Towards understanding the differences between reading on paper and screen: measuring attention changes in brain activity

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Research paper

Abstract

Non-intrusive experimentation and measurements can be obtained from the latest neuroscience scanning techniques and technologies. Such technologies are now quite affordable and could possibly be used for the reading process research in information and communication sciences. The research experiment focuses on measuring the changes in attention while reading the text on different media (devices). The pilot experiment showed that cheap and easy to use brainwave measuring devices can be used for testing reading processes by measuring attention (concentration). The results revealed that a reading medium (device) affects the level of attention and suggested that less attention is needed to read from paper compared to any size or type of screen. Reading books (in a foreign language) can mostly be considered neutral on the attention level scale (slightly shifted towards 53 on a 1-100 scale).

KEYWORDS: reading, paper vs. screen, attention, brain activity

Introduction

In the last years neuroscientists have often argued about excitingly fresh ways of non-intrusive experimentation, measurements that can be obtained from sophisticated scanning techniques and technologies that include electroencephalography, positron emission tomography, functional magnetic resonance imaging, magnetoencephalography (Sturges 2014). Such technologies have become cheap and affordable and could possibly be used for the reading process research in information and communication sciences. The overview of previous research showed that eye movement metrics, perceived affordances, blink patterns, questionnaires (asking about the level of ocular discomfort during the task) were used to identify the differences between reading on paper and screen.

The experiment on how different text presentation modes affect eye movement metrics revealed that the differences in presentation format have a significant effect on fixation duration, number of fixations per minute, and number of regressions (Sharmin, Špakov and Räihä 2012). Another eye movement analysis of reading from computer displays, e-readers and printed books suggested that subjects' reading behavior is similar to reading from a printed book (Zambarbieri and Carniglia 2012). The perceived affordances of reading and writing on paper and digitally were compared by analyzing written essays and the results showed that readers perceive more positive than negative affordances regarding reading on paper, while reading on screen attracts fewer virtues (Taipale 2014). Yet another study compared blink patterns when reading from either a desktop computer monitor or a hard copy printed text under equivalent viewing conditions and found that when compared with an equivalent hard copy control condition, blink rates were not reduced during computer operation (Chu, Rosenfield and Portello 2014). Experiment on symptoms (ocular discomfort) following sustained computer use showed significantly worse results than those reported after hard copy fixation under similar viewing conditions (Chu et al. 2011).

This research experiment focuses on measuring the changes in attention while reading the text on different media (devices). Two research questions were formulated: (1) Can cheap and easy to use brainwave measuring devices be used for exploring reading processes by measuring activities such as attention (concentration) or meditation (relaxation)? (2) Does the reading medium (paper, screens of different type and size) affect the level of concentration (attention)?

Methodology

The last century of neuroscience research has greatly increased our knowledge about the brain and, in particular, the electrical signals emitted by neurons firing in the brain. The patterns and frequencies of these electrical signals can be measured by placing a sensor on the scalp. The *MindSet* hardware (Fig. 1) with the *NeuroSky ThinkGear*™ technology was chosen for the experiment (http://neurosky.com).

This equipment measures the analog electrical signals, commonly referred to as brainwaves, and processes them into digital signals to make the measurements available for games, applications or further analysis. The headset is an easy to use, non-invasive single dry sensor that reads brainwave impulses. In 2015 the price of the set was around $ 100. Together with this hardware, the *MindRec* software was used (in 2015 its price was $ 200; http://store.neurosky.com/products/mindrec). *MindRec* (Fig. 2) provides monitor-filtered raw signal, spectrum transition in real time and other electroencephalography components, such as delta, theta, alpha, etc. and attention, meditation data in real time. Also, the software allows the data recorded in real time to be exported into a CSV file for further analysis in SPSS or other analysis tools.

Figure 1. *MindSet* hardware

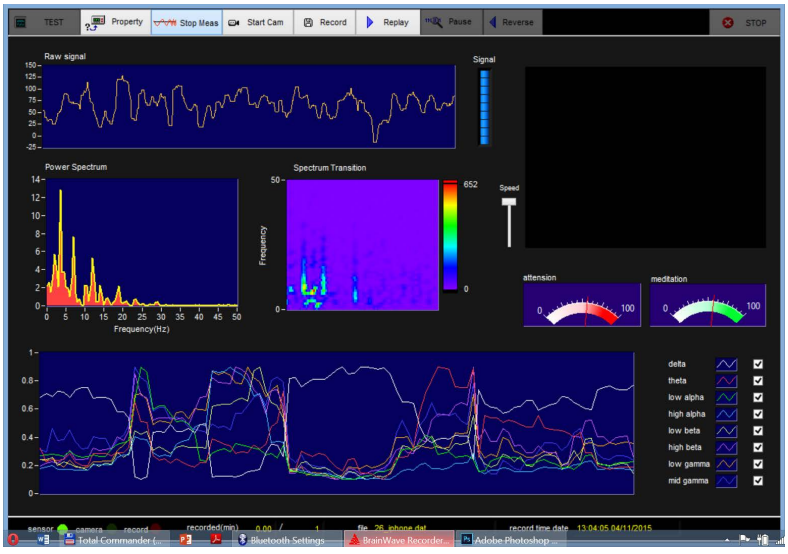

Figure 2. *NeuroSky MindRec* software

The technology includes the sensor that touches the forehead, the contact and reference points located on the ear pad, and the on-board chip that processes all of the data. Both the raw brainwaves and the *eSense Meters* (attention and meditation) are calculated. *eSense*™ is a *NeuroSky*'s proprietary algorithm for characterizing these mental states which have powerful capabilities when integrated into education, sports coaching, meditation, and other mind-controlled games. To calculate *eSense*, the *NeuroSky ThinkGear* technology amplifies the raw brainwave signal, removes the ambient noise and muscle movement. Then the *eSense* algorithm is applied to the remaining signal, resulting in the interpreted *eSense* meter values. Later, the values can be translated into effect or exported for further analysis. These values do not describe an exact number; instead, they describe the ranges of activity as a way

to show how effectively the user is engaging attention (similar to concentration) or meditation (similar to relaxation). In general, attention level can be controlled through a visual focus on a singular idea while meditation is a sense of peace and calm when the mind is clear of thoughts and distractions.

For each different type of *eSense* (i.e. attention, meditation), the meter value is reported on a relative *eSense* scale of 1 to 100. A value between 40 to 60 at any given moment in time is considered neutral and is similar in notion to baselines that are established in conventional brainwave measurement techniques (though, according to *NeuroSky*, the method for determining a *ThinkGear* baseline is proprietary and may differ from conventional brainwaves). A value from 60 to 80 is considered slightly elevated, and may be interpreted as levels tending to be higher than normal. Values from 80 to 100 are considered elevated, meaning that they are strongly indicative of heightened levels of that *eSense*. On the other end of the scale, values between 20 and 40 indicate reduced levels of the *eSense*, while values between 1 and 20 indicate strongly lowered levels.

The *eSense* attention meter indicates the intensity of a user's level of mental focus or attention, such as that which occurs during intense concentration and directed (but stable) mental activity. Distractions, wandering thoughts, lack of focus, or anxiety may lower the attention meter level. The reliability of such cheap headset device in measuring levels of attention (based on Alpha waveforms) is confirmed by few studies which suggests that result using such devices are comparable to EEG recorded from conventional lab-based equipment. The results of the experiment of Rebolledo-Mendez at al. (2009) suggest that the NeuroSky's MindSet provides accurate readings regarding attention, since there is a positive correlation between measured and self-reported attention levels. Another team of researchers (Rogers at al., 2016) evaluated the reliability of such single-channel, wireless EEG portable system using test-retest and reliable change analyses. They concluded, that a portable device may provide a viable alternative to conventional lab-based recording systems for assessing changes in electrophysiological signals, and further application to the study of brain function using the system can be encouraged. The results of Johnstone et al. (2012) study also suggest that the portable device has potential utility in certain EEG recording situations where ease of use is a priority.

In the course of the pilot experiment, silent reading of 6 respondents was carried out. Convenience sampling was used and two requirements on selecting respondents were considered: age 18-27 and familiarity with experiment devices (at least one year of experience on reading on smartphone, tablet computer and e-reader). Each respondent had to read the same excerpts from 2 books in English for 10 minutes with each device (iPad, iPhone, Kindle and printed book). All respondents were reading the texts in the same order on a different devices. After reading on one device,

respondents continue reading the given text on different device. English was not the respondents' native language, but they could speak and write in English fluently. The respondents were put in a quiet room with no disturbance and were reading silently on all four devices.

The reading devices were selected in order to cover various screen sizes (small to large) and types (LCD and e-ink). The main characteristics of the devices used (Fig. 3):

- Printed book (soft cover, pocket size);
- *iPad Air 2* with a large screen (9.7-inch, 2048x1536 pixel resolution at 264 ppi, LED-backlit with IPS technology);
- *Kindle Paperwhite* with a middle size screen (6-inch, 1334x750 pixel resolution at 212 ppi; Carta e-paper technology, 16-level gray scale);
- *iPhone 6* with a small screen (4.7-inch, 1334x750 pixel resolution at 326 ppi, LED-backlit with IPS technology).

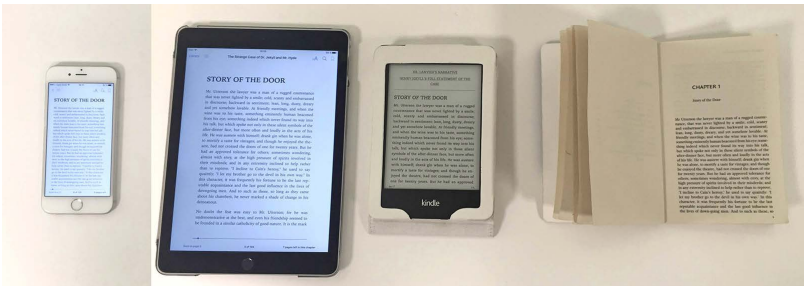

Figure 3. Devices used in the experiment

Two classical books were selected for the experiment: R. L. Stevenson's *The Strange Case of Dr Jekyll and Mr Hyde* (drama, horror fiction, thriller) first published in 1886 and A. Christie's *Appointment with Death* (crime fiction) published in 1938. These books were published in a pocket size format and as e-books in EPUB format.

Findings

During the experiment the *MindSet* hardware was put on each respondent's head and attention (one of *eSense* parameters) was measured with the *MindRec* software. In average 1964 measures (N) of attention (every each second of reading) was done with each device with six respondents. Later, the mean attention levels and other statistics (Table 1) were calculated for all readings ('one reading' means one respondent reading part of text from one book on one device) on different devices and books. The results showed that the printed book had the smallest mean value of attention, whereas iPad had the largest mean value (Fig. 4).

Table 1. Attention measuring statistics

Attention measures	iPad	iPhone	Kindle	Print
Mean	54.17	52.93	53.35	51.59
N	1975	1941	1976	1963
Std. Error of Mean	.432	.381	.441	.428
Median	54.00	53.00	53.00	51.00
Mode	54	53	50	50
Std. Deviation	19.196	16.766	19.613	18.944

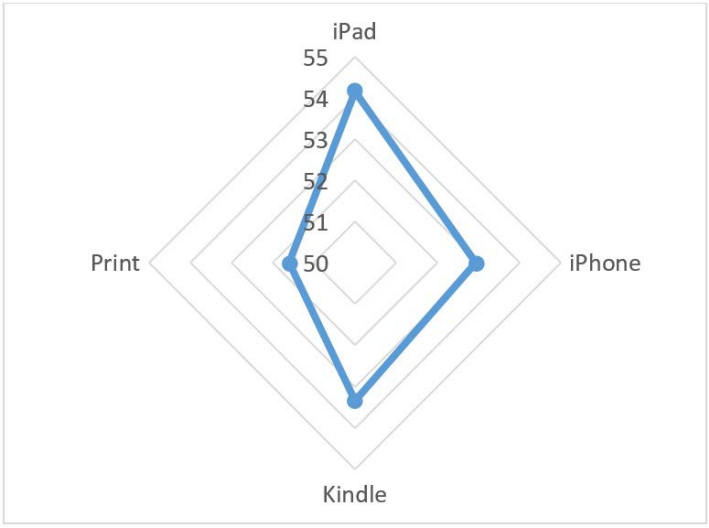

Figure 4. Mean attention levels for different reading devices

Later, the statistical significance of differences between the mean attention levels of four reading devices was calculated. Each of the four reading devices was paired to each other (Fig. 5); the paired samples test was completed and the paired differences of the mean attention levels were calculated. The paired samples test showed (with a 95% confidence interval) that the differences of the mean scores of all pairs are significant (the significance value for the change in attention is less than 0.05), except for the *iPhone-Kindle* pair (the significance value for the change in attention is more than 0.05).

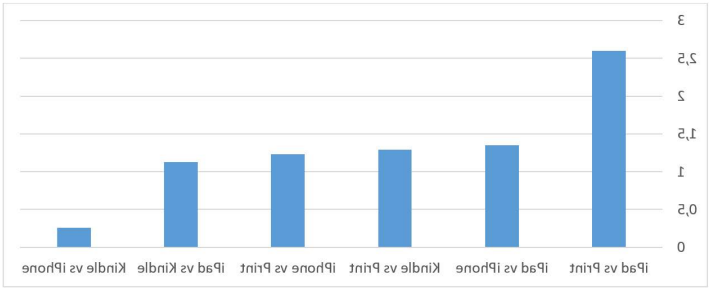

Figure 5. Differences in the mean attention levels between reading devices

What is more, the overall level of attention when reading on different devices (*iPad*, *iPhone*, *Kindle* and printed book) was analyzed. Taking the standard deviation (Fig. 6) into account, we can see that most of attention measurement values when reading books are in the neutral attention level and on the lower part of a slightly elevated attention level of *eSense*. Also, some of the values belong to the very upper part of the reduced attention level.

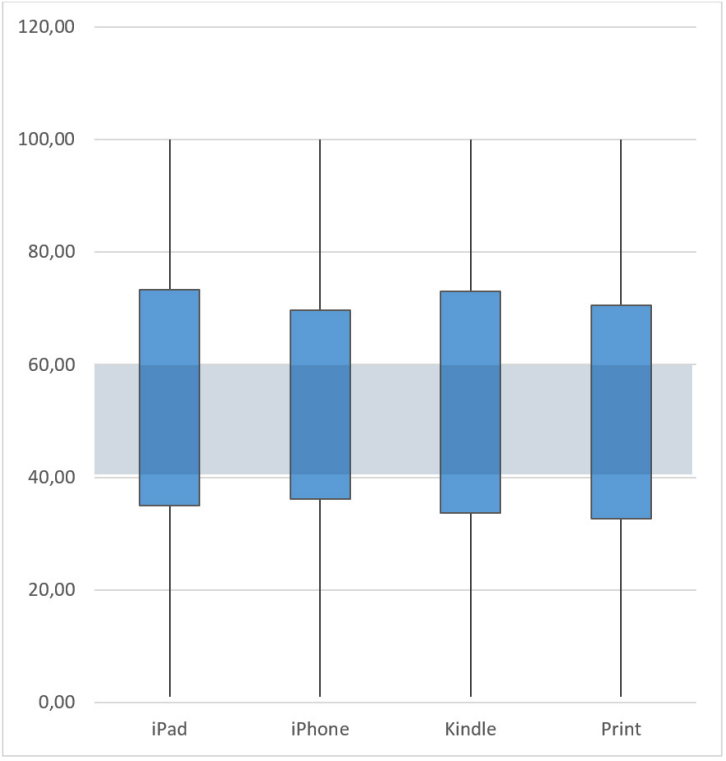

Figure 6. Attention measurement values when reading books on different devices

Standard deviation which means the amount of variation is the largest for a set of data values represented by *Kindle* and *iPad* devices and the smallest for *iPhone*.

The attention level measurements between two books showed very close (without a statistically significant difference) mean values: the overall mean attention score for Stevenson's book was 53.24 and 52.78 for Christie's book. It means that the content of the book was not affecting the level of attention or this effect was hardly noticeable. The books were close in their genre but by different authors and published with a 52-year interval.

Conclusions

The pilot experiment showed that cheap and easy to use brainwave measuring devices can be used for testing reading processes by measuring attention (concentration). The results when reading in English as a foreign language revealed that a reading medium (device) is affecting the level of concentration (attention). The *eSense* lowest mean attention level was measured when printed books were read and the highest for *iPad*, but *Kindle* and *iPhone* were also close. It suggests that less attention (concentration) is needed to read from paper in comparison to any size or type of screen. Therefore, the limitation of the pilot experiment (small convenience sampling of respondents) must be taken into account and in the future the results must be re-tested on a bigger sample. For the future studies measuring readers' understanding and remembrance of the texts they have read may also contribute to better understanding the differences between reading on paper and screen.

Reading books in a foreign language can mostly be considered neutral on the *eSense* scale representing the level of attention (slightly shifted towards 53 on a 1-100 scale). However, it should be noted that a minor part of measurements gets into the lower part of a slightly elevated attention level and some of the values belong to the very upper part of the reduced attention level. The two books used in the experiment were of similar genre and content and had very close mean attention levels, which supports the assumption that the reading medium (device) has an impact on the reading process.

For more accurate conclusions a larger respondent sample and more books of different genres and in different languages are required for the test.

Acknowledgements

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Sažetak

Prema razumijevanju različitosti u čitanju na papiru i ekranu: mjerenje promjena pozornosti u moždanoj aktivnosti

Nove tehnike i tehnologije skeniranja u neuro-znanosti nude neinvazivne eksperimente i mjerenja. takve tehnologije sada su pristupačne i mogu se koristiti za istraživanja procesa čitanja u informacijskim i komunikacijskim znanostima. Istraživački eksperiment usmjeren je na mjerenje promjena pozornosti tijekom čitanja teksta na različitim medijima (uređajima). Pilot-eksperiment je pokazao da se uređaji za mjerenje moždanih valova, koji su jeftini i jednostavni za korištenje, mogu koristiti za testiranje procesa čitanja mjereći pozornost (koncentraciju). Rezultati su pokazali da medij (uređaj) za čitanje utječe na razinu koncentracije i sugeriraju da je manje pozornosti potrebno prilikom čitanja na papiru u usporedbi s ekranom bilo koje veličine ili vrste. Čitanje knjiga (na stranom jeziku) većinom se može smatrati neutralnim na ljestvici razine pozornosti (malo pomaknuto prema 53 na 1-100 ljestvici).

Ključne riječi: čitanje, papir vs. ekran, pozornost, moždana aktivnost