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The visual search method in map perception research

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Abstract. The way of presenting reality on a map influences the user's perception, so it also affects the image of reality created in the user's mind. Therefore, for centuries maps have been considered cognition tools that influence people's image of the world. Twentieth-century cartographers came to the conclusion that the centuries-old way of map development based on intuition can and should be modified to better reflect the reality, using theories and methods of research from other disciplines, especially psychology. Taking methods from psychology contributed to the development of cognitive cartography. The basic features that distinguish it from other research directions in cartography are that it focuses on the map user, the analysis of map reading and the interpretation process, using experiment as a basic research method and the transfer of experiences and methods, and often the research problems, from psychology to cartography.
The way of map use and the cognitive abilities and limitations of the user are important issues that have been taken up by cartographers for decades. The problem of map effectiveness should be resolved through the use of knowledge of editorial problems and the user's cognitive abilities. The first psychological research in cartography was focused on one of the sub-disciplines of psychology – psychophysics. It is one of the oldest psychological research areas, which studies the relation between a physical stimulus and the behaviour, intellectual or mental experience caused by the stimulus. After a period of high interest in experimental research in the 1970s, by the beginning of the next decade, a wave of growing research criticism had appeared. The popularization of computer techniques contributed to a decrease in interest in perception research. When the major part of the basic problems regarding the implementation of computer techniques in cartography had been solved, it was computers that led to a renewal of interest in map perception research. It facilitated map studies and broadened the range of research methods, and also led to the emergence of new types of maps, such as animated and interactive maps, three-dimensional presentations, which have changed the way of map use and required relevant research to be conducted. The adjustment of new forms of cartographic works to human perceptive possibilities is considered one of the basic objectives of cartography.
One kind of psychological perceptive research is *visual search*. It requires the respondent's attention engagement while performing tasks involving finding and identifying particular targets in a complex visual configuration, full of various distractors. The visual search theories explain how people search for particular objects and pick them from among many others. Such research is used in medical studies, marketing and advertising.

Keywords: cartography, visual search in map perception, feature integration theory, attention engagement theory, guided search theory

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1. Introduction

Maps are popular tools used in different areas of human activities thanks to several unique features. Firstly, they simplify the details of the surrounding world, making information presented on maps more understandable. Secondly, maps are precise; namely they present spatial relations between objects in a clear way, much more effectively than any text. Thirdly, they are evocative pictures (Muehrcke and Muehrcke, 1992). These properties indicate that a map does not reflect the world accurately, but represents reality by presenting part of it in a simplified way in order to facilitate perception to a map user. The way the reality is presented on a map affects user perception; thereby it influences the image of reality produced in the user's mind. For this reason maps have been and will be considered as cognition

tools that form human perception of the world (Montello, 2002). Twentieth-century cartographers came to the conclusion that the intuition-based way of preparing maps which had been used for centuries should be modified to better reflect reality. This process should use theories and methods of research borrowed from other disciplines, particularly psychology (Fisher et al., 1993).

2. The beginning of psychological research in cartography

Borrowing methods from psychology led to the development of a new direction within the cartographic discipline: cognitive cartography. The characteristics of cognitive cartography, distinguishing it from other cartographic research directions, are its concentration on the map user, the analysis of the process of map reading and interpretation, the use of experiment as a basic research method, and the application of psychological methods to research problems originally dealt within psychology. The way maps are used as well as the cognitive abilities and limitations of map users are important issues raised by cartographers for decades. The issue of map effectiveness should be resolved by using knowledge of editorial problems and the user's cognitive abilities (Robinson et al., 1995). These are complementary issues: the knowledge of the map user is useful while defining editorial rules, while knowledge of mapping methods is important when examining the process of map use. Editorial rules, based on centuries-old experience, have been developed by cartographers for years, whereas the scope of map use has been the object of scientific interest for a relatively short time.

The first call to take up psychological research of map perception appeared in the first half of the 20th century (e.g. Wright, 1942), but it was only Robinson's ideas (Robinson, 1952) which became an impulse for cartographers' interest in the map reading process. According to Robinson, the primary task of cartography is to provide information to a map user, and the effectiveness of this message depends on the presentation methods. He pointed out that previously map design took into account only the artistic point of view, which could result in a decrease in their level of functionality. In order to exploit the communication process more effectively using maps, a better knowledge of cartographic presentation methods is needed, as well as their influence on the map user's perception. Therefore, Robinson was in favour of systematic research, including map perception research, which would allow the fundamental principles of graphic presentation in cartography to be formulated. These principles were opposed to the cartographic conventions that had been developed in an intuitive way and which have not always been the optimal solutions.

3. The development of psychophysical research on the cartographic field

The study of the perception of symbols used on maps was launched shortly after the publication of the book "The look of maps" and concentrated on one of the sub-disciplines of psychology, psychophysics (Gilmartin, 1981). Psychophysics, one of the oldest research areas of psychology, is the study of the relation between a physical stimulus and the behaviour, psychological or intellectual experience that is caused by the stimulus (Zimbardo, 1999). There were also attempts to present these relations in a mathematical way, e.g. as Steven's law (Stevens, 1957; Lindsay and Norman, 1984). This research derived from behaviourism (Eastman, 1985), the specialization in psychology focused on the relations between observed stimuli and observed reactions (Sternberg, 1999). The assumptions of psychophysical research were easy to transfer into the language of cartography: the cartographical symbols were treated as a stimulus, and their perception, i.e. the way the map user reads them, was the reaction to the stimuli.

The first strictly cartographic use of the psychophysical approach in the field of cartography was the research carried out in 1956 by Flannery (Flannery, 1971), which consisted of the estimation of the size of pie charts. Also the research of Williams (1954), and Dobson (1975) regarded the ways of determining the size of geometric figures. Within the quarter of a century since Robinson's book was published, numerous psychophysical experiments were carried out. In the following years, the research regarding the estimation of the size of pie charts and other figures, the area of which was proportional to the estimated size of the phenomenon,

was eagerly adopted by cartographers (Ekman et al., 1961; Wood, 1968; Crawford, 1973; Meihoefer, 1973; Gilmartin, 1981; Shortridge, 1982; Castner, 1983). Other experiments were conducted in order to examine the diversification in the perception of symbols (Potash, 1977), dot maps (Castner, 1964), grey scales (Crawford, 1971; Kimerling, 1975), fonts and lettering (Shortridge, 1982) as well as colours (Cuff, 1973; Olson, 1981; Brewer, 1992). A significant part of the psychophysical research on the perception of point symbols presented in different graphic forms was carried out by students of various universities' geographic specializations, but was never published in cartographic journals. Therefore, the knowledge of these studies is mainly second-hand (Morrison, 1976).

Although the majority of map perception research involved statistical maps, it is worth mentioning that research on topographic map perception was also conducted (Hsu and Robinson, 1970; Griffin and Lock 1979; Shurtleff and Geiselman, 1986; Eley, 1987). Much research on perception and improvement of map quality, especially of topographic maps, was not conducted by scientists and was not based on a strictly scientific basis, but was prepared by cartographic publishers. The results of the experiments were not discussed in cartographic journals but directly used to improve cartographic studies (Castner, 1983).

4. The decrease in interest in psychological map perception

The 1970s were the period of the greatest interest in experimental cartographic research (Gilmartin, 1992). At the beginning of the 1980s, however, this research was heavily criticized. The accusations regarded the lack of direct reflection of the results of experiments in the map edition process, and the fact that they did not lead to clear conclusions. Other accusations were that often studied nuances were meaningless in cartographic practice and also that the conclusions did not contribute anything new, but just confirmed long-standing practical experience. There were also some allegations that map perception research was not satisfactory, since it was based on incorrect assumptions on how people use maps, i.e. people always have clear questions and search for the answers on the map. Major differences were observed in map design approach between editors and scientists: the first group think in a synthetic way, while in the second group the analytical approach dominates (Petchenik, 1974).

A major complaint was the excessive simplification of the research: its subject was in fact simple constructions called *pseudo maps* or *quasi-maps*. The elements of editing maps were not included, even though they influence the perception of symbols: the spatial context they appear in or the background the figure is situated on. The tasks concerned simple perception operations without referring to the higher level cognitive processes that are involved in the process of map use (Guelke, 1979). In psychophysical research, it was not only the influence of map image simplification that was omitted, but also the experience and knowledge of map users. Many factors that impact the way of reading and perceiving map content were not taken into consideration (Cole, 1981).

The critical voices suggesting that map perception research did not have an influence on cartographical practice were considered to be not fully justified by cartographers. Their arguments were that map perception research had been conducted for 50 years; hence the initial errors and incorrect assumptions could be justified by the novelty of the research itself. Besides, generally the results of experimental studies were taken up in basic sciences, such as physics, and were used in practice after some time. Cartography is an applied science, but the lack of a direct and immediate effect of the results gained on cartographic practice did not exclude, in their opinion, the validity of map perception research, and undoubtedly enriched the knowledge of human perception (Slocum et al., 2005). On the other hand, there are scientists who naively believe that their research will be immediately used in the mapping process. Perception research has already taught and will certainly continue to teach how to develop better maps, but it will never replace the wisdom and graphic intuition of an experienced editor. However, it can confirm intuitive choices (Montello, 2002).

Apart from the above allegations against the assumptions of the research and the disappointment in its results, another cause of the decrease in interest in map perception research was the development and dissemination of computer technology and

thus the appearance of new research issues (Petchenik, 1983). The fascination in computer technology was prompted by the possibility of significantly accelerating the map editing process and by the development of repeating operation sequences, which enabled automation. Many scientists disappointed in the limited usage of map perception research focused their studies on the implementation of computer technology in cartography. As a result in the 1980s the popularity of map perception research was weakened.

5. The re-growth in interest in psychological map perception

When a significant part of the basic problems regarding the implementation of computer technology in cartography had been resolved, computers led to renewed interest in map perception studies. The use of modern computer technologies facilitated studies on maps and extended the scope of research methods and led to the development of new types of maps, e.g. animated maps, interactive maps, and 3D presentations that changed the way of map use and required relevant tests to be conducted (Brewer and McMaster, 1999). The adjustment of new forms of cartographic works to human perceptive possibilities was considered one of the fundamental cartographic tasks (MacEachren, 1995; MacEachren and Kraak, 2001). Map user research gained a different character. The simple psychophysical research was limited and replaced by broader research problems, considering different map perception aspects. The different levels of map reading were considered, and there was also interest in ways of interpreting and remembering the content.

Attempts to avoid previous mistakes and simplifications were made. It was assumed that map reading entails perception processes of different levels and depends on the kind and task of the user's map. The new research approach brought a change in the questions asked and problems to be solved based on the map. The recent tasks are more complex. Apart from searching for an answer to the question "*How does a person react to a map?*", questions such as "*How do people read and interpret the map?*" appear. It was decided to study maps closer to the cartographic works used in practice in order to make the experiment results more reliable and enable the experiments themselves to picture real map usage situations (Castner, 1983).

6. Visual search

One kind of psychological perception research is visual search. It concerns the respondent's engagement while performing tasks of searching for and identifying certain objects in a complex visual configuration full of various distracting objects. The visual search theories explain the way people search for particular objects and notice them among many others. This kind of research is also used in, for example, medical studies, marketing and advertising. The measures of the effectiveness of visual search are time and the level of correct answers (Driver et al., 1992).

Visual search consists of map research in a broader context than psychophysical research. Due to the implementation of a visual search it was possible to establish that a certain sign or map modification can influence its general perception, expressed in time and answer correctness (Castner, 1983). The research, using the visual search theory, was conducted on a variety of materials, from sign visibility for visually impaired people to planning maps based on aerial photos. The visual search studies resulted in many ideas which are useful in solving problems in the map editing process (Lloyd, 2000).

6.1. Feature integration theory

There are a few theories within the visual search method (Lloyd, 1997). One of them is the feature integration theory. It describes the process of visual information integration and the way map space is searched through in order to find a specific object. While working with a map the user receives complex, multidimensional information (Shortridge, 1982). Treisman and Gelade (1980) treat this multidimensionality as a complete range of variables, analysed separately by independently functional perceptive sub-systems. As an example they give position, size and orientation (spatial features) and colour, shape and texture (attribute features). The feature is understood as a specific value of a particular attribute, e.g. small, red, horizontal or round (Kosslyn and Koenig, 1992).

The basic assumption of the feature integration theory is that before the careful and conscious reading of the map, some of the object features reach the consciousness. The objects themselves, as a sum of different features, are identified in the conscious attention stadium (Treisman and Gelade, 1980). This theory assumed that various sensory object features such as colours, shapes, sizes and direction are coded in different ways, by specialized modules. For example, the feature red, green or blue is coded in the colour module, whereas the feature vertical, horizontal or lateral is coded in the orientation module (Fig. 1). The objects of unique feature value on the scale of the map are easily identified on the map. It is easy to imagine that among yellow triangles, the red triangle will stand out on the map. If the object being searched for is characterized by a unique feature from the range of the particular module, then the searching time is not related to the number of distractor objects on the map.

Finding the distinguished object, based on two or more features, e.g. colour and shape, involves the engagement of conscious attention (Wolfe, 1994). When the attention is focused on searching for an object consisting of a sum of features (e.g. red, square, small), particular modules are searched through, and certain features are noticed to locate the required object. The object from a specific location is compared with the object being searched for and if both of them are identical with regard to the features mentioned, in the human mind there appears the awareness of finding the required object. However, when the features appear to differ, then in the user's consciousness appears the information that the given object is not identical to the one being searched for and the search has to be continued (Lloyd, 1997).

When the object being searched for does not have unique features, which is common on maps, then it does not stand out on the map background and the search for it is more difficult and time consuming. If the required object is, for example, a green circle among green squares and blue circles, neither the colour feature, nor the shape is unique; therefore location of the object will not be performed during the first, subconscious look at the map. Only attention engagement will allow the map user to choose the object linking both features (Treisman, 1991).

6.2. Attention engagement theory

Another theory is called the *attention engagement theory*. It explains that the difficulty of visual search does not depend only on whether the visual search is serial or parallel, but also on the conditions it is performed in. This theory defines the object search area as a 3D space (model), used to determine the theoretical difficulty of the search (Fig. 2). The similarity between the targets and distractor objects is placed on the *x* axis, and similarities between the distractor objects are marked on the *y* axis. The inclination of function, that is, time reaction regression and number of distractor objects, is measured on the *z* axis. The search where the target stands out on the map gives a flat line (regression factor equals zero), while the more difficult tasks (regarding parallel search) have a more inclined curve on the graph. The shape of the surface under the curve determining the difficulty of visual search is related to an interaction between two variables – the target and the distractor object and between the two distractor objects. Based on this model Duncan and Humphreys (1992) derive three assertions. The first of them claims that if the targets are sufficiently distinguishable in comparison to distractors, then the curve is flat, regardless of the similarities between the distractor objects. In the second assertion Duncan and Humphreys state that the curve gradually rises with the increase in similarity between the target and the distractor objects, even when all the distractor objects are the same. Finally, the third assertion claims that the visual search is difficult when the distractor object is similar to the target and different from other distractors.

6.3. Guided search theory

The *guided search theory* claims that no decisions regarding finding the target are made during the subconscious viewing of the map, but only attention concentration on the given target lets the user state whether the particular target was definitely the object being searched for. Before the user's attention is focused on the searching process, certain information about objects and their distribution on the map reach the user. It gives the recipient the opportunity to start the conscious search in the most probable locations of the required object (Quinlan and Humphreys, 1987).

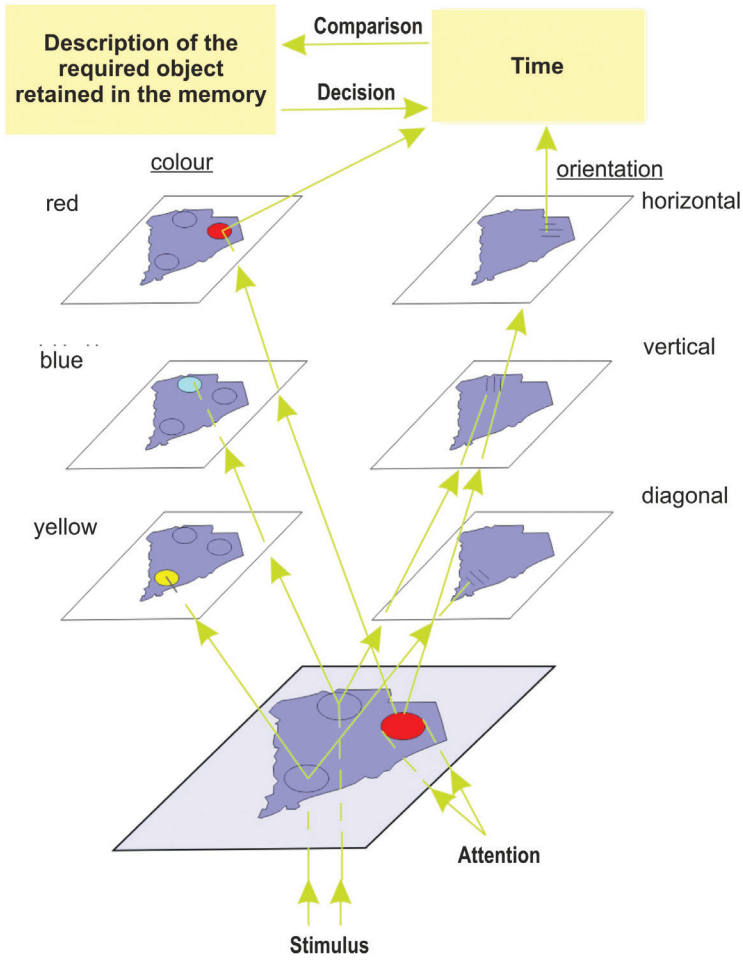

Fig. 1. Integration of the features of different modules in order to conduct a visual search for an object (Treisman, 1988)

7. Summary and conclusions

The basic task of a map user is to determine the kind of objects shown on it. This is achieved by sign identification, which means noticing and distinguishing the required sign from other signs. It involves assigning specific meanings to signs and determining the targets' features, which are encoded in cartographic signs. Board (1978) called this first type of information processing gained from the map *map reading*. According to him *map reading* includes symbol recognition and identification. By recognizing the symbol, the map user admits he or she has seen it before and by identification, links it with a particular meaning. These processes are subconscious. Morrison (1976) had a similar opinion. He stated that *map reading* refers to basic processes such as detecting the symbol, distinguishing it from other symbols and linking it with the meaning. In this case, map perception applies to detailed information with a low degree of processing. During the identification of one sign or one type of signs, the sensory (iconic) memory and short-term memory, which stores a little information for a short period of time, are launched. Due to the low degree of processing the identification is fast and relatively true (Bonin, 1989).

Map analysis is a slightly more complicated task. It engages more complex cognitive operations, involving noticing and determining the relations, and identifying differences between the signs, including location, size, colour, shape etc. In tasks

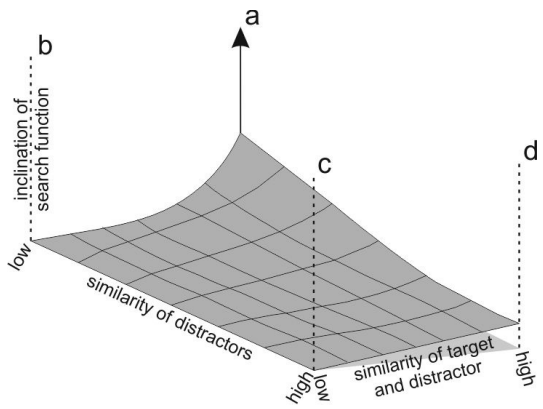

Fig. 2. A hypothetical 3D space, indicating the relative difficulty of visual search, measured on the horizontal axis as an incline of the surface linking the time of reaction and the number of distractor objects. The most difficult visual search is in the corner of the hypothetical 3D space, where the distractors are not similar to each other but they are similar to the search target. The pop out effect is maximized in the c corner where the distractors are similar to each other but differ from the target (Duncan and Humphreys, 1989).

involving determining spatial relations, map perception requires identification of a greater number of signs with a larger range of relation variability. In this case the iconic and short-term memories are insufficient to cover all positions needed for the intellectual operation. Then it is necessary to transfer certain information to the long-term memory, which implies a change of information coding and the need to recreate this information in the memory (Grabowska and Budohoska, 1992). Such operations are a common source of errors in map perception.

While studying the effectiveness of maps, it should be borne in mind that its reception may refer to different levels of intellectual engagement – from the basic perception operations (noticing the symbol in a certain place by determining that one symbol is larger than another or that the symbols are in different colours) to more complex cognition processes (creation and modification of knowledge about the surroundings (Slocum et al., 2005). The kind of map and the way it is used determine the perception level at which the map is analysed. Due to the large number of variables influencing the map perception process, i.e. a type of map, its purpose, the way of use, cartography has not developed one standard method of studying map effectiveness. The research on map use has gained a slightly different character. The simple psychophysical research has been limited, in favour of broader research problems considering different aspects of map perception. The various levels of map reading are taken into account, and there is interest in the ways of interpreting them as well as memorizing their content.

Visual search is a basic activity in every map reading process; therefore these studies were included in cartographic applied research (Lloyd, 1997). The effective visual search enables more efficient map reading and due to that easier transition to further map work stages, that is, analysis and interpretation. The studies using visual search, covering the perception of individual symbols, were used in the case of tourist maps (Ostrowski, 1974), crisis maps (Akella, 2009) and city plans (Ciołkosz-Styk, 2011).

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Metoda poszukiwania wizualnego w badaniach percepcji map

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Streszczenie. Sposób zaprezentowania rzeczywistości na mapie wpływa na jej odbiór przez użytkownika, a więc rzutuje również na obraz rzeczywistości, jaki zostanie wytworzony w jego umyśle. Dlatego też mapy od wieków były i nadal są uznawane za narzędzia poznania, kształtujące wyobrażenia ludzi o świecie. Dwudziestowieczni kartografowie doszli do przekonania, że wielowiekowy, bazujący na intuicji, sposób opracowywania map nie tylko można, ale wręcz należy zmodyfikować, aby lepiej odzwierciedlały one rzeczywistość, wykorzystując w tym celu teorie i metody badawcze z innych dziedzin, w tym szczególnie z psychologii. Zaczerpnięcie metod z psychologii przyczyniło się do rozwoju kartografii poznawczej. Jej podstawowymi cechami, odróżniającymi ją od innych kierunków badawczych w kartografii, było zwrócenie się w stronę użytkownika mapy, analiza procesu jej czytania i interpretacji, stosowanie eksperymentu jako podstawowej metody badawczej oraz przenoszenie na grunt kartografii doświadczeń i metod, a często również samych problemów badawczych, zaczerpniętych z psychologii.
Sposób wykorzystania mapy oraz predyspozycje i ograniczenia poznawcze jej użytkownika należą do istotnych zagadnień podejmowanych przez kartografów od kilkudziesięciu lat. Problem efektywności map powinien być bowiem rozwiązywany dzięki wykorzystaniu wiedzy zarówno na temat zasad ich redakcji, jak również zdolności poznawczych użytkownika. Pierwsze badania psychologiczne w kartografii skoncentrowały się na jednej z subdyscyplin psychologii – psychofizyce. Jest to jeden z najstarszych obszarów badawczych psychologii, zajmujący się badaniem zależności między bodźcem fizycznym a zachowaniem, doznaniem psychicznym lub umysłowym, które ten bodziec wywołuje. Po okresie dużego zainteresowania badaniami eksperymentalnymi w latach 1970. już na początku lat 1980. badania te zaczęły spotykać się z narastającą krytyką. Do spadku zainteresowania badaniami nad percepcją map przyczynił się również rozwój i upowszechnienie technik komputerowych. Kiedy znacząca część podstawowych problemów dotyczących wdrażania technik komputerowych w kartografii została rozwiązana, to właśnie komputery przyczyniły się do ponownego wzrostu zainteresowania badaniem percepcji map. Ułatwiły bowiem badanie map oraz rozszerzyły zakres metod badawczych, a także umożliwiły powstanie wielu nowych rodzajów map, na przykład map animowanych, interaktywnych, prezentacji trójwymiarowych, które zmieniły sposób korzystania z mapy i wymagały przeprowadzenia odpowiednich badań. Dostosowanie nowych form opracowań kartograficznych do możliwości percepcyjnych człowieka zostało uznane za jedno z fundamentalnych zadań kartografii.
Jednym z rodzajów stosowanych percepcyjnych badań psychologicznych jest poszukiwanie wizualne (ang. *visual search*). Wymaga ono zaangażowania uwagi respondenta podczas wykonywania zadań, polegających na odnalezieniu i identyfikacji zadanych obiektów w złożonym układzie wizualnym, pełnym różnorodnych obiektów rozpraszających jego uwagę. Teorie poszukiwania wizualnego zajmują się wyjaśnianiem, w jaki sposób ludzie poszukują konkretnych obiektów i wyłapują je spośród wielu innych. Badania te są stosowane również m.in. w medycynie, marketingu oraz reklamie.

Słowa kluczowe: kartografia, poszukiwanie wizualne w percepcji map, teoria integracji cech, teoria zaangażowania uwagi, teoria poszukiwania kierowanego

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