Chapter 11
Cognitive Aspects of Interpretation of Image Data

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Abstract Interpretation of image data (one of the basic geographic skills—Řezníčková et al., Standards and research in geography education. Current trends and international issues, pp 37–49, 2014) is a complex of complicated intellectual operations, which is based on visual perception (for example, when working with a map, then we can talk about mapping skills—Hanus and Marada, Geografie 119 (4):406–422, 2014). The theoretical part of the study summarizes the scientific knowledge of processes of visual perception applied in the process of visual interpretation of satellite, aircraft and map image data. The author presents partial phases of image data interpreting process: from the initial recording of the image to detection, identification and objects classification. The complexity of the cognitive process with regard to biological and psychological characteristics of the individual are highlighted. The research section presents the results of image data interpretation research according to gender of individuals/research respondents. The research results show (1) a consistent success rate and (2) a consistent speed of problem solving when dealing with image data of aerial and satellite images. The results were slightly surprising with respect to research results concerning map interpretation where respondents attain different degrees of success rate depending on gender.

Keywords Visual interpretation · Visual perception · Image interpretation · Image data · Satellite data · Airborne data · Aerial photo · Map

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Š. Hošková-Mayerová et al., *Mathematical-Statistical Models and Qualitative Theories for Economic and Social Sciences*, Studies in Systems, Decision and Control 104,
DOI 10.1007/978-3-319-54819-7_11

11.1 Visual Perception with Regard to Map and Image Data Interpretation

The interpretation of images and maps—image in general *involves a complex of cognitive operations* characterised by *general features*. They are influenced by *particular differences* among individuals. In professional literature a set of mental processes associated with identifying and recognizing what we see is referred to as *visual perception*. The following text is dedicated to the *basics of visual perception, emphasizing the relations and connections with the image and map interpretation*.

Visual perception is a relatively complex mental process involving a number of analytic and synthetic intellectual operations. Although the perception is often carried out naturally and without any conscious effort, it is in fact an extremely complex process employing a significant part of the mind (cognitive, executive and emotional processes), and of the capacity of brain activity (Šikl 2012; Hoskova and Mokra 2010). The main purpose of visual perception is, according to Šikl (2012, p. 10) "speed, efficiency, ability to chart the observed scene in the shortest possible time, and to obtain meaningful and relevant data." Gregory (1966) considers the visual perception a dynamic quest to find the best interpretation of the available data. Crick (1997) defines the visual perception as a creative process during which the brain simultaneously responds to many different "features" of a visual scene and tries to merge them into meaningful wholes. Eysenck and Keane (2008) define the visual perception as a complex process of transformation and interpretation of incoming sensory information. According to Sternberg (2002) the visual perception is in its entirety understood as processes by which the information obtained from the visible range of the electromagnetic radiation falling onto visual sense organs is identified, sorted and is given a meaning. According to Broadbent (1958) the stimulus processing is performed by elementary perceptual processes. During this first phase, which means the input and the entire process opening, a prior experience and human interest in the object are already involved (see the text about individual differences in visual perception). A distinction between bottom-up processing and top down processing of a stimulus is usually drawn (Neisser 1976).

When *applied to map and satellite and airborne image data reading*, we could say that the first approach (bottom-up processing) assumes the parameters of the source—an image (its colour, resolution, display area etc.) to be determining for information processing. It should be noted that although the spatial resolution and other physical parametres of imagery are very important, the interpretability of an image can be severely affected by other influences (Kovarik 2012; Hoskova-Mayerova et al. 2013; Talhofer et al. 2016; Talhofer and Hoskova-Mayerova 2016). The later type—top-down processing assumes an influence of a particular person on the whole process—i.e. their biological determinateness, and mental conditions, and knowledge and skills (images will be read differently by a child, an experienced professional, etc.). The important fact related to the process of information processing dealt with in *this research on visual interpretation of image data and maps is especially* that the symbols are processed using the processes of transformation into other symbols related to objects of the outside world.

To use some simplification concerning the interpretation of cognitive aspects of image interpretation the processes involved in the visual perception can be grouped according to the level of their complexity:

- *Low complexity level* of visual perception: perceptual organization (its goal is to organize the chaos of stimuli based on retinal cells responses to the impact of electromagnetic radiation), the whole (figure) dividing, which means the principal information and subjective perception. It results in the creation of sub-units (entities) made from the original tangle of stimuli. Sub-processes: edge detection, image segmentation, separating an object from its background, partial elements organizing and structuring, a modal perception, parsing (image "compartmentalization").
- *Intermediate complexity level* of visual perception: entities operations, processing of information related to the colour entity, shape, brightness transformation, texture, shadow and size over time.
- *High complexity level* of visual perception: the identification of the object entity. Sub-processes: recognition, classification, categorization, vision-driven mindset.

The image projected on the retina is segmented perceptually completed, then integrated, identified and classified as a representative of a general category. When applying to image interpretation we can imagine that during the process we transform the tangle of forms and colour parts (likewise pixels), create clusters (entities, clusters of pixels), further we attribute them with other characteristics

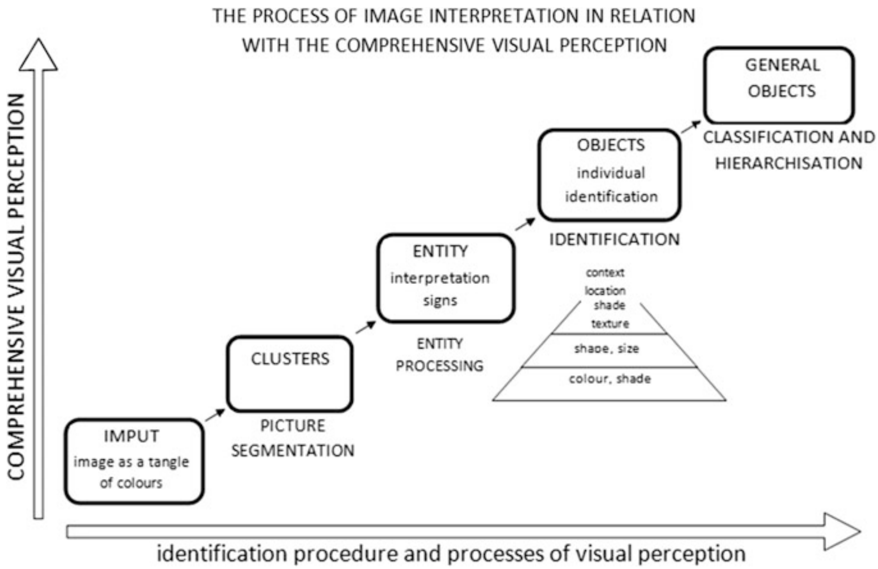

Fig. 11.1 Visual perception and the process of identifying objects in an image

(colours), which help us to recognize them individually (this is an object, e.g. a lake) and subsequently we also categorize them in general (this lake belongs to the class of the lake and this one to a water area).

In relation to the object identification *a scheme* has been processed see Fig. 11.1 *showing the sequential steps—Phases of visual perception during image interpretation—object identification.*

11.1.1 The Cues for the Perception of Space in the Picture

The perception of space captured in the image involves the use of so called monocular cues (sometimes referred to as pictorial cues), see Fig. 11.2:

- the shading means the observer correctly concludes that the object casting the shadow must be three-dimensional. This cue is also applied when reading the images.
- texture perspective—a typical spatial arrangement (texture gradient), (Gibson 1979), an example of a textural cue used for image interpretation can be a texture created upon a canopy closure of treetops of deciduous forest, a square or rectangular arrangement of streets, a paving, etc.)
- covering—in pictures some objects may be covered (a brook in the woods, two buildings right behind each other in an oblique image etc.)
- linear perspective—the observer may perceive the lines as if they converged—which generates the impression of depth; this cue applies when reading an oblique picture bearing the perception of perspective,
- the perception of oblique images involves other picture cues, especially the height within the visual field and the atmospheric perspective.

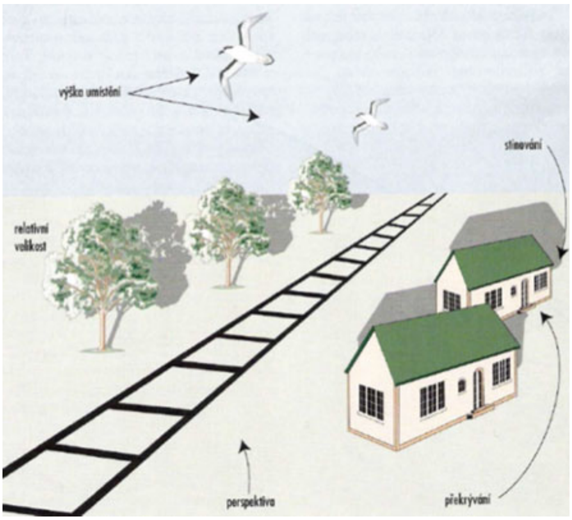

Fig. 11.2 A sample of image cues for perception of a spatial depth—relative size, location in an image plane, perspective, interposition, and shading. (*Source* Atkinson 2003)

11.1.2 Interpretative Signs of Object Recognition in Images

During the image perception the above mentioned cues valid for visual perception in general are applied. The range of cues described above can be involved in the process of *visual interpretation of images*; to recognize the objects within the pictures we use their so called *interpretative signs*. They are mainly the shape and size of the object (or the ratio of width to length), the colour, cast shadow, position or relative position—the context of the position in relation to other objects. We recognize most of the objects in the images by their shapes (contours) and typical details. The objects displayed from the top view are for readers unfamiliar. On that account, it often depends on detail resolution, especially if two different objects have similar plan views. Similarly, the objects with the same layout but different heights and different purposes may be displayed in the same way. The object dimension depends directly on the scale of the image. It is possible to calculate the measuring scale using the real size of the object and its dimension in the picture. The comparing of the respective object dimensions with other well known objects is also used to interpret the images. The length and width ratio helps identify individual buildings, railway lines, highways, roads, streets, etc. (Svatoňová and Lauermann 2010). The colour of the object is an important interpretative sign (Kubicek et al. 2016). For the purpose of interpretation, the specific colour syntheses of satellite data are therefore in true or false colours. The surveys (Svatonova and Rybanský 2014; Svatonova 2016a, b; Hofmann and Hoskova-Mayerova 2016) showed that satellite images in false colours are as successfully interpreted by the readers as the images in true colours. Aerial images are currently acquired mostly in their true colours resembling reality. The object shadow highlights the plasticity of the object body, more precisely its shape. The drop shadow allows determining the depth, width and height of the object. An important fact is that the **drop shadows** of objects and terrain shapes displayed in the image must always point **toward the evaluator** or from **left to right**. In this manner the proper plasticity of the image is required. If these conditions are met, a false perception appears—e.g. a valley seems like ridges and ridges like a valley. We encounter a problem when interpreting the drop shadows of clouds because they partly cover the part of the territory, and the drop shadow of clouds can be easily mistaken for an object (a pond, wet soil…). The object position expresses its spatial relationship to other objects. There exists a causality between the interpreted objects and terrain features in the landscape (a water stream flows through the valley, the dam is built on a watercourse, bridges lead across roads, excavations and embankments are along the roads, railway stations are on the railway lines, etc.). To interpret the image a context position of the object is therefore used: the object is recognized thanks to its usual position in relation with the other organization (i.e. the bridge is always across the watercourse). The context as a parameter of recognition appears to be very important in a series of studies. Many studies have demonstrated that it is precisely the context in everyday life that is an important part of object recognition and not only the individual object which is presented during set laboratory conditions. The studies by Biederman et al. (1982) showed that the inconsistency of the relation "object vs scene context" leads to a decrease of identification accuracy and to prolongation of reaction time. Similar results have been reached by Hock et al. (1974) and Potter and Davenport (2004).

11.1.3 Individual Differences in Relation to the Images' Interpretation

In the process of image interpretation, thus identification of sub-objects in the picture, the properties of the image itself (including interpretive signs of objects that are displayed in the image) are applied, as well as the personal characteristics of the person observer (interpreter), particularly their *biological status* (age, gender, vision—acuity, colour vision, sensitivity to contrast and *mental and social condition* (e.g. priming, motivation and interest).

11.1.3.1 Biological Characteristics of the Individual in Relation with the Image Interpretation

Age: It is the most important for visual perception among all biological characteristics. Increasing age is connected to a series of changes of retinal images, including a decrease of the number of photoreceptors (Scialfa 2002). The measurable characteristics of an older person prove poorer perceptual performance in comparison to a younger one (Šikl 2012). Three year-old children and older ones begin to understand aerial images as a representation of the real world, even if the full understanding is developing up to their adulthood (Blaut 1997; Downs and Liben 1997; Liben and Downs 1997). *In relation with the image interpretation there exist differences in the perceptual performance*; e.g. the age deteriorates detection and identification of objects and stimuli (Madden and Allen 1991; Davis et al. 2002); the reaction time is extended with age (Salthouse and Somberg 1982; Salthouse 2000; Madden 2001), the age-deteriorates the perception of space, orientation and navigation (Baker and Graf 2008). Aspect of age then goes hand in hand with the cognitive aspect of maturity, which in young individuals often develops in accordance with the procedure of the educational process. Age is a crucial factor for working with graphical visualization, in this case with the maps, then this research also identified Hanus and Marada (2016).

Gender: It is another wildly discussed biological characteristic relative to visual perception. According to Šikl (2012, p. 31) "visual perception is one of the few activities of the mind, for which there are no widely accepted stereotypes regarding the difference between men and women. The research findings indicate some differences, but they should not be overestimated." A significant number of studies showed that the differences of average results between groups were smaller than the variance of the results within one group by gender (Mather 2006). Men showed somewhat better results in tests aimed at solving spatial tasks (Linn and Petersen 1985; Voyeur et al. 1995; Marmor and Zaback 1976). Women recognized colours faster and better (Nowaczyk 1982) and recalled the colours better (Pérez-Carpinelli et al. 1998). Hund and Gill (2014) researched the effect of stimuli and memory related to orientation and route search. They found that women are faster if they have more incentives when it comes to spatial tasks; men did not show any difference in time to find the way. A unique study by Campbell et al. (2014) examines the influence of age and gender on a mental topographical map of a user's town. The research involved 63 adult respondents aged between 20 and 79 years in Sydney and its surroundings. The subtest included tasks related to the identification of important elements in the landscape orientation (landmarks), map describing, route plotting and the evaluation of orientation. The best results concerning the orientation were reached by middle-aged men, while in women the orientation deteriorated with age; i.e. the gender and age influenced the orientation in a familiar environment; testing of other tasks concerning the topographical memory of well known sites did not show any differences between women and men, and age. Lloyd et al. (2002) however pointed out that many studies (e.g. by Schaefer and Thomas 1998; Stumpf 1998; Dunn and Eliot 1999) focusing on spatial abilities related to gender rarely used standardized tests. A number of studies evaluate spatial abilities in relation to short-term or long-term memory, possibly with visual memory (Silverman and Eals 1992; Barnfield 1999). The research by Linna and Petersen (1985), Halpern and Crothers (1997) indicate that men are more successful in solving spatial tasks where it is necessary to use short-term memory, whereas women can better recall spatial information from long-term memory (Galea and Kimura 1993; Birenbaum et al. 1994).

Visual impairment: Visual perception of reality can be influenced by various visual impairments: reduced sharpness, sensitivity to contrast and colour vision deficiency. An observer with worsening visual acuity may not have sufficient distinctive ability to find and correctly evaluate all the image features important to understand the map or image. A lower-level ability to distinguish different levels of brightness may result in homogeneous perception of various sections of the map or image. Finally, another important cue for recognizing objects in maps is *colour*, especially if it is a distinctive feature of the object. The inability to detect the colours affects the object identification, its accuracy and speed. Colour-blindness affects about 8% of men and 0.4% of women (Jenny and Kelso 2007). There are different cases of colour blindness. The most common one is the inability to distinguish the colours of long wavelengths. The affected person perceives them as yellowish-brown. Research focused on the relationship between the colour-blindness and map reading and processing were conducted by e.g. Brewer (1997), Olson and Brewer (1997), Harrower and Brewer (2003).

11.1.4 Biological Characteristics and States of the Individual in Relation with the Image Interpretation

Experience: The interpretation of the visual scene is influenced by the experience with an impulse (with map and image). Different knowledge and experience is manifested in various degrees of attention to certain details. Both the experience and the expertise help create an effective structuring of stimulus information (Šimeček and Šikl 2011). Image interpreting may be influenced by a certain form of *anticipation of the object features.* The research by Palmer (1975) has shown that the speed and success of recognition is higher, if the stimulus is semantically consistent with the scene. Maruff et al. (1999) show that the search strategy is being developed with the experience; we search the required information more efficiently in case we have previous experience. The interpretation also positively reflects that *the experience in terms of knowledge of the type of territory*, and anticipation of possible objects set within the territory, i.e. the objects expectation and spatial context are very important in the process of visual interpretation (Hollingsworth and Henderson 1999; Chun 2000). Also interpretation using the typical features of the objects is connected to prior experience—what features might be expected when dealing with a common object (Rosch 1973; Rosch and Mervis 1975; Lloyd et al. 1996). The research test included a task focusing the identification of a nuclear power plant. Without any prior knowledge and visual imagination of the object (the typical sign of a nuclear power plants are cooling towers) the object identification would not be possible. Experienced image readers proceed faster when data interpreting, they have more numerous but shorter eye movements within the image (Rayner 1978).

Experience and skills also relate to a broader concept of *cartographic literacy and literacy applied in image reading*. An experienced analyst of these images uses strong and weak features of each format to get an overview of the area and a variety of valuable information (Small 1999). The geographers are good experts in image reading thanks to their knowledge of object relation in the landscape (Dyce 2013). The study by Davies et al. (2006) focuses on monitoring the models of the visual attention depending on the type of image, image exposure time, the reader's expertise and the type of displayed landscape. Despite researchers' expectations experts were those who tended to have unevenly distributed attention concerning the image interpretation. Muir and Blaut (1969) tested five and six-year-old children (USA) before and after working with black and white vertical images. Children having worked with images, showed a better ability to interpret maps compared to children who did not participate in that activity. Van Coillie et al. (2014) analysed the accuracy of images digitizing by adult respondents with various degrees of experience with image working, with various degrees of their motivation. The accuracy of digitization of monitored respondents was generally very different and even less accurate.

Lloyd et al. (2002) prepared three cognitive experiments conducted with human subjects viewing a series of aerial photographs and categorizing the land use for target locations. Reaction time, accuracy, and confidence were considered as dependent variables related to the success of the categorization process. Subjects had significantly more success with photographs they viewed more than one time. Male subjects were significantly faster, more accurate, and more confident than female subjects at doing the categorization task. By the seventh learning round the male advantage in reaction time and accuracy was no longer significant, but the male advantage in confidence continued through seven learning rounds.

Šikl and a Svatoňová (being prepared) investigated how the fact of being an expert and the type of depicted landscapes in the picture influenced the ability to remember these images. 120 people with various degrees of expertise were tested. The individual's expert experience proved to be significant in the ability to remember the image. The experts were able to correctly remember on average roughly more than 10% of the previously viewed images than laymen. Different results were also achieved in relation to the type of landscape. Concerning the sub-types (urban areas, housing estate areas, parks and gardens, industrial landscapes, transport landscapes), as the most difficult ones to memorize were settlement with a regular structure of built area without any significant elements. However, it is interesting that these differences were not as significant among the experts as they were among the laymen.

11.1.5 The Influence of Stress on Cognitive Processes and Image Interpretation

Stress weakens cognitive functions, concentration, logic and abstract thinking. As the cause of the weakening high levels of emotional activity disturbing the information processing is reported. Mental processes are disrupted by thoughts connected with a possible failure. The weakening of cognitive functions may also result in rigidities or alternative actions. Some people tend to resort to their pre-matured modes of behaviour (Atkinson et al. 1995). Taking into account the psychological description of the effect of stress on thinking in relation with crisis management and image and map interpretation, it is necessary to note especially the first phase of a catastrophic syndrome associated with a loss of orientation concerning the rescued effect of stress on the mind, and weakening of abstract thinking. Therefore, it seems more appropriate to use a simpler basis to transmit spatial information, which is not as demanding as abstract operations.

11.2 The Survey—Comparing the Success of Aerial and Satellite Image Interpretation by Gender

The survey presents the results of the successful visual interpretation of aerial and satellite images assessed by gender and expert experience of individuals. The main aim of the research was to test hypotheses concerning the evaluation of differences in problem solving tasks according to selected biological features and expert knowledge of the respondents. Hypotheses to be verified were: H1—Men and women are equally successful in the interpretation of aerial and satellite data, H2—Men and women are equally quick in interpreting aerial and satellite data. A successful interpretation was assessed with two parameters—the accuracy of solution to the problem and the speed of problem solving by the respondents with regard to their gender and expert experience. The following documents were used to prepare the problem solving tasks concerning the aerial and satellite data and map interpretation: a basic topographic map, scale 1:10 000 and 1:25 000 and 1:50 000; a coloured aerial vertical image, resolution of 0.5 m; orthophoto scale of 1:10 000 resolution 0.5 m; oblique colour image, resolution of 0.5 m and without any resolution; satellite image in natural colours (Landsat 7, RGB 321), scale 1: 100,000, resolution 30 m; satellite image in an unnatural colours (Landsat 7, RGB 742), scale 1: 100,000, resolution 30 m; Aqua satellite image, passive multispectral spectral radiometer MODIS, natural colours, resolution of 250 m. The sources of images and maps were: Map Server "National INSPIRE geo-portal" map server "mapy.cz" NASA website, the website Project Copernicus Emergency Management Service.

11.2.1 Research Respondents—The Structure by Gender, Age and Expert Knowledge

The research included 151 respondents, 67 men and 84 women. 67% of respondents were aged 20–25, 10% of respondents 26 to 30, 23% of respondents were over 31 years old. 59 respondents worked in their job with maps and aerial or satellite data.

11.2.2 Results of Testing

Pairwise testing and the corresponding data processing were used to verify the set hypotheses. The hypotheses were tested at a significance level of 0.05. The hypotheses were tested using non-parametric methods (Wilcoxon test) and parametric methods (t-test, parameter binomial distribution, chi2 test, McNemar test). The testing and data processing was executed using the computing program MATLAB 8.1, results image processing was executed using the program Statistics and MS Excel. The average success rate (accuracy) and the speed of problem solving of an aerial photograph and map were different: it was 82% when reading images, 74% when reading maps. The averages concerning correct answers differed: the image value was 8.2 and map value was 7.4, the median value was equal. The statistical dispersion of responses was higher when reading maps. The respondents were able to solve the tasks quicker when reading aerial images. Both the hypotheses H1 and H2 concerning the comparison of problem solving by gender were confirmed.

11.3 Conclusion

We found that the results of successful solutions of respondent groups are the equal, i.e. women and men are equally successful when identifying objects on aerial photographs, maps, images using true and false colours. The results which prove that men and women are equally successful in solving problems related to map reading are not consistent with some of the other research supporting the greater success of men (Chang and Antes 1987). Šikl (2012) however believes that the results of the comparison by gender should not be unambiguously interpreted; a significant number of studies showed that the differences of the average results between male and female groups were smaller than the variance of the results within one group by gender (Mather 2006). Linn and Petersen (1985), Voyeur et al. (1995), Marmor and Zaback (1976) prove that men showed slightly better results when testing solutions to spatial tasks. Some studies by Kempf et al. (1997), Johnson and McCoy (2000) approach the assessment of greater success from a different point of view; Men are more confident because they are faster and more decisive in problem solving than women who reassure and try to fulfil the task very carefully.

The satellite and aircraft image data represent a realistic view of the landscape, which is what differs fundamentally both the sources from the maps: the map is a model of reality using the signs to represent the objects. The map is therefore more demanding on abstract thinking, and it can be assumed that they are the reasons that men usually succeed more in the map interpretation (Hanus and Marada 2016 demonstrated it too). The results of the interpretation of the satellite and aircraft data images research showed that on this basis both the genders are equally successful.

Acknowledgements This research has been supported by funding from Masaryk University under the grant agreement No. MUNI/M/0846/2015, which is called ‘Influence of cartographic visualization methods on the success of solving practical and educational spatial tasks’.

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