CONTRIBUTION OF NEUROSCIENCE RELATED TECHNOLOGIES TO CARTOGRAPHY

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Abstract
Neuroscience is very promising for cognitive cartography. How and which parts of our brain works when interacting with map-related tasks is directly correlated with the neurons responsible for our mental maps. As visualization is a cognitive process, user centered design (UCD) plays an important role in usability research. How our brain can cope with huge data and how it picks up certain information is a subject of attention that can be either overt and covert. Overt attention can externally be observed and measured by a commonly used eye tracking method, whereas covert attention is not visible from outside and measured by neuroscientific methods. This paper aims to investigate the use of neuroscientific methods (EEG, fMRI and eye tracking) for usability of cartographic visualizations and their contribution to usability research. The research also introduces the possibilities of integrating eye tracking with EEG and fMRI in order to gain a better insight of map-user behaviors.

Keywords*: visualization, cognitive cartography, map usability, user issues, neuroscience, fMRI, EEG, eye tracking*

INTRODUCTION

The neuroscience of navigation has been the center of attention with the discovery of place cells/grid cells by O'Keefe, Edvard and May-Britt Moser who won Nobel prize in 2014. The place cells are the neurons which are responsible for our mental maps and inner navigation [URL 1]. The perception, cognition and neurological process underlying map use behaviors of individuals have gained importance in terms of user centered design (UCD) approach of maps or so-called neocartographic products (Cartwright, 2012). UCD is very important for understandability and usability of neocartographic products, since they are widely available on internet for everyone. However, as Ooms and De Maeyer (2015) pointed out, these designs do not consider user needs and there is not sufficient user feedback regarding their usability.

This situation is not much different for design procedures of conventional cartographic representations. In "Semiology of Graphics", Bertin (1967) introduced the famous seven visual (or retinal as he called) variables that must be taken into consideration for cartographic design. These variables are position, size, shape, value, color, orientation, and texture (Figure 1). Bertin also identified the characteristics of visual variables and ranked them whether they are selective, associative, quantitative, and based on order and length. Most of map makers accepted Bertin's design rules for communicating prominent information via maps. However, Fabrikant opposes that these principles were mostly not based on empirical cognitive research. As she stated, there is obviously a need to understand "*how design rules actually play into how users read a map, how users make inferences from the design elements on a map, and how mapmakers can work to make their maps more perceptually salient?*" [URL 2].

This paper aims to investigate the use of neuroscientific methods (EEG, fMRI and eye tracking) for usability of cartographic visualizations and their contribution to usability research. In addition, the possibilities of integrating eye tracking with EEG and fMRI will be introduced in order to gain a better insight of map-user behaviors. In this context, an extensive review of literature on spatial cognition, UCD and usability research and usability methods are presented.

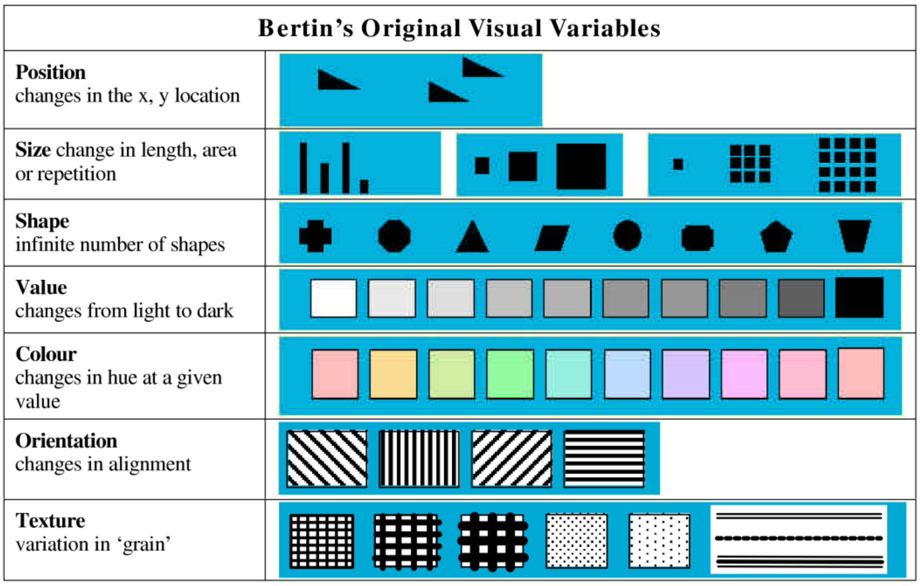

Figure 1. Visual variables (Bertin, 1967)

SPATIAL COGNITION

Cognition is defined as '*the intelligent process and products of the human mind includes such mental activities as perception, thought, reasoning, problem solving and mental imagery*'. Mental image is an important topic in cognition studies. 'The mental image is an internal representation similar to sensory experience but arising from memory' (Peterson, 1994). On the other hand, spatial cognition can be defined as restructuring the space on a mental level and its assimilated reflection. Similar to perception, spatial cognition is related to both physical environment and abilities of individuals regarding socio-cultural, economic and political characteristics of their daily life. As Boulding (1956) and Lynch (1960) introduced spatial cognition can be explained by two terms spatial image (other terms used instead are mental map, cognitive map) and cognitive mapping. In this context, spatial image refers to a cognitive representation of the nature and attributes of the spatial environment, whereas

> *…cognitive mapping is process composed of a series pf psychological transformations by which an individual acquires, codes, stores, recalls and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment.*

Thus, human spatial behavior is dependent on the individual's cognitive map of the spatial environment. Because cognitive mapping is considered as the basic component of human adaptation and the cognitive map is a must for everyday environmental behavior. These environmental behaviors occur when seeking answers for *'where certain valued things are'* and *'how to get to where are from where we are'* (Downs & Stea, 1973).

Due to the above definitions, cognitive mapping process is characterized by how individuals make use of the information existing in different environments and how it affects spatial behavior (coping with complex data, interpretation, etc.). Hence, the perception of environment plays a significant role for improvement of spatial images. It is important that individuals perceive and comprehend a foreknown concept with its spatial relationships. That is how cognitive maps occur (Güç, et al., 2012). In this context, a cognitive map is not necessarily a map, it is actually an analogy to explain its function is familiar with cartographic map. In fact, a cartographic map itself has a huge impact on our spatial images and our concept of a cognitive maps (Boulding (1956); Downs & Stea, 1973). Montello (2002) also stated that map design is about human cognition design and according to him, this can be termed as "intuitive map psychology". In spite of the situation before, the intuition of maps become a formal part of cartographic education in 20th century. By this way, cartographers proposed that intuitions about map cognition can be developed by borrowing theories and methods of psychology in a more systematic way. This approach created a new research area called cognitive cartography. Applying cognitive theories and methods to understand maps, and map applications to understand cognition are subjects of cognitive cartography (Montello, 2002).

According to Montello (2002), cognition includes perception, learning, memory, thinking, reasoning and problem-solving, and communication. Related to that, cognitive cartography consists of three research area; map-design, map-psychology and map-education. Map-design deals with understanding of maps, mapping, and map use in order to improve them in a more efficient, effective and rewarding way. The goal of map-psychology research, is the understanding of human perception and cognition while map-education aims to improve education with maps and about maps (Montello, 2002).

Abstraction of physical reality shows differences in geometry and cognition. In geometry, the spatial world can be described in terms of points, lines, and areas. On the contrary, in cognition, basic entities usually are not points; they may be entire physical objects like books or chairs. Figure 2 demonstrates how to conceptualize a physical object in geometry and in cognition. The cognitive apparatus is flexible as to which level in a huge lattice of part-whole relations to select as 'basic level'; it can also focus either on the relation between an object and a configuration of objects, or on the relation between an object and its parts (Freska, 2013). For this reason, to increase the understandability of a cartographic visualization, we need to link geometric fundamentals to cognitive processes. Within map design, the relationships between geometry and cognition should be taken into account as the premise criteria. The understandability of a cartographic representation is highly correlated with the effectiveness of its design. For instance, the visual variables that will be used in the design can be decided based on the strategy of Shneiderman's (1996) visual information mantra; overview first, zoom&filter, details on demand.

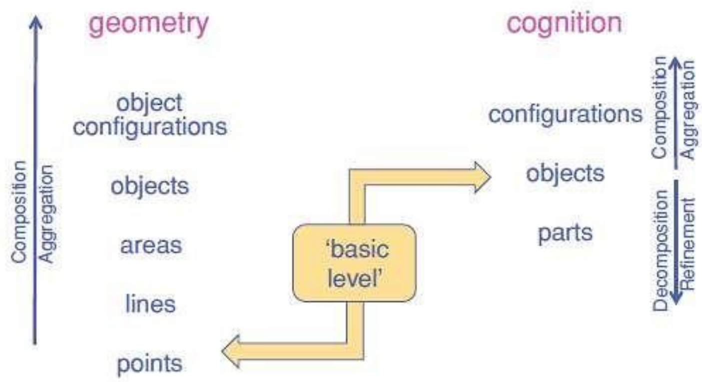

Figure 2. Left: In geometry, aggregation of structures from atomic point entities. Right: In cognition, no matter geometrical complexity or meaningfulness, basic entities can be decomposed into more elementary entities or aggregated into more complex configurations; without invoking elementary constituents (Freska, 2013).

USER CENTRED DESIGN (UCD) AND USABILITY RESEARCH RELATIONSHIP

While user centered design (UCD) can be described as an approach to the design and development process focusing on gaining a deep understanding of who will be used the product [URL 3], usability is a measure of user experience interacting with the design. According to International Organization for Standardization (ISO) definition, usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. In this context, usability standards (ISO 9241-11) are categorized as primarily concerned with:

- the use of the product (effectiveness, efficiency and satisfaction in a particular context of use)
- the user interface and interaction
- the process used to develop the product
- the capability of an organization to apply user centered design [URL 4]

As a component of the product use, effectiveness refers whether users complete tasks, achieve goals with the product. Another issue is efficiency which is mostly measured in time and is about how much effort users require to do a specific task. Lastly, satisfaction can be described as users' conception on the products ease of use. There are also some fundamental factors affecting the use of product such as users, their goals and context of use. Users can be highly trained, experienced or novice. The use purposes of the product may vary based on where and how the product is being used [URL 5]. Related to ISO 9241-11, ISO 13407 defines UCD activities for the entire life cycle of interactive computer-based systems including human factors, ergonomics knowledge and techniques as presented in Table 1 [URL 4]. This standard is the basis for many UCD methodologies.

Table 1. Usability Metrics defined by ISO 13407:1999, ISO 9241-11:1998

Usability measurement type	**Definition**
Effectiveness	The accuracy and completeness with which users achieve specified goals
Efficiency	The resources expended in a relation to the accuracy and completeness with which users achieve goals
Satisfaction	Freedom from discomfort, and positive attitude to the use of the product
Context of use	Characteristics of the users, tasks and the organizational and physical environments
Goal	Intended outcome
Task	Activities required to achieve a goal

Above stated standards can also be applied for usability research of cartographic products. In this context, firstly user tasks should be prepared and classified based on specific criteria. Throughout the task design procedure; user group, goal, context of use and the tasks expected to achieved by users should be taken into consideration. User group may diversify in terms of education level, expertise, age, gender, culture, and sensory disabilities, and those factors directly affect spatial perception as well as the perception of cartographic products (Slocum, et al, 2001).

After determining the user group and user goals, the context of use, which was one of the usability measurement types defined by ISO, should be considered. The context of use is related to visualization environment, visualization method (whether it is 2D, 3D, static, dynamic or interactive) and the advantages and/or disadvantages of visualization method. For instance, MacEachren et al (1999) introduced four criteria (immersion, interactivity, information density, intelligence of display objects) for usability evaluation of geospatial virtual environments (GeoVEs). Immersion refers to the sensation of being enveloped by the environment, while interactivity allows manipulating the characteristics of environment components. Information density handles the level of detail in the geovisualization environment. Last criteria, which is intelligence of display objects, can be described as assisting components that helps users to interpret the representation on the screen.

To design user-tasks, it is good to follow a task taxonomy. In literature, there are many task taxonomies developed for cartographic representations (Amar, et al., 2005; Casner, 1991; Kveladze, 2015; Roth & Mattis, 1990; Roth, 2012; Wehrend & Lewis, 1990). For instance, Armstrong & Densham (1995) offers a sequence of steps that normally are followed in formulating and solving the location-selection problem, whereas Knapp (1995) produced a six-step task analysis model. Knapp's task analysis model includes task (what is to be accomplished), goal (why it is to be accomplished), physical actions (how it is to be accomplished), mental actions (thought process while accomplishing it), data (the data set with which it will be accomplished) and visual operators (primitive operators for visual interaction with display) that users associated with. In addition, user tasks may incorporate from simple to complex questions based on the visualization and its abilities.

The ability of users on performing user tasks is measured by identifying the methods used to test user behaviors. There are several theoretical and empirical methods to test the usability. Empirical methods allow ideas to be generated and verified by systematic observation and measurements. Systematic observations are standardized, controlled, recorded, repeatable, and publicly verifiable. In that manner, systematic empiricism should be held separate from trial-and-error map design approach developed by cartographers over the years. Similarly, informal experiments held by cartographers to evaluate the effectiveness of a design should be distinguished. As all empirical research on cartography does not include cognitive theories or human subjects, it is not possible to claim that only empirical methods leads the truth. However, it is obvious that combination of empirical research and predictive and explanatory ideas can lead scientific outcomes (CCS, 1995; Montello, 2002). As Slocum et al. (2001) stated that building an effective visualization method is a two-step process which involves theory-driven cognitive research and usability engineering to evaluate existing methods. Theory-driven cognitive research covers studies to understand how users create and make use of mental maps of real world phenomena when they interact maps. If theories related to these are developed, there will not be much need for user tests of a specific geovisualization techniques. On the other hand, usability engineering refers identification of methods to analyze and enhance the usability of software. Usability term here means both ease of use and effectiveness, efficiency and satisfaction, just as mentioned by ISO. “User testing” and “user studies” applied in cartography show significant similarities with the empirical research subjected to usability engineering (Slocum, et al., 2001).

All in all, the key to developing highly usable cartographic products is employing UCD and employing UCD requires usability research that focuses on user behaviors and needs [URL 3].

USABILITY RESEARCH METHODS

Keeping in mind the empirical and theoretical classification of usability research mentioned in Chapter 3, practical usability methods can be categorized as qualitative and quantitative. Qualitative research includes user’s experiences, actions and behaviors including their feelings, opinions and emotions to gain insight into reason or motivation of their reactions. The methods may vary but qualitative research generally seeks for explanation about influences and processes of user experience from discussion, interview or so. Qualitative methods can be categorized into seven groups; focus group, post-experience interview, think aloud, observation, video recording, audio recording, and screen recording (Van Elzakker, 2004; Kveladze, 2015; Ooms, 2012). These methods are used often for usability of 2D, 3D static, dynamic and interactive visualizations.

Usability evaluation methods such as interview and think-aloud protocols are widely used due to the fact that they require no measurement apparatuses and allow usability experts to measure usability of software systems in a relatively easy way. However, analyzing and evaluating the collected data from these methods are time consuming. Additionally, the results of the analysis may be hard to replicate because the collected data is based on qualitative evaluations. To overcome this limitations, quantitative evaluation methods have been developed (Kimura, et. al., 2009). Different than qualitative methods, quantitative research allows measuring, quantifying and counting issues considered in a usability study (Kveladze, 2015). Task analysis, questionnaire and eye tracking can be counted as frequently used quantitative methods. Eye tracking is one of the neurocognitive methods and it allows measuring user actions and behaviors that are observed from the outside. However, perception is highly depending on the attention which cannot be measured not only from outside. It also requires monitoring and quantifying psychological state and brain activities by brain imaging techniques such as fMRI (functional magnetic resonance imaging) and EEG (electroencephalogram).

Eye tracking

Eye tracking is one of the quantitative usability research methods and a frequently used user experience technique for user interfaces and websites (e.g., Djamasbi, et al., 2010; Fleetwood & Byrne, 2006). It allows tracking the movements of the participant’s eyes: his point of regard (POR) is registered at a certain sampling rate. From this long list of (x, y) positions, eye movement metrics such as fixations and saccades can be derived (Ooms, 2012).

A fixation is a stable POR during a certain time span (at least 80 to 100 ms) and indicates the users’ content interpretation at that location. A saccade is a rapid eye movement between two fixations, typically completed in tens of milliseconds. A scan path can be described as a succession of fixations and saccades (Ooms, 2012).

The first eye tracking application in user experience domain was conducted by Fits, et al. (1950), who used motion picture cameras to study the movements of pilots’ eyes (Ooms, 2012). Jenks (1973) initiated eye tracking use for cartographic purposes by exploring the scan paths of users looking at a dot map. Although a few more studies followed this first one, no significant eye tracking study on assessment of the cartographic products have been implemented for almost 10 years because of the following reasons presented by Jacob and Karn (2003): (i) technical problems related to capturing the actual eye movements that may cause inaccurate and unreliable results (ii) complicated and time-consuming data extraction and (iii) difficulty in interpretation of extracted data. However, later advances in eye-trackers and eye tracking software and their decreasing costs concluded that eye tracking technology is useful for interpretation of visual information efficiently while performing a complex visual and cognitive task (Duchowski, 2007; Jacob & Karn, 2003; Ooms, 2012). It is also possible to execute detailed analysis and eye tracking contributed to psychological research on cognitive processes linked with visual search (Ooms, 2012). For instance, Çöltekin et. al. (2010) studied users' visual interaction with highly interactive interfaces. The study mainly investigated whether the efficiency of users can be characterized by specific display interaction event sequences, and whether studying user strategies could be employed to improve the design of the dynamic displays. Another research intended to combine eye tracking with user logging (mouse and keyboard actions) with cartographic products and referenced screen coordinates to geographic coordinates in order to know which geographic object corresponds to the gaze coordinates at all times. This approach is promising in terms of efficiently studying user behavior with interactive and static stimuli in multiple research fields (Ooms, et al., 2014).

Monitoring brain activities in the context of spatial cognition

Developments in medical research have led observing neurons in the brain with a high spatial and temporal resolution. The discovery of place cells (see Chapter 1) also marks an attention to research on spatial cognition. Place cells are located in entorhinal cortex which is a part of temporal lobe and functionate as the center of memory and navigation. The entorhinal cortex is the main interface between the hippocampus and neocortex (Figure 3). Understanding activity of the place cell in the hippocampus equals to understanding how neurons code complex cognition. Hence, '*... any discussion of the hippocampal neurophysiology of spatial cognition needs to start from the fact that spatial location is a primary driver of neural firing patterns in the rodent hippocampus and spatial firing is clearly the best first-order description of rodent hippocampal representations*' (Redish & Ekstrom, 2013).

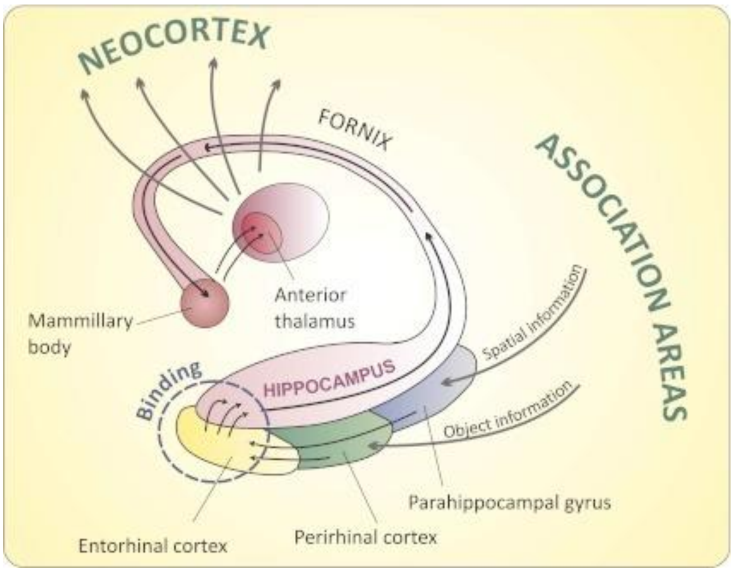

Figure 3. Hippocampal system (Kessels & Kopelman, 2012)

There are several researches on spatial representations in the medial temporal lobe. Hippocampal lesions lead various deficiencies on spatial cognition such as impairments in forming spatial relationships and spatial learning abilities. For instance, patients with hippocampal lesions succeeded retrieving a single route to a hidden location, unlike retrieving the location of multiple hidden objects within a spatial environment (Bohbot et al., 1998, 2007). These findings implied that calculations including multiple routes and environments are mostly related to hippocampus.

Besides hippocampus, the neural basis of human spatial memory depends on parahipocampal cortex and retrosplenical cortex which include visual-spatial scene processing and survey representation (Redish & Ekstrom, 2013). Patients with hippocampal deficiencies still keep on activities involving spatial memory such as locating a recently learned object within a room (Bohbot et al, 1998). In this context, the patient who was widely studied and known by his initials, H.M., played an important role in the development of cognitive neuropsychology. H.M. was a memory disorder patient who had a "bilateral resection of the entire (pyriform–amygdaloid–hippocampal) complex including the hippocampal gyrus extending posteriorly for a length of 8–9 cm from the tips of the temporal lobes in an attempt to cure his epilepsy (Corkin et al, 1997). Some research conducted with H.M. showed that he succeeded in many spatial memory tasks, including knowledge of the layout of his apartment. The posterior parts of his hippocampus, which might be important for spatial processing, were not damaged. However, he was unable to learn, store and retrieve new spatial routes, especially multiple routes. This situation suggested that the parts of his hippocampus which are responsible for spatial processing were damaged (Redish & Ekstrom, 2013). In addition, posterior parahipocampal cortex that receives signals from visual areas, allows allocentric processing of visual-spatial information. For instance, some studies involving the same spatial tasks presented that patients with parahippocampal lesions encountered very serious deficiencies, whereas patients with more profound hippocampal lesions did not show deficits (Bohbot et al, 1998; Ploner, et al., 2000). Another example is that compared with sighted ones, parahippocampal cortex of blind participants who imagine navigating showed less activation (Deutschländer et al., 2009). Due to results of the previous studies, parahippocampal cortex plays a valuable role in visual-spatial processing (Redish & Ekstrom, 2013).

All above findings were acquired by fMRI which allows measuring neural activity indirectly by using blood oxygen–level dependent (BOLD) signal. fMRI facilitates imaging brain activity with a high spatial resolution (~1mm), depending on the oxygen consumption in the activated brain area, and the increment and decrement in metabolism energy. Shortly, it measures the metabolic activity related whole-brain changes. Despite the fact that fMRI is unable to measure the activity of single neurons such as place cell activity, it ensures significant information related to the functions of hippocampus and parahippocampal cortex during navigation, in this case. Since it is not an invasive method, it can be employed for healthy participants as well (Redish & Ekstrom, 2013) [URL 6].

Although it has been used rarely in cartography, fMRI provided some essential information how user perceive maps and respond map-related tasks. One of the studies implemented on fMRI technology showed that the ability to find targets embedded within complex visual environments requires the dynamic programming of visuomotor search behaviors based on fMRI results. The research revealed many significant results. For instance, visuomotor search resulted a greater activation in the posterior parietal cortex and the frontal eye fields in the right hemisphere. Furthermore, the activity in a network of cortical regions have an influence on the search-dependent variance in superior colliculus activity. Saccadic eye movements, covert shifts of attention, and visuomotor search occurred overlapping but not identical zones of activation. Lastly, this study focused on functional anatomy of overt spatial exploration rather than covert shifts of spatial attention (Gitelman et al., 2002) Another research carried out by Lobben et al. (2005) attempted to measure and analyze users' navigational abilities by using fMRI. In this context, individual performances of users and activated brain areas were determined while they perform rotation and sleuthing tasks. The research had some interesting results such as; during sleuthing, activation in the right and left hemispheres were similar. However, rotation task activated the right hemisphere more. In addition, while rotation caused more activation in the lateral occipital gyri which is the center of visual processing, sleuthing activated middle frontal gyrus, postcentral gyrus, and the angular gyrus more than rotation task.

Similar to fMRI, EEG is the recording of electrical activity along the scalp produced by the firing of neurons within the brain. In this method, electrodes placed in specific parts of the brain, which vary depending on which sensory system is being tested-make recordings that are then processed by a computer. Obviously a single neuron is not sufficient to draw a measurable potential at the scalp. Thus, the aggregate of synchronized neurons is considered during EEG. What generally recorded in EEG is called ERP (event-related potentials) that allows checking an EEG in certain moments when subjects received the event. ERP can be considered any measured brain response that is directly the result of a thought or perception. Since EEG is an electrical measurement, it provides high temporal resolution (milliseconds), resolves changes depending on different cognitive processes while performing certain tasks. However, because of the electrical activity is measured by electrodes placed at few specific regions, it is difficult to tell where in the brain the activity comes from (Lee et. al., 2009) [URL 6].

Possibilities to integrate eye tracking with EEG and fMRI

As stated in Chapter 4.1, eye tracking studies provide valuable information about use/user issues of cartographic products. On the other hand, some other spatial cognition research employed brain imaging techniques to understand user behaviors (Chapter 4.2). Linking the psychological/mental processes underlying the sensations we experience in everyday life to their underlying physiological biochemical processes is a challenging research area. To achieve this goal, we have to understand perception, in other words, how our brain makes sense out of the signals coming from our senses. Not only 'how this perception is processed', but also 'attention' (how our brain can cope with the huge data and how it selects certain information)' should be understood (Görgen, 2010). There are two types of attention; overt and covert. Overt attention is defined as selectively processing one location over others by moving the eyes to point at that location. Covert attention is defined as paying attention without moving the eyes. While overt attention is externally observed, covert attention process is not visible from outside. To investigate covert attention, one can use psychophysical experiments or apply techniques like EEG or fMRI. For overt attention, one can use eye tracking to find out what actually guides the process and whether physical features of pictures play a role in guiding our attention. In this case, although eye tracking provides valuable information about the gaze location, it does not provide any information about neuronal activity. Likely, EEG or fMRI do not directly provide information about the gaze position (Görgen, 2010). Hence we need a holistic approach to understanding and interpreting map user behaviors. Considering the functions of both EEG and fMRI, the combination of two methods is indeed provides better insight. Because these methods can be thought complementary in terms of EEG's high temporal resolution and fMRI's high spatial resolution. Thus, EEG and fMRI can be executed simultaneously in order to monitor, measure and interpret task-related brain activities including map use or in other words, usability research of cartographic products.

Combined EEG and eye tracking has been used in many research areas. For instance, one of recent studies introduced a concept to explore customer experiences in service design by considering an augmented customer journey (Alves, et. al., 2012). Another research intended to enhance mental performance in sport by measuring neurocognitive activity and visual focus in real time which can be used to provide immediate feedback to the coach, in 'real world' settings, for optimizing training protocols for the individual athlete. In addition, the research aimed examining the relationship between eye movement and neuro activity (e.g. saccades and gamma waves) and in athlete coaching interventions such as sports visual scanning strategies, Eye Movement Desensitization & Reprocessing (EMDR) therapy, focused relaxation, etc. (Bartfut, et. al., 2012).

DISCUSSION

Visualization is considered as a mental process and perception is strongly connected to memory. The representations in memory are a form of mental image which are intellectually processed and generalized representations. To imply of the findings of cognitive neuroscience for cartographic visualization, Peterson (1994) proposed that displays should consist of different levels of generalization. This may enhance how maps are remembered and mentally processed. On the other hand, spatial processing (especially motion detection for dynamic displays) is accomplished in the visual cortex, not in the eye. Thus, training and experience are factors enhancing spatial processing abilities. Again, as Peterson (1994) suggested, video games may be useful for training the visual cortex to process dynamic displays and this ability may benefit individuals to be more capable of interpreting dynamic displays.

If cartography is a way of organizing, representing, communicating the scientific data, the visualization is an important component of cartography. Progress in cognitive neuroscience appears to be closely linked to our ability to visualize phenomena with the help of computer technology (Revonsuo, 2000). Thus we, cartographers, should collaborate colleagues that are expert in cognitive neuroscience to carry out such research. As Lobben et al. (2005) indicated, 'there may be important implications for some very hard questions that overlap between psychology, physiology, and cartography/GIS such as which tasks use similar brain regions even though the tasks themselves seem to be very different or which tasks use different brain regions even though the tasks seem to be very similar.' This multidisciplinary research can bring different perspectives to the cognitive map research and certainly has a potential to improve new methodologies related to usability of cartographic designs.

In conclusion, cognitive neuroscience is very promising in terms of understanding map user behaviors and it is surely beneficial for designing better maps. The usability of a cartographic representation depends on how effective its design is. Thus, cartographic design can borrow UCD theories and standards to produce more understandable visualizations. For further usability research, it is also possible to gain a better insight of user groups within different age, education, gender or cultural characteristics that can be considered in user centered design.

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