Paper vs. Electronic Media: Work Efficiency and Environmental Impact

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Abstract

This presentation quantitatively compares paper and electronic media from the perspectives of CO_2 emissions and work efficiency. Should we reject paper out of hand based on environmental considerations? Can electronic reading devices replace paper books for leisure and work? I discuss these issues based on various analyses and experiments.

Introduction

Although the paperless office has been repeatedly dismissed as a myth [1], since 2008, the consumption of office paper in Japan has actually declined. With the advent of electronic reading devices such as Apple's iPad and the Amazon Kindle, the idea of the paperless office is back in the spotlight. How seriously should we take this second coming of the paperless office? What will happen to paper? What are the relative merits of paper and electronic media? My colleagues and I at Fuji Xerox are currently at work on a research project that seeks to answer these questions.

This presentation consists of two parts. The first part compares paper to electronic media from an environmental perspective, comparing CO_2 emissions generated by paper vs. electronic media (e.g., computer displays, projectors) for reading or reference work. I also compare work efficiency for paper vs. computer displays. The second part compares paper books and electronic reading devices (e.g., iPad, Kindle) and discusses whether electronic books might actually take the place of paper books.

This paper is a brief report and addresses only the results of these specific analyses and experiments.

Environmental Impact: Paper vs. Computer Displays

CO_2 Emissions

Table 1 presents CO_2 emissions per unit quantity for each product. This data is based on figures for life cycle CO_2 emissions for each product obtained in November 2010 from the website of the Japan Environmental Management Association for Industry [2].

Figure 1 compares CO_2 emissions associated with each medium when reading an eight-page document. Reading from paper generates CO_2 emissions only at the time the document is printed. In this case, the hours spent reading do not affect CO_2 emissions. On the other hand, when we read from displays, CO_2 emissions increase in proportion to the time spent reading. For extended reading sessions, CO_2 emissions tend to be lower for paper; for reading many short documents, CO_2 emissions tend to be lower with computer displays.

Table 1. CO_2 emissions per unit quantity for each product

Product	Specifications	CO_2 emissions per unit quantity
Standard Desktop PC	CPU: Intel Core Memory: Less than 4GB	49.60 g/hour
High-Performance Desktop PC	CPU: Intel Core Memory: More than 4GB	98.42 g/hour
17-inch Display	TFT	23.36 g/hour
19-inch Display	TFT	26.34 g/hour
Notebook PC		27.59 g/hour
Projector	Resolution: More than 1290x800	163.58 g/hour
Printer	Electro Photo A3 Printers	2.58 g/sheet

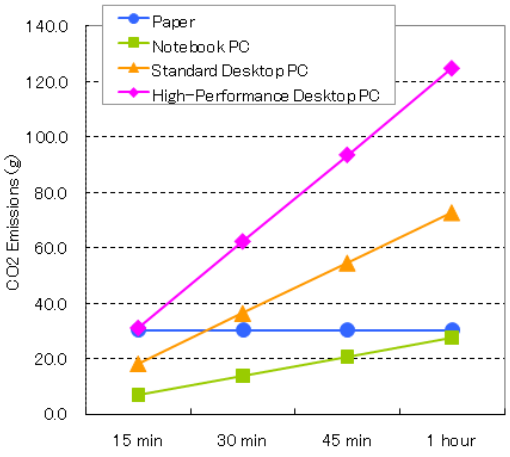

***Figure 1**. CO_2 emissions associated with reading*

Figure 2 compares CO_2 emissions for each medium for the case of a ten-page document shared in a meeting. If we deliver this document on paper, CO_2 emissions increase in proportion to the number of individuals attending. If we use a projector and a single notebook PC, the number of participants doesn't affect CO_2 emissions. In general, if we are sharing documents for a large meeting, CO_2 emissions are lower when we use projectors than when we distribute on paper. When we share short documents in small groups of two or three, CO_2 emissions tend to be lower when we distribute documents on paper.

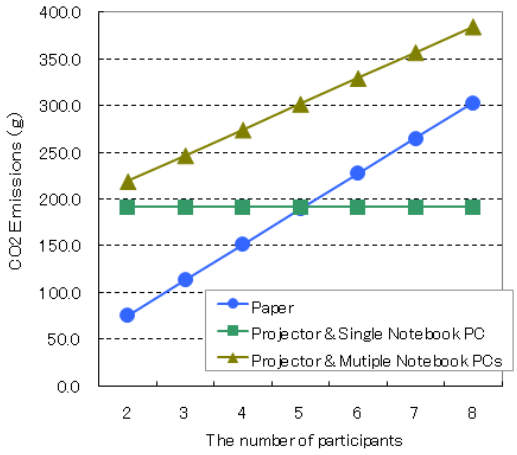

***Figure 2**. CO_2 emissions associated with meeting documents*

Work Efficiency

The analyses of the previous section assume equal work efficiency for all media. However, efficiency may actually vary with different media. Lower work efficiency means longer working hours, which in turn can mean higher CO_2 emissions, since elements of the workplace infrastructure (e.g., ventilation and lighting) need to run longer. I'll describe three experiments that compare reading performance for each medium.

The first experiment examines how different media affect proofreading when the goal is to detect contextual errors. Figure 3 presents reading speed and percentage of errors detected when using paper vs. computer displays. Reading from paper was 11.9% faster than reading from the displays. There was no significant difference between media in percentage of errors detected.

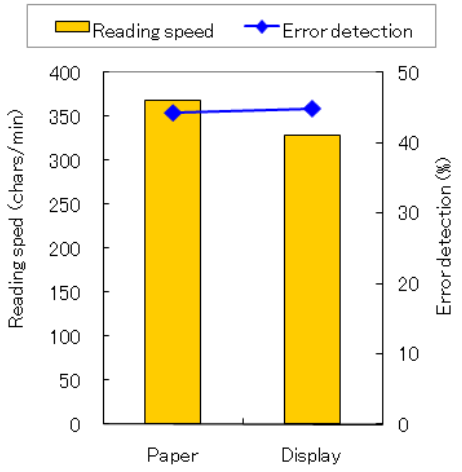

***Figure 3**. Reading speed and the percentage of errors detected in proofreading to detect contextual errors (N = 20)*

The second experiment looked at reading when the task required frequent switching back and forth between pages [3]. Figure 4 compares reading speed and scores for a recognition test of key words in text when using paper and when using computer displays. Reading from paper was 6.8% faster than reading from displays. There was no significant difference between the media in the recognition test of key words. Paper allows faster reading without loss of understanding.

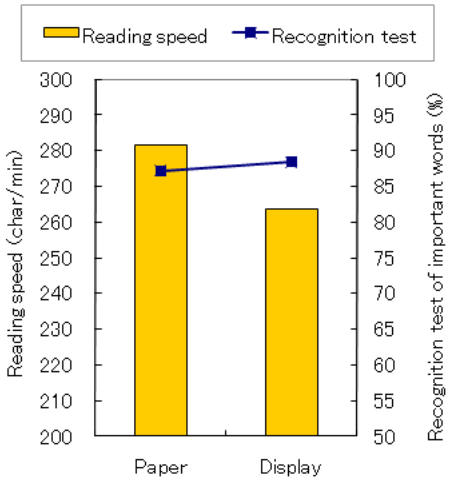

***Figure 4**. Reading speed and scores for a recognition test of key words when reading with frequent page turning (N = 18)*

The third experiment involved cross-reference reading for multiple documents [4]. Figure 5 compares reading speed and percentage of errors detected when using paper vs. computer displays. Reading from the paper was 23.2% faster than reading from displays. Moreover, more errors were detected (a difference of 11.5%) with paper than with computer displays. In both speed and accuracy, paper was superior to displays in cross-reference reading.

***Figure 5**. Reading speed and the percentage of errors detected in cross-reference reading for multiple documents (N = 24)*

Discussion

Comparisons of CO_2 emissions from paper and electronic media indicate that the nature of a task determines which is more eco-friendly. The three experiments here point to the superiority of paper for different reading tasks: proofreading, reading with frequent movement back and forth between pages, and cross-reference reading for multiple documents. Clearly, this is hardly an exhaustive listing of all tasks that involve reading. Still, the results suggest paperless work is not always the most eco-friendly work style. Paper should not be rejected out of hand on environmental grounds. Rather, we should select paper or electronic media depending on the specific task.

Work Efficiency: Paper vs. Electronic Reading Devices

Reading fiction

As a typical example of reading for leisure, I evaluated electronic reading devices such as iPad and Kindle for reading fiction. Figure 6 shows reading speed with a paper book, an iPad, a Kindle, and a notebook PC. For reading that did not involve moving from one page to the next, I found no significant difference in reading speed among the four media. For reading that required page turns, I found that reading from the iPad was as fast as reading from paper books, but that reading from the Kindle was slower than reading from paper books. This suggests that the iPad is just as suited as paper books for tasks like reading fiction.

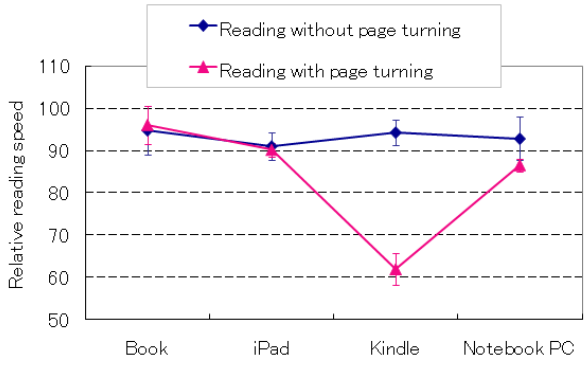

***Figure 6**. Reading speed: Paper book vs. electronic media (N = 26)*

Reading to answer questions

Adler et al. [5] observed various work-related reading tasks in actual work situations and assigned each instance to one of ten categories. Among the most frequently observed tasks was cross-reference reading using multiple documents. Clearly, the current generation of electronic reading devices does not permit cross-reference reading. These devices do not allow us to view multiple documents at the same time, and their form factors are too cumbersome to overlap or otherwise move frequently. For this reason, I evaluated these devices for the second-most common task in the study by Adler et al.: scanning text to answer questions.

Figure 7 compares task completion times and accuracy (percentage of correct answers) for each medium in an experiment involving scanning a manual to find answers. Subjects performed this task 38.6% faster with the paper book than with the iPad and 60.2% faster than with the Kindle. Of the five media, paper books were fastest for scanning text for answers.

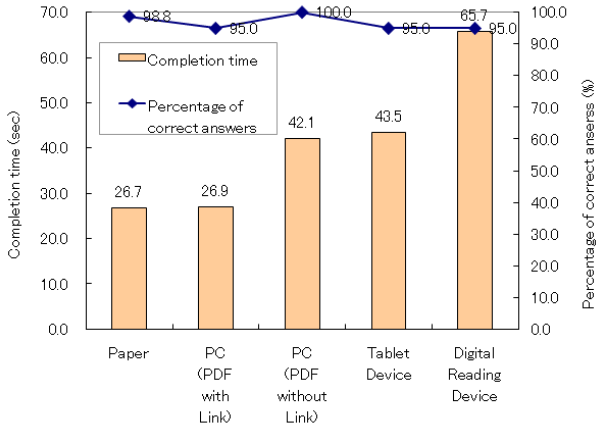

***Figure 7**. Completion time and percentage of correct answers when scanning text to locate answers to questions (N = 20)*

Discussion

For reading fiction, our experiment showed iPads and paper books offered equal reading speed for reading with and without page turns. This suggests that the current generation of electronic reading devices is perfectly suitable for reading for leisure, at least from the perspective of efficiency. Clearly, other factors such as cost, weight, and design will also determine whether such devices gain widespread acceptance for this purpose.

Paper books proved the fastest of all five media in the experiment involving scanning text to find answers to questions, the reading task ranked as the second most common in the study by Adler et al. Moreover, as discussed above, the current generation of electronic reading devices remains poorly suited for cross-reference reading, the reading task ranked as the most common. These results suggest that the electronic reading devices currently available do not adequately cover the wide range of reading tasks required for knowledge work.

Trademarks

References

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Author Biography

Hirohito Shibata received his MS in mathematics from Osaka University (1994) and his PhD in engineering from the University of Tokyo (2003). He is currently a research scientist at the Research and Technology Group, Fuji Xerox Co., Ltd. Research interests include cognitive science and human-computer interactions. His current research involves investigations of the strengths and weaknesses of presentation media from cognitive perspectives. He is a member of Association for Computing Machinery (ACM), The Information Processing Society of Japan (IPSJ), The Japanese Society for Artificial Intelligence (JSAI), and Human Interface Society (HIS).