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The usability of selected base maps for crises management—users' perspectives

Milan Konečný · Petr Kubíček · Zdeněk Stachoň · Čeněk Šašinka

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Abstract Cartography has become an important tool for supporting decision-making processes in the field of crisis management. Maps (or GIS) can be used for solving various problems, e.g. the localization of accident site, the delimitation of endangered areas, the formulation of evacuation plans and others. People involved in decision-making processes use various procedures to solve these problems. However, a suitable and efficient form of cartographic support for particular situations and crisis management cycle stages is still missing. The main goal of the experiment was twofold. First, we wanted to assess the interdisciplinary (cartography–psychology) web-based testing environment and achieve the first usability results. Second, the use of different cartographic base map representations was analysed in order to judge the efficiency for specific situations. Testing was focused on various types of tasks, e.g. simple sign selection, the possibility of memorizing important information from the map and the choice of the optimal evacuation route. The overall testing was performed within the interactive web environment, based on predefined templates, automatically recorded and calibrated against the evaluation of the pretest users' abilities. Preliminary testing results provide valuable inputs concerning the usability of selected base maps for supporting decision-making processes during various crisis situations.

Keywords Cartography · Crises management · Decision making

M. Konečný · P. Kubíček · Z. Stachoň (✉) · Č. Šašinka
Masaryk University,
Brno, Czech Republic
e-mail: zstachon@geogr.muni.cz

Introduction

Most research involving people usually needs an interdisciplinary approach. In the case of map cognition and usability, it is very important to establish cooperation between cartography and psychology. Cartography focuses on maps and uses information about the human mind provided by psychology. The International Cartographic Association (2010) has established issues of map usability within its research topics agenda. According to this agenda, map design should always be user-oriented (user-centred design) and be based on a good knowledge of the elements of usability. Today, maps are most often digital and interactive, and thus users are able to dynamically retrieve data for display and analysis from databases. The representation of information needs to be different for different user groups (Bandrova and Nikolova 2005). The creation of usability tests—both qualitative and quantitative—for different types of maps or visualisations is quite a challenge International Cartographic Association (2010). This fact is even more important when the maps are used within the field of crisis management (CM). Crisis management involves many cartographic applications from maps for the general public, e.g. escape and evacuation plans, etc., to maps for highly skilled professionals, e.g. fire fighters, policemen, etc. The research deals with the second part of this range—maps for professionals involved in the decision-making process of crisis management.

Different attitudes to cartographic applications in the field of CM can be found in Konečný et al. (2010), Kubíček et al. (2008), Erharuyi and Fairbairn (2005), Horak et al. (2008), Řezník T (2010), Bandrová et al. (2009) and Diehl et al. (2006). These diverse theoretical and methodological approaches do not usually involve the testing of users' behaviours whilst working with maps, or usability measures. The approach used in this research is based on the concept of adaptive cartography, where maps modify themselves according to their location as well as the preferences of users. The concept of the system of user testing situation-adapted maps is presented in this article.

Cartographic support for crisis (emergency) management

The role of cartography within crisis management

Contemporary cartographic support for emergency management involves either using copies of ordinary analogue maps as a base map background or the simple static visualisation of features stored in geodatabases. Technology nowadays offers much wider possibilities for making cartographic representations. The main idea is to create a real-time individual cartographic representation from a common data source that is continuously updated in order to achieve efficient support for decision-making processes in emergency situations. Cartographic visualisations of relevant real-world phenomena represent a very effective way of exploring spatially related data so that necessary decision making can be accelerated. Dynamic visualisation also overcomes the main bottleneck associated with analogue maps—their inflexibility; they simply cannot reflect all possible information that is useful for a topical situation. On the other hand, analogue maps are usually overloaded with information which is hardly legible for ordinary people, and only staff trained in particular map reading are fully able to use all the information available. GIS client software allows the symbolizing of geodata according to attributes, but the creation of a sensible visual representation takes time and needs cartographically skilled staff. In this context, we need to establish processes automatically able to generate cartographic representations on demand and simplify the reading for dedicated persons or user groups.

Cartographic visualisation in emergency management can play a key role, such as an instant decision support tool. Future maps for emergency management must be more schematic and individualized than contemporary maps. According to the user environment, it is necessary to undertake thorough research in the area of usability (focusing on both map content and map controls) in order to improve the intuitiveness of usage. Maps need to be tailored to the user, not the user to the map, especially in this domain.

Basic principles of adaptive mapping

Erharuyi and Fairbairn (2005) describe the adaptation of geographic information as an optimization process that enables the provision of objects of high utility that satisfy a user's current situational context. The adaptation of GI can be carried out at various levels—at the data level, at the communications level, at the task-specific level, or at the platform level. For example, GI can be adapted to a special format, adapted for transmitting over a wireless network, or adapted to a specific device. GI is produced and used by people to support better informed and faster decision making. This potential can only be exploited adequately if the purpose (tasks) for which the user needs the data is taken as an important intervening variable (operator) for the optimization process (Erharuyi and Fairbairn 2005).

The principles of adaptation deal with the development of so-called contexts. The context is a set of determinants identifying particular cartographic representations. If something happens around the map device, its context is changed and an appropriate visual representation is selected. For a detailed discussion of the various aspects of adaptive mapping, see, e.g. Erharuyi and Fairbairn (2005), Reichenbacher (2003), Kubicek and Stanek (2006).

An extension to the Web Map Service called Contextual Web Map Service was designed and implemented by Kozel (2009) and Kozel and Stampach (2010) in order to test cartographic adaptation in a contextual mapping service aimed at emergency management decision makers and other relevant actors/users. This technological solution is based on a general service approach to adaptive mapping and is derived from a general Web service, which is a software system designed to support interoperable machine-to-machine interaction over a network.

Psychological aspects in map reading and understanding

Important characteristics of users

Slocum et al. (2001) described generally the characteristics of users which can play a key role in map reading. He spoke about individual and group differences such as expertise, culture, sex, age and sensory disabilities. Expertise includes three dimensions of user experience with (a) the tool, (b) the problem domain and (c) computers in general. Cultural differences evoke the need to translate linguistic information that is part of a geovisualisation method (e.g. differences between a lake and a pond). Furthermore, iconic symbols derive their meanings from people's experience and are thus culturally dependent.

Developmental psychology provides us with knowledge about human age-related qualities of perception and cognition, which can be useful in the creation of maps for different user age groups. Kail (1997), for example, demonstrates that performance relating to spatial memory span depends on visualisation skills, which are related to age and processing time.

Personality traits or transitory psychic states can also influence map reading. The influence of acute stress on cognitive processes has been verified in many studies (see Vedhara et al. 2000; Dror et al. 1999; Bourne and Yaroush 2003; Matthews et al. 2000), and there are presently models of how humans perform activities under stressful conditions. It is important to emphasise that stress, as an environmental demand and a physiological response, as well as the transaction between these, is not a discrete state. It is, instead, a continuous stream of cyclic activity. The demands fluctuate in intensity and humans continuously adapt to these (Hancock and Szalma 2008).

Cognitive style and the usefulness of the concept in cartography

The concept of symbolic representation is a core concept within cognitive science dealing with modes of information representation and processing (Isaksen and Kaufmann 1992). The concept of cognitive styles refers to the distinction between how different people process information and which form of information presentation they prefer. The measurement of cognitive style is rooted in the study of perception and personality (Isaksen and Puccio 2008). Sternberg and Grigorenko (1997) argued that cognitive styles are the link between personality and cognition. Cognitive styles were described as developmentally stabilized cognitive controls that are relatively invariant across situations (Sternberg and Zhang 2001). Cognitive style describes the way individuals think and perceive information or their preferred approach to using such information to solve problems (see Fig. 1).

Riding and Sadler-Smith (1997) further mention that cognitive style does not appear to be related to intelligence and reflects qualitative rather than quantitative differences between individuals in their thinking processes. We can generally hypothesize that if the method of map visualisation corresponds with the cognitive style of the concrete user, he or she will achieve better results in map reading. The usefulness of this concept in the cartographic field consists in the possibility of adapting the map visualisation to a group of users with defined and known cognitive styles.

The concept of cognitive style is currently still not unambiguously defined, and there are many approaches which explore this problem domain from a different point of view. Indeed, different researchers have used a variety of labels for the styles they have investigated, e.g. Witkin and his field-dependent and field-independent style (Witkin et al. 1977), Kirton's (2003)) adaptation–innovation theory and Hudson's (1966)) convergers–divergers. Riding and Cheema (1991) surveyed approximately 30 different cognitive styles and concluded that most of them measured two broad style dimensions: a verbal–imagery dimension (which indicates a preference for representing information using pictures or words) and a wholistic–analytic dimension (which indicates a preference for information to be structured in order to get the big picture or the detail).

The wholistic–analytic dimensions

'Wholists', as the term suggests, tend to see the whole of a situation, have an overall perspective and appreciate the total context. In contrast, 'analytics' will see the situation as a collection of parts and will often focus on one or two of these at a time, to the exclusion of the others (Rezaei and Katz 2004). Whilst the wholistic–analytic dimension is concerned with the mode of organisation and information arrangement, the verbal–imagery dimension reflects more an individual's habitual mode of representation in memory during thinking. Verbalisers 'consider' the information they read, see or listen to in words or verbal associations. Imagers, on the other hand, when they read, listen to or consider information, experience "fluent, spontaneous and frequent pictorial mental pictures" (Riding and Sadler-Smith 1997).

The verbal–object imagery–spatial imagery dimensions

Blazhenkova and Kozhevnikov (2009) challenge traditional approaches to visual–verbal cognitive style as a unitary bipolar dimension and instead suggest a new three-dimensional cognitive style model developed on the basis of modern cognitive science theories that distinguish between object imagery, spatial imagery and verbal dimensions. Object imagers prefer to construct vivid, concrete and detailed images of individual objects (e.g. visual artists), and spatial imagers prefer to use imagery to schematically represent spatial relations among objects and to perform complex spatial transformations. They developed the Object-Spatial Imagery Questionnaire (OSIQ), which is a self-report questionnaire designed to distinguish between two different types of imagers.

It can be supposed that the transmission of geographic information coded in visual form will be more effective when the cartographic method of visualisation is in correspondence with the cognitive style of the user. Some kinds of cartographic visualisation methods could be characterised as more pictorial whilst others are more schematic. Blazhenkova and Kozhevnikov (2009) offered a tool for the measurement of these concepts. We are able to discover the preferences of users in visual information processing with the help of OSIQ.

The usability testing environment

So far, the process of cartographic adaptation has been described from the theoretical and technological viewpoint.

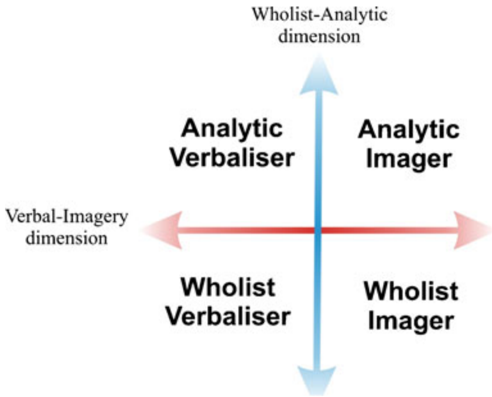


Fig. 1 Two main dimensions of cognitive style (adapted from Riding and Sadler-Smith 1997)

However, one of the important issues is the map's effectiveness, which can be generally addressed by map usability research (Wachowicz et al. 2005; Van Elzakker 2004) and supplemented by cognitive map design research (Montello 2002). This kind of research involves the long-term study of map use in combination with the implementation of usability testing within an electronic environment.

Evaluation by map users plays a key role in usability testing. Nivala et al. (2007) proposed combined perception testing, user surveys and cartographic experiences to establish a set of principles for the creation of alternatives which are then subjects of usability testing.

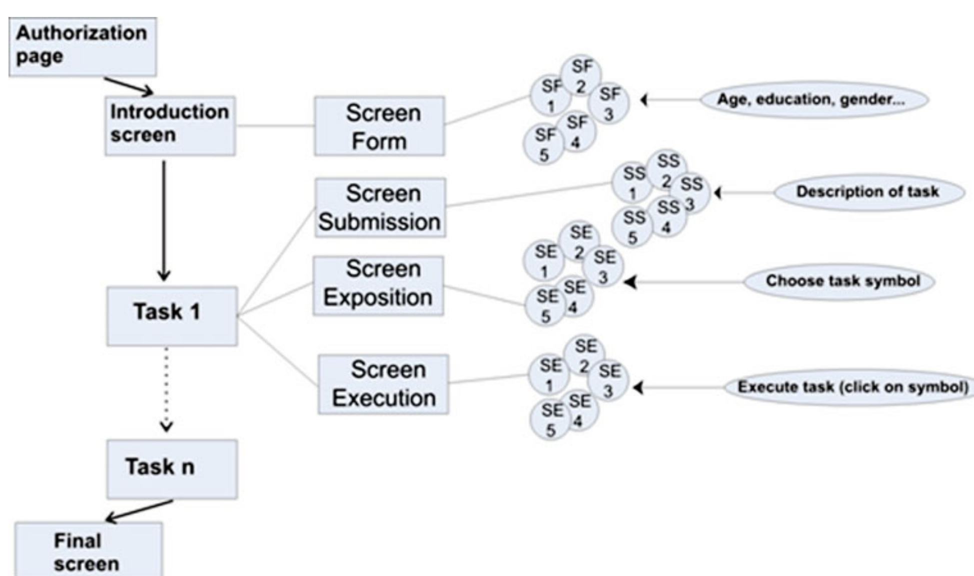
The formalization of cartographic knowledge usually involves some kind of empirical research like interviews or text analysis, which is, in most cases, very tedious and time-consuming. Despite several attempts to compare different cartographic outputs (Dvorský et al. 2009), there does not exist a multidisciplinary environment enabling both cartographic inputs and psychological measurement and testing. Therefore, an interactive web-based testing tool (GP test) was designed and an early prototype developed. The tool was devised in order to test a wide variety of inputs, from isolated cartographic symbols or symbol sets to complex map composition, both static and interactive.

The core of the application is based on the framework of the Google Web Toolkit, and the cartographic part relies on Open Layers libraries. The overall architecture consists of three basic modules—client, server and database. The client module communicates with the server site, and its GUI works within the standard web browser (IE, Firefox). The server module processes the client requirements and returns demanded data or information.

Individual tests are stored in a database and consist of tasks and scenes (Fig. 2). Each task embraces at least one scene, but usually three scenes in a standardised sequence—submission, exposition and execution. Each scene is based on an XML template supplemented by the specific scene content. Both template and content together constitute the graphic interface. Map compositions can be defined by three different types of cartographic inputs—Google Maps (standard topographic and street map, satellite and aerial images, hybrid map); WMS sources; and static image substituting the analogue map composition.

Basic test functionality includes test person identification and pretest calibration of the individual computer and cartographic abilities. Within the test environment, there exist three basic types of tasks—forms with pull-down menus with predefined testing answers; visual choice scenes, where the test person is forced to choose one or more possibilities of visual variables; and localisation tasks, where the test person must place the symbol on the right position or draw the line or polygon according to the

Fig. 2 General conceptual schema of usability testing. Each test begins with the introduction screen collecting background information about participants. Abbreviations (*SF* screen form, *SS* screen submission, *SE* screen exposition or screen execution) represent different types of templates. Examples of screens are given in Fig. 5



defined task. Both reaction times and positional accuracy are stored and further processed. The technological background of the system is further described in Kubicek and Kozel (2010).

Methodology

The objectives of the test were as follows. The main objective was the verification of the usability of the designed test and simultaneously whether the participants of the test were able to fulfil the settings of the experiment. A secondary objective was the comparison of the operations of two groups of participants on various cartographic base maps. We expected that participants working on the topo base map would need less time to fulfil their tasks than participants working with the orthophoto map. A secondary hypothesis was that participants familiar with working on maps would need less time to fulfil their tasks.

We also explored the influence of some user characteristics—in particular, his/her map use skills level on the processing time. It was expected that users with a high level of map use skills would need less time to fulfil the task than participants with a low level of map skills. We expected, at the same time, that the differences would be stronger when more complex tasks were fulfilled. We verified the applicability of the psychological test OSIQ in this context and measured also the cognitive style of the users. The OSIQ test is primarily designed for the identification of two specific visual cognitive styles: spatial imaginers and object imaginers (see Fig. 3). Cognitive style, as previously mentioned, represents information on how spatial data are absorbed by the different groups of participants; therefore, cognitive style information can be useful for cartographers. Psychological information acquired from the OSIQ test was only supportive at this stage of the research, and only the feasibility of merging psychological and cartographic tests was verified.

Experiment design

The experiment involved two schemes of evaluation. The first scheme was designed to detect map use differences between two types of cartographic visualisations (see Table 1).

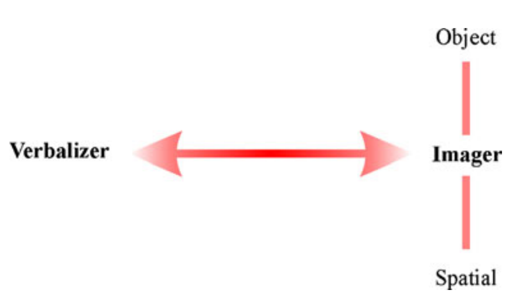


Fig. 3 The verbal–object imagery–spatial imagery dimensions

Table 1 Experiment design I

	Experimental population
Cartographic visualisation A	
Cartographic visualisation B	

The second scheme took in the comparison of two user groups. User groups differ in various characteristics which can play a role in the map reading process (e.g. cognitive style, sex, etc.). This research was focused on map use skills (see Table 2).

All participants were supervised by test administrators. Supervision was used to reveal possible problems with test operation, use of various tools, etc. Subsequently, participants were interviewed by administrators to obtain their subjective opinions and other relevant information about the difficulty of the tasks, the clarity of settings, etc.

Participants

Twenty-three participants (52% males, 48% females) took part in this study. The age of participants ranged from 20 to 27 years. Participants were students at the University of Defence and the Institute of Geography, Masaryk University.

Students were divided into two main groups. The first group was represented by students specializing in cartography; therefore, higher map use skills were expected in this group. The second group was constituted by students specializing in different fields of science except for cartography.

Procedure

A test set composed of a series of consecutive tasks was submitted to the participants (see Fig. 5). The test environment for all participants of the test was comparable.

The design of the test set is described in the following section. Only the 'Simple map symbol identification' task, the 'multiple map symbol identification' task and the 'described route identification' task were statistically processed and used to generate results for this contribution.

We assumed the existence of high and comparable computer skills among all participants (university students) of the test.

Table 2 Experiment design II

	Cartographic visualisation
characteristic of user A	
characteristic of user B	

Personal data

First, participants had to fill in some personal data important for test evaluation, e.g. age, gender, possible eye defects, etc.

Training tasks

Training tasks were designed to introduce the tools and types of task which the test was composed of. All participants should have been familiar with the test procedure after successfully completing the training tasks.

The training tasks were of primary importance because they identified participants who were not able to manage the tools of the test or had other possible disabilities, which may have influenced the test.

Psychological test—OSIQ

The OSIQ psychological test played a role in our experiment. OSIQ identified the cognitive styles of the participants (see "The verbal–object imagery–spatial imagery dimensions"). The original English questionnaire was localized and adapted for the Czech environment. Nevertheless, the Czech version was not yet standardised, and we explored its validity and usability in the context of map reading. The questionnaire contains 30 items. About half of the questions focus on the preferences of participants for object imagery or spatial imagery. An extended version of OSIQ is now available. The new version of the questionnaire OSVIQ also contains items which explore preferences for the verbal kind of cognitive processing. Also, many performance tests exist in addition to the self-report test OSIQ, which measure the same aspects of cognitive processing. Their advantage consists in the fact that they also measure objective achievements and not only the subjective preferences of participants.

Intuitive judgement of symbol meaning

Participants had to identify the proper term for the revealed symbol. The task compared the associativeness of symbols chosen from a map legend. A legend designed for emergency management was used, and the results showed the need for changes in 20% of the tested symbols. We are currently developing a more sophisticated method and system of evaluation for the testing of map legends.

Map legend presentation

The legend was presented to the participants before the task. The goal of this task was to teach participants the basic structure of the used system of symbols in the tested legend. This was designed to remove the possible influence of a lack of knowledge with respect to the tested map legend.

Simple map symbol identification

The structure of the task is shown in Fig. 4. The task consisted of three steps: submission, legend exposition and map exposition. The structure of the task allowed us to observe two different variables. At the beginning, the participant had to locate and point out the selected symbol in the legend. In this phase, we were able to obtain information about the logical structure of the map legend, whilst the participant obtained information about the appearance of the map symbol. In the second phase, the participant had to find and point out the selected symbol in the map field. The time taken to complete this task and whether or not the task was completed correctly were recorded.

If the participant accomplished the task successfully, the next task was automatically generated immediately.

Multiple map symbol identification

Multiple map symbol identification is a comparable task to simple map symbol identification. The difference lies only in the number of symbols to be identified. The participant had to search through the map field and identify all symbols of a chosen type.

The total time necessary for accomplishing the task and the participant's reliability rate were obtained. The task was finished by the participant pressing the 'next' button. Our hypothesis is that the base map has a significant influence on the performance of this task.

'Variety of symbol' identification

The participant had to identify symbols of different types. The task enables the sequence of symbols chosen for the identification and use of legend to be monitored.

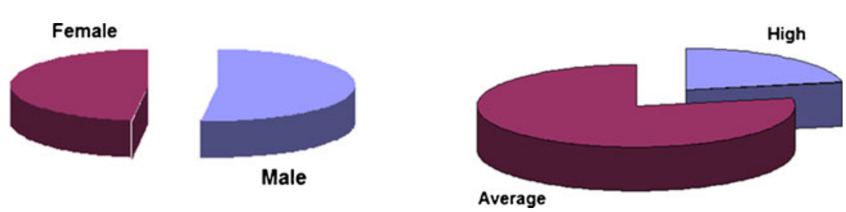


Fig. 4 Structure of the gender and map use skills of participants of the test

Fig. 5 Simple map symbol identification flowchart

The intentional memorizing of map symbols

First, the complete map field is presented to the participants for 30 s in order for them to memorize as much information as possible included in the map field. In the next step, the participants have to point out the positions of the selected symbols.

This very complex task was designed to verify the hypothesis that differences between base maps can influence the process of reading, understanding and memorizing map information.

Described route identification

A verbal route description was first presented to the participant (e.g. start by the theatre then continue down the hill, turn left by the post office and continue to the bridge over the Svitava River). There were at least three routes on the map, and the participant had to decide which one matched the verbal description.

This task contained higher cognitive relevance. Participants were able to create an image of the route whilst reading the verbal description. In the next step, the created

Table 3 Results of statistical *t* test

	Average time			
	Orthophoto	Topographic	*T*	Significance level
Simple symbol identif.	5.664	4.966	1.514357	0.132256
Multiple symbol identif.	13.87111	11.51286	1.076920	0.293732
Route	41.20111	33.39857	0.984553	0.336052

result was compared with the presented map. Here, the style of verbal representation can possibly influence the completion time for this task (e.g. a verbal description can mention directions, points, lines, polygons or a combination of objects).

The unintentional memorizing of map symbols

This task involved the presentation of various map symbols and terms. The participant had to decide whether these symbols or terms were on the previous map (Yes × no choice). Participants did not know about the task beforehand; therefore, they were only able to use unintentional memory.

Selected route marking

This task is a modification of the previous task. The difference is that the participants had to draw the selected route by hand. Apart from map reading, this also involved autonomous planning of the route according to the verbal description (e.g. mark the shortest path from the church to the theatre).

The evaluation of this task was problematic because it involved the manual comparison of chosen routes. Another disadvantage was the high-level influence of computer skills (particularly mouse use) in this task.

A future intention is to implement this task on touch screen displays.

The unintentional memorizing of map symbols II

This task is comparable to the 'described route identification' task. The difference is that participants not only have to decide whether the presented symbol was on the previously presented map but also point out the exact position of the symbol.

The degree of success and completion time for the task can be affected by the time spent on the previous task. There is a possible disadvantage for participants who accomplish the previous tasks faster.

Preliminary results

The externality of results was provided by statistical processing. Only the results of the 'simple map symbol identification' task, the 'multiple map symbol identification' task and the 'described route identification' task were statistically processed for this contribution.

Two different variables were studied during the test—the time taken to accomplish the task and whether or not the task was completed correctly. Both variables were used in the evaluation.

Base map comparison

First, the correctness of the participants' answers and the average completion times (for the 'simple map symbol identification', 'multiple map symbol identification' and 'described route identification' tasks) for all participants using different base maps (mentioned in "Methodology") were compared. Next, statistical *t* test was applied to the results (see Table 3).

The results revealed differences between various base maps. Average task completion time was lower in the case of topographic maps compared with orthophoto maps. The *t* test did not confirm the significance of differences.

Comparison of user groups

The next aim of the test was to compare user groups with different map use skills. Average task completion time was lower in the case of users with higher map use skills. In the

Table 4 Results of statistical *t*-test

	Map use skills			
	Average	High	*T*	Significance level
Simple symbol identif.	5.352	4.272	2.000327	0.048775
Multiple symbol identif.	11.76889	11.05200	0.246506	0.809457
Route	37.12333	26.69400	0.972881	0.349816

case of the most simple task (simple symbol identification), statistical *t* test showed significant differences (Table 4).

Conclusions and future work

The main research goal—to asses an interdisciplinary web-based testing environment and carry out the first psycho-cartographic usability test—was accomplished. The web-based application enabled parallel testing of heterogeneous user groups, automatic recording of test results and semiautomatic processing for final evaluation. The prototype of the GP test is currently undergoing further development vis-a-vis the carrying out of more complex tasks and the implementation of a more user-friendly administration and interpretation module.

Only selected tasks of the experiment described above were evaluated for the purposes of this contribution. The testing demonstrated the usability of most of the designed tasks, except for tasks focused on unintentional memorizing, which were regarded as too sophisticated. The complexity of these tasks was supported by the existence of a floor effect. A floor effect occurs (Ary et al. 2009) when a test is too difficult and many scores are near the minimum possible score.

Preliminary results were limited by the small number of participants taking the test. Nevertheless, the results of statistical analysis show some trends. The preliminary results of our base map usability test can be summarised as follows:

- Time completion for all tasks was lower in the case of topo base maps; therefore, it can be suggested that the use of orthophotos as base maps worsens the user's map reading conditions, cognitive processes, etc.
- Comparing groups with various map use skills showed that more highly skilled participants achieved better results in all types of tasks. Differences were also surprisingly marked in the relatively simple perception tasks. We expected that the level of map use skills would become most apparent in the complex types of tasks in which high-level cognitive processes are involved. These preliminary findings will have to be further explored and verified in future research.

The methods and principles of testing were discussed with each participant and were found to be acceptable, although some level of optimization was deemed necessary. Several technical changes based on the participants' test experience were implemented: for example, the use of serif font instead of sans serif font for the settings of the tasks and the extension of the training part of the test, etc. The prototyped web-based testing environment has potentially a much wider use in a variety of applications. Further combination with psychological tests (OSIQ) is not only possible but also quite useful for the detailed profiling of users.

The concept of adaptive cartography needs more input from the users' point of view, and base map usability testing is just the first introductory step towards the process of map reading optimisation for crisis management. Map usability research based on the theory of adaptive mapping is only at an early stage of development. Its importance is stressed both by the demands of commercial applications and academia (ICA 2010). Approaches in psychology reveal new knowledge about human perception processes and should be combined with contemporary cartographic research in order to establish a broad interdisciplinary platform for map usability research.

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