Electronic vs. Printed: A Mobile Eye Tracking Study of Attention During Reading

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Abstract. Over 90 million people in the U.S. use e-readers. While there are many advantages to using e-readers, recent studies show that readers are more likely to correctly remember material from printed books than e-readers. It is not clearly understood why differences in memory emerge between the different mediums; however, it is thought that attentional differences could play a role. Information processing theories show that attention is one of the first steps in processing information and can affect later memory. In this study, we tested whether attention differs between these two mediums of reading. We used new mobile eye tracking technology to assess visual attention when reading both printed and electronic books to test if readers pay more attention to printed books than electronic books. In this experiment, 19 young adult participants read passages from a Kindle and printed book. We calculated the dwell time spent on text (i.e. time spent visually fixating on the text out of total fixations while reading) for both the Kindle and printed book conditions using Tobii Studio eye tracking software. We hypothesized that participants would spend more time looking at the text when reading a printed book compared to a Kindle. As hypothesized, participants had a significantly higher proportion of fixations on the text when reading on the printed book compared to the Kindle ($t = 2.75$, $p = 0.013$). Participants fixated on the text 87% of the time when reading on the printed book and 83% of the time when reading on the Kindle. These results suggest that people pay better attention when reading on books than on e-readers, which could help to explain why information is often remembered more successfully when using print mediums. This has important implications considering the large number of people who use e-readers. This study suggests that reading school or work-related passages on an e-reader may negatively affect both attention and information processing.

Keywords: eye movements, reading, electronic devices

1 Electronic vs. Printed: A Mobile Eye Tracking Study of Attention During Reading

According to a 2018 poll, nearly one in three people in the U.S. owns an e-reader [1]. This new technology has transformed the way our society reads and obtains knowledge, which may affect how we process information. However, little is currently known about the effects of this new technology on our ability to process information. Some advantages of reading on electronic books include their portability, the customizability of font sizes, styles, spacing, and lighting, and the ability to access over one million books through just one small screen through programs like Kindle Unlimited (Amazon.com, Inc., Seattle, WA). However, there may also be some disadvantages to using e-readers instead of printed books.

Studies suggest that printed books are better for memory, specifically information recall, compared to e-readers. A experiment led by researchers at Stavanger University in Norway gave students a short story and asked half of them to read the passage on a Kindle, while the other half read it from a printed copy [2]. Results showed that the Kindle readers were more likely to be unable to correctly remember the order of major plot points than the print readers. Another experiment provided participants with a PDF form of a text. Some read the material on a computer screen while others read a printed-out version of the PDF file3. Similar to the former study, this experiment showed that participants who read from the printed text were better able to recall and reproduce the material compared to the participants who read on the e-reader. Researchers are currently unsure of the cognitive mechanisms behind this difference.

One possible explanation lies in Atkinson and Shiffrin's Information Processing Theory [4]. Figure 1, which depicts this theory, shows that information is processed along several steps in a connected pathway that includes environmental input, attention, and memory. In this study, we focused on attention as an earlier stage of information processing that may have substantial downstream effects on memory.

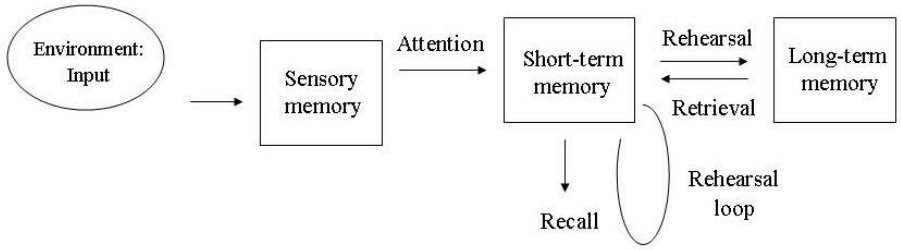

Fig. 1. Atkinson & Shiffrin's Information Processing Model ((from McLeod, S., 2017, February. Multi Store Model of Memory. Retrieved from https://www.simplypsychology.org/simplypsychology.org-Multi-Store.pdf))

According to the Information Processing Theory, when the brain is faced with stimuli from the environment, it goes through a filtering system that begins with sensory memory. In this step, the brain automatically perceives the stimuli and retains sensory impressions that last after the stimuli have ended. Next, the attention system is directed toward relevant or engaging stimuli. Information that is attended to then becomes stored in memory, starting with short term memory and entering into long-term memory after sufficient rehearsal. Attention is, therefore, the mechanism that is used to attain memory, meaning that to successfully remember something, you must first successfully perceive and then pay attention to it. Following this model, we propose that people are better able to retain information when reading printed books because they may pay better attention to the words when reading on print.

Millennials and Generation Z have grown up using electronics, most often for social media, games, television, and other fun activities that do not require much thought or attention span. Because of this, we are used to needing only a short attention span when on electronics, and we are generally not used to paying full attention to the content on various types of electronic screens5. It may be that as a result of this, users generalize the screen of an e-reader to other types of electronic screens containing the relatively thoughtless information they are accustomed to seeing. Therefore, users have potentially been trained to not use all of their mental resources if there is a screen in front of them as opposed to an actual piece of paper.

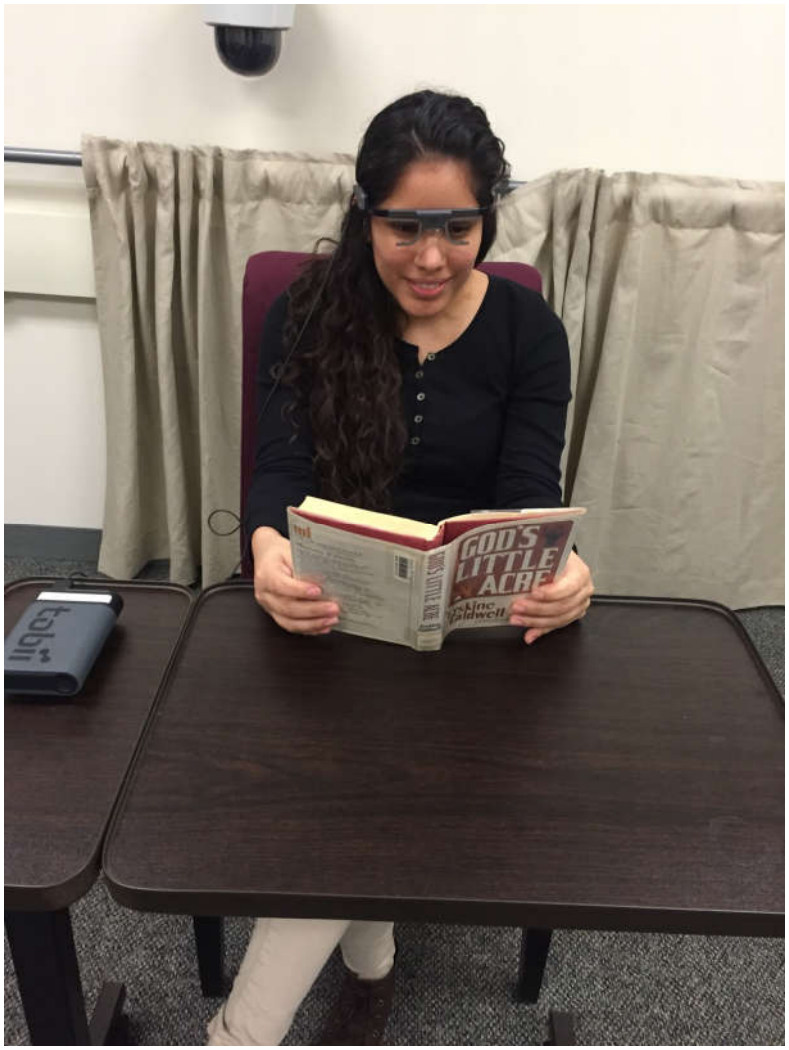

Fig. 2. Participant Wearing Eyetracking Glasses

Eye tracking is an ideal method for studying attention because it is a way to objectively observe people's gaze, which is a measure of their visual attention. When people look away from the words in a book, it means they are having a lapse in visual attention. In the past, eye tracking technology was not possible to use with printed books, because it only worked with computerized tasks. However, mobile eye tracking glasses have recently been designed and used to measure where people are looking while they do normal activities such as talking to a parent6, or in the case of this study, reading. The glasses, shown in Figure 2, look like regular reading glasses but have cameras facing both in and out, and use 3D technology to analyze exactly where the person wearing them is actually looking. In the current study, we utilized this new mobile eye tracking technology to test the possibility that people may pay more attention to printed books than electronic books. To test this, we had participants read passages from both a Kindle and printed book, and then we determined which medium resulted in more visual attention towards the text of the book. We hypothesized that participants would spend more time looking at the text when reading a printed book than when using a Kindle.

2 Methods

2.1 Participants

This study used 19 young adult participants, ranging in age from 20 to 32 years old (M = 25.26 years, SD = 3.62; 94.74% female; 94.74% Caucasian; 5.26% Hispanic/Latinx). Participants were graduate students, undergraduate students, and staff at a local university. They were recruited through electronic forms sent to possible participants. The inclusion of participants was limited to young adults aged 18 to 35, excluding people with serious health problems and people who need glasses to see.

2.2 Materials

Tobii Pro Glasses 2 (Tobii Technology, Inc., Falls Church, VA) were used to capture participants' gaze. Tobii's eye tracking glasses have four sensors, each with a 50 Hz sampling rate. There are infrared illuminators built in the glasses in order to support the sensors. Above the nose, there is a high definition camera used to capture the visual field (extending 80° horizontally and 52° vertically) of the participant wearing the glasses. This camera uses an image of the user's visual field to map out the location of their gaze within the field they are viewing. A printed version (published by The Modern Library) and Kindle version (published by Open Road Integrated Media) of the book God's Little Acre by Erskine Caldwell was selected for reading. This book was selected because it was similar to the Kindle in size and font. No participants reported having previously read this book. We used four different orders, alternating between having participants read the Kindle and printed book first, and between passage one and passage two of the book being read first. The reason we needed to counterbalance these variables was to control for any possible attention effects based on differences in order.

2.3 Procedure

First, participants signed a consent form and then put on the eye tracking glasses. In order to ensure that the glasses were correctly measuring where the participant was looking, we calibrated the glasses by placing a small card with a target in front of participants. A seven-minute timer was set and participants completed the reading task, following one of the four orders. After seven minutes, the participant was told to stop reading, given a short break if needed or requested, and asked to read from the other medium and passage for another seven minutes.

2.4 Data Processing and Analysis

We used Tobii Pro Glasses Analyzer software (Tobii Technology, Inc., Falls Church, VA) to estimate the position of participants' gaze point and the eyes' positions. We classified eye movements (e.g., fixations, saccades) based on procedures used in previous research with the Tobii glasses78. A consecutive string of raw data points with a velocity threshold of fewer than 30 degrees per second was considered a fixation. The "Real-World Mapping" function of Tobii's analyzer software superimposed each participant's fixations and raw gaze data onto a still snapshot from the glasses camera. We manually checked that the location of each individual fixation point was in the same place as the fixation projected onto the still image. If the location of the projected fixation was in a different place from the actual fixation captured, we manually corrected the individual fixation point. Participants who had less than 50% valid gaze data, as calculated by Tobii software, were not included in the final dataset. Twenty participants were recruited originally; however, one participant had to be removed due to insufficient gaze data, so our final dataset only consisted of 19 participants.

In order to analyze our data, we calculated the dwell time on the text for both the Kindle condition and the print condition. The dwell time on the text is a measure of the proportion of time participants were fixated on the words of the passages. To find this proportion, we drew an AOI, or area of interest, and Tobii Studio calculated the proportion of time each participant's gaze fixation was inside the AOI out of the amount of time participants fixated anywhere in the scene (i.e. whitespace, furniture, floor, etc.).

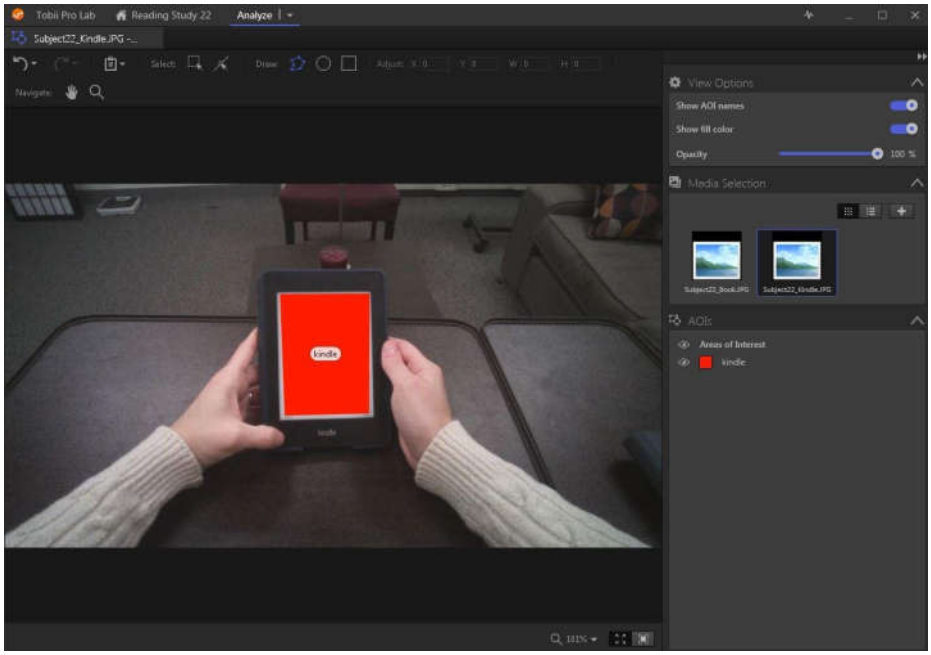

Fig. 3. Kindle AOI

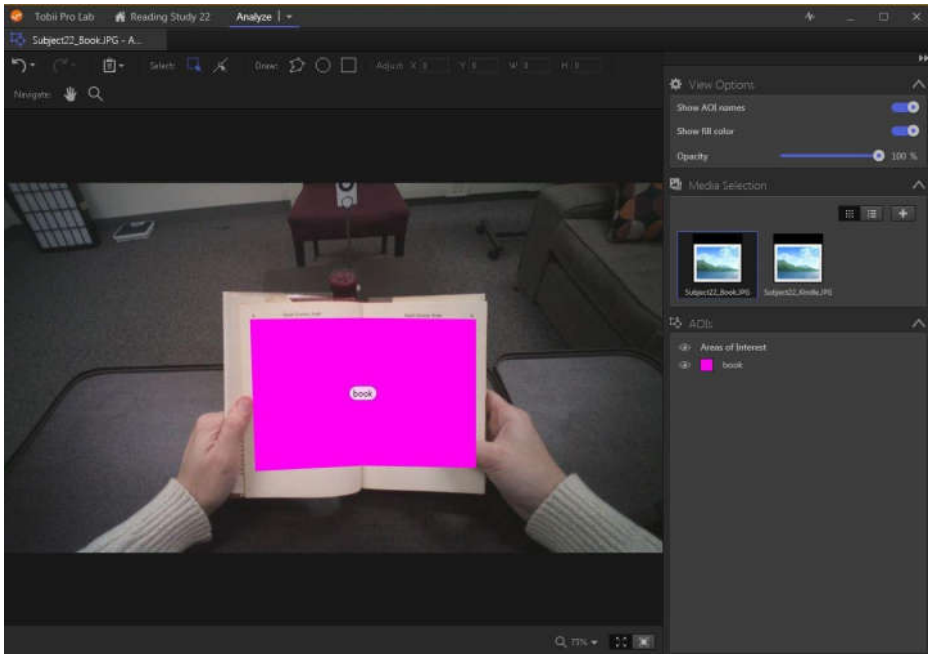

Fig. 4. Printed Book AOI

Figures 3 and 4 show AOI's drawn on the Kindle and printed book and Figure 5 shows the raw fixation data. Across all of the participants, dwell time inside the text while reading in the Kindle condition was compared with dwell time while reading in the print condition. Comparisons were made visually, by creating bar graphs, and statistically, by computing a paired sample t-test.

3 Results

ID	Fix_on_book	Total_Fix_w/Book	Proportion_Fix_Book	Fix_on_Kindle	Total_Fix_Kindle	Proportion_Fix_Kindle
1	1196	1363	0.88	1235	1371	0.90
2	1140	1413	0.81	829	1379	0.60
3	1195	1340	0.89	1376	1430	0.96
4	1025	1135	0.90	1064	1097	0.97
5	1187	1328	0.89	1175	1341	0.88
6	949	1041	0.91	952	1133	0.84
7	1606	1637	0.98	1604	1659	0.97
8	1217	1301	0.94	1115	1309	0.85
9	1309	1405	0.93	1381	1469	0.94
10	1373	1439	0.95	1100	1220	0.90
11	841	981	0.86	816	1038	0.79
12	1234	1527	0.81	1016	1434	0.71
13	1426	1630	0.87	1440	1662	0.87
14	1099	1407	0.78	1052	1337	0.79
15	1149	1177	0.98	981	1176	0.83
16	936	1326	0.71	731	1262	0.58
18	1038	1477	0.70	1040	1569	0.66
19	1157	1367	0.85	1232	1517	0.81
20	1327	1429	0.93	1315	1482	0.89

Fig. 5. Raw Fixation Data

The paired sample t-test showed that participants did differ in the proportion of fixations on the book compared to the proportion of fixations on the Kindle ($t = 2.75$, $p = 0.013$).

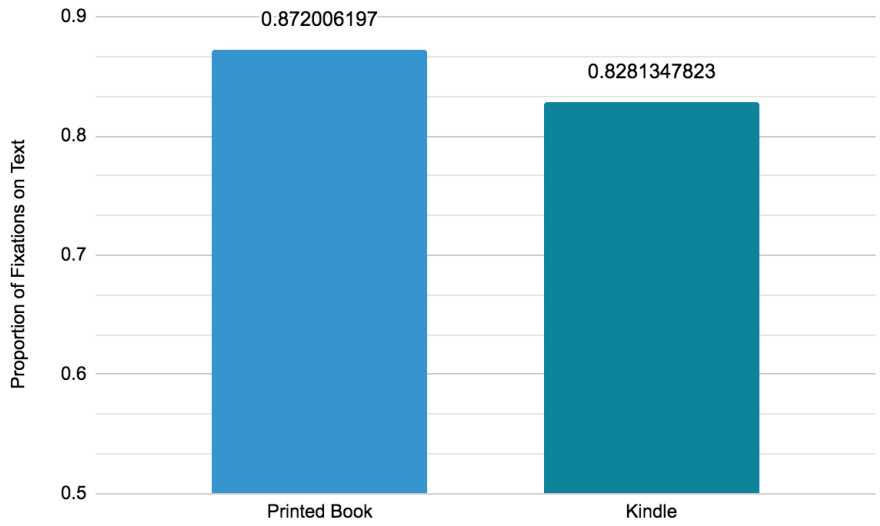

Fig. 6. Proportion of Fixations on Text w/ Kindle vs. Printed Book

As shown in Figure 6, the average proportion of time participants fixated on the text when reading the printed book (out of the total number of fixations on and off text when reading the printed book) was $M = 0.87$ ($SD = 0.08$). This means that participants were focused on the text 87% of the time when reading on the printed book. In contrast, the average proportion of time participants fixated on the text when reading the Kindle was $M = 0.83$ ($SD = 0.12$), indicating that participants fixated on the Kindle's text 83% of the time.

4 Discussion

The results of this study supported our hypothesis that participants would pay more attention to the text on a printed book than on a Kindle. Our results, which were statistically significant according to the t-test we conducted, showed

participants looking at the text of the passages about 87% of the time when reading on the printed book compared to 83% when reading on the Kindle. This suggests that people have more lapses of attention when reading on Kindles, and improved attention when reading the same material on a printed book.

This experiment has important implications considering how many people use e-readers. According to a 2018 survey, 90.5 million people in the U.S. use an e-reader [9]; therefore, these findings are relevant to a very large group of people. While reading for pleasure on an e-reader may not pose any significant disadvantages since content comprehension and accurate information recall are not required, it may be less advisable to use e-readers for school or work. This is because, based on the information suggested in this study, reading passages on an e-reader may negatively affect your ability to pay attention to and process the included information.

This finding could help explain why people have better memory when reading on printed books [10-11]. As shown in Figure 1, attention has downstream effects on memory processing [12], so if readers cannot maintain visual attention as successfully with electronic books as they can with printed books, then it will be much harder for the stimuli to be successfully processed in order arrive at short-term– and then long-term– memory rehearsals.

One limitation of this experiment is the small number of participants included. Due to our counterbalancing, there were only four to five participants per condition, so they may not have been representative of a larger population. Furthermore, we were unable to determine if there were any differences in attention based on the order in which participants read. Future research on this possibility could be conducted by reproducing this experiment and analyzing attentional differences between printed and electronic books across the different orders. It is also important to note that if any participants had requested a break in between reading the two passages, this could have led to inconsistencies that could have also had an effect on lapses in attention. However, since no participants in this study did request a break, our data were not affected by this possibility.

In addition, the majority of participants were Caucasian and female, so our results might not generalize to more diverse populations. It is also important to acknowledge that slight differences in layout existed between the printed and electronic forms of the text, and that these differences could have potentially contributed to differences in attention. For example, the printed book shows two pages at once, while the Kindle only shows one. Future research should rule out this factor as an alternative explanation by finding a book that only has text on either the right or left side of pages, or by creating a simulation of a book via printed PDFs.

It is also notable that even when reading from the printed book, participants still only paid attention to the text 87% of the time. Causes could include that they were in an unfamiliar setting, wearing unusual glasses, and reading a passage from a book they had never read before, so they could have been more interested in looking at their surroundings than reading the book. Alternatively, participants might have tried to pay more attention to the text than usual due to the Hawthorne Effect, which states that people tend to change their behavior when they know their actions are being observed [13]. However, potential effects of this phenomenon may have been lessened due to the fact that participants did not know that we were studying attention: only that we were using mobile eye tracking glasses to explore how people read on printed and electronic books. The fact that participants only paid attention to the text of the book 87% of the time at best could also suggest that young adults have problems with attention during reading in general.

It should be acknowledged that although the difference between the proportion of fixations on the printed and Kindle versions of the book was statistically significant, a 4% difference is still relatively small. Regardless, this difference may still significantly impact memory retention and information recall. Geoffrey R. Loftus, a professor at the University of Washington, conducted a study exploring the correlation between recognition memory and fixations on pictures. The experiment showed that as the number of fixations on an image increased, the likelihood of the participant correctly recognizing the image also increased. Furthermore, five additional fixations on a picture of a face resulted in a 22% increase in memory for that face [14]. This shows that not only is there a strong correlation between visual attention and memory, but even a small number of fixations has a large positive effect on memory. So, while the difference between fixating on the text of a book 83% of the time versus 87% of the time may not seem impactful, previous research shows that it may have a significant effect on memory and information retention. Still, future research should test how visual attention and memory affect one another in the context of reading specifically by replicating our study, having participants complete memory tests, and then analyzing the correlation between correct information recall and the number of fixations on the text.

This study had several strengths. First, the experiment was highly ecologically valid, because by using the mobile eye tracking glasses we were able to simulate a realistic reading experience. The glasses allowed participants to read the passages on printed books and Kindles as opposed to on a computer screen. This gives us more confidence in the accuracy of our results in relation to real-world experiences with reading. Additionally, we selected participants that are representative of e-reader users. Of the 90.5 million people who reported using an e-reader in 2018, 34% were 18 to 29

year olds [15]. In addition, the Amazon Kindle is the most commonly used e-reader, so our study utilized the most relevant age group by testing them with the most-used type of e-reader.

It is still unclear why people might pay more attention while reading on printed books than electronic ones. As we only tested young adults (all falling under the generational age group of Millennials), this study cannot indicate if the results are specific to digital natives, who have been exposed to e-readers from an early age, or if our findings are applicable to other age groups as well. Since digital natives tend to use electronic screens in their daily lives for essentially thoughtless activities (i.e. television, games, mindless scrolling on the internet or social media, etc), they may not fully engage all of their mental resources when they read on a screen. This could be because they've been conditioned to interact with screens for thoughtless entertainment. Future research should investigate whether people who use screens for these mindless activities at higher rates show reduced visual attention when reading on e-readers (in addition to reduced information comprehension and recall) compared to those who use screens for this entertainment at lower rates.

Future research could build upon the implications of this experiment by using varied age groups, like adolescents and older adults, to test whether attention to screens might differ based on age. We could also study how results might differ for people with specific disorders such as Attention Deficit Hyperactivity Disorder (ADHD), for example. We might hypothesize that people with ADHD would pay more attention to an e-reader, because abilities such as easily skipping to the other side of a page or physically feeling how many pages are left might make printed books more distracting than a Kindle. We could also study how to make electronic books better by testing what aspects of printed books contribute to more visual attention. We could do this by listing the aspects of printed books that differ from Kindles, and then systematically testing each to see which features actually contribute to higher rates of attention.

5 References

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