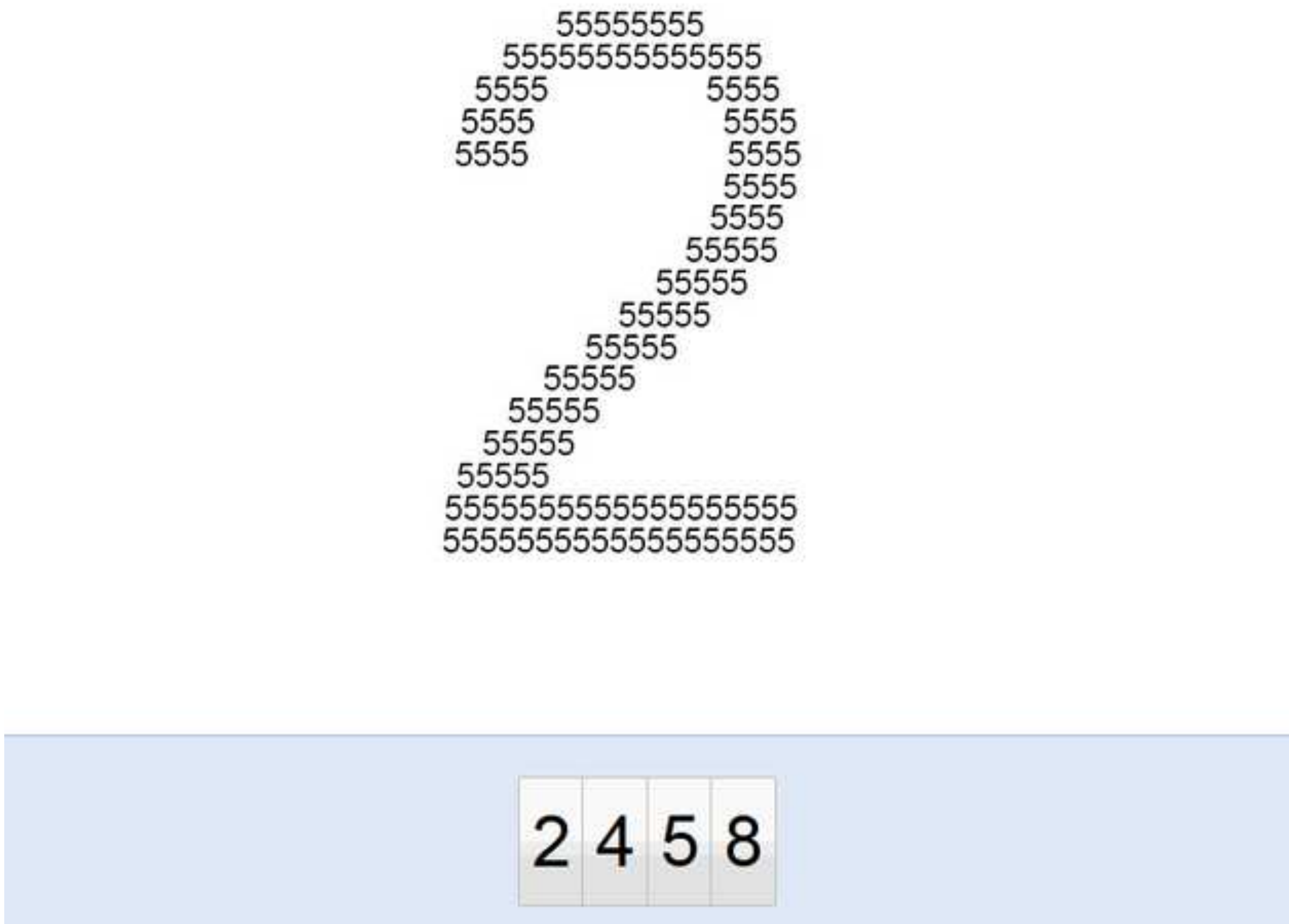

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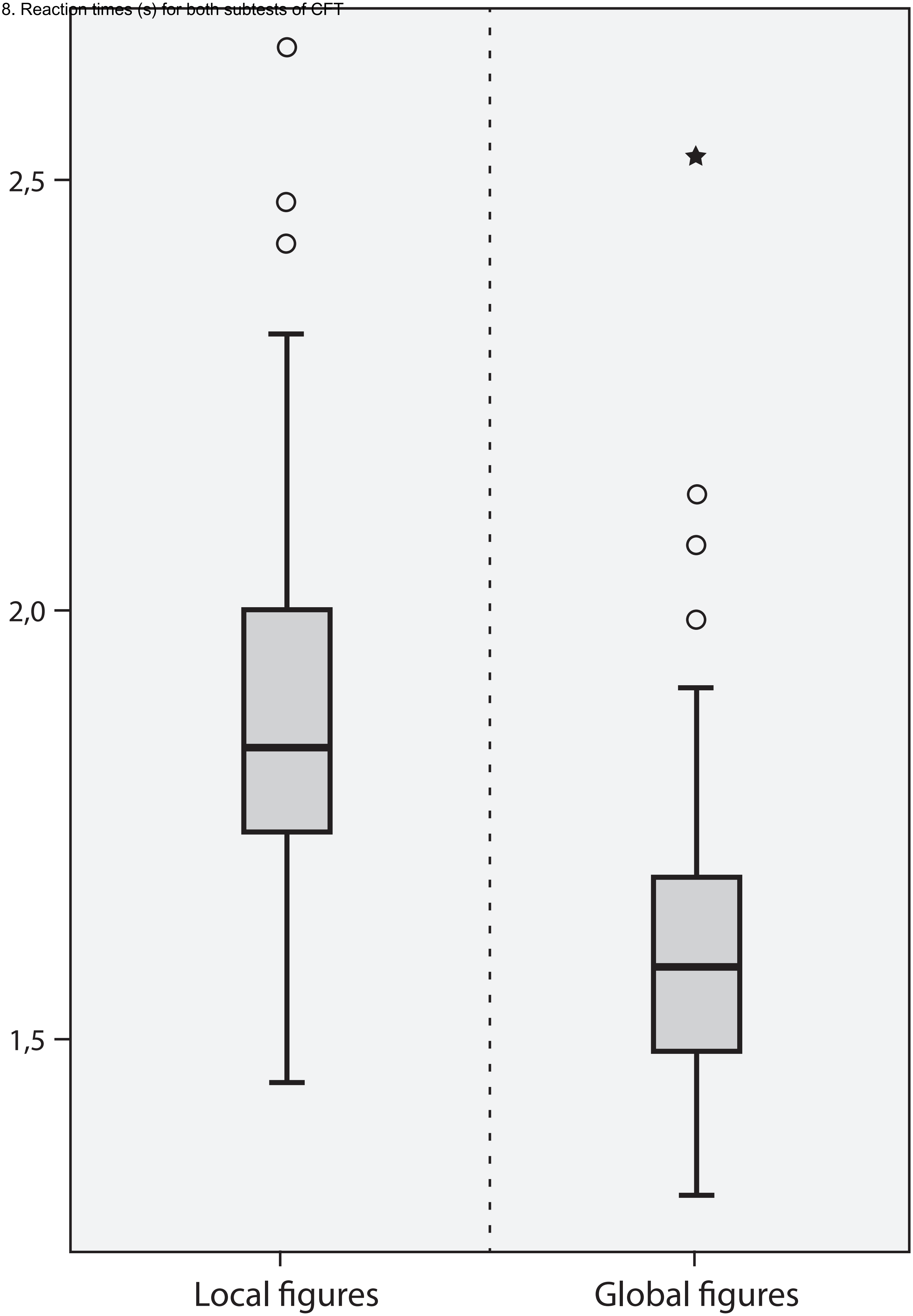

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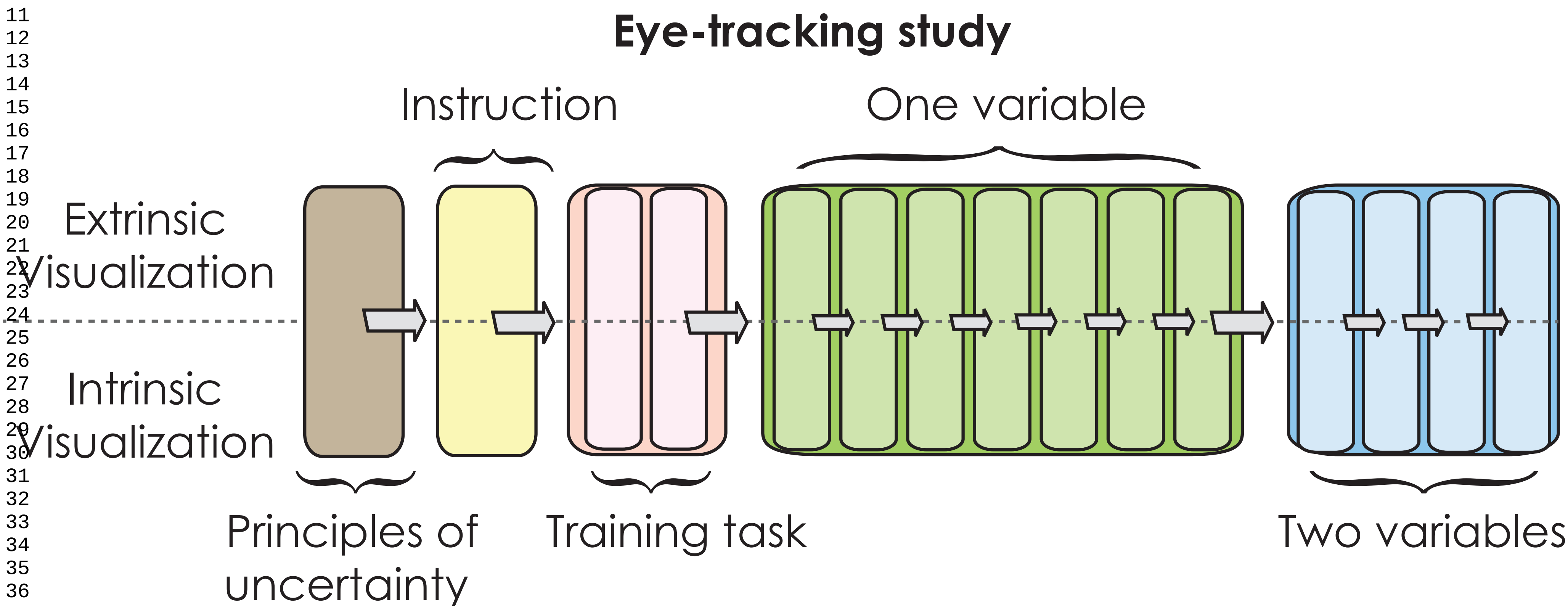


Figure 11. LEFT Trial duration (in ms; left)

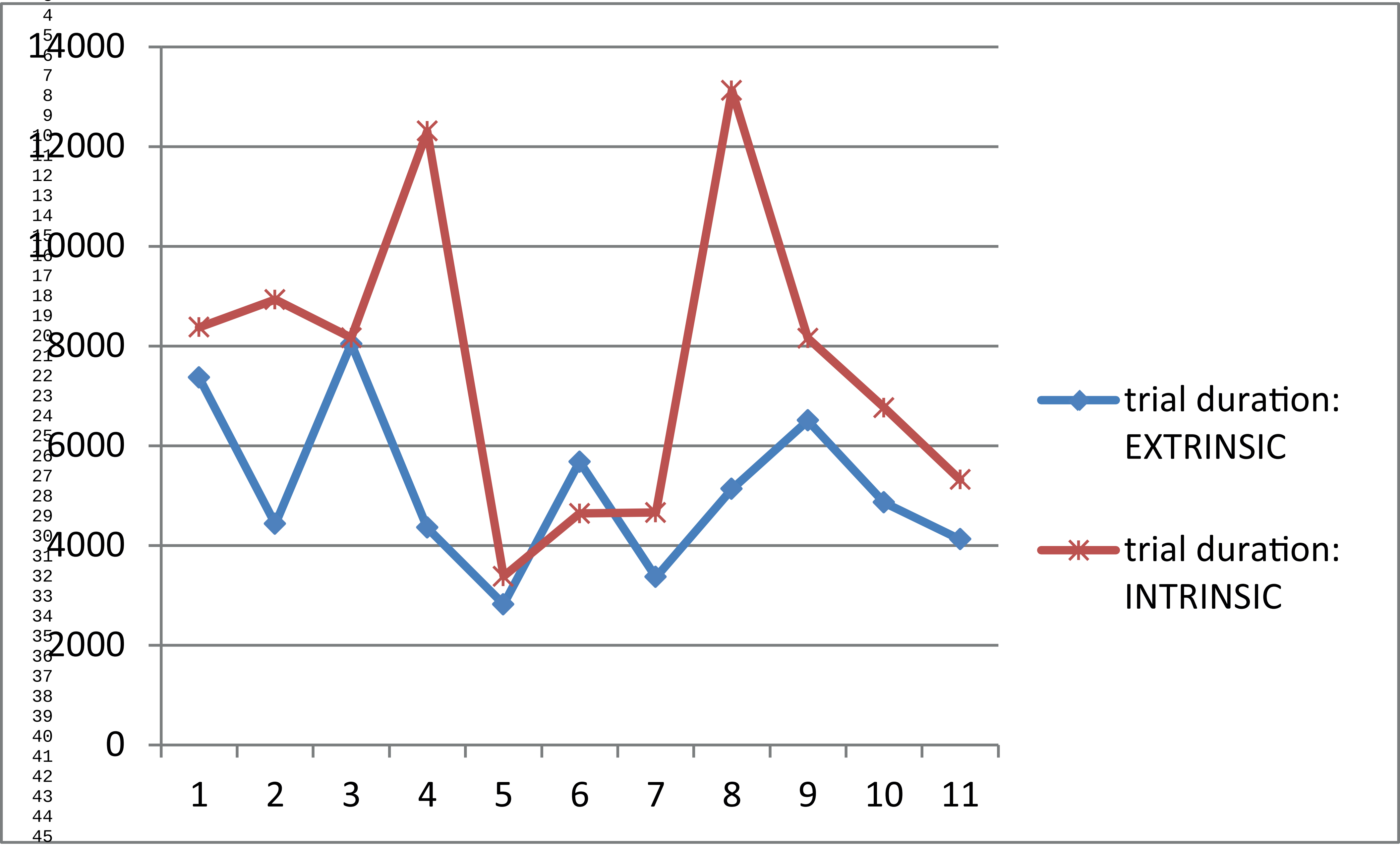
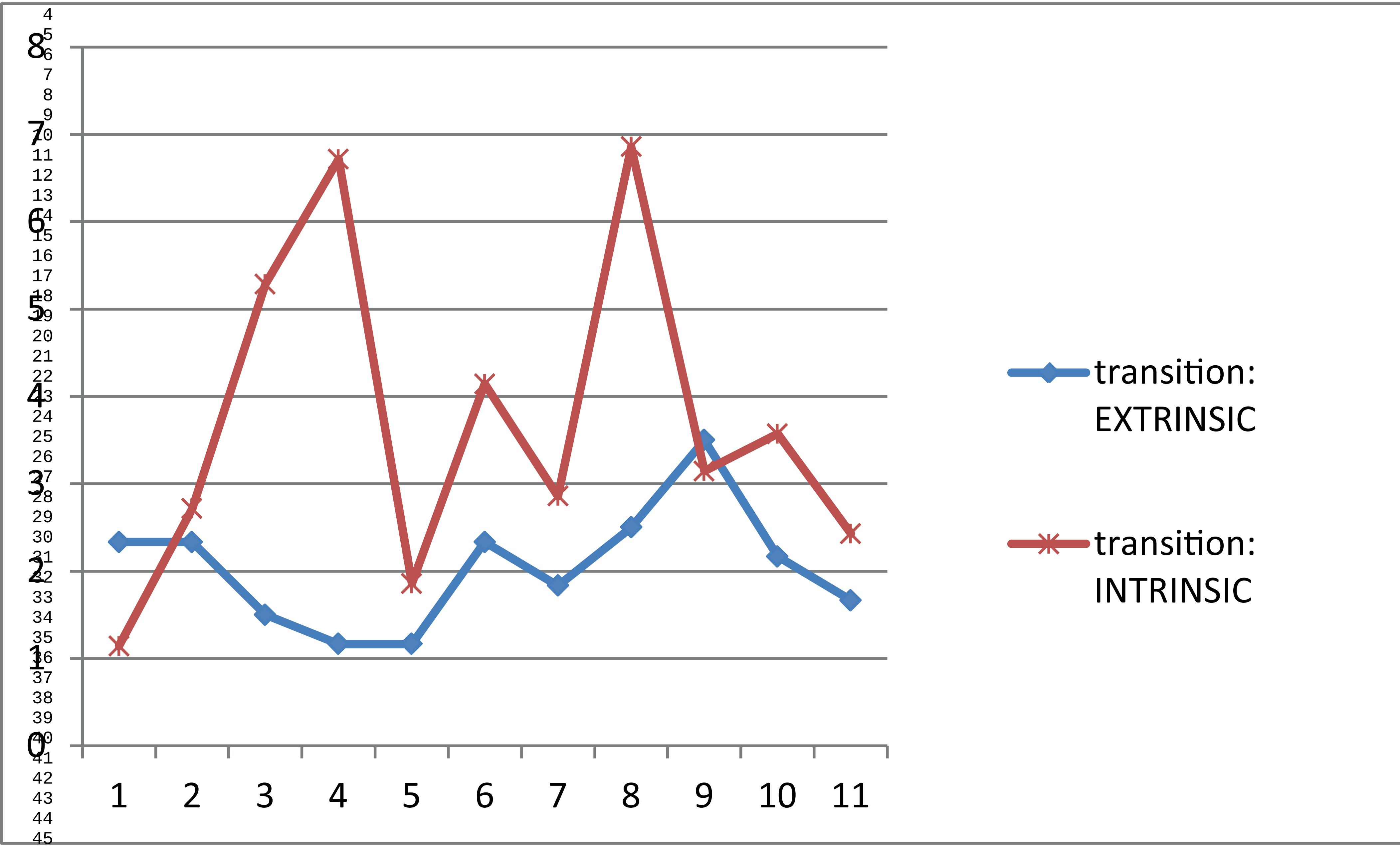


Figure 11. (right) between the map and the legend



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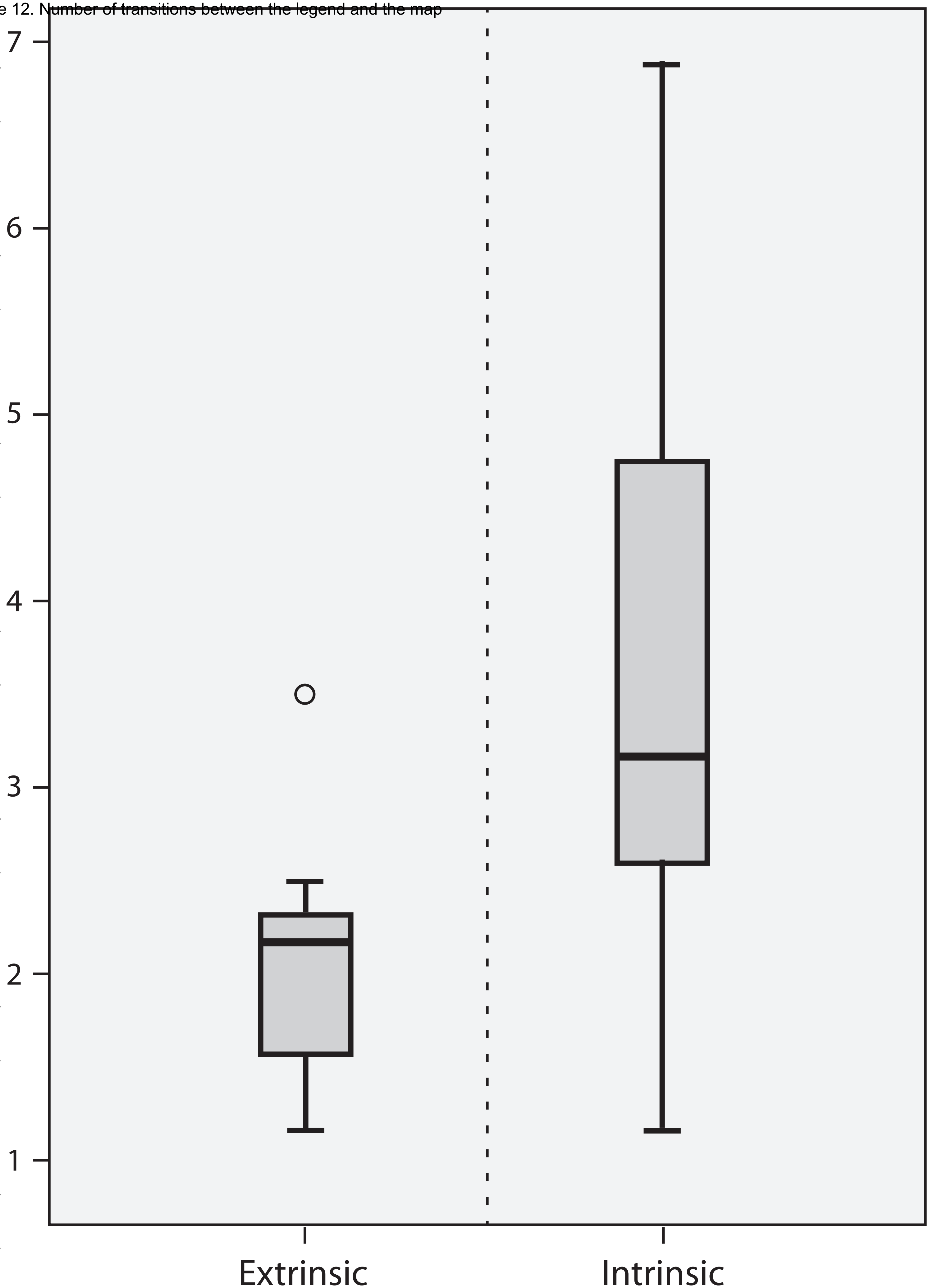


Figure 13. left Dwell times related to the map and the legend in extrinsic

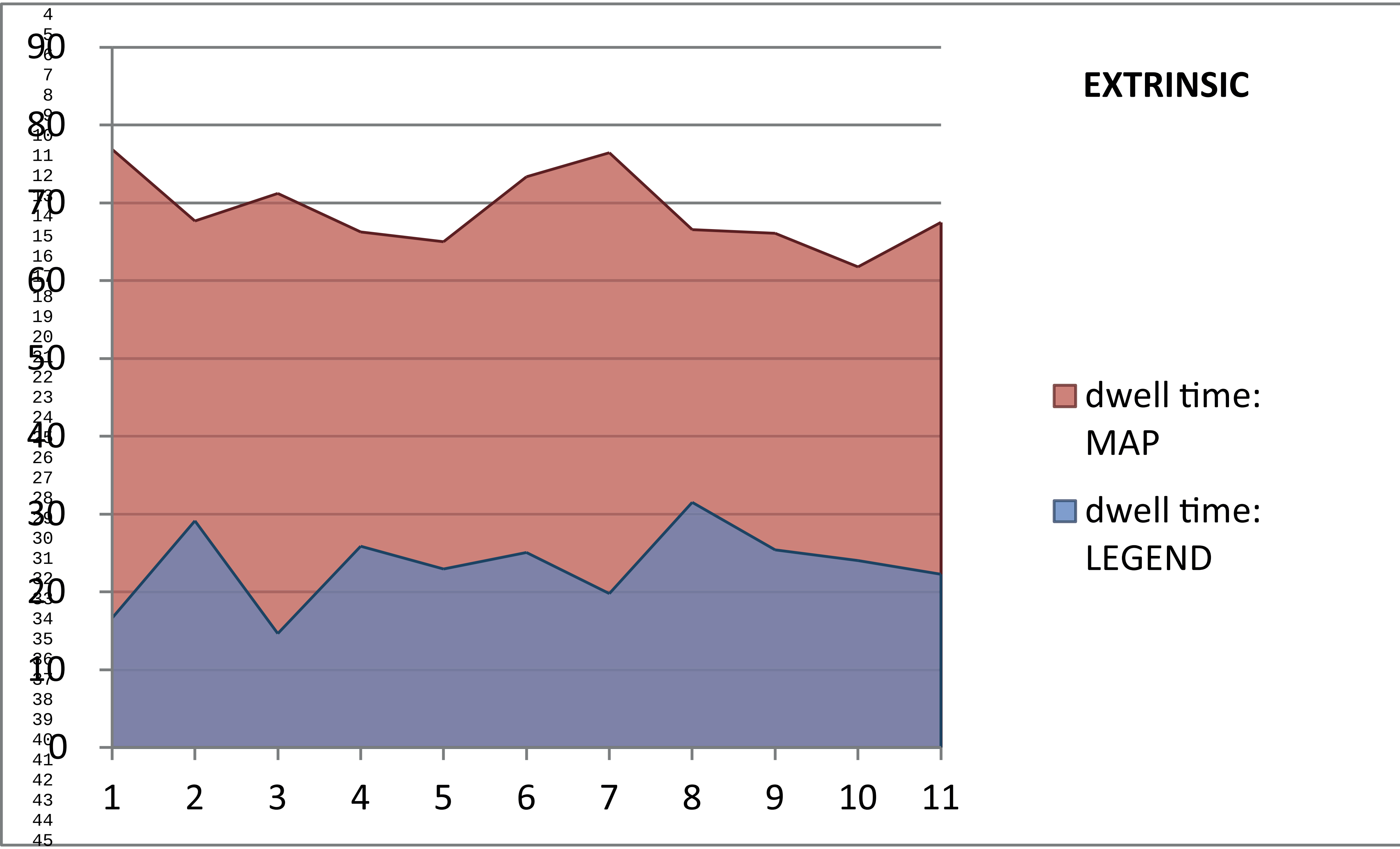


Figure 13. (right) visualization tasks (in %)

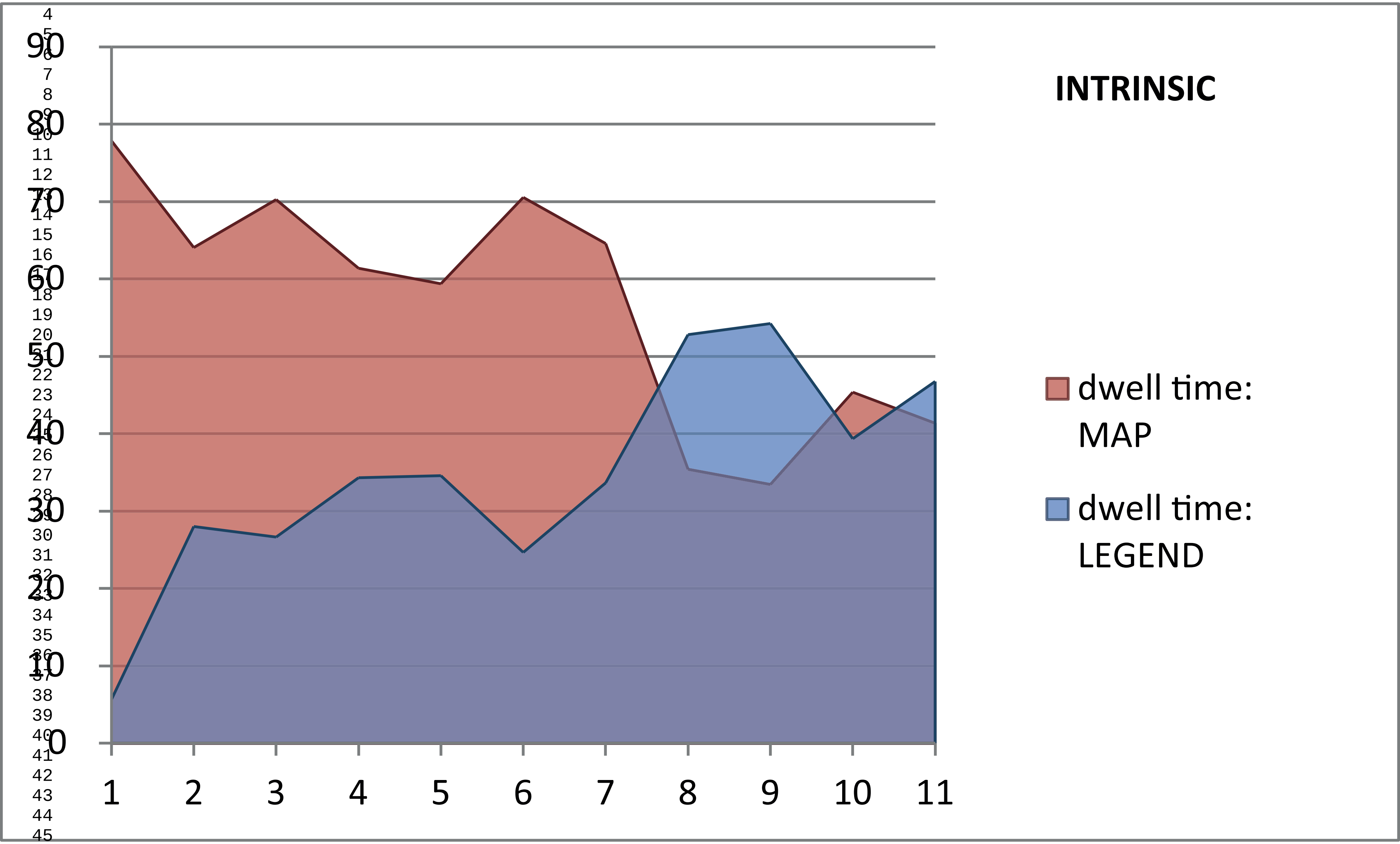


Figure 14. LEFT Fixation durations related to the map and the legend in extrinsic (left) and intrinsic

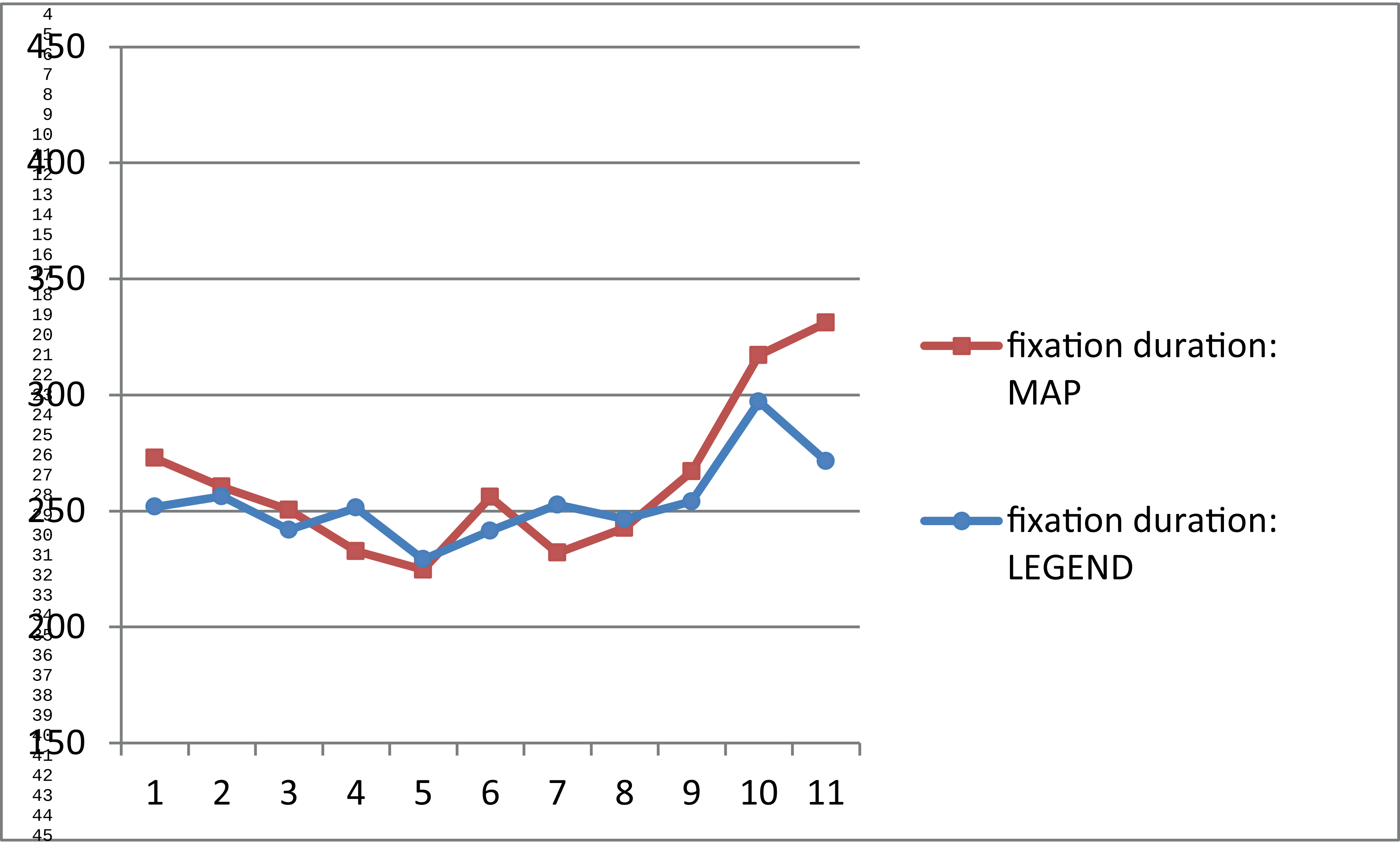


Figure 14. (right) visualization tasks (in ms)

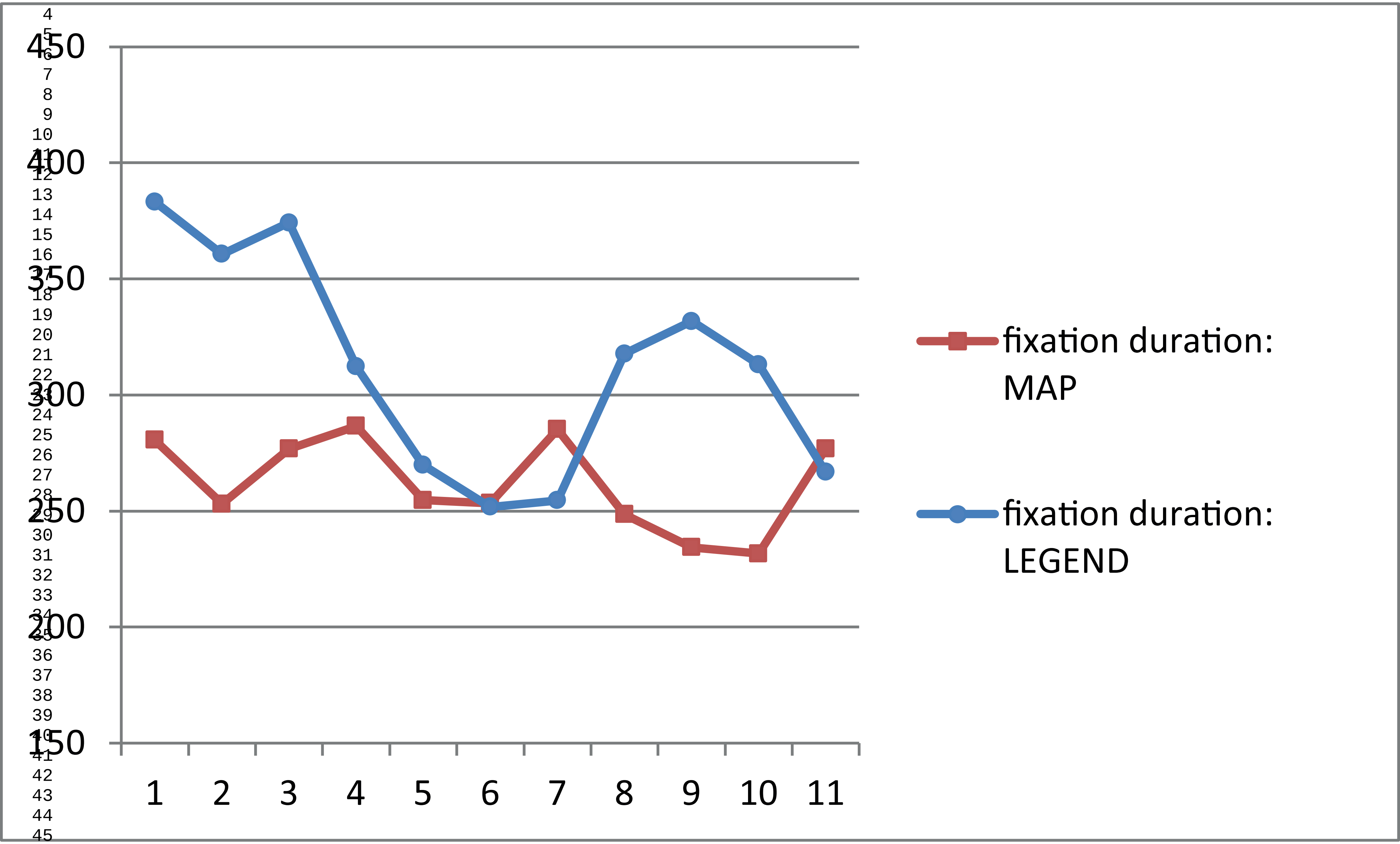
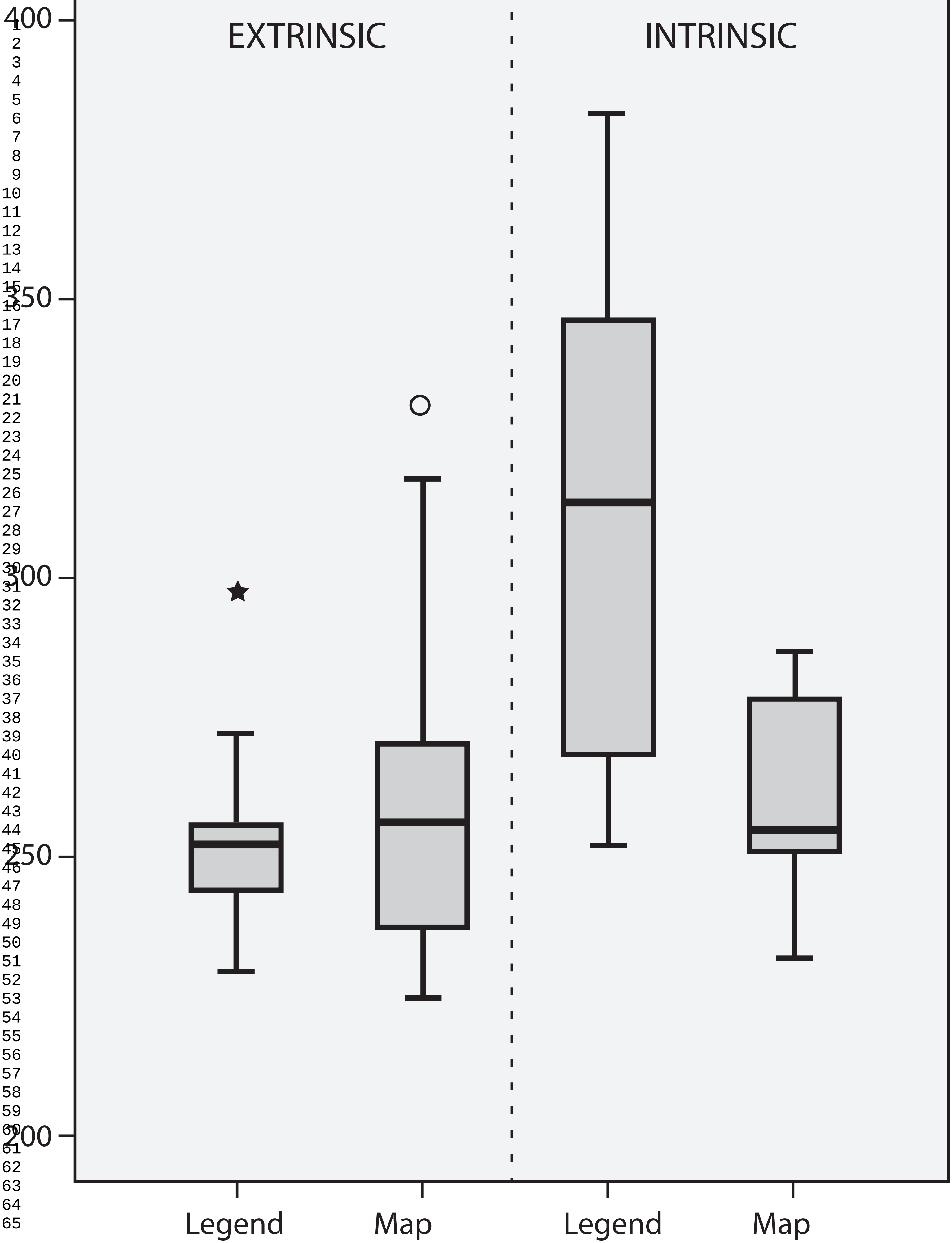


Figure 15. Fixation durations related to the map and the legend in extrinsic (two boxplots on the left) and intrinsic (two boxplots on



The Impact of Global/Local Bias on Task-solving in Map-related Tasks Employing Extrinsic and Intrinsic Visualization of Risk Uncertainty Maps

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The form of visual representation affects both the way in which the visual representation is processed and the effectiveness of this processing. Different forms of visual representation may require the employment of different cognitive strategies in order to solve a particular task; at the same time, the different representations vary as to the extent to which they correspond with an individual's preferred cognitive style. The present study employed a Navon-type task to learn about the occurrence of global/local bias. The research was based on close interdisciplinary cooperation between the domains of both psychology and cartography. Several different types of tasks were made involving avalanche hazard maps with intrinsic/extrinsic visual representations, each of them employing different types of graphic variables representing the level of avalanche hazard and avalanche hazard uncertainty. The research sample consisted of two groups of participants, each of which was provided with a different form of visual representation of identical geographical data, such that the representations could be regarded as "informationally equivalent". The first phase of the research consisted of two correlation studies, the first

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Keywords: Geovisualization method, avalanche risk, cognitive style, Navon's hierarchical figure, combined extensive-intensive research design, eye-tracking.

1. Introduction

Space and time play a crucial role during hazardous events in general and natural hazards in particular. Successful decision making during emergency situations depends on the availability and relevancy of information presented in the right time and an understandable way. Such information improves the transparency and credibility of the decisions taken.

Only "raw" spatial data is currently available for emergency management support. Emergency decision makers all around the world have available maps with natural hazards (such as flood, avalanche, and landslides), vulnerable zones, land use or geology, and make decisions based on implicit information inferred from such map sources. Such implications are not straightforward and may even differ according to the different professional background of a particular decision maker. Or more generally, the form of information visualization should be adjusted to the cognitive characteristics of the users. The responsible persons are able to process only a limited number of graphics (maps) in case of an emergency. This situation is even more critical when working under severe time pressure. The visualization form can significantly influence the final decision. Zhang and Goodchild (2002) proved that visual form can improve the communication about spatial data uncertainty within spatial analysis and spatial decision support. Uncertainty often possesses spatial patterns. Uncertainty visualization can thus reveal such patterns and serve not only for presentation but also for exploration and visual analysis of spatial data.

The present study is a continuation of an earlier research project on crisis management (Konečný et al., 2011; Staněk et al. 2010). The study focuses on perception and cognitive processing of different forms of bivariate visual representation, using alternative visual representations derived from identical avalanche hazard datasets (Kunz, 2011; Kunz and Hurni, 2011). The employment of different cartographic bivariate visualizations of the same area and topic made it possible to create meaningful and complex stimuli that were visually different and at the same time fulfilled the requirement of informational equivalence (Larkin and Simon, 1987).

A map functions as a communication channel (Koláčný, 1977), and when used as a stimulus material in psychological experiments, it enables the researcher to purposely manipulate the form of the communicated information. The objective of the study was to investigate the impact of different types of visualization and different cognitive styles on the effectiveness of solving map-related tasks.

2. Uncertainty visualization and the use of bivariate visualization

MacEachren (1992) suggested the use of Bertin's graphic variables to depict uncertainty and even added specialized variables for depicting uncertainty including crispness, resolution, and transparency. Gershon (1998) grouped these into intrinsic and extrinsic visual variables depending on whether the variable is visually separable from the variable depicting the actual attribute. While extrinsic variables are separable, intrinsic variables are not. Another logical step is to describe how these variables including possible additions or modification, might be logically matched with different components of data uncertainty (Buttenfield 1991, MacEachren 1992, Leitner and Buttenfield 2000). MacEachren (1992), for instance, stated that the graphical variables size and color value are most appropriate for depicting uncertainty in numerical information, while color hue, shape, and perhaps orientation can be used for uncertainty in nominal information.

More recently MacEachren et al (2012) focused on discrete symbols that could be used to signify the uncertainty of individual items within information graphics, maps. The experiments examine relative effectiveness of a set of uncertainty representation solutions—differing in the visual variable leveraged and level of symbol iconicity. Trau and Hurni (2007) and Kunz (2011) theoretically analyzed the suitability of visual variables and visualization techniques for uncertainty depictions in hazard prediction maps.

Most applied uncertainty visualizations in the field of natural hazards are simplistic univariate representations where hazard related data are displayed in one map and inherent uncertainties are depicted in a second map display (Kunz 2011). Kunz was among the first to propose the use of bivariate depiction of studied phenomenon and its uncertainty, applied this approach in the dynamic environment and even presented brief feedback from expert users.

Capabilities and limitations of bivariate map types based on the combination of visual variables and symbol dimensionalities (point, line, and polygon) were studied and tested also by Elmer (2013). Using the selective attention theory, he empirically tested eight bivariate map types for map reading tasks recording their accuracy and response time. These tests also included the combination of size/value (Choropleth/Graduated symbols) and value/hue-saturation (Bivariate Choropleth) which are relevant for our study. Both aforementioned combinations performed above average for accuracy and response time and were also rated positively by users as an appropriate combination to read and understand the information on the map. However, the author himself concluded that the study only revealed significant differences in perceived combinations and further research is needed in order to understand different mental strategies of users and identify their cognitive behavior.

Cognitive cartography encompasses the application of cognitive theories and methods to understanding maps and mapping and the application of maps to understanding cognition (Montello 2002).

Different ways of displaying the same spatial information can dramatically affect problem-solving performance. Spatial cognition research uses distinct concepts of informational and computational equivalence of representations (Simon 1978). Alternative cartographic visualizations follow the premise of information equivalency. The possibility to visualize (code) the same spatial information in an alternative way which is informationally equivalent offers valuable input material for comparison of cognitive processes used for decoding. Such a comparative principle enables better understanding of the human cognitive apparatus. Differences in representations deal not only with various visual forms but also with different operations necessary for their decoding and interpretation.

Cognitive assumptions are closely connected with visual variables used for uncertainty visualization. Both methods differ in the type of visualization method and visual variables (intrinsic and extrinsic). The perception of variables has a close connection with the theory of pre-attentive perception (Treisman and Gelade 1980, Wolfe et al 1989). The extrinsic graphical variable size is generally considered to be a pre-attentive feature. Such features are appropriate for the determination of presence or absence or particular elements or boundary detection. On the other hand intrinsic graphical variable saturation has not been confirmed as pre-attentive.

However, the situation is rather different when using a combination of both uncertainty portraying variables with a main attribute variable. The intrinsic visualization method combines color hue for the main attribute value and saturation for its uncertainty. The resulting map legend is comprised of 9 categories and constitutes a higher potential cognitive load for users. The extrinsic visualization method combines color saturation for the main attribute value and proportional circle size for uncertainty. The map legend is comprised of only 6 categories.

3. Cognitive Style in Map-Related Tasks

Kozhevnikov (2007) defines cognitive style as heuristics (i.e. strategy derived from experience with similar problems used for processing external information). An individual's cognitive style can be detected at all levels of perception, from the elementary and highly automated ones to those that are complex and conscious. The concept is used to refer to the way individuals think, perceive and orient themselves in the environment. According to Brigham et al. (2007), cognitive style is a pervasive bipolar dimension that is stable over time and can be studied using psychometric techniques. He further states that a cognitive style may be value-differentiated, meaning that it describes differences concerning value rather than quality. However, cognitive style is far from a well-defined construct, both with respect to its content and application to different levels of the personality system. A vast range of different interpretations of cognitive styles exist (see Witkin, 1967; Rayner, 2000; Kirton, 1989; Pask, 1976). Riding and Cheema (1991) surveyed more than 30 conceptions of cognitive style, concluding that each of the investigated conceptions pertains to one of two principal dimensions. The verbal-imagery dimension encompasses an individual's preference for representing information in words/verbal associations, or in mental pictures. The wholist–analytic dimension is characterized as an individual's preference for processing information either in integrated wholes or in discrete parts. Given the nature of the tasks used in the study and the differences between intrinsic and extrinsic visual representations (see Fig. 2), it was the wholist–analytic dimension that was of greater importance for the present study. According to Graff (2003), wholist–analytic cognitive style can be defined as a tendency to process information either as an integrated whole or in discrete parts of that whole. The wholist-analytic cognitive dimension is based on the conception of global/local bias (see Dale and Arnell, 2014) related to whether visual information is perceived at a broad (global) level, or at a more focused (local) level, with more attention being paid to partial characteristics of objects and phenomena and to their analytical processing. Rezaei and Katz (2004) add that globally-oriented individuals consider phenomena in a broader perspective and context. Analytically-oriented individuals, on the other hand, view each situation as an aggregate of discrete elements, typically preferring to focus on one or two elements at a time at the expense of other elements/aspects. Graff (2003) further states that analytically-oriented individuals are better at apprehending concepts in parts, but may experience difficulty integrating such concepts into complete, consistent wholes, while globally-oriented individuals view concepts as wholes, but are unable to separate individual aspects of the concepts into discrete parts. According to Kozhevnikov (2007), the analytical cognitive style tends to be characterized as convergent, differentiated, sequential, reflective and deductive, whereas the "global" style has been described as divergent, intuitive, impulsive, inductive, and creative. Globality is often discussed in connection with e.g. attentional breadth in selective attention (Dale and Arnell, 2014) and rapid scene categorization (Brand and Johnson, 2014).

The level of an individual's performance in map-related tasks is a result of the interaction of three variables: a) user characteristics; b) task type and situational context; c) map-related characteristics/type of visual representation (Fig. 1). Wehrend and Lewis (1990) constructed a comprehensive catalogue of map-related operations, including identification (identifying visual characteristics of features on the map), localization (determining the absolute or relative position) or categorization (placing in specifically defined divisions in a classification; this may be done by color, shape or size). Map-related tasks can be ranked depending on their relative difficulty, from relatively easy operations of “finding the shortest path” (e.g. Jones, 1997) to highly complex tasks (Smith Mason et al., 2016) of “planning military operations” (Hofmann et al., 2015), which require several concepts to be explored simultaneously, compared and integrated. Working with a map always needs to be viewed as mental manipulation with semantically rich material rather than a mere visual search and processing of visual stimuli (MacEachren and Taylor, 1994, Montello, 2009, Roth et al., 2011). The highest-level performance in fulfilling the task can be expected if the cognitive style of the user matches the nature of the task (Hammond, 1996) and the form of visual representation used. For instance, at a task requiring analytical thinking, an analytically-oriented individual can be expected to perform better than a globally-oriented individual with the same degree of cartographic literacy (Hojnik and Hus, 2013) and domain knowledge (Alexander, Kulikowich and Schulze,1994). Additionally, a form of visualization allowing for sequential analytical processing will result in a better performance than a visualization requiring simultaneous and intuitive processing. The user’s performance will be the best if all three of the areas (i.e. type of task, type of cognitive style and form of visualization) are in consonance.

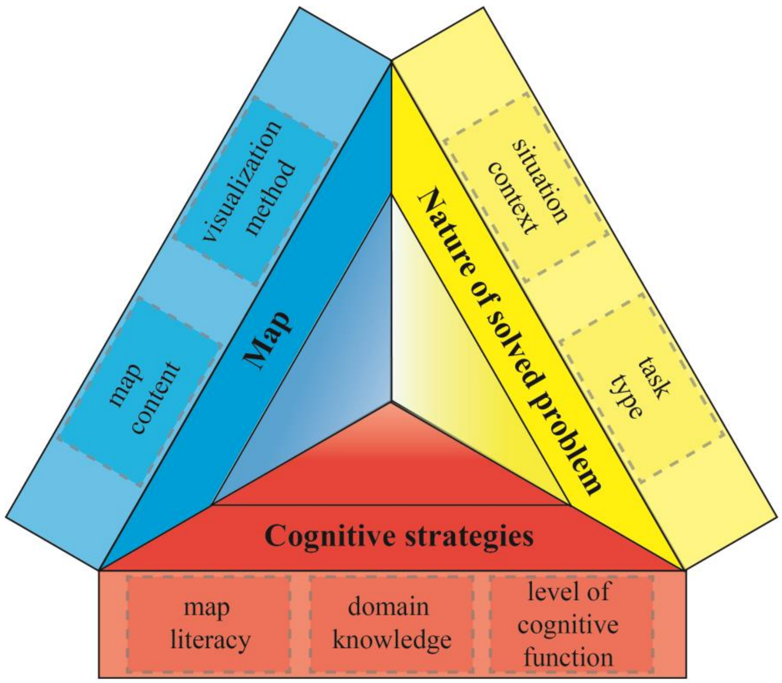


Figure 1. Triarchic structural model of performance when solving map-related task

From the point of view of experimental psychology, maps are highly valuable as stimulus material (Olson, 1979) in that they constitute complex external representations with variables amenable to accurate control and change of value. By representing identical content (data), different forms of visualization are informationally equivalent, enabling computational equivalence to be studied (Larkin and Simon, 1987). Any differences in performance and in the way an individual works with different maps can be viewed as directly linked to the difference in visual presentation of the same content. In the present study, avalanche hazard maps were used with intrinsic vs. extrinsic visual representations (Fig. 2, right and left, respectively).

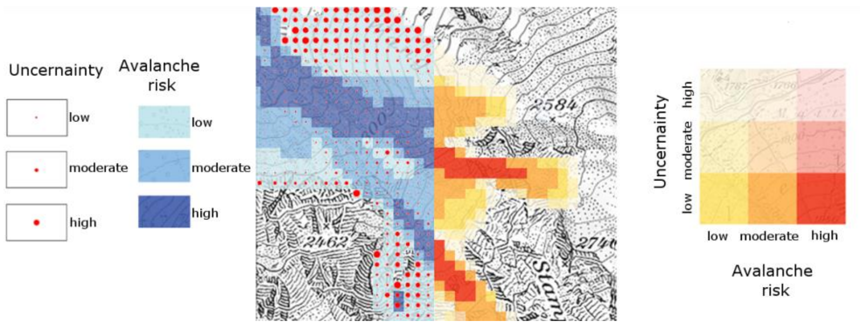


Figure 2. Snow avalanche hazard and hazard uncertainty map: left – extrinsic visual representation; right – intrinsic visual representation (adapted from Kunz, 2011)

The difference between the extrinsic and intrinsic representation exists in the way the two thematic layer variables (snow avalanche hazard and snow avalanche hazard uncertainty) are represented. In extrinsic representation, the avalanche hazard level is expressed in terms of variation in the saturation of the color blue, while hazard uncertainty is represented by the size of the dots. In intrinsic representation, the same map base is used, with the avalanche hazard expressed in terms of hue, and hazard uncertainty expressed in terms of variation in the saturation of the hue. Both types of visual representations use a combination of two graphic variables. However, while the extrinsic type uses two different modalities (hue and size) for the presentation of two phenomena, intrinsic representation is expressed in terms of variation of two properties (hue and saturation) of a single modality (color). There is a clear difference in categorization between the two types of representations. In the intrinsic visual representation, 9 (3 x 3) categories are encoded explicitly; the extrinsic visual representation, on the other hand, has separate categories for each of the two phenomena it represents (3 for avalanche hazard level and 3 for hazard uncertainty), with only 6 categories being encoded explicitly (although there are a total of nine combinations as well). Even though color properties (hue and saturation in this particular case) tend to be regarded as two independent variables in the field of cartography (Bertin, 1973), in the psychology of perception color properties are viewed as interacting with each other (D'Zmura, 1991, Itti and Koch, 2000; Lindsey et al, 2010). For instance, a desaturated blue on light (white) background will be less luminous and thus more salient than a fully saturated yellow (e.g. Nothdurft, 2000; see Fig. 3). The phenomenon can be applied to map reading as well.

Figure 3. Differences in the encoding of variables between the extrinsic (first column) and intrinsic (second column) form of visualization; third column shows the difference in salience between a fully saturated yellow (1) and partially desaturated blue (6) on white and black backgrounds

The objective of the presented study was to investigate the relationship between different forms of bivariate visual representation and an individual's cognitive style as reflected by their performance in Navon's test of hierarchical figures (see section 4.2.1). We hypothesize (1) a link between global processing efficiency and extrinsic visualization abilities, and (2) a link between local processing efficiency and intrinsic visualization abilities. We thus consider that a variation of both hue and saturation using a single color modality (intrinsic) would refer to a more local approach, whereas two types of independent graphic hues and size variables (extrinsic) will be considered a more global approach. In other words, the elaboration of two parameters (hue and saturation) of one modality - color (intrinsic) would be linked to local processing abilities, while considering two different parameters, hue and size (extrinsic), simultaneously would be linked to global processing abilities.

4. Method

The study uses a mixed (confirmatory-exploratory) research design, with the aim to combine extensive research (for data collection and subsequent statistical analyses) with a more in-depth exploratory data analysis (EDA; see Andrienko and Andrienko, 2005). The advantages of the mixed research design, along with its theoretical grounding, have been described by Šterba et al. (2014), who also provide a sample study. The authors use the term "mixed-research design", which, however, tends to be viewed as referring to a combination of qualitative and quantitative methods, particularly in the context of social sciences and constructivist approaches (see Leech and Onwuegbuzie, 2009; Creswell, 2003). In order to distinguish between the two concepts we propose the term "combined extensive-intensive research design". A combined mixed extensive-intensive research works primarily with objective data, combining a confirmatory stage of the research with an exploratory stage. The first (confirmatory) phase of our research comprised two correlation studies. The first consisted of the collection of data on subjects with a high degree of map literacy (students of cartography), while the second focused on subjects with a low degree of map literacy (students of psychology). After the confirmatory phase, an exploratory phase followed which was represented by a comparative eye-tracking study. The aim of the comparative study was to reveal possible differences in task-solving strategies depending on the type of visualization employed by usage of an exploratory data analysis. The structure of the research is shown in detail in Fig.4. While extensive methods are concerned only with the effect of stimulus on behavioral outputs in the sense of speed or correctness intensive methods concentrate on the process alone, as in, what happens between stimulus and reaction? And this is also the purpose of the eye-tracking comparative study which can deeper illuminate results of the previous phase of the study.

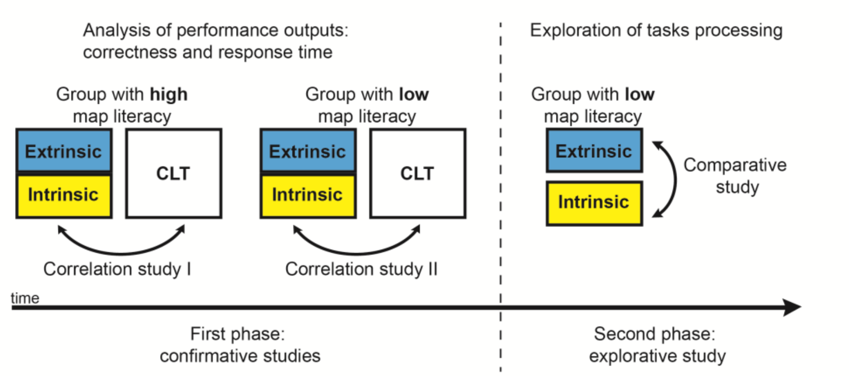


Figure 4. Structure of used combined extensive-intensive research design

5. Correlation Studies I and II

The objective of the first phase of the research was to investigate the relationship between an individual's cognitive style and the type of visualization used. By way of the first phase, two correlation studies were conducted. The design of the second study was adjusted based on the results of the first study. More specifically, several items were added to the subtest involving a one variable. The second study also included tasks focused on the degree of understanding of the concept of visualization of snow avalanche hazard and hazard uncertainty. These more complex tasks are not part of the present article, which focuses primarily on lower cognitive processes (e.g. visual search as reflecting an individual's cognitive style).

5.1. Participants

In the first correlation study, the research sample consisted of students of geography in the 1st to 3rd year of their studies. A total of 73 volunteers aged 19 to 27 years were tested. For the extrinsic visualization task, there were 37 subjects (19 male, 18 female), while 35 subjects (19 male, 16 female) were given a task employing intrinsic visualization. In the second correlation study, a total of 62 volunteers aged 19 to 55 years were tested, all students of psychology in the 1st to 3rd year of their studies. For the intrinsic visualization task, there were 35 subjects (8 male, 27 female), most of them aged 19 to 25 years, with one male outlier aged 37 years; 27 subjects (3 male, 24 female) were given the extrinsic visualization task. Most of the subjects were 19 to 28 years, with one male outlier aged 55 years. None of the subjects had any previous experience of participation in cartographic visualization testing.

5.2. Aparatus

The test was created and administered in MuTeP (Multivariate Testing Program; see Kubíček et al., 2014, Kubíček et al., 2016, Štěrba et al., 2015). After every data collection a group discussion followed. Participants were asked about their subjective experience by elaboration of the test battery.

5.3. Stimulus Material - Map-related Tasks

In the correlation studies, avalanche maps were used showing both the level of the snow avalanche hazard (expressed in terms of load on the snowpack) and the level of avalanche hazard uncertainty. Both variables were expressed by means of a three-level scale (Low – Moderate – High). The map consisted of a base layer and a thematic layer, with the latter being explained by the legend of the map. In the experimental tasks, the base layer played only a very marginal role. The subjects' performance depended on their ability to comprehend the instructions, decode the legend, and perform a visual search to locate the four numbered target areas and decide which of them meets the criteria given. There was always only one correct answer. The visual scene consisted of a map, a map legend, task instructions located at the top of the computer screen and numbered "buttons". The instructions were always presented separately on a blank screen. No time limit for the instructions was given so that there would be enough time for the participants to comprehend the instructions. The overall test structure was as follows:

1. Training – 2 training tasks
    a. identify the level of variable A (avalanche hazard)
    b. identify the level of variable B (avalanche hazard uncertainty)
2. One variable tasks
    a. identify the level of variable A (avalanche hazard) – low, moderate, and high respectively.
    b. identify the level of variable B (avalanche hazard uncertainty) – low, moderate, and high respectively.
3. Two variable tasks
    a. identify the level of variable A (avalanche hazard) and variable B (avalanche hazard uncertainty) –

combination of low, moderate, and high respectively).

Both tests were made up of one- and two-variable tasks. In the first correlation study, the participants were given five test tasks (see Fig. 5 top line) – two for one variable and three for two variables. In the second correlation study (performed on subjects with a low degree of map literacy) the batch of one-variable tasks included four items instead of two (see Fig. 5 bottom line).

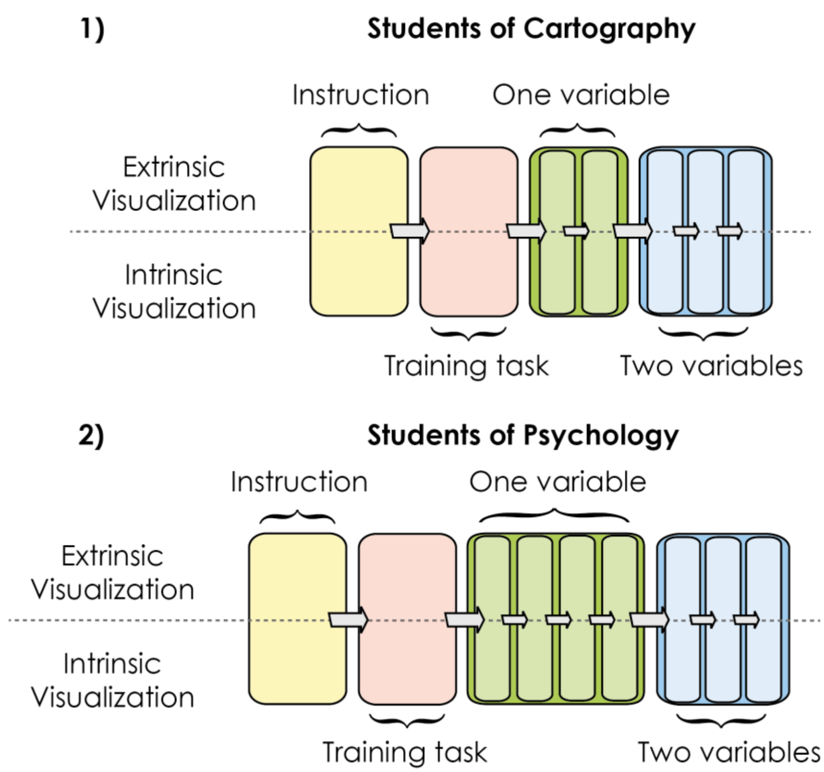


Figure 5. Structure of map-related tasks (students of cartography – top; students of psychology – bottom)

Visualizations used in training were similar to the rest of the test. Sample instructions of one variable task are as follows: "Select the area with a moderate level of avalanche hazard" (see Fig. 6 left). The subjects completed each task by clicking on the respective "button". Instructions of two variables task were formulated in a following way: "Select the area with a high level of avalanche hazard accompanied by a low level of avalanche hazard uncertainty" (see Fig. 6 right).

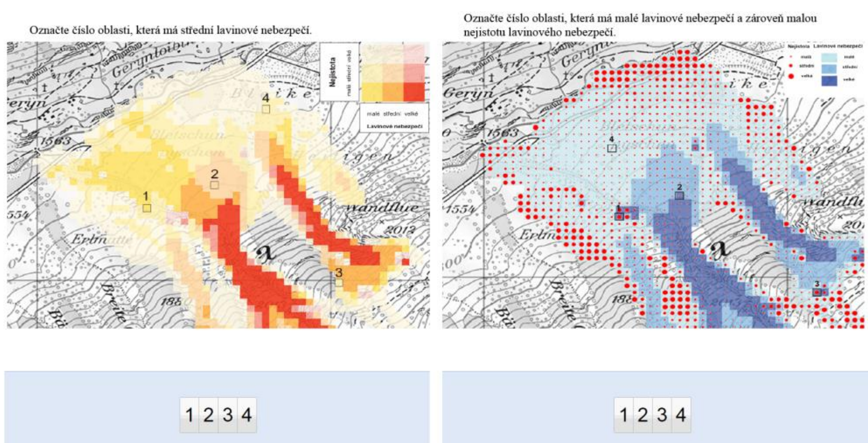


Figure 6. Sample map-related tasks: Left (intrinsic visualization) – Select the area with a moderate level of avalanche hazard. Right (extrinsic visualization) – Select the area with a high level of avalanche hazard accompanied by a low level of avalanche hazard uncertainty.

5.4. Stimulus Material - Compound Figures Test

The second part of the test battery consisted of a psychological test of cognitive style. It contained a variation of Navon's Hierarchical Figures Test (Navon, 1977) – a compound figures test (see Fig. 7, left) which was designed for the purposes of the present study using MuTeP. Navon's test (Navon, 1977) is one of the most frequently used methods for the measurement of the wholist-analytic dimension of cognitive processing (e.g. Brand and Johnson, 2014; Duchaine et al., 2007; Yovel et al., 2005, Milne and Szczerbinski, 2009). It enabled us to measure a person's ability to direct attention either to the local level of the visual stimulus material or to the global level. Bouvet et al. (2011) used tasks based on the Hierarchical Figure test and found evidence that participants exhibit a similar processing style across modalities with respect to both vision and audition modalities. Thus these findings support the theory that Navons Hierarchical Figures can be understood and used more generally as a measure of wholistic-analytic cognitive style and not only in the narrower way, as an indicator of a visuo-attentional global/local style. The compound figures test included instructions, several training items and 32 test items. The stimulus material consisted of a set of large, single-digit numbers compounded of small numbers. There were two subtests, local and global, each comprising 16 items. The participants were instructed to identify the small numbers in the first subtest and the large numbers in the second subtest by clicking on one of four available buttons as quickly as possible (see Fig. 7, left). The overall response time of the respondents was recorded electronically; the average response time per item was calculated.

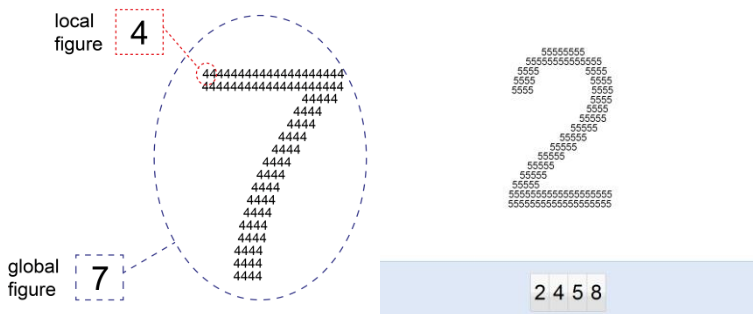


Figure 7. A compound stimulus (left); an item from the Compound Figures Test adapted into the MuTeP environment (right).

5.5. Results

Two subjects with a high error rate for CFT were excluded from further analyses. One student of cartography erred 5 times in the local subtest and 6 times in the global subtest. One student of psychology erred 12 times in the first subtest. The number of mistakes made by the other participants was insignificant; most of them achieved 100% accuracy, others erred less than three times. Reaction times of the outlying errors were included in the analyses. The overall score for the local and global subtests were counted based on 15 items from each subtest. The first item of each subtest was excluded from the analysis. In line with previous findings, the internal consistency (Cronbach's alpha) for both subtests was found to be high ($\alpha = 0.805$ and $\alpha = 0.864$, respectively). Differences in reaction times between the two subtests (Fig. 8) were found to be in agreement with previous findings as well. A paired t-test revealed faster processing of global figures by 15% (N=133; mean reaction time for the local subtest s=1.9; SD=0.2; mean reaction time for the global subtest s=1.6; SD=0.17; df=132; p=0.01). The results showed a positive correlation between the two subtests ($r=0.437$, $p<0.01$).

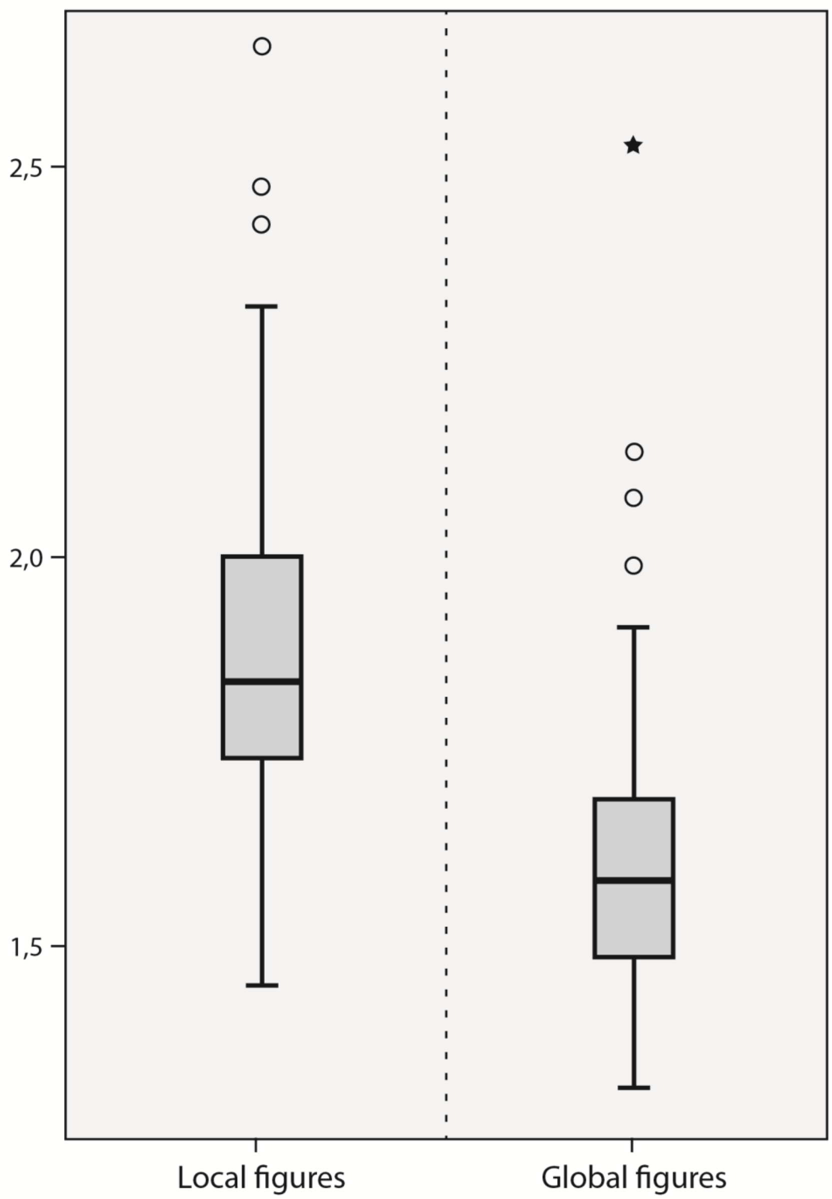

2,5
2,0
1,5
Local figures
Global figures

Figure 8. Reaction times (s) for both subtests of CFT

The error rate of students of cartography was 7.2% for intrinsic visualization and 9.7% for extrinsic visualization. Students of psychology exhibited a significantly higher error rate in both subtests: 13.8% for intrinsic visualization and 20.0% for extrinsic visualization. The overall error rate was counted from the individual error rates of all the subjects who completed the cartographic part of the research, including outliers, which were, however, excluded from further analyses. Outlying subjects in the research sample of students of cartography were those who erred two and more times (out of the total of five items (i.e. those with an error rate >40%; intrinsic visualization – 1 participant; extrinsic visualization – 4 participants). As regards the research sample consisting of students of psychology, 4 subjects were excluded (extrinsic visualization) who erred three and more times (out of 7; error rate >40%). Although the above outliers were excluded from further analyses, all reaction times of remaining participants were (as in CFT) included (see Tab. 1 and 2).

Students of Cartography	Intrinsic visualization (n=34)		Extrinsic visualization (n=33)	
	local subtest	global subtest	local subtest	global subtest
One Variable	.400**	.180	-.021	.375*
Two variables	.168	-.114	.304*	.302*
Overall Score	**.387***	**.050**	**.176**	**.384***

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

Table 1. Students of Cartography: Relationship between Map-related Task Performance (response time) and CFT Results (Pearson's Correlation; one-tailed)

Students of Psychology	Intrinsic visualization (n=35)		Extrinsic visualization (n=23)	
	local subtest	global subtest	local subtest	global subtest
One Variable	.211	.222	.100	.291
Two Variables	.106	.230	-.079	-.140
Overall score	**.221**	**.266**	**.027**	**.135**

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

Table 2. Students of Psychology: Relationship between Map-related Task Performance (response time) and CFT Results (Pearson's Correlation; one-tailed)

5.6. Interpretation of the Results

The results of the CFT employing a variation of Navon's hierarchical figures test confirmed the effect of global precedence; the average response time in the global subtest was lower by 15% compared with the local subtest. In addition, the results showed a positive correlation between the two subtests, which is in line with the expectation that an individual's processing capacity in both tasks will be driven by the same psychomotor speed (Spirduso, 1980). After the exclusion of subjects with high error rates (either in CFT or in map-related tasks) the subjects' results in CFT and map-related tasks were tested for possible correlations. The analysis was conducted by means of comparison of overall response times in map-related tasks with response times in CFT. The results of the first correlation study (on subjects with a high degree of map literacy) revealed a positive correlation between scores obtained in the local subtest and response times in map-related tasks employing intrinsic visualization; at the same time, a positive correlation was found to exist between global-subtest response times and response times in map-related tasks employing extrinsic visualization. The fact that no cross-correlation was found between either the local subtest and extrinsic visualization or between the global subtest and intrinsic visualization (although the subjects' performance in map-related tasks was also driven by the same psychomotor speed) renders the above findings even more significant. In the second correlation study (on students of psychology), no significant relationship between the variables was found. We suppose that the absence of any correlation might have been caused by low levels of map literacy, which was reflected in comparatively high error rates.

6. Comparative Study: Eye-tracking

The reason for replicating the correlation studies using an eye-tracking system was to obtain additional information which would provide deeper insight into the process of solving map-related tasks and related cognitive strategies. With the decrease in cost of the technology, eye-tracking became a more widely utilized method, not one only used in cartographic studies (see Alaçam and Dalci, 2009; Çöltekin et al., 2009; Popelka and Brychtová, 2013; Popelka and Dědková, 2014; Ooms et al., 2012). The aim of the eye-tracking study was to investigate the impact of different types of cartographic visualization on task-processing. While the confirmatory phase of the research focused on the speed and "correctness" of reaction to visual stimuli, the exploratory phase consisted of investigating the very process of task-solving (see Fig. 9).

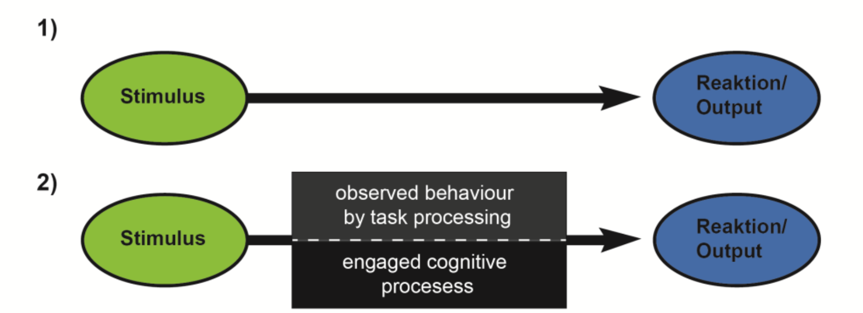


Figure 9. Process of investigating variables: 1) stimulus -> output; 2) stimulus -> cognitive processing and associate behavior -> output

6.1. Participants

A total of 14 subjects aged 21 to 35 years volunteered to participate in the study; they were either university students or had already completed their university studies. None of the participants received any education in cartography or related fields. The participants were divided into two groups of seven.

6.2. Apparatus

The device used in the study was EyeLink 1000, a remote eye-tracking system manufactured by SR Research. The original test battery presented in MuTeP was adapted to the environment of Experiment Builder, a software tool by SR Research for creating eye-tracking experiments.

Eye-tracking data were saved in a format enabling an exploratory data analysis to be carried out in EyeLink Data Viewer, software that can be used for viewing, filtering and processing eye-tracking data recorded with an EyeLink eye-tracker. The application offers a range of eye-tracking metrics. In addition, it enables the analysis of transitions between defined areas of interest (AOIs). In the analysis, visualization tools such as an attention map and video analysis were also used. After every single data collection an individual inquiry followed. Participants were asked about their subjective experience by elaboration of a test battery,

6.3. Stimulus Material

The original test structure was slightly modified (see fig. 10) and several new training tasks were added to the original test battery. A detailed graphical explanation of the principles of avalanche risk and uncertainty was added in order to properly introduce both the risk mapping and its uncertainty. These should enhance the understanding of the experiment by non-experts.

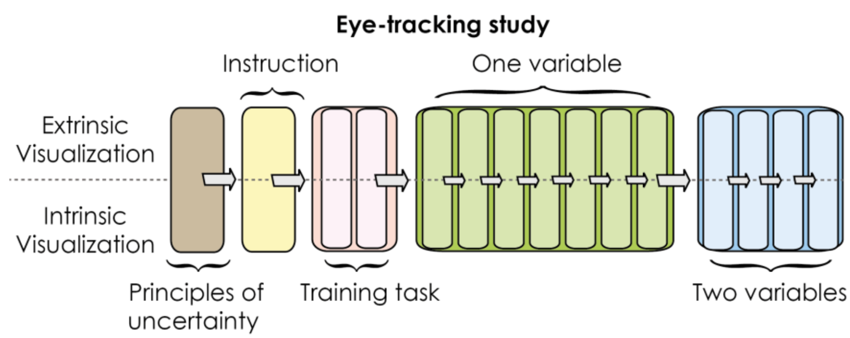


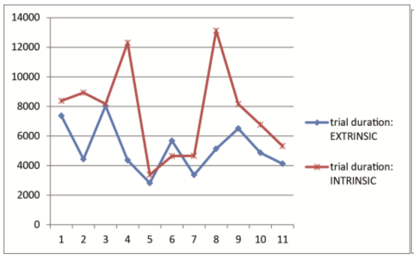
Figure 10. Structure of map-related tasks in the eye-tracking study

6.4. Results and Interpretation

The exploratory data analysis was performed at both the subject level and group level (extrinsic vs. intrinsic visualization). One participant from the extrinsic visualization group was excluded from the analysis due to a heavy data dropout. Several areas of interest were defined, with key AOIs being set around the legend and the map. The following measures were analyzed: trial duration, number of transitions between the legend and the map, the number of fixations on the legend and on the map, dwell time[1] on the legend andon the map, and fixation durations.

Fig. 11 (graph on the left) shows average trial durations for the eleven tasks used in the study. The first seven tasks employ only one variable (level of avalanche hazard or avalanche hazard uncertainty), while the rest of the tasks inquire about both variables. The area represented by the map was identical in all the tasks. The graph on the right in Fig. 11 shows the number of transitions between the map and the legend for each task (in both directions). Fig. 12 (box plots) shows the average number of transitions and their spread for both extrinsic and intrinsic visualization tasks. As is evident from the graphs, the subjects' performance across the individual tasks was much more homogeneous when working with extrinsic visualization; the subjects' performance at intrinsic visualization tasks, on the other hand, appears to have been more sensitive to the nature of the task. The higher variability might have been caused by greater differences in the difficulty of discriminating between different levels of brightness (caused by the interaction between hue and saturation). The differences in brightness (see Fig. 2 right and Fig. 3 second and third columns) make it e.g. easier to distinguish between low uncertainty/low avalanche hazard and low uncertainty/moderate avalanche hazard than between high uncertainty/low hazard and high uncertainty/moderate hazard.

[1] *dwell time* refers to the sum duration of fixations falling within a particular AOI; *fixation duration* refers to the duration of individual fixations.



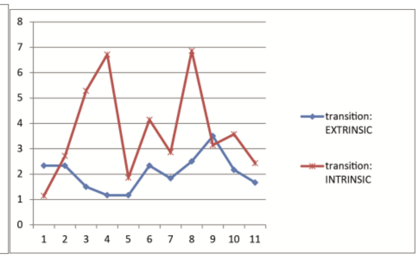


Figure 11. Trial duration (in ms; left) and number of transitions (right) between the map and the legend

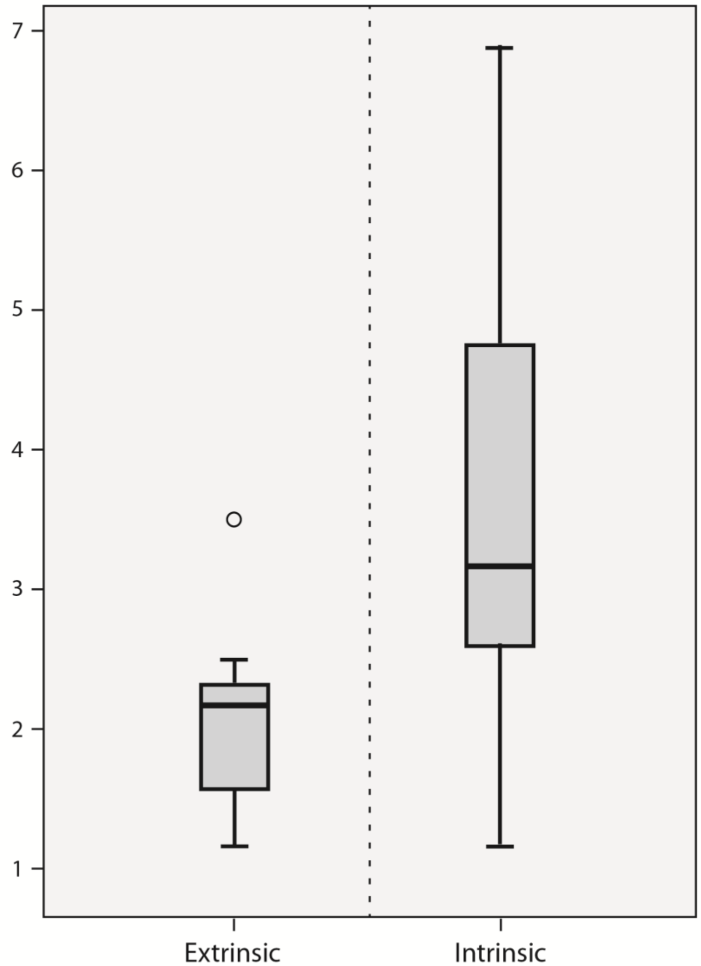


Figure 12. Number of transitions between the legend and the map

The following analyses focus on the differences between extrinsic and intrinsic visualization as reflected by the differences in dwell times and fixation durations (related to the legend and the map). Graphs in Fig. 13 show the percentages of map/legend dwell time for all the tasks. For extrinsic visualization tasks, the legend dwell time ranges from 10 to 30% (of the total dwell time); visual search time (map dwell time) ranges from 60 to 80%. Intrinsic visualization, on the other hand, exhibits a far greater variability across the individual tasks; for the legend, the dwell time ranges from below 10% in one task to over 50% in another. In the latter case, the time needed for decoding the legend even exceeds the time needed to locate the target in the map.

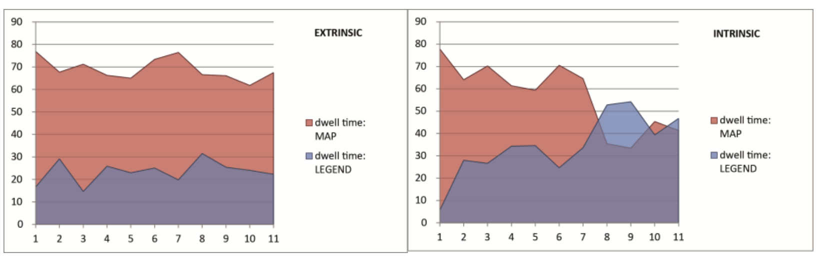


Figure 13. Dwell times related to the map and the legend in extrinsic (left) and intrinsic (right) visualization tasks (in %)

Fig. 14 presents a comparison of map and legend fixation durations in intrinsic (right) and extrinsic (left) visualization tasks. Fig. 14 shows the average fixation durations and spreads. As with dwell times, the data show lower variability across the individual tasks for extrinsic visualization: the curves of fixation durations are nearly identical (see, for instance, the data concerning the second task, with fixation durations slightly above 250 ms for both the legend and the map). Intrinsic visualization, however, led to a different situation during the same (second) task: legend-related fixations were on average more than 100 ms longer than map-related fixations. From Fig. 15 it can be seen that extrinsic visualization caused average fixation durations to last approximately 250 ms for the map and the legend alike. In the case of intrinsic visualization, the same value was true for map-related average fixation durations; the average duration of legend-related fixations, however, far exceeded 300 ms.

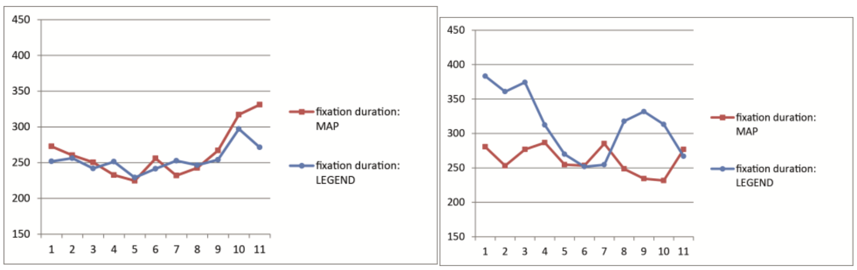


Figure 14. Fixation durations related to the map and the legend in extrinsic (left) and intrinsic (right) visualization tasks (in ms)

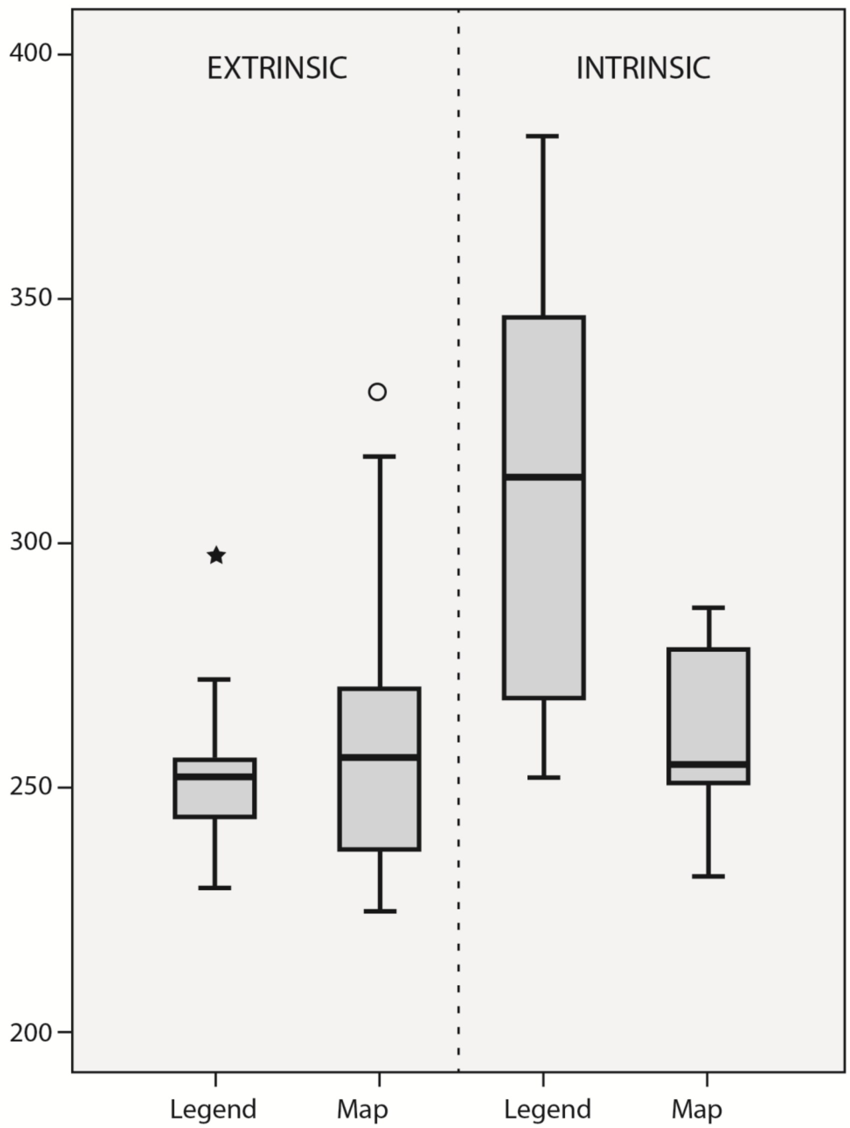

400
350
300
250
200
EXTRINSIC
INTRINSIC
Legend
Map
Legend
Map

Figure 15. Fixation durations related to the map and the legend in extrinsic (two boxplots on the left) and intrinsic (two boxplots on the right) visualization tasks (in ms)

7. Discussion and conclusion

The primary objective of the study was to investigate the relationship between the participants' cognitive style and their performance at map-related tasks employing different forms of visualization. First, a Compound Figures Test (a variation of Navon's Hierarchical Figures Test) was administered using MuTeP in order to discriminate between analytically- and globally-oriented individuals. The test was already been successfully employed in previous studies (Kubíček et al., 2016, Horváth, 2012). The results of the test confirmed the effect of global precedence (Poirel, Pineau and Mellet, 2008). Subsequently, two independent correlation studies were conducted in order to establish the relationship between the participants' performance at global and local subtests of the CFT and their performance at map-related tasks employing different forms of cartographic visualization (intrinsic and extrinsic). Each correlation study used a research sample with a different level of map literacy. The first research sample with a high degree of map literacy consisted of students of cartography, while subjects with low levels of map literacy were represented by students of psychology. In contrast with the first study, the second correlation study showed no significant correlation between the participants' performance at CFT and their performance at map-related tasks. We suppose that the absence of any correlation might have been caused by low levels of map literacy and the resulting subjective difficulty of the map-related tasks. In a post-experimental inquiry, the students of psychology more often reported that they had difficulties understanding the notion of "avalanche risk uncertainty". The above was reflected in comparatively high error rates displayed by the students of psychology. We believe that comprehension problems acted as an intervening variable and might have been a source of significant “noise” in the collected data. The studies focused on the investigation of low-level cognitive processes, particularly the visual decoding of the legend and subsequent visual search for target areas in the map. It is, however, important to realize that a map represents a complex communication channel and its thematic layer (if present) triggers high-level cognitive processes which may override the underlying low-level cognitive processes. Thus, the amount of time needed for solving the map-related tasks did not primarily depend on the type of visualization used or the speed of visual processing, but rather on the degree and speed of understanding the instructions. According to Booth (2006), tasks involving low-level cognitive processes are less prone to invoking between-task differences in the subjects' performance than tasks involving high-level cognitive processes, where local/global processing styles are overridden by executive/strategic processes. Thus, if a medium-strong correlation is found between a simple, selective attention task (such as CFT) and a complex map-related task, it can be viewed as indicating that identical cognitive processes are at play in both cases.

In the first correlation study, which worked with a group of participants with high levels of map literacy, significant correlations were established between the participants' cognitive style and the type of visualization used in map-related tasks. A statistically significant positive correlation ($r= .387$; $p<0.05$) was established between scores obtained in the local subtest and response times in map-related tasks employing intrinsic visualization. No relationship was found between intrinsic visualization and scores obtained in the global subtest. Similarly, while a positive correlation ($r= .384$; $p<0.05$) was found to exist between global-subtest response times and response times in map-related tasks employing extrinsic visualization, no relationship was found between extrinsic visualization and the local subtest. Thus, it can be concluded that subjects with high levels of map literacy exhibit differences in their performance at map-related tasks depending on their cognitive style and on the type of visualization employed. Analytically-oriented individuals were better at tasks involving intrinsic visualization, while globally-oriented individuals performed better at tasks employing extrinsic visualization. The fact that no cross-correlation was found between either the local subtest and extrinsic visualization or between the global subtest and intrinsic visualization renders the findings even more significant. Following the two correlation studies in the first phase, a comparative eye-tracking study was conducted in the second phase with the aim of obtaining deeper insight into the cognitive processes which were at play during task-solving; it was not designed to test pre-defined hypotheses or compare types of visualization with respect to their effectiveness.

The results of the eye-tracking part of our research indicate a high dependency of performance at intrinsic visualization tasks on the nature of the tasks (i.e. on the values of target variables). An example of the above is represented by the high across-task variability in the number of map/legend transitions. At the same time, intrinsic visualization tasks exhibit a far greater number of transitions than extrinsic visualization tasks, requiring more “checking look-backs” at the legend. Another analyzed parameter was represented by the map/legend dwell time ratio. For extrinsic visualization tasks, the legend dwell time was relatively short, ranging from 10 to 30% (of the total dwell time), while visual search time (map dwell time) ranged from 60 to 80%. Intrinsic visualization, on the other hand, exhibited a far greater variability across the individual tasks. For the legend, the dwell time ranges from below 10% in one task to over 50% in another. Time spent on visual search amounted to more than 70% of the total dwell time in some tasks and less than 40% in others. In some cases, the time needed for decoding the legend even exceeded the time needed to locate the target in the map. In addition, intrinsic visualization resulted in longer fixation durations and greater fixation duration variability across the individual tasks. The results indicate that in intrinsic tasks, decoding the legend may in some cases require significant cognitive effort (see Longo and Barrett, 2010). An instance of the above may be represented by the established across-task variability in the difficulty of legend decoding in intrinsic visualization tasks. The findings regarding intrinsic and extrinsic visualization support the hypothesis that the different types of visualization are not computationally equivalent and that each of them requires a different cognitive strategy. It can be assumed, further, that an individual's performance will be the best if his/her cognitive style and the preferred cognitive strategy are in consonance with the type of task given (see Fig. 1). We believe, based on the results of the first correlation study, that analytically-oriented individuals were better able to decode the legend (i.e. discriminate between the employed variables), which resulted in shorter task times.

The results of the first correlation study and of the comparative eye-tracking study confirmed the hypothesis that the process of solving map-related tasks is, to a large extent, dependent on the type of visualization used in the task. The correlation study established a difference between the participants in their map-related performance depending on their cognitive style, indicating that different cognitive strategies might have been at play. Globally-oriented individuals were better at extrinsic visualization tasks, where two variables were represented by two different modalities which needed to be processed simultaneously; intrinsic visualization tasks, on the other hand, allowing for sequential processing of two variables represented by a single modality (color), were "easier" for locally- (analytically-)oriented individuals. The eye-tracking study enabled to record the participants’ eye movements during the experiments and to learn about possible differences in task-solving in a more direct way.

We are currently working on a replicative study with a modified research design so that the findings of the present study can be fully confirmed. The new design will avoid the term “uncertainty”; care will be taken to ensure that only concepts familiar to individuals with low levels of map literacy are used. In addition, a more in-depth analysis of the participants’ performance in map-related tasks will be carried out. A new testing system will be used, enabling the interconnection of SW Hypothesis (Štěrba et al., 2015) with SW Ogama (Voßkühler et al., 2008) and the eye-tracking system Eye Tribe or SMI RED250mobile (Popelka et al., 2016): The system uses a presentation interface which allows for extensive and intensive data collection to be conducted simultaneously.

Acknowledgement

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The Impact of Global/Local Bias on Task-solving in Map-related Tasks Employing Extrinsic and Intrinsic Visualization of Risk Uncertainty Maps

The form of visual representation affects both the way in which the visual representation is processed and the effectiveness of this processing. Different forms of visual representation may require the employment of different cognitive strategies in order to solve a particular task; at the same time, the different representations vary as to the extent to which they correspond with an individual's preferred cognitive style. The present study employed a Navon-type task to learn about the occurrence of global/local bias. The research was based on close interdisciplinary cooperation between the domains of both psychology and cartography. Several different types of tasks were made involving avalanche hazard maps with intrinsic/extrinsic visual representations, each of them employing different types of graphic variables representing the level of avalanche hazard and avalanche hazard uncertainty. The research sample consisted of two groups of participants, each of which was provided with a different form of visual representation of identical geographical data, such that the representations could be regarded as "informationally equivalent". The first phase of the research consisted of two correlation studies, the first involving subjects with a high degree of map literacy (students of cartography) (intrinsic method: N = 35; extrinsic method: N = 37). The second study was performed after the results of the first study were analyzed. The second group of participants consisted of subjects with a low expected degree of map literacy (students of psychology; intrinsic method: N = 35; extrinsic method: N = 27).The first study revealed a statistically significant moderate correlation between the students' response times in extrinsic visualization tasks and their response times in a global subtest (r=0.384, p<0.05); likewise, a statistically significant moderate correlation was found between the students' response times in intrinsic visualization tasks and their response times in the local subtest (r=0.387, p<0.05). At the same time, no correlation was found between the students' performance in the local subtest and their performance in extrinsic visualization tasks, or between their scores in the global subtest and their performance in intrinsic visualization tasks. The second correlation study did not confirm the results of the first correlation study (intrinsic visualization/"small figures test": r = 0.221; extrinsic visualization/"large figures test": r = 0.135). The first phase of the research, where the data was subjected to statistical analysis, was followed by a comparative eye-tracking study, whose aim was to provide a more detailed insight into the cognitive strategies employed when solving map-related tasks. More specifically, the eye-tracking study was expected to be able to detect possible differences between the cognitive patterns employed when solving extrinsic- as opposed to intrinsic-visualization tasks. The results of an exploratory eye-tracking data analysis support the hypothesis of different strategies of visual information processing being used in reaction to different types of visualization.

Keywords: Geovisualization method, avalanche risk, cognitive style, Navon's hierarchical figure, combined extensive-intensive research design, eye-tracking.

1. Introduction

Space and time play a crucial role during hazardous events in general and natural hazards in particular. Successful decision making during emergency situations depends on the availability and relevancy of information presented in the right time and an understandable way. Such information improves the transparency and credibility of the decisions taken.

Only “raw” spatial data is currently available for emergency management support. Emergency decision makers all around the world have available maps with natural hazards (such as flood, avalanche, and landslides), vulnerable zones, land use or geology, and make decisions based on implicit information inferred from such map sources. Such implications are not straightforward and may even differ according to the different professional background of a particular decision maker. Or more generally, the form of information visualization should be adjusted to the cognitive characteristics of the users. The responsible persons are able to process only a limited number of graphics (maps) in case of an emergency. This situation is even more critical when working under severe time pressure. The visualization form can significantly influence the final decision. Zhang and Goodchild (2002) proved that visual form can improve the communication about spatial data uncertainty within spatial analysis and spatial decision support. Uncertainty often possesses spatial patterns. Uncertainty visualization can thus reveal such patterns and serve not only for presentation but also for exploration and visual analysis of spatial data.

The present study is a continuation of an earlier research project on crisis management (Konečný et al., 2011; Staněk et al. 2010). The study focuses on perception and cognitive processing of different forms of bivariate visual representation, using alternative visual representations derived from identical avalanche hazard datasets (Kunz, 2011; Kunz and Hurni, 2011). The employment of different cartographic bivariate visualizations of the same area and topic made it possible to create meaningful and complex stimuli that were visually different and at the same time fulfilled the requirement of informational equivalence (Larkin and Simon, 1987).

A map functions as a communication channel (Koláčný, 1977), and when used as a stimulus material in psychological experiments, it enables the researcher to purposely manipulate the form of the communicated information. The objective of the study was to investigate the impact of different types of visualization and different cognitive styles on the effectiveness of solving map-related tasks.

2. Uncertainty visualization and the use of bivariate visualization

MacEachren (1992) suggested the use of Bertin's graphic variables to depict uncertainty and even added specialized variables for depicting uncertainty including crispness, resolution, and transparency. Gershon (1998) grouped these into intrinsic and extrinsic visual variables depending on whether the variable is visually separable from the variable depicting the actual attribute. While extrinsic variables are separable, intrinsic variables are not. Another logical step is to describe how these variables including possible additions or modification, might be logically matched with different components of data uncertainty (Buttenfield 1991, MacEachren 1992, Leitner and Buttenfield 2000). MacEachren (1992), for instance, stated that the graphical variables size and color value are most appropriate for depicting uncertainty in numerical information, while color hue, shape, and perhaps orientation can be used for uncertainty in nominal information. More recently MacEachren et al (2012) focused on discrete symbols that could be used to signify the uncertainty of individual items within information graphics, maps. The experiments examine relative effectiveness of a set of uncertainty representation solutions—differing in the visual variable leveraged and level of symbol iconicity. Trau and Hurni (2007) and Kunz (2011) theoretically analyzed the suitability of visual variables and visualization techniques for uncertainty depictions in hazard prediction maps.

Most applied uncertainty visualizations in the field of natural hazards are simplistic univariate representations where hazard related data are displayed in one map and inherent uncertainties are depicted in a second map display (Kunz 2011). Kunz was among the first to propose the use of bivariate depiction of studied phenomenon and its uncertainty, applied this approach in the dynamic environment and even presented brief feedback from expert users.

Capabilities and limitations of bivariate map types based on the combination of visual variables and symbol dimensionalities (point, line, and polygon) were studied and tested also by Elmer (2013). Using the selective attention theory, he empirically tested eight bivariate map types for map reading tasks recording their accuracy and response time. These tests also included the combination of size/value (Choropleth/Graduated symbols) and value/hue-saturation (Bivariate Choropleth) which are relevant for our study. Both aforementioned combinations performed above average for accuracy and response time and were also rated positively by users as an appropriate combination to read and understand the information on the map. However, the author himself concluded that the study only revealed significant differences in perceived combinations and further research is needed in order to understand different mental strategies of users and identify their cognitive behavior.

Cognitive cartography encompasses the application of cognitive theories and methods to understanding maps and mapping and the application of maps to understanding cognition (Montello 2002).

Different ways of displaying the same spatial information can dramatically affect problem-solving performance. Spatial cognition research uses distinct concepts of informational and computational equivalence of representations (Simon 1978). Alternative cartographic visualizations follow the premise of information equivalency. The possibility to visualize (code) the same spatial information in an alternative way which is informationally equivalent offers valuable input material for comparison of cognitive processes used for decoding. Such a comparative principle enables better understanding of the human cognitive apparatus. Differences in representations deal not only with various visual forms but also with different operations necessary for their decoding and interpretation.

Cognitive assumptions are closely connected with visual variables used for uncertainty visualization. Both methods differ in the type of visualization method and visual variables (intrinsic and extrinsic). The perception of variables has a close connection with the theory of pre-attentive perception (Treisman and Gelade 1980, Wolfe et al 1989). The extrinsic graphical variable size is generally considered to be a pre-attentive feature. Such features are appropriate for the determination of presence or absence or particular elements or boundary detection. On the other hand intrinsic graphical variable saturation has not been confirmed as pre-attentive.

However, the situation is rather different when using a combination of both uncertainty portraying variables with a main attribute variable. The intrinsic visualization method combines color hue for the main attribute value and saturation for its uncertainty. The resulting map legend is comprised of 9 categories and constitutes a higher potential cognitive load for users. The extrinsic visualization method combines color saturation for the main attribute value and proportional circle size for uncertainty. The map legend is comprised of only 6 categories.

3. Cognitive Style in Map-Related Tasks

Kozhevnikov (2007) defines cognitive style as heuristics (i.e. strategy derived from experience with similar problems used for processing external information). An individual's cognitive style can be detected at all levels of perception, from the elementary and highly automated ones to those that are complex and conscious. The concept is used to refer to the way individuals think, perceive and orient themselves in the environment. According to Brigham et al. (2007), cognitive style is a pervasive bipolar dimension that is stable over time and can be studied using psychometric techniques. He further states that a cognitive style may be value-differentiated, meaning that it describes differences concerning value rather than quality. However, cognitive style is far from a well-defined construct, both with respect to its content and application to different levels of the personality system. A vast range of different interpretations of cognitive styles exist (see Witkin, 1967; Rayner, 2000; Kirton, 1989; Pask, 1976). Riding and Cheema (1991) surveyed more than 30 conceptions of cognitive style, concluding that each of the investigated conceptions pertains to one of two principal dimensions. The verbal-imagery dimension encompasses an individual's preference for representing information in words/verbal associations, or in mental pictures. The wholist–analytic dimension is characterized as an individual's preference for processing information either in integrated wholes or in discrete parts. Given the nature of the tasks used in the study and the differences between intrinsic and extrinsic visual representations (see Fig. 2), it was the wholist–analytic dimension that was of greater importance for the present study. According to Graff (2003), wholist–analytic cognitive style can be defined as a tendency to process information either as an integrated whole or in discrete parts of that whole. The wholist-analytic cognitive dimension is based on the conception of global/local bias (see Dale and Arnell, 2014) related to whether visual information is perceived at a broad (global) level, or at a more focused (local) level, with more attention being paid to partial characteristics of objects and phenomena and to their analytical processing. Rezaei and Katz (2004) add that globally-oriented individuals consider phenomena in a broader perspective and context. Analytically-oriented individuals, on the other hand, view each situation as an aggregate of discrete elements, typically preferring to focus on one or two elements at a time at the expense of other elements/aspects. Graff (2003) further states that analytically-oriented individuals are better at apprehending concepts in parts, but may experience difficulty integrating such concepts into complete, consistent wholes, while globally-oriented individuals view concepts as wholes, but are unable to separate individual aspects of the concepts into discrete parts. According to Kozhevnikov (2007), the analytical cognitive style tends to be characterized as convergent, differentiated, sequential, reflective and deductive, whereas the “global” style has been described as divergent, intuitive, impulsive, inductive, and creative. Globality is often discussed in connection with e.g. attentional breadth in selective attention (Dale and Arnell, 2014) and rapid scene categorization (Brand and Johnson, 2014).

The level of an individual’s performance in map-related tasks is a result of the interaction of three variables: a) user characteristics; b) task type and situational context; c) map-related characteristics/type of visual representation (Fig. 1). Wehrend and Lewis (1990) constructed a comprehensive catalogue of map-related operations, including identification (identifying visual characteristics of features on the map), localization (determining the absolute or relative position) or categorization (placing in specifically defined divisions in a classification; this may be done by color, shape or size). Map-related tasks can be ranked depending on their relative difficulty, from relatively easy operations of “finding the shortest path” (e.g. Jones, 1997) to highly complex tasks (Smith Mason et al., 2016) of “planning military operations” (Hofmann et al., 2015), which require several concepts to be explored simultaneously, compared and integrated. Working with a map always needs to be viewed as mental manipulation with semantically rich material rather than a mere visual search and processing of visual stimuli (MacEachren and Taylor, 1994, Montello, 2009, Roth et al., 2011). The highest-level performance in fulfilling the task can be expected if the cognitive style of the user matches the nature of the task (Hammond, 1996) and the form of visual representation used. For instance, at a task requiring analytical thinking, an analytically-oriented individual can be expected to perform better than a globally-oriented individual with the same degree of cartographic literacy (Hojnik and Hus, 2013) and domain knowledge (Alexander, Kulikowich and Schulze,1994). Additionally, a form of visualization allowing for sequential analytical processing will result in a better performance than a visualization requiring simultaneous and intuitive processing. The user's performance will be the best if all three of the areas (i.e. type of task, type of cognitive style and form of visualization) are in consonance.

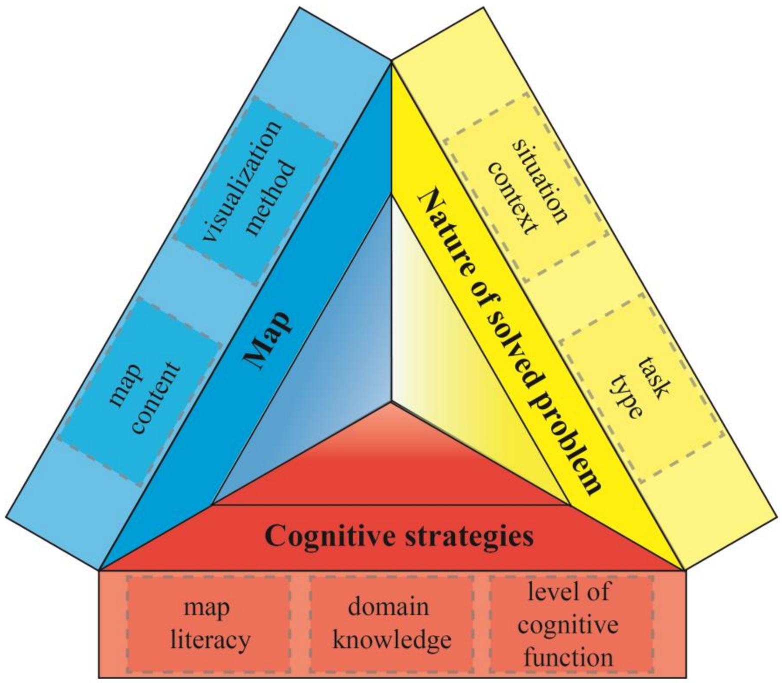

Figure 1. Triarchic structural model of performance when solving map-related task

From the point of view of experimental psychology, maps are highly valuable as stimulus material (Olson, 1979) in that they constitute complex external representations with variables amenable to accurate control and change of value. By representing identical content (data), different forms of visualization are informationally equivalent, enabling computational equivalence to be studied (Larkin and Simon, 1987). Any differences in performance and in the way an individual works with different maps can be viewed as directly linked to the difference in visual presentation of the same content. In the present study, avalanche hazard maps were used with intrinsic vs. extrinsic visual representations (Fig. 2, right and left, respectively).

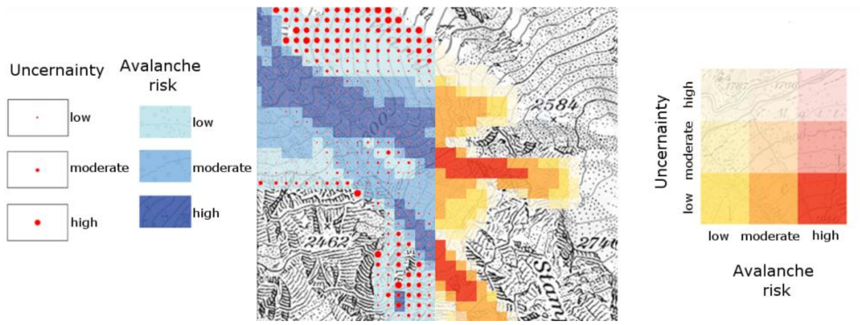

Figure 2. Snow avalanche hazard and hazard uncertainty map: left – extrinsic visual representation; right – intrinsic visual representation (adapted from Kunz, 2011)

The difference between the extrinsic and intrinsic representation exists in the way the two thematic layer variables (snow avalanche hazard and snow avalanche hazard uncertainty) are represented. In extrinsic representation, the avalanche hazard level is expressed in terms of variation in the saturation of the color blue, while hazard uncertainty is represented by the size of the dots. In intrinsic representation, the same map base is used, with the avalanche hazard expressed in terms of hue, and hazard uncertainty expressed in terms of variation in the saturation of the hue. Both types of visual representations use a combination of two graphic variables. However, while the extrinsic type uses two different modalities (hue and size) for the presentation of two phenomena, intrinsic representation is expressed in terms of variation of two properties (hue and saturation) of a single modality (color). There is a clear difference in categorization between the two types of representations. In the intrinsic visual representation, 9 (3 x 3) categories are encoded explicitly; the extrinsic visual representation, on the other hand, has separate categories for each of the two phenomena it represents (3 for avalanche hazard level and 3 for hazard uncertainty), with only 6 categories being encoded explicitly (although there are a total of nine combinations as well). Even though color properties (hue and saturation in this particular case) tend to be regarded as two independent variables in the field of cartography (Bertin, 1973), in the psychology of perception color properties are viewed as interacting with each other (D'Zmura, 1991, Itti and Koch, 2000; Lindsey et al, 2010). For instance, a desaturated blue on light (white) background will be less luminous and thus more salient than a fully saturated yellow (e.g. Nothdurft, 2000; see Fig. 3). The phenomenon can be applied to map reading as well.

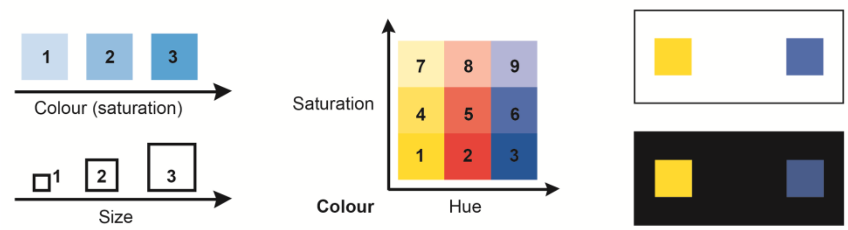

Figure 3. Differences in the encoding of variables between the extrinsic (first column) and intrinsic (second column) form of visualization; third column shows the difference in salience between a fully saturated yellow (1) and partially desaturated blue (6) on white and black backgrounds

The objective of the presented study was to investigate the relationship between different forms of bivariate visual representation and an individual's cognitive style as reflected by their performance in Navon's test of hierarchical figures (see section 4.2.1). We hypothesize (1) a link between global processing efficiency and extrinsic visualization abilities, and (2) a link between local processing efficiency and intrinsic visualization abilities. We thus consider that a variation of both hue and saturation using a single color modality (intrinsic) would refer to a more local approach, whereas two types of independent graphic hues and size variables (extrinsic) will be considered a more global approach. In other words, the elaboration of two parameters (hue and saturation) of one modality - color (intrinsic) would be linked to local processing abilities, while considering two different parameters, hue and size (extrinsic), simultaneously would be linked to global processing abilities.

4. Method

The study uses a mixed (confirmatory-exploratory) research design, with the aim to combine extensive research (for data collection and subsequent statistical analyses) with a more in-depth exploratory data analysis (EDA; see Andrienko and Andrienko, 2005). The advantages of the mixed research design, along with its theoretical grounding, have been described by Šterba et al. (2014), who also provide a sample study. The authors use the term "mixed-research design", which, however, tends to be viewed as referring to a combination of qualitative and quantitative methods, particularly in the context of social sciences and constructivist approaches (see Leech and Onwuegbuzie, 2009; Creswell, 2003). In order to distinguish between the two concepts we propose the term "combined extensive-intensive research design". A combined mixed extensive-intensive research works primarily with objective data, combining a confirmatory stage of the research with an exploratory stage. The first (confirmatory) phase of our research comprised two correlation studies. The first consisted of the collection of data on subjects with a high degree of map literacy (students of cartography), while the second focused on subjects with a low degree of map literacy (students of psychology). After the confirmatory phase, an exploratory phase followed which was represented by a comparative eye-tracking study. The aim of the comparative study was to reveal possible differences in task-solving strategies depending on the type of visualization employed by usage of an exploratory data analysis. The structure of the research is shown in detail in Fig.4. While extensive methods are concerned only with the effect of stimulus on behavioral outputs in the sense of speed or correctness intensive methods concentrate on the process alone, as in, what happens between stimulus and reaction? And this is also the purpose of the eye-tracking comparative study which can deeper illuminate results of the previous phase of the study.

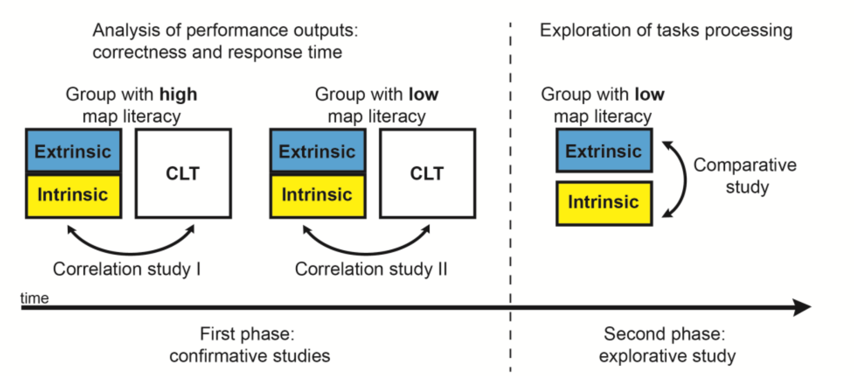

Figure 4. Structure of used combined extensive-intensive research design

5. Correlation Studies I and II

The objective of the first phase of the research was to investigate the relationship between an individual's cognitive style and the type of visualization used. By way of the first phase, two correlation studies were conducted. The design of the second study was adjusted based on the results of the first study. More specifically, several items were added to the subtest involving a one variable. The second study also included tasks focused on the degree of understanding of the concept of visualization of snow avalanche hazard and hazard uncertainty. These more complex tasks are not part of the present article, which focuses primarily on lower cognitive processes (e.g. visual search as reflecting an individual's cognitive style).

5.1. Participants

In the first correlation study, the research sample consisted of students of geography in the 1st to 3rd year of their studies. A total of 73 volunteers aged 19 to 27 years were tested. For the extrinsic visualization task, there were 37 subjects (19 male, 18 female), while 35 subjects (19 male, 16 female) were given a task employing intrinsic visualization. In the second correlation study, a total of 62 volunteers aged 19 to 55 years were tested, all students of psychology in the 1st to 3rd year of their studies. For the intrinsic visualization task, there were 35 subjects (8 male, 27 female), most of them aged 19 to 25 years, with one male outlier aged 37 years; 27 subjects (3 male, 24 female) were given the extrinsic visualization task. Most of the subjects were 19 to 28 years, with one male outlier aged 55 years. None of the subjects had any previous experience of participation in cartographic visualization testing.

5.2. Aparatus

The test was created and administered in MuTeP (Multivariate Testing Program; see Kubíček et al., 2014, Kubíček et al., 2016, Štěrba et al., 2015). After every data collection a group discussion followed. Participants were asked about their subjective experience by elaboration of the test battery.

5.3. Stimulus Material - Map-related Tasks

In the correlation studies, avalanche maps were used showing both the level of the snow avalanche hazard (expressed in terms of load on the snowpack) and the level of avalanche hazard uncertainty. Both variables were expressed by means of a three-level scale (Low – Moderate – High). The map consisted of a base layer and a thematic layer, with the latter being explained by the legend of the map. In the experimental tasks, the base layer played only a very marginal role. The subjects' performance depended on their ability to comprehend the instructions, decode the legend, and perform a visual search to locate the four numbered target areas and decide which of them meets the criteria given. There was always only one correct answer. The visual scene consisted of a map, a map legend, task instructions located at the top of the computer screen and numbered "buttons". The instructions were always presented separately on a blank screen. No time limit for the instructions was given so that there would be enough time for the participants to comprehend the instructions. The overall test structure was as follows:

1. Training – 2 training tasks
    a. identify the level of variable A (avalanche hazard)
    b. identify the level of variable B (avalanche hazard uncertainty)
2. One variable tasks
    a. identify the level of variable A (avalanche hazard) – low, moderate, and high respectively.
    b. identify the level of variable B (avalanche hazard uncertainty) – low, moderate, and high respectively.
3. Two variable tasks
    a. identify the level of variable A (avalanche hazard) and variable B (avalanche hazard uncertainty) –

combination of low, moderate, and high respectively).

Both tests were made up of one- and two-variable tasks. In the first correlation study, the participants were given five test tasks (see Fig. 5 top line) – two for one variable and three for two variables. In the second correlation study (performed on subjects with a low degree of map literacy) the batch of one-variable tasks included four items instead of two (see Fig. 5 bottom line).

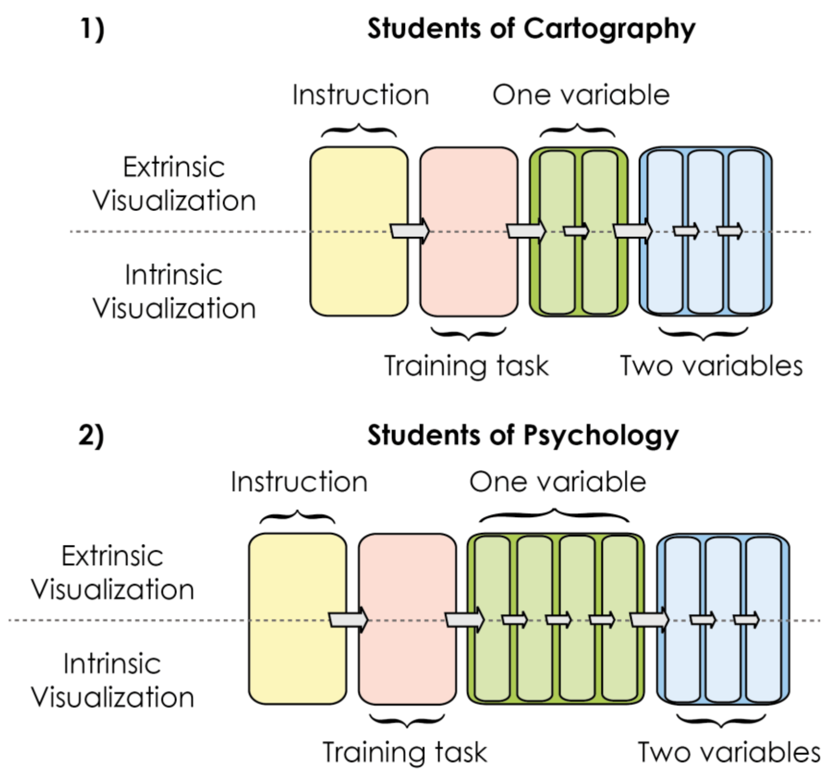

Figure 5. Structure of map-related tasks (students of cartography – top; students of psychology – bottom)

Visualizations used in training were similar to the rest of the test. Sample instructions of one variable task are as follows: “Select the area with a moderate level of avalanche hazard” (see Fig. 6 left). The subjects completed each task by clicking on the respective “button”. Instructions of two variables task were formulated in a following way: “Select the area with a high level of avalanche hazard accompanied by a low level of avalanche hazard uncertainty” (see Fig. 6 right).

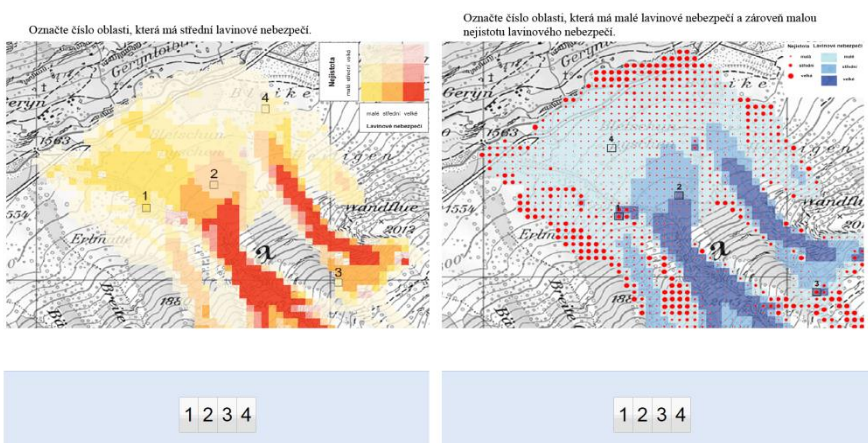

Figure 6. Sample map-related tasks: Left (intrinsic visualization) – Select the area with a moderate level of avalanche hazard. Right (extrinsic visualization) – Select the area with a high level of avalanche hazard accompanied by a low level of avalanche hazard uncertainty.

5.4. Stimulus Material - Compound Figures Test

The second part of the test battery consisted of a psychological test of cognitive style. It contained a variation of Navon’s Hierarchical Figures Test (Navon, 1977) – a compound figures test (see Fig. 7, left) which was designed for the purposes of the present study using MuTeP. Navon's test (Navon, 1977) is one of the most frequently used methods for the measurement of the wholist-analytic dimension of cognitive processing (e.g. Brand and Johnson, 2014; Duchaine et al., 2007; Yovel et al., 2005, Milne and Szczerbinski, 2009). It enabled us to measure a person's ability to direct attention either to the local level of the visual stimulus material or to the global level. Bouvet et al. (2011) used tasks based on the Hierarchical Figure test and found evidence that participants exhibit a similar processing style across modalities with respect to both vision and audition modalities. Thus these findings support the theory that Navons Hierarchical Figures can be understood and used more generally as a measure of wholistic-analytic cognitive style and not only in the narrower way, as an indicator of a visuo-attentional global/local style. The compound figures test included instructions, several training items and 32 test items. The stimulus material consisted of a set of large, single-digit numbers compounded of small numbers. There were two subtests, local and global, each comprising 16 items. The participants were instructed to identify the small numbers in the first subtest and the large numbers in the second subtest by clicking on one of four available buttons as quickly as possible (see Fig. 7, left). The overall response time of the respondents was recorded electronically; the average response time per item was calculated.

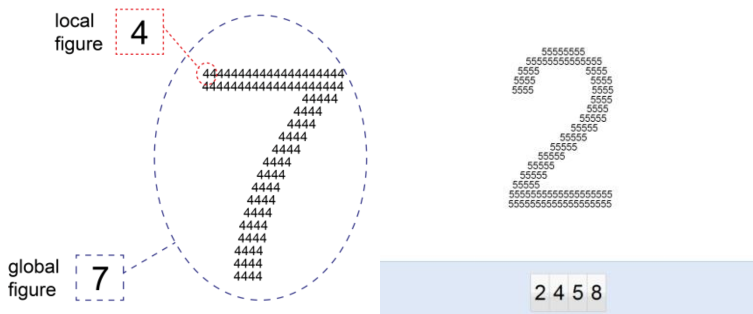

Figure 7. A compound stimulus (left); an item from the Compound Figures Test adapted into the MuTeP environment (right).

5.5. Results

Two subjects with a high error rate for CFT were excluded from further analyses. One student of cartography erred 5 times in the local subtest and 6 times in the global subtest. One student of psychology erred 12 times in the first subtest. The number of mistakes made by the other participants was insignificant; most of them achieved 100% accuracy, others erred less than three times. Reaction times of the outlying errors were included in the analyses. The overall score for the local and global subtests were counted based on 15 items from each subtest. The first item of each subtest was excluded from the analysis. In line with previous findings, the internal consistency (Cronbach's alpha) for both subtests was found to be high ($\alpha = 0.805$ and $\alpha = 0.864$, respectively). Differences in reaction times between the two subtests (Fig. 8) were found to be in agreement with previous findings as well. A paired t-test revealed faster processing of global figures by 15% ($N=133$; mean reaction time for the local subtest $s=1.9$; $SD=0.2$; mean reaction time for the global subtest $s=1.6$; $SD=0.17$; $df=132$; $p=0.01$). The results showed a positive correlation between the two subtests ($r=0.437$, $p<0.01$).

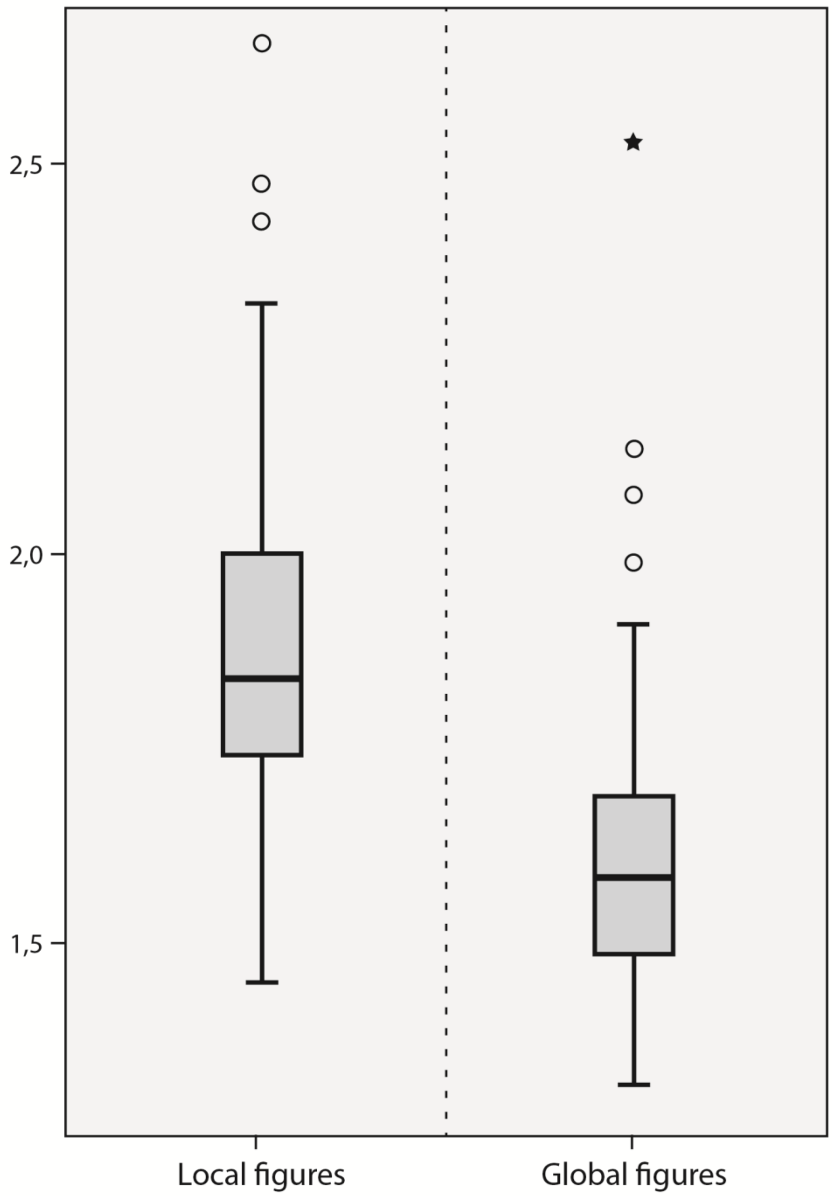
2,5
2,0
1,5
Local figures
Global figures

Figure 8. Reaction times (s) for both subtests of CFT

The error rate of students of cartography was 7.2% for intrinsic visualization and 9.7% for extrinsic visualization. Students of psychology exhibited a significantly higher error rate in both subtests: 13.8% for intrinsic visualization and 20.0% for extrinsic visualization. The overall error rate was counted from the individual error rates of all the subjects who completed the cartographic part of the research, including outliers, which were, however, excluded from further analyses. Outlying subjects in the research sample of students of cartography were those who erred two and more times (out of the total of five items (i.e. those with an error rate >40%; intrinsic visualization – 1 participant; extrinsic visualization – 4 participants). As regards the research sample consisting of students of psychology, 4 subjects were excluded (extrinsic visualization) who erred three and more times (out of 7; error rate >40%). Although the above outliers were excluded from further analyses, all reaction times of remaining participants were (as in CFT) included (see Tab. 1 and 2).

Students of Cartography	Intrinsic visualization (n=34)		Extrinsic visualization (n=33)	
	local subtest	global subtest	local subtest	global subtest
One Variable	.400**	.180	-.021	.375*
Two variables	.168	-.114	.304*	.302*
Overall Score	**.387***	**.050**	**.176**	**.384***

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

Table 1. Students of Cartography: Relationship between Map-related Task Performance (response time) and CFT Results (Pearson's Correlation; one-tailed)

Students of Psychology	Intrinsic visualization (n=35)		Extrinsic visualization (n=23)	
	local subtest	global subtest	local subtest	global subtest
One Variable	.211	.222	.100	.291
Two Variables	.106	.230	-.079	-.140
Overall score	**.221**	**.266**	**.027**	**.135**

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level

Table 2. Students of Psychology: Relationship between Map-related Task Performance (response time) and CFT Results (Pearson's Correlation; one-tailed)

5.6. Interpretation of the Results

The results of the CFT employing a variation of Navon's hierarchical figures test confirmed the effect of global precedence; the average response time in the global subtest was lower by 15% compared with the local subtest. In addition, the results showed a positive correlation between the two subtests, which is in line with the expectation that an individual's processing capacity in both tasks will be driven by the same psychomotor speed (Spirduso, 1980). After the exclusion of subjects with high error rates (either in CFT or in map-related tasks) the subjects' results in CFT and map-related tasks were tested for possible correlations. The analysis was conducted by means of comparison of overall response times in map-related tasks with response times in CFT. The results of the first correlation study (on subjects with a high degree of map literacy) revealed a positive correlation between scores obtained in the local subtest and response times in map-related tasks employing intrinsic visualization; at the same time, a positive correlation was found to exist between global-subtest response times and response times in map-related tasks employing extrinsic visualization. The fact that no cross-correlation was found between either the local subtest and extrinsic visualization or between the global subtest and intrinsic visualization (although the subjects' performance in map-related tasks was also driven by the same psychomotor speed) renders the above findings even more significant. In the second correlation study (on students of psychology), no significant relationship between the variables was found. We suppose that the absence of any correlation might have been caused by low levels of map literacy, which was reflected in comparatively high error rates.

6. Comparative Study: Eye-tracking

The reason for replicating the correlation studies using an eye-tracking system was to obtain additional information which would provide deeper insight into the process of solving map-related tasks and related cognitive strategies. With the decrease in cost of the technology, eye-tracking became a more widely utilized method, not one only used in cartographic studies (see Alaçam and Dalci, 2009; Çöltekin et al., 2009; Popelka and Brychtová, 2013; Popelka and Dědková, 2014; Ooms et al., 2012). The aim of the eye-tracking study was to investigate the impact of different types of cartographic visualization on task-processing. While the confirmatory phase of the research focused on the speed and "correctness" of reaction to visual stimuli, the exploratory phase consisted of investigating the very process of task-solving (see Fig. 9).

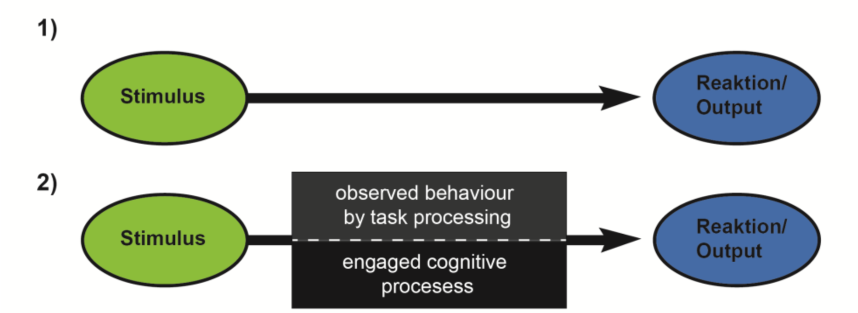

Figure 9. Process of investigating variables: 1) stimulus -> output; 2) stimulus -> cognitive processing and associate behavior -> output

6.1. Participants

A total of 14 subjects aged 21 to 35 years volunteered to participate in the study; they were either university students or had already completed their university studies. None of the participants received any education in cartography or related fields. The participants were divided into two groups of seven.

6.2. Apparatus

The device used in the study was EyeLink 1000, a remote eye-tracking system manufactured by SR Research. The original test battery presented in MuTeP was adapted to the environment of Experiment Builder, a software tool by SR Research for creating eye-tracking experiments.

Eye-tracking data were saved in a format enabling an exploratory data analysis to be carried out in EyeLink Data Viewer, software that can be used for viewing, filtering and processing eye-tracking data recorded with an EyeLink eye-tracker. The application offers a range of eye-tracking metrics. In addition, it enables the analysis of transitions between defined areas of interest (AOIs). In the analysis, visualization tools such as an attention map and video analysis were also used. After every single data collection an individual inquiry followed. Participants were asked about their subjective experience by elaboration of a test battery,

6.3. Stimulus Material

The original test structure was slightly modified (see fig. 10) and several new training tasks were added to the original test battery. A detailed graphical explanation of the principles of avalanche risk and uncertainty was added in order to properly introduce both the risk mapping and its uncertainty. These should enhance the understanding of the experiment by non-experts.

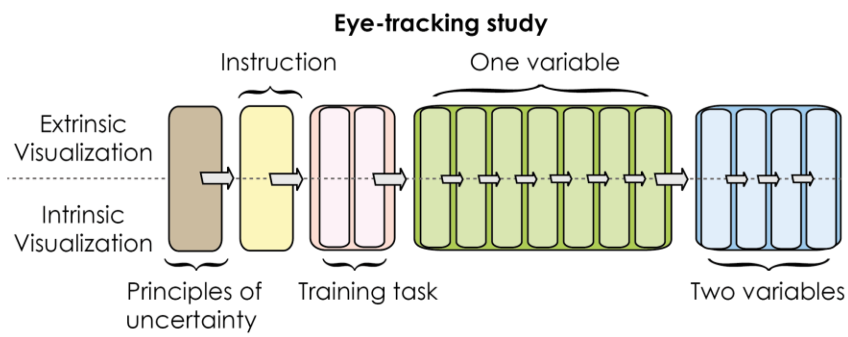

Figure 10. Structure of map-related tasks in the eye-tracking study

6.4. Results and Interpretation

The exploratory data analysis was performed at both the subject level and group level (extrinsic vs. intrinsic visualization). One participant from the extrinsic visualization group was excluded from the analysis due to a heavy data dropout. Several areas of interest were defined, with key AOIs being set around the legend and the map. The following measures were analyzed: trial duration, number of transitions between the legend and the map, the number of fixations on the legend and on the map, dwell time[1] on the legend andon the map, and fixation durations.

Fig. 11 (graph on the left) shows average trial durations for the eleven tasks used in the study. The first seven tasks employ only one variable (level of avalanche hazard or avalanche hazard uncertainty), while the rest of the tasks inquire about both variables. The area represented by the map was identical in all the tasks. The graph on the right in Fig. 11 shows the number of transitions between the map and the legend for each task (in both directions). Fig. 12 (box plots) shows the average number of transitions and their spread for both extrinsic and intrinsic visualization tasks. As is evident from the graphs, the subjects' performance across the individual tasks was much more homogeneous when working with extrinsic visualization; the subjects' performance at intrinsic visualization tasks, on the other hand, appears to have been more sensitive to the nature of the task. The higher variability might have been caused by greater differences in the difficulty of discriminating between different levels of brightness (caused by the interaction between hue and saturation). The differences in brightness (see Fig. 2 right and Fig. 3 second and third columns) make it e.g. easier to distinguish between low uncertainty/low avalanche hazard and low uncertainty/moderate avalanche hazard than between high uncertainty/low hazard and high uncertainty/moderate hazard.

[1] *dwell time* refers to the sum duration of fixations falling within a particular AOI; *fixation duration* refers to the duration of individual fixations.

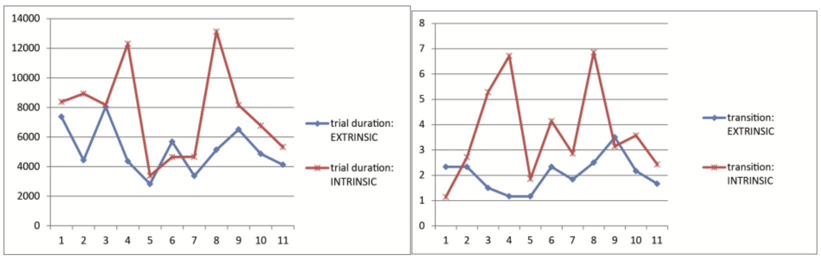

Figure 11. Trial duration (in ms; left) and number of transitions (right) between the map and the legend

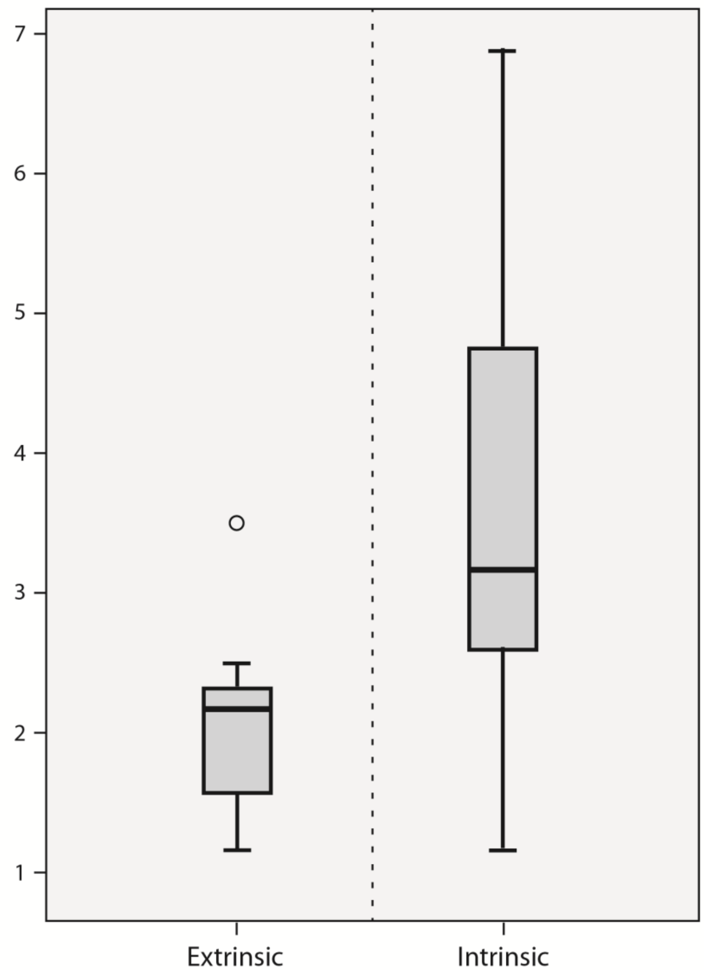

Figure 12. Number of transitions between the legend and the map

The following analyses focus on the differences between extrinsic and intrinsic visualization as reflected by the differences in dwell times and fixation durations (related to the legend and the map). Graphs in Fig. 13 show the percentages of map/legend dwell time for all the tasks. For extrinsic visualization tasks, the legend dwell time ranges from 10 to 30% (of the total dwell time); visual search time (map dwell time) ranges from 60 to 80%. Intrinsic visualization, on the other hand, exhibits a far greater variability across the individual tasks; for the legend, the dwell time ranges from below 10% in one task to over 50% in another. In the latter case, the time needed for decoding the legend even exceeds the time needed to locate the target in the map.

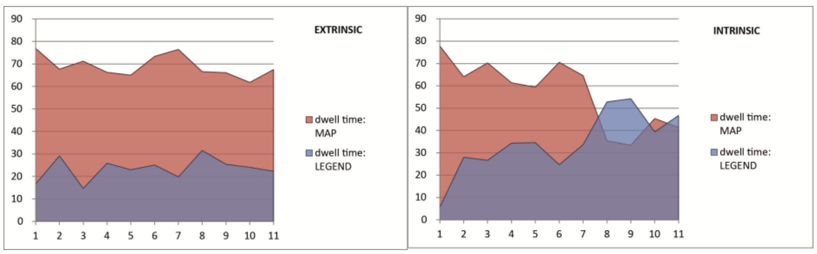

Figure 13. Dwell times related to the map and the legend in extrinsic (left) and intrinsic (right) visualization tasks (in %)

Fig. 14 presents a comparison of map and legend fixation durations in intrinsic (right) and extrinsic (left) visualization tasks. Fig. 14 shows the average fixation durations and spreads. As with dwell times, the data show lower variability across the individual tasks for extrinsic visualization: the curves of fixation durations are nearly identical (see, for instance, the data concerning the second task, with fixation durations slightly above 250 ms for both the legend and the map). Intrinsic visualization, however, led to a different situation during the same (second) task: legend-related fixations were on average more than 100 ms longer than map-related fixations. From Fig. 15 it can be seen that extrinsic visualization caused average fixation durations to last approximately 250 ms for the map and the legend alike. In the case of intrinsic visualization, the same value was true for map-related average fixation durations; the average duration of legend-related fixations, however, far exceeded 300 ms.

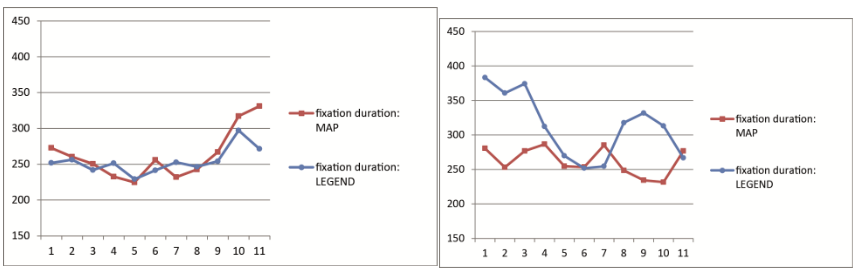

Figure 14. Fixation durations related to the map and the legend in extrinsic (left) and intrinsic (right) visualization tasks (in ms)

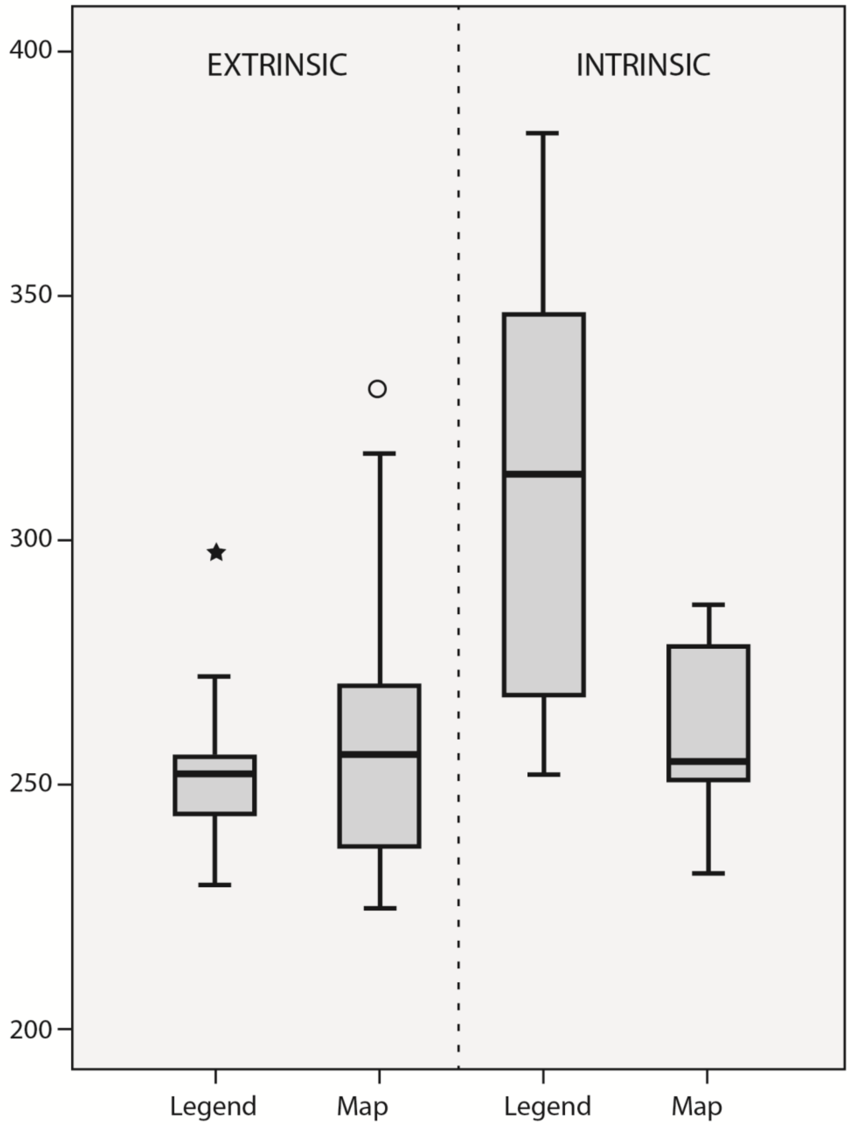
400
350
300
250
200
EXTRINSIC
INTRINSIC
Legend
Map
Legend
Map

Figure 15. Fixation durations related to the map and the legend in extrinsic (two boxplots on the left) and intrinsic (two boxplots on the right) visualization tasks (in ms)

7. Discussion and conclusion

The primary objective of the study was to investigate the relationship between the participants' cognitive style and their performance at map-related tasks employing different forms of visualization. First, a Compound Figures Test (a variation of Navon's Hierarchical Figures Test) was administered using MuTeP in order to discriminate between analytically- and globally-oriented individuals. The test was already been successfully employed in previous studies (Kubíček et al., 2016, Horváth, 2012). The results of the test confirmed the effect of global precedence (Poirel, Pineau and Mellet, 2008). Subsequently, two independent correlation studies were conducted in order to establish the relationship between the participants' performance at global and local subtests of the CFT and their performance at map-related tasks employing different forms of cartographic visualization (intrinsic and extrinsic). Each correlation study used a research sample with a different level of map literacy. The first research sample with a high degree of map literacy consisted of students of cartography, while subjects with low levels of map literacy were represented by students of psychology. In contrast with the first study, the second correlation study showed no significant correlation between the participants' performance at CFT and their performance at map-related tasks. We suppose that the absence of any correlation might have been caused by low levels of map literacy and the resulting subjective difficulty of the map-related tasks. In a post-experimental inquiry, the students of psychology more often reported that they had difficulties understanding the notion of "avalanche risk uncertainty". The above was reflected in comparatively high error rates displayed by the students of psychology. We believe that comprehension problems acted as an intervening variable and might have been a source of significant “noise” in the collected data. The studies focused on the investigation of low-level cognitive processes, particularly the visual decoding of the legend and subsequent visual search for target areas in the map. It is, however, important to realize that a map represents a complex communication channel and its thematic layer (if present) triggers high-level cognitive processes which may override the underlying low-level cognitive processes. Thus, the amount of time needed for solving the map-related tasks did not primarily depend on the type of visualization used or the speed of visual processing, but rather on the degree and speed of understanding the instructions. According to Booth (2006), tasks involving low-level cognitive processes are less prone to invoking between-task differences in the subjects’ performance than tasks involving high-level cognitive processes, where local/global processing styles are overridden by executive/strategic processes. Thus, if a medium-strong correlation is found between a simple, selective attention task (such as CFT) and a complex map-related task, it can be viewed as indicating that identical cognitive processes are at play in both cases.

In the first correlation study, which worked with a group of participants with high levels of map literacy, significant correlations were established between the participants’ cognitive style and the type of visualization used in map-related tasks. A statistically significant positive correlation ($r= .387$; $p<0.05$) was established between scores obtained in the local subtest and response times in map-related tasks employing intrinsic visualization. No relationship was found between intrinsic visualization and scores obtained in the global subtest. Similarly, while a positive correlation ($r= .384$; $p<0.05$) was found to exist between global-subtest response times and response times in map-related tasks employing extrinsic visualization, no relationship was found between extrinsic visualization and the local subtest. Thus, it can be concluded that subjects with high levels of map literacy exhibit differences in their performance at map-related tasks depending on their cognitive style and on the type of visualization employed. Analytically-oriented individuals were better at tasks involving intrinsic visualization, while globally-oriented individuals performed better at tasks employing extrinsic visualization. The fact that no cross-correlation was found between either the local subtest and extrinsic visualization or between the global subtest and intrinsic visualization renders the findings even more significant. Following the two correlation studies in the first phase, a comparative eye-tracking study was conducted in the second phase with the aim of obtaining deeper insight into the cognitive processes which were at play during task-solving; it was not designed to test pre-defined hypotheses or compare types of visualization with respect to their effectiveness.

The results of the eye-tracking part of our research indicate a high dependency of performance at intrinsic visualization tasks on the nature of the tasks (i.e. on the values of target variables). An example of the above is represented by the high across-task variability in the number of map/legend transitions. At the same time, intrinsic visualization tasks exhibit a far greater number of transitions than extrinsic visualization tasks, requiring more "checking look-backs" at the legend. Another analyzed parameter was represented by the map/legend dwell time ratio. For extrinsic visualization tasks, the legend dwell time was relatively short, ranging from 10 to 30% (of the total dwell time), while visual search time (map dwell time) ranged from 60 to 80%. Intrinsic visualization, on the other hand, exhibited a far greater variability across the individual tasks. For the legend, the dwell time ranges from below 10% in one task to over 50% in another. Time spent on visual search amounted to more than 70% of the total dwell time in some tasks and less than 40% in others. In some cases, the time needed for decoding the legend even exceeded the time needed to locate the target in the map. In addition, intrinsic visualization resulted in longer fixation durations and greater fixation duration variability across the individual tasks. The results indicate that in intrinsic tasks, decoding the legend may in some cases require significant cognitive effort (see Longo and Barrett, 2010). An instance of the above may be represented by the established across-task variability in the difficulty of legend decoding in intrinsic visualization tasks. The findings regarding intrinsic and extrinsic visualization support the hypothesis that the different types of visualization are not computationally equivalent and that each of them requires a different cognitive strategy. It can be assumed, further, that an individual’s performance will be the best if his/her cognitive style and the preferred cognitive strategy are in consonance with the type of task given (see Fig. 1). We believe, based on the results of the first correlation study, that analytically-oriented individuals were better able to decode the legend (i.e. discriminate between the employed variables), which resulted in shorter task times.

The results of the first correlation study and of the comparative eye-tracking study confirmed the hypothesis that the process of solving map-related tasks is, to a large extent, dependent on the type of visualization used in the task. The correlation study established a difference between the participants in their map-related performance depending on their cognitive style, indicating that different cognitive strategies might have been at play. Globally-oriented individuals were better at extrinsic visualization tasks, where two variables were represented by two different modalities which needed to be processed simultaneously; intrinsic visualization tasks, on the other hand, allowing for sequential processing of two variables represented by a single modality (color), were “easier” for locally- (analytically-)oriented individuals. The eye-tracking study enabled to record the participants' eye movements during the experiments and to learn about possible differences in task-solving in a more direct way.

We are currently working on a replicative study with a modified research design so that the findings of the present study can be fully confirmed. The new design will avoid the term "uncertainty"; care will be taken to ensure that only concepts familiar to individuals with low levels of map literacy are used. In addition, a more in-depth analysis of the participants' performance in map-related tasks will be carried out. A new testing system will be used, enabling the interconnection of SW Hypothesis (Štěrba et al., 2015) with SW Ogama (Voßkühler et al., 2008) and the eye-tracking system Eye Tribe or SMI RED250mobile (Popelka et al., 2016): The system uses a presentation interface which allows for extensive and intensive data collection to be conducted simultaneously.

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Biographical Picture

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