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Original citation & hyperlink:
Al-Samarraie, H., Eldenfria, A., Price, M. L., Zaqout, F., & Fauzy, W. M. (2019). Effects of map design characteristics on users' search performance and cognitive load: An empirical study. The Electronic Library, 37(4), 667-679.
https://dx.doi.org/10.1108/EL-10-2018-0202

DOI 10.1108/EL-10-2018-0202
ISSN 0264-0473

Publisher: Emerald

The Electronic l

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Journal:	*The Electronic Library*
Manuscript ID	EL-10-2018-0202.R2
Manuscript Type:	Article
Keywords:	Information visualization, Cognitive load, Information processing, Symbolic maps

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Abstract
Purpose - This study investigated the influence of map design characteristics on users' cognitive load and search performance. Two design conditions (symbolic versus non-symbolic) were designed and used to evaluate a user's ability to locate a place of interest.
Methodology - A total of 19 students (10 male and 9 female), 20-23 years old, participated in this study. The time required for subjects to find a place in the two conditions was used to estimate their searching performance. An electroencephalogram (EEG) device was used to examine students' cognitive load using event-related desynchronization percentages of alpha, beta, and theta brain wave rhythms.
Findings - The results showed that subjects needed more time to find a place in the non-symbolic condition than the symbolic condition. The EEG data, however, revealed that users experienced higher cognitive load when searching for a place in the symbolic condition. It was found that the design characteristics of the map significantly influenced user brain activity, thus impacting their search performance.
Values - Outcomes from this study can be used by cartographic designers and scholars to understand how certain design characteristics can trigger cognitive activity to improve users' searching experience and efficiency.

Keywords: Information visualization, Cognitive load, Information processing, Symbolic maps
Article classification: Research paper

Introduction

Visualizing representations of map information may vary from one application to another. Adding one or more graphical attributes to the visual representation of map data is particularly useful to individuals seeking to visualize and understand the physical structure of a place (Brown, 1993). The supply of visual characteristics of digital objects in the design of digital maps has increased explosively (DiBiase *et al*., 1992). This led, as a result, to an increase in the demand for effective graphic methods for data analysis and presentation (Al-Samarraie *et al*., 2017). In addition, the opinions on what good map design actually is, differ. Still, over time, different cartographic design guidelines for maps have been developed over the years (Jenny *et al*., 2008).

Examining the effects of different information representation formats on individuals' abilities to process information can help us reveal more insights into the design requirements for effective visual encodings (Al-Samarraie and Al-Hatem, 2018). Maps, represented in digital or paper-based format, are commonly used to provide geospatial data that people can use to quickly locate places of interest and their distributions in a visual manner (Zhou *et al*., 2016). Typically, there are different types of maps, such as contours, symbols, shading, or choropleth, and sized symbols used for many social and economic purposes, such as urban planning and tourism. The design characteristics of these maps varies depending on the purpose of use (Tickner, 2016). Tourism maps, for example, use unique features and symbols to communicate information to tourists (Wang *et al*., 2016). There is no standard for placing or distributing these features and symbols on a map. Yet, there seems to be little evidence on how symbolic map characteristics associated with certain places can help a person to quickly locate places of interest (Çöltekin *et al*., 2018; Schöning *et al*., 2014), particularly with a minimal cognitive effort (Collins, 2018). This is because the complexity of the design can potentially play a key role in affecting individuals' ability to process information (Gill and Murphy, 2011). Therefore, this study was conducted to determine how certain map design characteristics may influence users' cognitive load and search performance. To do so, the researchers designed two design conditions (symbolic versus non-symbolic) to evaluate users' ability to locate a place of interest. Outcomes from this study can be used by cartographic designers and scholars to apply the suitable map design characteristics in order to improve the search performance among users.

Literature review

It is commonly known that objects in maps are represented using a combination of symbol primitives, such as point, line, and area (Otto *et al*., 2011). These primitives may also take the form of dot, dash, and patch, or termed marker, line, and polygon (area) symbols in various geographical information system applications (Crampton, 2001). Highlighting certain areas of interest can be achieved by variations of the basic visual variables: shape, size, orientation, texture, or colour, which is believed to help in constructing a visual representation on the basis of the relationships between these variables (Kraak and Ormeling, 2013). The design of a map includes aspects, such as balance, clarity, and contrast. Shape is commonly used to add clarity and contrast to the design of a map relative to user ability (Nelson and Robinson, 2015). However, understanding how using symbolic and non-symbolic shapes in the design of a map would affect individuals' cognitive processing of information is not established in the literature. Many previous studies have reported the single effect of map design on map reading performance (Raposo and Brewer, 2014), but is has been argued that, employing the cognitive cartographic approach will create a non-representational approach to map design (Kitchin *et al*., 2009). This is believed to influence individuals' ability to construct meaning from map symbols (Fernández and Buchroithner, 2014), thus resulting in different performance outcomes (Demaj and Field, 2012).

Previous studies on multimedia cartography have been conducted to determine the importance of specific design features in facilitating individual recognition regardless of the medium of representation. For example, Tsai *et al*. (2017) examined how the use of simplification and metaphor can affect the design of tourist guidebooks. They found that the use of metaphor can be useful to achieve semantic conveyance. Wood (1995) investigated how simplifying a digital route of a map can influence individuals' concentration. He conducted a concentration test and found that the average concentration time when the curve of the map was simplified to a straight line. Harrower (2007) stated that certain mapping practices may trigger important cognitive consequences. Amedeo and Kramer (1991) studied individuals' perceptions of differences among versions of a bi-symbol map with regard to their usefulness for point estimating. They found that users' perceptions varied from one design to another.

This review of the literature leads to the conclusion that current research on the design of tourism maps remains under-examined in geography. This can be attributed to the evaluation methods (e.g., questionnaire, survey, etc.) used in previous studies, which may not adequately explain the state of individuals' cognitive processing. Current knowledge on how map design characteristics would influence the users' cognitive load is limited. Cognitive load is of a particular interest to instructional designers as it focuses on how individuals' interaction with the environment can be modulated by certain schemas (Sweller, 1994). This is because communication with maps differs significantly from other types of human communication. Maps are visual media and evoke visual stimuli that cause different reactions in people in comparison to books or conversations (Otto *et al*., 2011). Thus, it is advised that a visual balance is maintained in order to sustain the reader's attention on the map. Achieving balance in map design can be ensured through approximate symmetrical placement of resources (Reddad and Verbrugge, 2012).

A growing body of literature (e.g., Field and Kent, 2015; White, 2009) on cartography attempts to gain more scientific insight into how certain map design features may influence readers' cognitive processes. The methodological limitation is one possible reason for this lack of knowledge, which may limit researchers to study only certain aspects of human performance in real time. Measuring cognitive load has been an important tool and consideration in interface design (Grunwald and Corsbie-Massay, 2006). According to Jobst and Döllner (2008), adding several aspects to the design of a map may add additional cognitive load, which deflects from directed information extraction and thus complicates the usage of the map. In addition, Chen *et al*. (2012) stated that the characteristics of causal factors are based on the cognitive ability of a person in certain tasks (e.g., task complexity), the environment (e.g., noise), and their mutual relationship. Based on these observations, it was anticipated that using advanced computational imaging techniques, such as electroencephalogram (EEG) would allow the deep exploration of how map design characteristics effect individuals' cognitive load.

Many studies have examined the potential of using EEG as a measure of cognitive load, mainly due to its ability to provide a continuous measure of instantaneous cognitive load which enables researchers to look at data for specific instances of time. Such flexibility provides a more detailed, and likely more accurate, interpretation of the effects of certain interventions on the individual cognitive load than a single measure of overall load (Van Gog *et al*., 2009). Some previous studies, such as Bauer and Gharabaghi (2015), have addressed the feasibility of using EEG to estimate individuals' cognitive load during self-regulation of brain activity and neurofeedback with therapeutic brain-computer interfaces. According to Kuvaas and Kaufmann (2004), monitoring variations in cognitive load using EEG while an individual performs the task can help gain an understanding of the communicative changes in cognitive load based on how the material is presented. Anderson *et al*. (2011) asserted that EEG measurements are not corrupted by the participant's subjectivity or the benefit of hindsight, as may be the case during post-experiment surveys. Based on this, it can be said that EEG measurements are well-suited for determining the effectiveness of visualization, including insights into the cognitive load imposed on the viewer. From a biofeedback perspective, EEG can be used to provide a better assessment of human workload or cognitive load changes (Brunken *et al*., 2003). However, since brain wave behaviour varies as a function of age, brain volume, and individual differences (Spear, 2000), it is recommended that changes in the EEG signal due to a certain event or task should be analysed rather than using the absolute power of a specific frequency band (Antonenko *et al*., 2010). The literature addressed the potential of using event-related (de-) synchronization as a sufficient measure of rate-of-change for oscillatory EEG dynamics. This measure was developed by Pfurtscheller and Aranibar (1977) for the quantification of changes in the alpha band. It reflects the percentual decrease (event-related desynchronization; ERD) or increase (event-related synchronization; ERS) in band power during a test (activation) interval compared with a baseline (reference) interval (see also Pfurtscheller *et al*., 1994). Therefore, this study used ERD as a parameter to measure individuals' cognitive load while finding a place of interest on the map. Precisely, this study was conducted to answer the following questions: "How design characteristics of maps (symbolic versus non-symbolic) would influence users' performance in finding a place of interest?" and "How brain activation in these conditions would influence individuals' cognitive load?".

Method

Participants and stimulus materials

A total of 19 (10 male and 9 female) 20-23 year-old healthy students (self-reported) participated in this study (see Table I). During the recruitment process, the participants were asked to answer the following questions: "Have you been to the UK before?", "Are you familiar with the location of the main attractions in London?", and "Are you familiar with tourist maps and their use?". In the present study, subjects were selected who indicated that they had not been to the UK before, were unfamiliar with the places of attraction in London, and were familiar with tourist maps. These questions were essential to ensure that the participants' brain activation from searching maps in the two conditions was performed in as unbiased a setting as possible. Before the experiment began, each participant was asked to indicate their experience in using tourist maps, which ranged between 2-3 years for all participants involved in this study. It should be noted that the sample size for EEG analyses in the present study (19 subjects) is similar to that of other studies using brain imaging (e.g., Coan *et al*., 2006; Doppelmayr *et al*., 1998; Ito *et al*., 2010; Kober *et al*., 2012; Lansbergen *et al*., 2007; Smith *et al*., 2001).

Table I. Demographic background of the participants

Characteristics	**Frequency**	**Percentage**
Gender		
Male	10	53%
Female	9	47%
Age		
<20	0	0%
20-23	19	100%
>20	0	0%
Previous visit to the UK		
Yes	0	0%
No	19	100%
Familiarity with the main attractions in London		
Yes	0	0%
No	19	100%
Familiarity with tourist maps		
Yes	19	100%
No	0	0%

All participants had normal or corrected-to-normal vision and had no neurological, psychiatric, or medical problems (self-reported). The experiments were conducted in a university laboratory setting. An informed consent was obtained from each participant prior to the experiment. The materials used in this study consisted of cultural/tourist attractions in London. Two map designs (symbolic versus non-symbolic) were used to compare the effect of map design characteristics on users' cognitive load.

Apparatus and procedure

The Emotiv EPOC (mobile EEG headset) was used in this study to examine participants' brain activity in two conditions (symbolic map versus non-symbolic map). This device consists of 14 channels of EEG data with two additional electrodes used as references. The EEG channels are designed based on the International 10-20 system. A sample frequency of 128 Hz is transmitted wirelessly to a computer.

The experiment was individually administered in a laboratory where artificial and natural light were controlled. Additionally, the room was electrically and acoustically shielded. When participants arrived, they were seated at a distance of 60 cm from the stimulus screen, the EEG was then placed on their heads and checked for signal validity (see Figure 1).

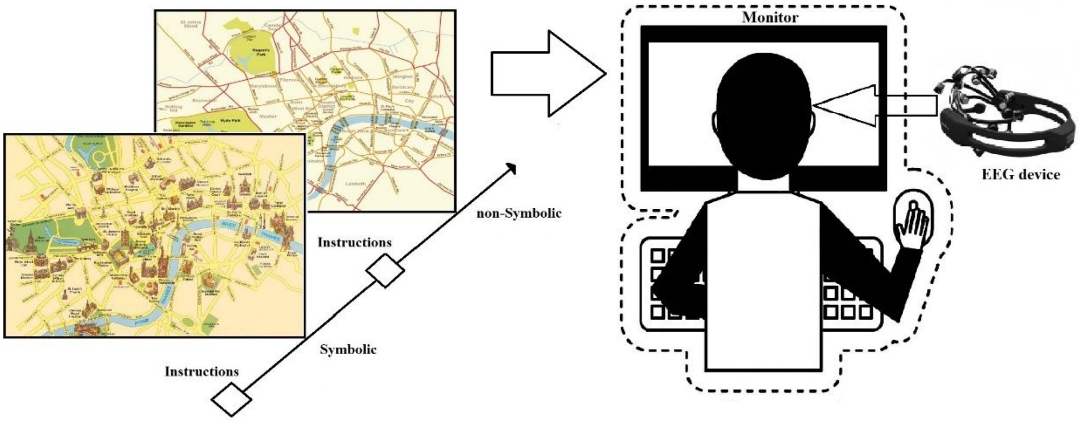

Figure 1. Experimental set-up (brain signals from the Subject [the "Sender"] were recorded using EEG while performing the searching task)

The participants were instructed not to consume any sleepiness inducing or revitalizing products 24 hours before and during testing. Before beginning, a brief description about the EEG device was given to the participants. They were also requested to try to reduce unnecessary physical movements during the experiment. At the time of experimentation, all participants were asked to sign a consent form before testing.

An instruction screen was presented and participants were told to search for a specific place on the map and, upon finding it, to click the mouse to move to the next screen where they were again instructed to search for a different place under different conditions. Prior to the commencement of the experiment a baseline period of 20 seconds was recorded with participants viewing a white screen. This was compared with signals received from searching tasks. The participants' exposure to the two searching conditions (symbolic and non-symbolic) was random.

EEG data processing

The EEG recordings were analysed off-line using the EEGLAB library in the MATLAB software. All the recorded EEG epochs were checked for artefacts (e.g., electrooculogram [EOG] and muscle [EMG] activity, eye blinks, electrical, and baseline noise). The pre-processing of the EEG signal started with removing the mean amplitude displacement. To enhance the signals and suppress the low-frequency background, a linear band pass filter (1-40 Hz) was used. The filtered EEG signals were subjected to independent component analysis (ICA) to remove blink and saccade artefacts present during the place searching stimulus. After the transformation of the EEG signals, non-artefact neural sources related to the searching task were selected and reconstructed (Stone, 2004). It helps to identify the unwanted artefacts from the original signals, such as muscle activity, eye blinks, and electrical noise. According to Comon (1994), in order for one to retrieve N independent source signals (S) $S(t) = \{S_1(t), S_2(t), ..., S_N(t)\}$ from N linear mixtures (X) $X(t) = \{X_1(t), X_2(t), ..., X_N(t)\}$, it is essential to model the result of multiplying the matrix of the source activity, known as "Waveforms" (S), by an unknown square matrix A, called mixing matrix.

$$X(t) = A.S(t) \cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

The main aim of the ICA algorithms is to recover the original sources s(t) from the observations x(t), and this is generally equivalent to that of finding a separating (de-mixing matrix) W such that:

$$\hat{S}(t) = W\,X(t) \text{ ....(2)}$$

given the set of observed values in $X(t)$, and where $\hat{S}(t)$ are the resulting estimates of the underlying sources. In addition, to reduce the human factor impact, multiple artefact rejection algorithm (MARA), proposed by Winkler *et al.* (2011), was applied to classify the general artefactual source components.

Data analysis

The search performance was measured based on the time spent by the participant to find the place of interest. The time spent on the activity or process has been used as the basic performance measure in many visual search studies (e.g., Grier *et al*., 2007; Han and Kwahk, 1994; Van Nes *et al*., 1987).

In order to estimate the participants' cognitive load, the filtered EEG data was analysed in three frequency bands (alpha, theta, and beta) using event-related desynchronization percentage (ERD%) as online measures of brain activity, as suggested by Pfurtscheller and Da Silva (1999). The literature (e.g., Başar *et al*., 1997; Klimesch *et al*., 2005; Pfurtscheller and Da Silva, 1999) showed that an increment in individuals' cognitive load can be corresponded to the higher brain wave *desynchronization* for alpha and beta, and higher brain wave *synchronization* for theta. Higher brain wave usually occurs when participants move from a relaxed state (baseline, when eyes are closed) to active state (eyes are open). In addition, the percentage of ERD from computing the brain wave power in relaxed and active states is represented by a positive number for the participants' alpha and beta bands (desynchronization), and a negative number for the theta band power (synchronization). According to Pfurtscheller and Da Silva (1999), an increase in the desynchronization and synchronization values means a higher cognitive load. The following formula by Pfurtscheller and Da Silva (1999) was used to compute the ERD percentage in alpha, theta, and beta bands:

$$ERD\% = \frac{baseline\ interval\ band\ power\ - test\ interval\ band\ power}{baseline\ interval\ band\ power} * 100$$

Results

The t-test results for search performance showed that participants spent more time (a statistically significant difference) searching the non-symbolic map (M = 12.95, *SD* = 4.33 s) than in the symbolic condition (M = 9.05, *SD* = 2.31 s) (F(1,18) = 3.44, p = .020).

Then, an independent-samples t-test was conducted to compare the effect of map characteristics on individuals' cognitive load. The brain wave rhythms of (a) ERD percentages of alpha; (b) beta, and (c) theta were compared in symbolic and non-symbolic map conditions.

There were significant differences in brain wave rhythm results for ERD alpha ($F_{(1,18)}$ = 0.49.86, $p < 0.01$), beta ($F_{(1,18)}$ = 0.74.50, $p < 0.01$), and theta ($F_{(1,18)}$ = 0.52.72, $p < 0.01$). These results suggest that the presence of map characteristics (symbolic features) have significantly influenced the participants' cognitive load performance. Table II shows that mean alpha, beta, and absolute value of theta ERD% in the symbolic condition was higher than in the non-symbolic condition. These findings reveal lower cognitive load in the non-symbolic condition. Specifically, the results suggest that adding symbolic features to the map can facilitate individuals' searching performance of places.

Table II. Descriptive statistics for measures of cognitive load

	Alpha ERD%		Beta ERD%		Theta ERD%	
	Symbolic	non-Symbolic	Symbolic	non-Symbolic	Symbolic	non-Symbolic
M	0.79	0.60	0.68	0.55	0.46	0.35
SD	0.11	0.08	0.15	0.03	0.06	0.01

Figure 3 shows the topographical maps for power bands of theta, alpha, and beta in the symbolic and non-symbolic conditions. From the figure, it can be noted that searching for a place in symbolic conditions increased users' brain activity, across all bands power, significantly as compared to searching in non-symbolic conditions.

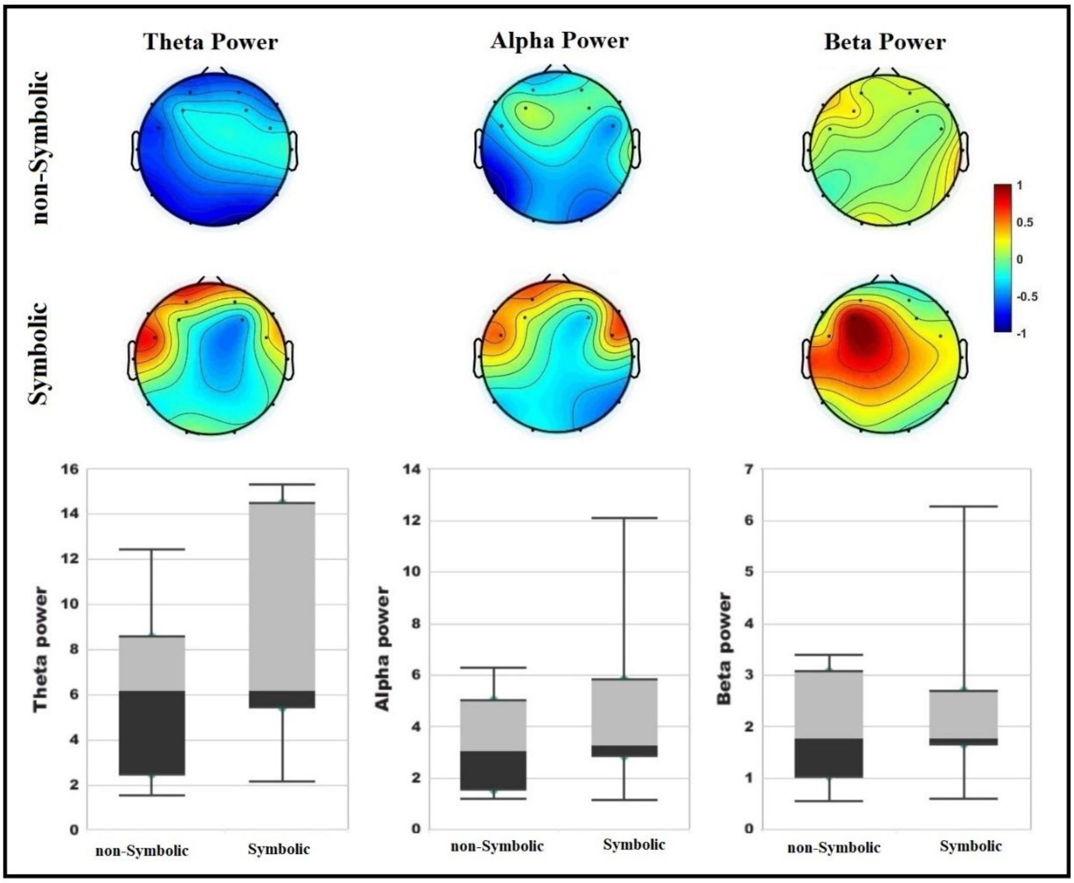

Figure 3. Grand average topographical maps of EEG relative power for theta, alpha, and beta in symbolic and non-symbolic conditions

Discussion

This study found that using symbolic maps can potentially increase users' cognitive load and facilitate their searching performance of places, while the opposite was found when users used non-symbolic maps. It is possible that the features of the symbolic objects may effectively play a key role in altering users' brain activation by increasing activities in the frontal and parietal lobe (Ghika *et al*., 1995), which ultimately could have influenced students' reasoning and judgment of the searching behaviour. According to Schrader and Bastiaens (2012), cognitive load of individuals can be associated with the design-characteristics and cognitive processes. Thus, by adding more features to characterize a place instance, usually by emphasizing certain attributes, users will probably need to invest more mental effort in order to quickly recognize and identify the place of interest. Such experience can possibly increase the efficiency of search performance, but at the cost of higher cognitive load on the user. This is why using non-symbolic maps could limit users' cognitive processing to certain textual information that typically requires less cognitive effort as they are more direct and intuitive.

This study provides empirical support for the effectiveness of symbolic and non-symbolic maps in facilitating users' searching performance and cognitive load. It supports the work of Tversky (1993) who argued that people seem to have coherent representations of the coarse spatial relations among elements, which may not allow accurate metric judgments. The association between symbolic characteristics and cognitive processing adds to the framework of Zhang *et al*. (2016) on the key determinants of an individual's familiar area and activity space. In addition, featuring the place of interest with design attributes may offer a better way of discovery and the search for the next great map style, supported by Kent (2009).

Outcomes from this study can be used by cartographic designers and scholars to understand how certain design characteristics can trigger the cognitive activity to improve users' searching experience and efficiency. For example, it seems intuitively likely that certain symbolic features of an object are easier for people to understand and thus more likely to lead to effective decisions (Allen *et al*., 2014). According to Edland and Svenson (1993), the processing and recognition of a point on a graph is a largely automatic cognitive process required for a person to translate information into action. It is anticipated that individuals' recognition of symbolic information in a map involve more or less concurrent activity in all the relevant areas of the brain.

More specifically, individuals' behavioural decision of the non-symbolic scenario requires several judgments in combination. First, the decision requires the identification of a point on the graph that represents the current circumstances. Second, it requires identifying clues for behaviour that would, ultimately, facilitate the individual reflections to find a place of interest. Third, responses to a minimal visual stimulus usually results in a higher cognitive load (Baigelenov *et al*., 2017). Based on these, it can be said that when making behavioural decisions with symbolic features, individuals typically use the available visual aids to accurately make judgments about the place of interest. This includes weighing whether the symbolic characteristics are relevant to the characteristics of place name. For example, when a person is asked to search for a specific place (e.g., university), the visual characteristics of object image features in a scene will be recalled and used in interpreting the symbolic meaning of an object in the stimuli.

As regards the methodological implications, this study presented the potential of using the brain-computer interface method and illustrated its application in a multimedia cartography context and its superiority over the employment of other methods, such as eye-tracking, questionnaire, and interviews. The distinctive characteristic of using EEG is that it allows, by using filtered brain waves, to stamp the exact cognitive effect of map design characteristics (symbolic features) on the multiple components of individuals' cognition, rather than using less accurate self-generated feedback (e.g., questionnaires). This methodological capability is significant as it allows investigating the cognitive reactions of individuals in a real-time searching environment that is during the actual cognitive processing. Finally, this method also complements other self-reported ones by helping map users' automatic neural activity, hence providing a more complete understanding of users' cognitions at the time of using a map to locate a place of interest. It is hoped that the illustration of the EEG method, and guidelines presented herein, will be useful to cartography researchers willing to investigate individuals' cognitive functioning and performance with the application of a brain-computer interface.

Based on these, this study suggests that the design of maps and map symbols should be characterized by the symbolic features of the place. Meanwhile, associating the textual information with symbolic visualization would be more effective in reducing the time needed for a person to find a place on the map. By studying how different map design characteristics would impact cognitive performance, the researchers encourage map-makers to explore ways of designing effective symbolic gestures that would support individuals' cognitive processes when attempting to locate a place of interest.

Limitations

This research has provided empirical evidence on the effects of symbolic and non-symbolic maps on the user's cognitive load. There are several limitations that exists with this research and results which require further consideration. For example, the sample size of 19 students is one limitation in which more EEG signals from a larger number of subjects may allow a better statistical evaluation of the effect of symbolic and non-symbolic maps on individuals' cognitive processing and load. The results were obtained in a controlled laboratory condition and may differ in a more natural setting. The cultural background of the subjects involved were locally homogenous and the findings may differ when applied to more international environments, as the symbols may be interpreted differently among users from different cultures. The use of an eye tracking system together with the EEG device may help to triangulate the results and may potentially provide a richer dataset to be used for further analysis. In addition, the association between certain demographic characteristics, such as age, gender, cognitive style, and so on, and the participants' brain activation was not considered in this study. Bearing these in mind may thus not only result in different brain activation, but also help understand how certain characteristics may drive individuals to process and understand visual information and representations.

Therefore, there exists numerous avenues for future research to investigate, such as a larger sample size, gender, the use of other devices and technologies to collect alternate (but related) data, usage in a more natural setting, and the influence of users' cultural background on their processing of symbols.

Conclusion

This study investigated changes in performance and brain activation among individuals in two search conditions: symbolic and non-symbolic. Using EEG, it was found that symbolic in the design of a map enhanced individuals' performance and reduced their cognitive load as compared to the non-symbolic condition. It is anticipated that using features of visual objects, such as colour, texture, and shape, to characterize a place of interest can facilitate people's sense of place. Finally, to design an effective map, designers should characterize the symbolic features of the place in order to ensure a better searching performance in locating a place of interest.

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