How reading in single- and multiple-column types influence our cognitive load: an EEG study

Al-Samarraie, H., Eldenfria, A., Zaqout, F. & Price, M. L.

Original citation & hyperlink:
Al-Samarraie, H, Eldenfria, A, Zaqout, F & Price, ML 2019, 'How reading in single- and multiple-column types influence our cognitive load: an EEG study' The Electronic Library, vol. 37, no. 4, pp. 593-606.
https://dx.doi.org/10.1108/EL-01-2019-0006

DOI 10.1108/EL-01-2019-0006
ISSN 0264-0473

Publisher: Emerald

The Electronic l

How reading in single- and multiple-column types influence our cognitive load: An EEG study

Journal:	*The Electronic Library*
Manuscript ID	EL-01-2019-0006.R2
Manuscript Type:	Article
Keywords:	Reading, Cognition, Information management, E-content, Digital documents

How reading in single- and multiple-column types influence our cognitive load: An EEG study

Abstract

Purpose - The impact of different screen-based typography styles on individuals' cognitive processing of information has not been given much consideration in the literature, though such differences would imply different learning outcomes. This study made an attempt to enrich the current understanding of the impact of reading in single- and multiple-column types on students' cognitive processing.

Methodology - An electroencephalogram (EEG) was used to read the brain signals of 27 students in order to analyse the electrical behaviour while reading different text passages.

Findings - The results showed a significant difference in students' cognitive load levels when reading text from different types of columns. Reading text from two-column type was found to require less processing efforts, and as a result less cognitive load.

Originality/value - Using EEG, this study examined the neural consequences of reading in single- and multiple-column types on cognitive load. The findings can be used to enrich the current instructional design practices on the potential of using a certain number of columns in facilitating learners' cognitive performance.

Keywords: Reading and learning, Learning experience, Cognitive load, Typography, Information processing

Article classification: Research paper

Introduction

Determining how different screen-based typography settings influence users' ability to process and understand information has always been the main concern of instructional and system designers (Al-Samarraie *et al.*, 2017; Black *et al.*, 2017; Walker, 2017). Current research on screen-based typography has consistently encouraged researchers to provide a deeper insight into the impact of different reading settings in stimulating individuals to process information efficiently (Flynn, 2018; Triggs and Atzmon, 2017). This is mainly attributed to the lack of empirical evidence in previous studies which tend to heavily rely on traditional methods (reaction time, survey, observation, etc.) in testing users' interaction and information processing experiences (e.g., learning).

Research on typography emphasize the importance of identifying best design parameters that can increase information processing capacity (Craig *et al.*, 1999; Felici, 2011; Harrower and Elman, 1995). Precisely, they acknowledged the importance of layout design in facilitating individuals' processing of information under different conditions of presentation. Previous studies on information processing have mainly focused on how characteristics of typography affect users' performance in visual tasks (reading, searching, browsing, etc.), depending on the way the state and behaviour of the domain are mapped into the syntax and dynamics of visual forms. For example, Iwashita *et al.*, (2001) proposed a cognitive framework for understanding the relationship between task characterization and task performance by examining the association between task (e.g., type and format) and response characteristics (e.g., accuracy, fluency, complexity). In two studies, dos Santos Lonsdale (2007, 2014) reported significant differences in users' performance when reading from different typographic layouts, particularly when layouts were conforming to certain legibility guidelines. Despite these studies, there continues to be debate on ways to measure and report the impact of design layout on users' cognitive and behavioural experiences.

Reading text from different layout types can potentially influence individuals' behavioural and affective responses, as evident from change in reading duration and number of fixations. Moys (2014), in addition, found that typographic layout of information can potentially influence readers' overall impressions of the content. Al-Samarraie *et al.* (2017) examined and compared the perceptual experience of 23 students while reading text (repeated and non-repeated conditions) arranged in a multi-column layout. They found that subjects' eye movements performed best in a three-column layout for repeated reading, and with one column for normal reading. Yen *et al.* (2011) found that the characteristics of typography and layout can play a key role in directing individuals' attention to the task. This is why effective visualizations may influence certain aspects of human cognition (e.g., attention and memory) (Patterson *et al.*, 2014). Previous studies have also investigated the effect of layout model on individuals' scrolling and reading behaviours on a computer. For example Braganza *et al.* (2009) found that using a certain design layout to read textual documents on computer monitors may gradually lead users to use it once they were familiar with it. Yet, the influence of using different column types on individuals' processing of information is not comprehensively addressed in these studies.

Cognition is one important aspect that has been neglected in previous studies, possibly due to the methodology used. Cognition involves the general category of actions that may directly contribute to the learning process. Theories of cognition, such as cognitive load theory (Sweller, 1994), have been commonly used to deliver successful principles of instructional design in various domains (Tuovinen and Sweller, 1999). Different cognitive related theories from different areas may not necessarily provide a clear indication of how the differentiation of representational formats can contribute to individuals' processing of learning materials (Dutke and Rinck, 2006). In addition, it seems that previous studies in this domain were mostly concerned about the visual perceptions and impression of readers when processing information from different design layouts. For example, Dyson (2004) found that single spacing and double columns were among the characteristics associated with more positive judgements. However, as other characteristics were also varied, the individual contributions of interlinear spacing and columns cannot be identified. Based on these, it can be noted that previous studies in the field were mostly concerned about the impact of layout design on individuals' reading time, accuracy, and comprehension. This study, therefore, investigated the influence of reading in single- and multiple-column types/layouts on individuals' cognitive load. Outcomes from this study can be used to enrich the current instructional design practices and provide new insights into reading as an interactive process, based on the relationship between readers' cognitive process and design layout characteristics.

Literature review

The application of brain-computer interface (BCI) has prompted investigators to consider more effective paradigms of gaze-independent stimulation. In the domain of human-computer interaction (HCI), the idea of managing the presentation of information reflects the importance for creating an interactive experience in order to enhance individuals' learning experience (Cutrell and Tan, 2008). According to Mach *et al.* (2010), the impact of presentation format on individuals' cognitive abilities is considered to be one important theme in the field of HCI. It has been argued that having consistency in an interface will help reduce the cognitive load placed on the working memory of individuals in different situations (Mendel and Pak, 2009). This concept is described in the following section.

Cognitive load theory

Previous works (e.g., Paas *et al.*, 2004, 2010; Sweller, 1994) of cognitive scientists in the context of cognitive load theory (CLT) have been focused on understanding cognitive processes (e.g., working memory and executive functioning) along with various environmental settings that would contribute to the development of individuals' abilities to perform specific skills. This includes understanding the effects of cognitive load on the way individuals process information, thus maintaining an optimal level of load in various settings. As such, measures for estimating individuals' cognitive load plays a key role in CLT research (Ayres and Paas, 2012).

The CLT assumes a relationship between the limited working memory and the unlimited long-term memory (Baddeley *et al.*, 1986), including the situation in which the learning materials are presented according to the capacity of one's working memory (e.g., the information that constitutes the instruction). In this regard, the CLT focuses more on the working memory capacity and on ways to promote learning by imposing adequate levels of cognitive load. The CLT relies on the concept of working memory load affected by the inherent nature of the material (intrinsic cognitive load) and by the manner in which the material is presented (extraneous and germane cognitive load). Sweller *et al.* (1998) acknowledged that learning, reflected by performance change, requires working memory capacity. That is, it forces a germane cognitive load on the individual. Germane cognitive load is vital for the construction and storage of schemata into the long-term memory (Sweller, 2010). In addition, the promotion of adequate and rich schemata is particularly central for learners to develop personally meaningful and transferable knowledge and understanding. This is referred to as *intrinsic cognitive load*, which is the portion of load that is imposed by the intrinsic characteristics of the task or subject matter. According to the CLT, the limitations of working memory are rarely taken into account in conventional instruction (Paas *et al.*, 2003). This is because the way of presenting materials tends to impose an extraneous cognitive load on working memory, whereas learning something requires shifting from extraneous to germane cognitive load. Extraneous load is the unnecessary mental burden that is caused by cognitively inappropriate design and presentation of information; in other words, cognitive processes that induce extraneous load do not contribute to learning. Thus, the more working memory resources devoted to extraneous load, the less are available to deal with intrinsic load and so the less learned and the higher the total cognitive load (Sweller, 2010). These components of CLT can be measured using various subjective and continuous measures (see the following section for more information).

Cognitive load measurement

Sweller (1994) identified cognitive load as the load enforced on working memory by the cognitive processes that learning materials evoke, and it can be measured at different levels. Cognitive load forms the basis of the CLT, according to which the most important characteristic of complex learning is that individuals must learn to deal with materials by incorporating an enormous number of interacting elements. However, different structures influence this interacting knowledge that needs to be processed simultaneously in the working memory (Van Merriënboer and Sweller, 2005). Previous studies on information processing and management have addressed the needs for decreasing extraneous cognitive load, managing intrinsic load, and optimizing germane load (Chen and Wu, 2015; Eldenfria and Al-Samarraie, 2019; Maranges *et al.*, 2017; Van Merriënboer and Sweller, 2010). To do so, different techniques have been used in the past for measuring cognitive load. This review of the literature showed that most previous studies on the CLT have considered subjective rating scales when it comes to assess differences in cognitive variables (Leppink *et al.*, 2013), such as an adapted version of the NASA-Task Load Index (NASA-TLX) by Hart and Staveland (1988), or the nine-point symmetrical category mental effort rating scale by Paas (1992).

In general, educators and researchers use these scales to determine the level of cognitive load of individuals after completing an activity or task. For example, in the case of Paas's (1992) subjective cognitive load scale, researchers ask their subjects to answer one question (e.g., "Please rate the amount of mental effort invested in the task") using a Likert scale from "very low mental effort" to "very high mental effort". In addition, some researchers use these scales after engaging their subjects with a series of tasks, in which case they presumably represent the overall cognitive load (Antonenko *et al.*, 2010; Zarjam *et al.*, 2011). This led Antonenko *et al.* (2010) to argue that the use of subjective rating scales may not necessarily offer an insight into fluctuations in instantaneous load over time, unless they are applied repeatedly within a task of varying duration. However, applying subjective rating scales multiple times may still not be sufficient enough to explain changes in individuals' cognitive performance. This is mainly due to the relatively large time intervals between presentations of the rating scale (more details can be found at Antonenko *et al.* (2010)).

On the other hand, continuous measure of cognitive load during task performance can provide some inferences regarding the data for specific instances of time (Schmeck *et al.*, 2015). In addition, using continuous measure of cognitive and functional ability can offer feasible alternatives to more subjective approaches. There are different techniques of cognitive load that have been explored in the literature, which can provide continuous measures at all levels (instantaneous, peak, accumulated, average, overall). For example, recent studies on cognitive load have shown the potential of using various physiological measures, such as heart rate variability (e.g., McDuff *et al.*, 2014) and eye movement (e.g., Sarsam and Al-Samarraie, 2018), in estimating cognitive or affective states of individuals of various ability levels. The literature also showed the role of other physiological techniques that are used in neuroscience, such as positron emission tomography (PET) and EEG, in measuring cognitive load for a range of cognitive processes.

EEG is a popular neuroimaging technique used to analyse electrical activity produced by the brain via electrodes that are placed on the scalp of the subject. These measurements vary predictably in response to changing levels of cognitive stimuli (Anderson *et al.*, 2011). The reliability and validity of using the EEG have been reported in many previous studies, showing that the EEG was sensitive enough to differentiate cognitive load with high precision (Murata, 2005). Based on these, the potential of using BCI, focusing in particular on EEG, as a cognitive load measurement can open new and interesting avenues for the development of individuals' cognitive abilities in relation to reading in single- and multiple-column types.

Methodology

A total of 30 university students were recruited in this study, all volunteering for extra credit. All students (27-29 years; 22 male and 8 female) were undertaking different post-graduate courses. They were asked to answer a set of self-rating forms prior to the experiment in order to determine their neurological and psychological history, including prior diagnosis of learning disabilities, brain injury, seizures, and current drug use. In addition, to ensure that all participants had similar cognitive deviancies, which would necessitate excluding participants from a non-clinical sample (Angelakis *et al.*, 2002), five psychometric tests were administered to them. These subtests included measuring the participants' linguistic and visuospatial skills using vocabulary and block design subtests of the Wechsler Adult Intelligence scale III; followed by the Integrated Visual and Auditory Continuous Performance test which measures attention and hyperactivity; the Letter-Word Identification test which measures pronunciation and paralexic reading; the Reading Vocabulary scale for assessing differences in individuals' word semantic/conceptual skills; and the Passage Comprehension test for measuring reading comprehension skills. Three participants (1 male and 2 female) were eliminated from further analysis. One of them showed increased alpha (7 to 13 Hz) activity in the frontal location from the Lifespan Normative Database (the acquisition and decline of higher skill processes); and two scored lower to one standard deviation from the norms on the five psychometric tests which indicate a possible attention deficit with a reading difficulty. Hence, because of deviations from normative data, these three subjects were excluded from the study, leaving us with 27 participants (21 male and 6 female). All the 27 subjects had no self-reported history of neurological or psychiatric illness and had normal or corrected-normal vision. Finally, participants were asked about their familiarity with the reading topic and all reported no familiarity.

A 14-channel EEG device (EMOTIV EPOC+) was used to examine the brain activation of all the participants in three reading conditions: one-column, two-column, and three-column. Instead of using different reading materials, one book that could be divided into shorter chapters was chosen in which related reading materials were introduced for each session. This was essential to increase experimental control because if reading materials were taken from different sources, variables, such as the level of difficulty, contextual knowledge of the story, or personal interests, of each participant may impact comprehension and engagement outcomes. For these reasons, "dead starts" were selected from one book entitled *Black Holes and Strings: Searching for Nature's Secret Code* by Herman Verlinde as the main topic for this study, see Figure 1. The number of words in the three reading conditions was 205 words in one-column format, 213 in two-column format, and 191 words in three-column format.

The appropriateness of the reading materials was assessed by three English language experts (10-14 years of experience) in order to ensure that differences in brain activation among subjects are not affected when the content of reading materials changes. They were asked to assess the level of difficulty of reading materials across all sessions. This includes judging the syntactic and semantic plausibility of reading materials for each condition, which were achieved by asking them to rate the reading materials for each session. Although the selection of a suitable neutral condition can be problematic (Liu *et al.*, 1999), reading conditions similar to Baker (2006) and Al-Samarraie *et al.* (2017) served as the neutral baseline against which priming was measured. At the end of the reading materials assessment, the inter-rater reliability (r) results for the syntactic and semantic plausibility between the three experts were 0.87 and 0.94, respectively.

One-column text

Although their existence has only recently been recognized, black holes have already taken a significant place in our collective consciousness. This was especially evident two years ago, during the wave of publicity surrounding the launch of the ’Large Hadron Collider, the latest expensive particle accelerator near Gen ‘eve. Briefly there were whispered rumors that this device might be able to produce tiny, microscopic black holes. This rumor, while clearly unfounded, almost led to worldwide panic among the general public. This frightening reputation is largely deserved. A black hole is the embodiment of the destructive darkness, the emptiness from which information will never return, and the horizon where our knowledge ends. Even theoretical physicists, that try to unravel the mysteries of black holes from the safe perspective of mathematical equations have nightmares about them. For a long time, the simple fact of their existence seemed sufficient to seriously destabilize the three fundamental pillars of modern physics - relativity, quantum mechanics, and thermodynamics. Stephen Hawking, who gained his fame by robbing black holes of some of their most valuable secrets, even suggested that the natural laws may have to forego their last remaining predictive power. Einstein’s special theory of relativity describes how space and time are interdependent.

Two-column text

It is about time for string theory to enter the scene. String theory is based on the (at first sight bold) hypothesis that all elementary particles such as electrons, quarks, photons and gluons, look like tiny strings, vibrating filaments the size of the Planck length. From this assumption follows a fascinating world, which closely resembles the universe in which we find ourselves, and in which gravity and quantum mechanics can happily coexist. String theory was discovered more than forty years ago, partly by accident, from an attempt to understand the strong nuclear force. The approach was temporarily suspended because a better theory was found: quantum chromodynamics, the theory of quarks and gluons, which we discussed earlier. Luckily, Gerard ’t Hooft derived that quantum chromodynamics, when correctly viewed, looks exactly like a string theory. He showed that gluons, as befits true glue particles, tend to stick together by stringing up long cords, which bind the quarks together. This string of gluons creates the strong nuclear force, which hold the quarks captive inside atomic nucleus. As it turns out, a string of gluons behaves in exactly the same fashion as the ‘string’ in string theory. The existence of strings can thus be deduced, as a logical consequence of the experimentally confirmed theory of strong interactions.

Three-column text

A black hole is, as it were, trying to tear time apart: a perfectly functioning watch that is located very close to a black hole horizon, will appear to be standing still when viewed by an outside observer. A nanosecond on the horizon takes an eternity for an outside observer, a full millennium in our national history passes, when measured by the watch on the horizon in less than an instant. This absurd time distortion is reminiscent of Zeno’s paradox. And just as Achilles must surrender to the turtle, the black hole must abide by the rules of the world of the fastest and smallest: the theory of quantum gravity. But how can we find out what the surface of a perfectly smooth black sphere, a great dark nothing, looks like at the smallest scale? Here comes the third pillar, thermodynamics – the theory of ignorance, to the rescue. It turns out that black holes indeed behave according rules that look exactly like the laws of thermodynamics. Just as entropy can only increase with time, a large black hole can only become bigger and bigger by gobbling up more and more matter.

Figure 1. Reading materials

Prior to the experiment, each participant was briefed about the study prior to the experiment and asked to sign a consent form. All participants were asked to silently read text passages in the three conditions (randomly) by showing an instruction page on the screen for the subjects to read. Subjects were then asked if they understood what was required of them. Then, all the participants were asked to press the space bar to begin the reading task. During the experiment, the participants were sitting in a comfortable chair, the room was darkened and protected against noise. Each reading session took approximately 120-140 seconds with a five-second rest between reading sessions (Figure 2). All reading conditions were randomly displayed on 14.5" screen with viewing distance of 70 cm. For example, participants were asked to participate in three reading conditions (single-, two-, and three-column layout) with different reading materials in each condition. The order of these materials was random in order to control for a potential lateral bias. In the first reading session, nine subjects were assigned to a one-column layout at first, followed by a two-column layout, and a three-column layout. Then, another nine subjects were assigned to a two-column layout at first, followed by a one-column layout, and a three-column layout. Finally, nine subjects were assigned to a three-column layout, a one-column layout, and a two-column layout, respectively. Prior to the experiment, a baseline period of 15 seconds was recorded with participants looking at a white screen.

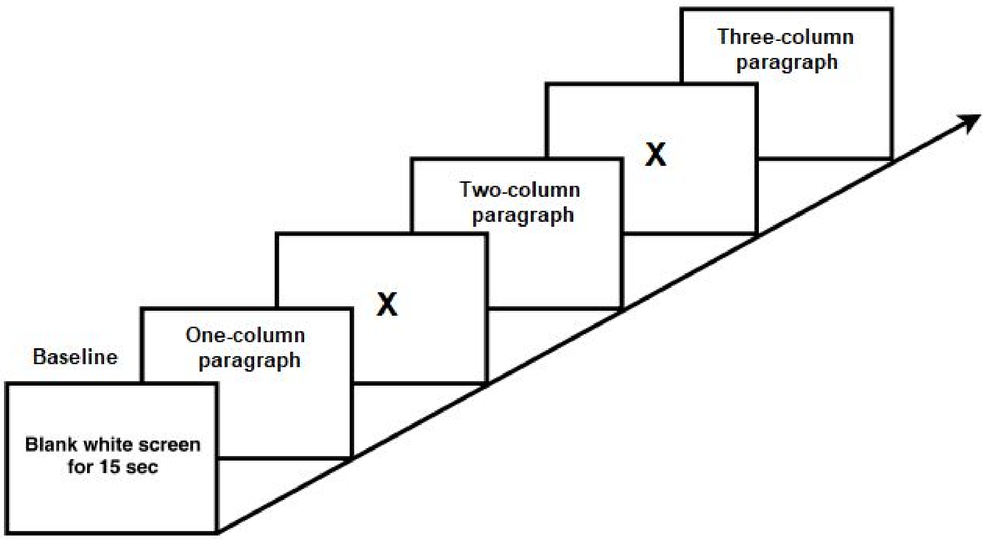

Figure 2. Reading flow (reading conditions were randomly assigned across subjects)

EEG data acquisition
The EEG data were recorded from 14 electrodes with two reference channels attached to the mastoid bones (behind the ears) of each participant. The location of each sensor was determined by the International 10-20 system using channel names of AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. A small USB dongle was used to transmit the EEG signals wirelessly from the subject's brain to the computer. Each second, 128 EEG signals were transmitted and converted to theta, alpha, beta, and sigma wave signals (ranging from 1 Hz to 40 Hz). Then Matlab software was used to process these signals.

Data pre-processing
Data from all participants were recorded and labelled using a unique code. The data were examined for potential noise and artefacts, such as eye blinks, eye movements, and muscle contractions, that could be included in the recording. These artefacts were identified and removed using the EEGLAB toolbox in the Matlab environment. Precisely, the continuous data were filtered with a low pass filter at lower edge 1 Hz in order to smooth the signal and eliminate higher frequency variations in the sampled data. Since the recorded EEG signals contained different data sources other than brain signals, independent component analysis (ICA) was used to separate and reject components that were linearly mixed in several sensors. The ICA method is designed based on the assumptions that the time series recorded on the scalp is a mixture of activities from independent sources of brain and artefacts, and that the summation of potentials arising from different parts of the brain, scalp, and body is linear at

the electrodes. The multiple artefact rejection algorithm (MARA) toolbox was then applied to identify and reject irrelevant components and noise. Precisely, MARA was used to reject all the EEG signals when participants clicked or performed any physical movement, including clicking the icon on the screen. As such, only EEG signals relevant to students' processing of reading materials were used for data analysis purposes.

Data analysis
To assess the participants' cognitive load from reading text in single- and multiple-column types, event-related desynchronization (ERD) and event-related synchronization (ERS) were used to estimate the activation interval divided by the baseline (reference) interval, based on the following equation (Pfurtscheller and Aranibar, 1977):

$$ERD/ERS\,\% = \frac{Baseline\ band\ power - task\ band\ power}{Baseline\ band\ power} * 100 \qquad \text{(Equation 1)}$$

According to Klimesch *et al.* (2005), measuring changes in alpha and theta brain wave rhythms can reveal what is happening in the individual's information processing situation, even if the person is unaware of the changes or is unable to verbalize them. This has led many researchers to consider measuring alpha and theta activity as an indication of individual's cognitive load in a variety of task demands.

Results and discussions
To ensure that reading materials used in this study did not affect the participants' brain activation in the three column formats, a one-way ANOVA was used. The ANOVA results confirmed there was no statistically significant difference between the participants related to their brain activation ($p = 0.84$). The brain activation of participants ($n = 27$ subjects) was not modulated by the reading materials. Then, the results of ERD/ERS in terms of alpha and theta brain wave bands for one-, two-, and three-column layouts were analysed. Changes in band powers from the baseline condition to the three design layouts were extracted and compared (Figure 3).

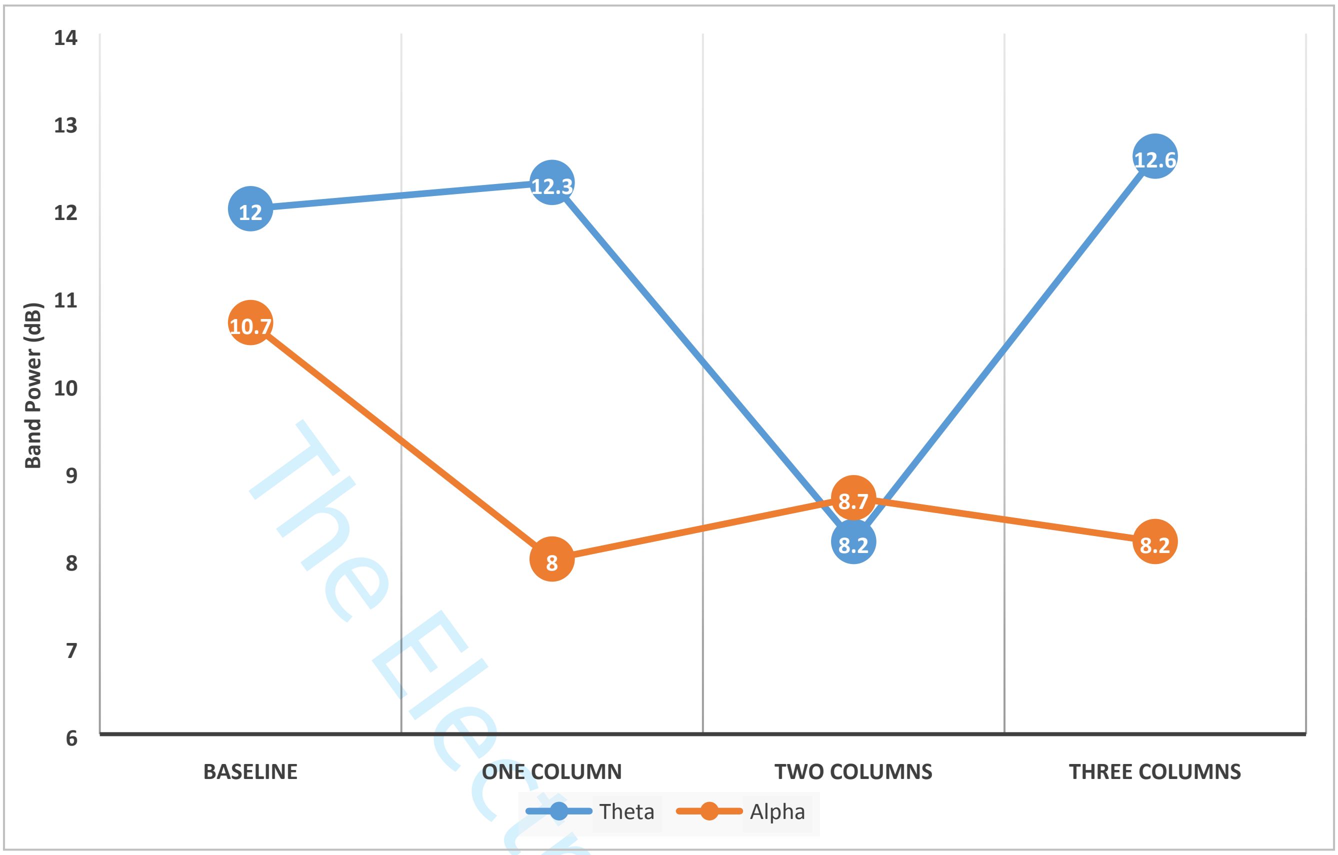

Figure 3. Theta and alpha band power changes when reading in single- and multiple-column types

From Figure 3, it can be seen that there is a significant difference (in both theta and alpha bands) in readers' cognitive load levels when reading in different column types. According to the theta rhythm (Table I), there was a statistically significant difference between reading conditions as determined by one-way ANOVA ($F(2,24) = 3.013$, $p = .020$). A Tukey post hoc test revealed that the theta results were statistically significantly lower when reading in two-column ($p = .046$) as compared to reading in one-column and three-column, respectively. There was no statistically significant difference between reading in the one-column and three-column layouts ($p = 0.262$).

According to the alpha rhythm, there was a statistically significant difference between reading conditions as determined by one-way ANOVA ($F(2,24) = 1.5733$, $p = .031$). A Tukey post hoc test revealed that the alpha results were statistically significantly lower when reading in two-column ($p = .041$) as compared to reading in three-column and one-column, respectively. There was no statistically significant difference between reading in the one-column and three-column layouts ($p = 0.262$).

Table I. Theta and alpha results

	Wave	Channels	Average power	
One-column		Channel T7	9.1	
	Theta	Channel P7	15.2	12.3 dB
	(4 – 8 Hz)	Channel T8	9.6	16.9
		Channel P8	12.4	
		Channel O1	8.2	8 dB
	Alpha	Channel O2	7.8	6.3

	(8 – 12 Hz)			
Two-column	Theta *(4 – 8 Hz)*	Channel T7	6.7	
		Channel P7	9.3	8.2 dB
		Channel T8	9	6.7
		Channel P8	7.4	
	Alpha *(8 – 12 Hz)*	Channel O1	7.1	8.7 dB
		Channel O2	9.9	7.5
Three-column	Theta *(4 – 8 Hz)*	Channel T7	11.8	
		Channel P7	12.7	12.6 dB
		Channel T8	11.9	18.3
		Channel P8	13.8	
	Alpha *(8 – 12 Hz)*	Channel O1	7.1	8.2 dB
		Channel O2	9.0	6.5

According to Gevins and Smith (2000), the theta band power increase or decrease according to the task difficulty (synchronizes), while the alpha band power decrease with the increase in task complexity (desynchronizes), and vice versa. A positive ERD/ERS value indicates a decrease in band power (ERD), whereas a negative value indicates an increase in band power (ERS). In the experiment, the ERD /ERS value for the theta and alpha bands was -6.8 percent and 46.2 percent, respectively, in one-column format; 58 percent and 36.6 percent in two-column format; and -15.5 percent and 44.4 percent in three-column format. Based on these, it can be concluded that reading text from two-column type had significantly lower the cognitive load level among students. On the other hand, reading text in single-column resulted in a higher cognitive load level.

In addition, Figure 4 shows the heat map of the participants' brain activity while reading in single- and multiple-column types. From the figure, it can be noted that both theta and alpha power bands were mostly activated in the layout of two-column, one-column, and three-column, respectively. This study confirms the assumption made by Al-Samarraie *et al.* (2017) that the design feature of two-column layout might be correlated with the cognitive workload a user needs to employ in order to learn from the text.

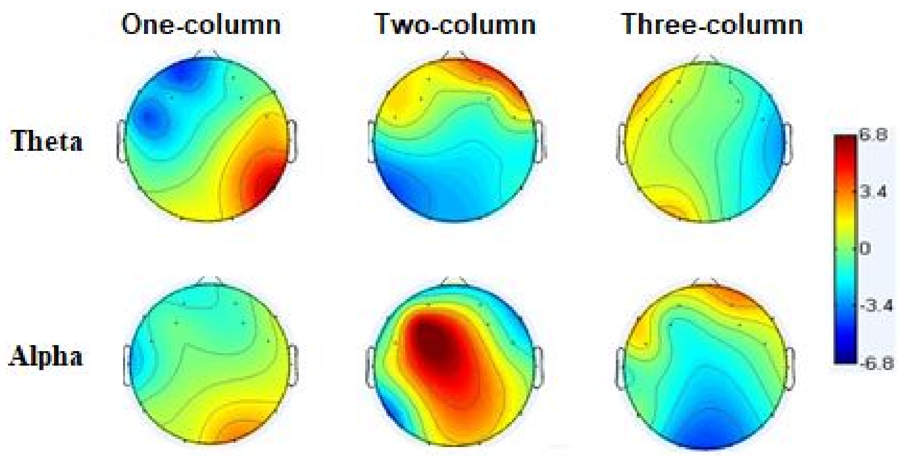

Figure 4. A heat map of the participants' brain activation while reading text in single- and multiple-column types

From a cognitive perspective, presenting information in single column text format typically requires a lot of eye-movements horizontally (Kurniawan and Zaphiris, 2001) which, as a result, may negatively influence the user's search for and processing of information. This is because reading straight text in one column makes it difficult for an individual to get to the next idea (Venig and Solovyova, 2016). However, presenting text in multiple-column formats may add additional difficulties to the user, thus influencing the efficiency of search performance. Still, reading text in two- or three- column layouts may impose particular visual cues to reinforce the cues within an individual's perceptual system (Al-Samarraie *et al.*, 2017).

As a summary, EEG channels of P7-8 and T7-8 (occipital lobe) have recorded a greater amplitude of brain activation in response to the two-column stimuli, followed by one- and three-column types. Brain activation in the occipital lobe, and slightly across the frontal lobe, can be visually inspected (Figure 3, two-column). Since activation of the occipital lobe is associated with processing visual stimuli and is consistent with reading-specific activation found in previous studies (e.g., Chilosi *et al.*, 2006; Sun *et al.*, 2013), it is reasonable to say that reading in two-column layout seems to add to this activation through the facilitation of cognitive information processing activities. The finding supports a few previous studies, such as Buchweitz *et al.* (2009), who found that more activation in the left inferior occipital lobe can be resulted when performing a reading comprehension task.

From a global perspective, analysing the brain activity of a person can enable researchers to determine the best design conditions needed for a person to process and acquire information from a document. This study provides some insights into the role of information layout design effect on individuals' cognitive load. It also provides directions for future research about the potential of using two-column layout in facilitating visual processing of the target stimuli and preventing confusion when processing stimuli irrelevant to the behavioural goal.

Conclusion

This study examined the cognitive processes that users experience when reading text from single- and multiple- column layouts. The EEG results (evident from the theta and alpha band power) showed that reading text in two-column layout can potentially offer a better reading experience by improving the cognitive functions associated with the way information is displayed. This means that the type of design layouts may impose additional cognitive burden on the user which can result in increasing or decreasing cognitive correspondence. Outcomes from this work can help typographic and educational designers to understand how using certain layouts can facilitate users' brain activity, thus improving cognitive performance. Despite this, there are still some limitations to be overcome. For example, this study was limited to examining students' cognitive load in a task-specific setting. In addition, the sample size of 27 students is suitable for EEG studies but not for other qualitative and quantitative studies. We believe that the representation of digital text should comply with modern users' demands. Therefore, future studies may consider examining other emotional and behavioural consequences from using different layout formats. Future studies may also explore individuals' brain activity during exposure to text in different languages and attentional contexts.

References

Al-Samarraie, H., Sarsam, S.M., and Umar, I.N. (2017), "Visual perception of multi-column-layout text: Insight from repeated and non-repeated reading", *Behaviour & Information Technology*, Vol. 36 No. 1, pp. 75-84.

Anderson, E.W., Potter, K.C., Matzen, L.E., Shepherd, J.F., Preston, G.A. and Silva, C.T. (2011, June), "A user study of visualization effectiveness using EEG and cognitive load", in *Computer Graphics Forum*, Vol. 30 No. 3, Blackwell Publishing Ltd, Oxford, pp. 791-800.

Angelakis, E., Lubar, J.F., Frederick, J. and Stathopoulou, S. (2002), "The role of slow-wave electroencephalographic activity in reading", *Journal of Neurotherapy*, Vol. 5 No. 3, pp. 5-25.

Antonenko, P., Paas, F., Grabner, R. and Van Gog, T. (2010), "Using electroencephalography to measure cognitive load", *Educational Psychology Review*, Vol. 22 No. 4, pp. 425-438.

Ayres, P. and Paas, F. (2012), "Cognitive load theory: New directions and challenges", *Applied Cognitive Psychology*, Vol. 26 No. 6, pp. 827-832.

Baddeley, A., Logie, R., Bressi, S., Sala, S.D., and Spinnler, H. (1986), "Dementia and working memory", *The Quarterly Journal of Experimental Psychology*, Vol. 38 No. 4, pp. 603-618.

Baker, R. (2006), *The Effects of Multiple Column Online Text on Reading Speed, Reading Comprehension, and Satisfaction*, Doctoral thesis (unpublished), Wichita State University, Wichita, KS.

Black, A., Luna, P., Lund, O. and Walker, S. (2017), *Information Design: Research and Practice*, Taylor & Francis, London.

Braganza, C., Marriott, K., Moulder, P., Wybrow, M. and Dwyer, T. (2009, April), "Scrolling behaviour with single- and multi-column layout", in *Proceedings of the 18th International Conference on World Wide Web*, ACM, pp. 831-840.

Buchweitz, A., Mason, R.A., Tomitch, L., and Just, M.A. (2009), "Brain activation for reading and listening comprehension: An fMRI study of modality effects and individual differences in language comprehension", *Psychology & Neuroscience*, Vol. 2 No. 2, pp. 111-123.

Chen, C.-M. and Wu, C.-H. (2015), "Effects of different video lecture types on sustained attention, emotion, cognitive load, and learning performance", *Computers & Education*, Vol. 80 No. 1, pp. 108-121.

Chilosi, A.M., Brovedani, P., Moscatelli, M., Bonanni, P. and Guerrini, R. (2006), "Neuropsychological findings in idiopathic occipital lobe epilepsies", *Epilepsia*, Vol. 47 No. 1, pp. 76-78.

Craig, J., Meyer, S.E. and Bevington, W. (1999), *Designing with Type: A Basic Course in Typography* (4th ed.), Watson-Guptill, New York, NY.

Cutrell, E. and Tan, D. (2008, April), "BCI for passive input in HCI", in *Proceedings of CHI*, Vol. 8, ACM Press, New York, NY, pp. 1-3.

dos Santos Lonsdale, M. (2007), "Does typographic design of examination materials affect performance?", *Information Design Journal*, Vol. 15 No. 2, pp. 114-139.

dos Santos Lonsdale, M. (2014), "The effect of text layout on performance", *Information Design Journal*, Vol. 21 No. 3, pp. 1-25.

Dutke, S. and Rinck, M. (2006), "Multimedia learning: Working memory and the learning of word and picture diagrams", *Learning and Instruction*, Vol. 16 No. 6, pp. 526-537.

Dyson, M.C. (2004), "How physical text layout affects reading from screen", *Behaviour & Information Technology*, Vol. 23 No. 6, pp. 377-393.

Eldenfria, A. and Al-Samarraie, H. (2019), "The effectiveness of an online learning system based on aptitude scores: An effort to improve students' brain activation", *Education and Information Technologies*, available at: https://doi.org/10.1007/s10639-019-09895-2 (accessed April 2019).

Felici, J. (2011), *The Complete Manual of Typography: A Guide to Setting Perfect Type*, Peachpit Press, Berkeley, CA.

Flynn, P. (2018), "Usability and digital typography", in *The Wiley Handbook of Human Computer Interaction*, Vol. 1 No. 1, pp. 89-108.

Gevins, A. and Smith, M.E. (2000), "Neurophysiological measures of working memory and individual differences in cognitive ability and cognitive style", *Cerebral Cortex*, Vol. 10 No. 9, pp. 829-839.

Harrower, T. and Elman, J.M. (1995), *The Newspaper Designer's Handbook*, McGraw-Hill, New York, NY.

Hart, S.G. and Staveland, L.E. (1988), "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research", *Advances in Psychology*, Vol. 25 No. 1, pp. 139-183.

Iwashita, N., McNamara, T., and Elder, C. (2001), "Can we predict task difficulty in an oral proficiency test? Exploring the potential of an information-processing approach to task design", *Language Learning*, Vol. 51 No. 3, pp. 401-436.

Klimesch, W., Schack, B. and Sauseng, P. (2005), "The functional significance of theta and upper alpha oscillations", *Experimental Psychology*, Vol. 52 No. 2, pp. 99-108.

Kurniawan, S.H. and Zaphiris, P. (2001), "Reading online or on paper: Which is faster?", in *Proceedings of the 9th International Conference on Human Computer Interaction*, Lawrence Erlbaum Associates, Inc., Mahwah, NJ, pp.220-222.

Leppink, J., Paas, F., Van der Vleuten, C.P., Van Gog, T. and Van Merriënboer, J.J. (2013), "Development of an instrument for measuring different types of cognitive load", *Behavior Research Methods*, Vol. 45 No. 4, pp. 1058-1072.

Liu, S.R., Chiarello, C. and Quan, N. (1999), "Hemispheric sensitivity to grammatical cues: Evidence for bilateral processing of number agreement in noun phrases", *Brain and Language*, Vol. 70 No. 3, pp. 483-503.

Mach, Q.H., Hunter, M.D. and Grewal, R.S. (2010), "Neurophysiological correlates in interface design: An HCI perspective", *Computers in Human Behavior*, Vol. 26 No. 3, pp. 371-376.

Maranges, H.M., Schmeichel, B.J. and Baumeister, R.F. (2017), "Comparing cognitive load and self-regulatory depletion: Effects on emotions and cognitions", *Learning and Instruction*, Vol. 51 No. 1, pp. 74-84.

McDuff, D., Gontarek, S. and Picard, R. (2014, August), "Remote measurement of cognitive stress via heart rate variability", in *36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE, pp. 2957-2960.

Mendel, J. and Pak, R. (2009, October), "The effect of interface consistency and cognitive load on user performance in an information search task", in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 53 No. 22, SAGE Publications, Los Angeles, CA, pp. 1684-1688.

Moys, J.-L. (2014), "Typographic layout and first impressions: Testing how changes in text layout influence reader's judgments of documents", *Visible Language*, Vol. 48 No. 1, pp. 1-17.

Murata, A. (2005), "An attempt to evaluate mental workload using wavelet transform of EEG", *Human Factors*, Vol. 47 No. 3, pp. 498-508.

Paas, F., Renkl, A. and Sweller, J. (2004), "Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture", *Instructional Science*, Vol. 32 No. 1, pp. 1-8.

Paas, F., Tuovinen, J.E., Tabbers, H. and Van Gerven, P.W. (2003), "Cognitive load measurement as a means to advance cognitive load theory", *Educational Psychologist*, Vol. 38 No. 1, pp. 63-71.

Paas, F., Van Gog, T., and Sweller, J. (2010), "Cognitive load theory: New conceptualizations, specifications, and integrated research perspectives", *Educational Psychology Review*, Vol. 22 No. 2, pp. 115-121.

Paas, F.G. (1992), "Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach", *Journal of Educational Psychology*, Vol. 84 No. 4, pp. 429-431.

Patterson, R.E., Blaha, L.M., Grinstein, G.G., Liggett, K.K., Kaveney, D.E., Sheldon, K.C., Havig, P.R. and Moore, J.A. (2014), "A human cognition framework for information visualization", *Computers & Graphics*, Vol. 42 No. 1, pp. 42-58.

Pfurtscheller, G. and Aranibar, A. (1977), "Event-related cortical desynchronization detected by power measurements of scalp EEG", *Electroencephalography and Clinical Neurophysiology*, Vol. 42 No. 6, pp. 817-826.

Sarsam, S.M. and Al-Samarraie, H. (2018), "Towards incorporating personality into the design of an interface: A method for facilitating users' interaction with the display", *User Modeling and User-Adapted Interaction*, Vol. 28 No. 1, pp. 75-96.

Schmeck, A., Opfermann, M., van Gog, T., Paas, F. and Leutner, D. (2015), "Measuring cognitive load with subjective rating scales during problem solving: Differences between immediate and delayed ratings", *Instructional Science*, Vol. 43 No. 1, pp. 93-114.

Sun, G., Yao, S. and Carretero, J.A. (2013, August), "Evaluating cognitive efficiency by measuring information contained in designers' cognitive processes", in *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (*ASME '13)*, American Society of Mechanical Engineers, pp. V005T06A029-V005T06A029.

Sweller, J. (1994), "Cognitive load theory, learning difficulty, and instructional design", *Learning and Instruction*, Vol. 4 No. 4, pp. 295-312.

Sweller, J. (2010), "Element interactivity and intrinsic, extraneous, and germane cognitive load", *Educational Psychology Review*, Vol. 22 No. 2, pp. 123-138.

Sweller, J., Van Merriënboer, J.J. and Paas, F.G. (1998), "Cognitive architecture and instructional design", *Educational Psychology Review*, Vol. 10 No. 3, pp. 251-296.

Triggs, T. and Atzmon, L. (2017), *The Graphic Design Reader*, Bloomsbury Academic.

Tuovinen, J.E. and Sweller, J. (1999), "A comparison of cognitive load associated with discovery learning and worked examples", *Journal of Educational Psychology*, Vol. 91 No. 2, pp. 334-341.

Van Merriënboer, J.J. and Sweller, J. (2005), "Cognitive load theory and complex learning: Recent developments and future directions", *Educational Psychology Review*, Vol. 17 No. 2, pp. 147-177.

Van Merriënboer, J.J. and Sweller, J. (2010), "Cognitive load theory in health professional education: Design principles and strategies", *Medical Education*, Vol. 44 No. 1, pp. 85-93.

Venig, S.B. and Solovyova, V.A. (2016), "Eye-tracking: Regularities of educational information searching", in *International Annual Edition of Applied Psychology: Theory, Research, and Practice,* Vol. 1 No. 3, pp. 1-23.

Walker, S. (2017), "Research in graphic design", *The Design Journal*, Vol. 20 No. 5, pp. 549-559.

Yen, N.-S., Tsai, J.-L., Chen, P.-L., Lin, H.-Y. and Chen, A.L. (2011), "Effects of typographic variables on eye-movement measures in reading Chinese from a screen", *Behaviour & Information Technology*, Vol. 30 No. 6, pp. 797-808.

Zarjam, P., Epps, J. and Chen, F. (2011, August), "Spectral EEG features for evaluating cognitive load", in *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE, pp. 3841-3844.