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# To Scroll or Not To Scroll: Scrolling, Working Memory Capacity, and Comprehending Complex Texts

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**Objective:** The purpose of these experiments was to examine the effects of user characteristics on learning from scrolling interfaces. **Background:** Although scrolling Web pages are now common, few studies have explored the effects of scrolling on understanding the content that is being conveyed. **Method:** This set of studies investigated whether presenting text in two particular formats has an effect on comprehension for readers who differ in working memory capacity. **Results:** Results from both studies indicated that a scrolling format reduced understanding of complex topics from Web pages, especially for readers who were lower in working memory capacity. **Conclusion:** These findings show that the way text is presented can interact with learner abilities to affect learning outcomes. **Application:** These results have implications for both educational technology and human interfaces that present information using displays that can vary in size and construction.

## INTRODUCTION

Many classroom activities and everyday learning contexts now involve the acquisition of information from Web pages. Whether students are asked to write a report from online sources, or adults want to learn more about a medical condition, Web pages are often used as a source of knowledge. A common feature of many Web pages is the presence of scrolling text. Quite simply, scrolling means that all information does not fit in a single screen, and information "overflows" off the screen out of immediate view. Individuals then access this off-screen information through the use of a toolbar, mouse, or other pointing device. A recent study has reported that nearly 91% of Web pages now include a scroll bar (ClickTale, 2006). Thus, the presence of scrolling pages seems to be nearly ubiquitous.

Likely reasons that scrolling pages have become common are disparities in display resolutions on which Web pages will be viewed by a given user and the increased use of small display devices, such as smart phones and Net books to access online information. However, the question remains as to whether this simple interface characteristic can affect learning.

Although some have suggested that scrolling enables more efficient skimming or scanning behaviors on visual search tasks (Bernard, Baker, & Fernandez, 2002; Duchnicky & Kolers, 1983; Monk, Walsh, & Dix, 1988; Spool, Scanlon, Schroeder, Snyder, & DeAngelo, 1999) and also might enhance participants' recall of hypertext structure (van Nimwegen, Pouw, & van Oostendorp, 1999), no study has demonstrated a significant effect of this presentation format on comprehension. However, one study has provided some suggestion that scrolling might harm learning. In Piolat, Roussey, and Thunin (1997), readers were asked to read a short expository text, "The Sanding Over of the Mont Saint-Michel," which described how tides were gradually sanding over the abbey and the steps that were being taken to preserve the location. When the text was presented in a more traditional pagelike format, readers were better able to relocate information than when the same information was presented in scrolling format. In addition, presentation in discrete pages led to better memory for details contained within

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the text. Furthermore, a nonsignificant trend was also found such that readers wrote better summaries of the text in the paginated condition than in the scrolling condition.

Although the authors intended the summary task as a measure of comprehension for this study, it is not clear that this task was the best way to assess understanding of the text. The authors had predicted that inferences and integrative activity would be more likely from paginated format and that this should have improved readers' summaries versus the scrolling condition. However, a good summary does not necessarily mean that the material has been understood well. For example, good memory for a topic sentence could also allow for the generation of a good summary (Kintsch, 1990). However, good surface memory for a text does not necessarily mean that the reader has good understanding of how concepts mentioned in a text relate to one another. Thus, it is possible that the inconclusive results on the summary measure may have been attributable to improved comprehension in some cases but improved memory in others. In summary, although scrolling formats may allow for more efficient skimming or scanning through pages, there is also some evidence that scrolling may negatively affect performance versus a segmented, discrete presentation. Furthermore, no previous work has demonstrated effects of presentation on learning from text using a measure of conceptual understanding.

In the present study, we test more directly for effects of page presentation on comprehension by asking participants to write a short causal essay after reading Web pages. Performance on this task should relate more directly and uniquely to the creation of a coherent mental model of the text, as the reader cannot complete this task using just memory for the text that was read, but rather, the task requires the reader to generate causal inferences from the reading material.

For example, it could be important that scrolling pages lack a static "place on the page" location for information. If learners are forced to reallocate resources from the comprehension process to maintain their surface memory for the text (e.g., representing the information and its location), this requirement could place a load on the reader that would reduce comprehension (Mayer & Moreno, 2003; Paas, Renkl, & Sweller, 2003; Sweller, Chandler, Tierney, & Cooper, 1990; van Merriënboer, Kirschner, & Kester, 2003). Furthermore, we might expect that readers who are more sensitive to such load might be most vulnerable to presentation effects.

A large body of work has shown that there are stable individual differences in the ability to process and store information simultaneously (Baddeley & Hitch, 1974; Conway & Engle, 1994), and this ability has been referred to as working memory capacity (WMC). Much prior research has shown that those who have higher WMC are better able to focus their attention on relevant task information, maintain goals, and otherwise ignore irrelevant information (Conway, Kane, & Engle, 2003). WMC has shown a positive relationship to successful performance on a myriad of complex tasks, ranging from reading comprehension to measures of general fluid intelligence (see Conway et al., 2005, for an in-depth review of the history of WMC). In the present context, readers who have lower WMC could be predicted to show the largest decrease in comprehension caused by scrolling, as they are less able to maintain both the surface representation of the text while also processing the relationships between the text units.

However, if scrolling is found to facilitate comprehension, lower-WMC individuals might also benefit more from scrolling because it allows for the whole text to be available at once, which might support the creation of a single, integrated representation of the text instead of many smaller structures (Gernsbacher, Varner, & Faust, 1990). Thus, a further concern of the current study, in addition to determining the overall effects of scrolling on a measure of comprehension, was to explore whether there are some individuals who are particularly vulnerable to these types of presentation effects.

The purpose of this study was to investigate the effects of scrolling on the comprehension of complex instructional texts. Across two experiments, the presentation format of a Web page was manipulated between groups while the actual textual content was held constant. In addition, each learner's WMC was measured with the use of a standard complex span test, which was then used to predict performance on the comprehension task.

## EXPERIMENT 1

## Method

### Participants

Participants in this study were 40 students ($N = 40$) from a large, public Southwestern university, 20 in each condition. An additional 4 participants were not retained in the final analyses (3 participants who failed to maintain 85% accuracy on the WMC task and 1 participant who was identified as high in prior knowledge). Participants were compensated with course credit in an Introductory Psychology class.

### Materials

*Initial survey.* All participants were required to complete an initial survey that contained a pretest on the content area of ice ages and a question about computer usage. Participants were asked to write a preliminary essay about what causes ice ages, which was then evaluated for the presence of the five critical concepts described later. Any participant who correctly reported more than one of the five concepts was considered high in prior knowledge and was omitted from the study. This focus on low-knowledge individuals was intentional to avoid the potential confound of prior knowledge of the content area overshadowing any manipulations. Participants were also asked to rate on a scale of 1 to 5 (1 being the least) how much time they spent on the Internet per week, including both work and pleasure.

*Text.* All participants read a text about the causes of ice ages that has been used in previous studies (Sanchez & Wiley, 2006). This text is approximately 2,700 words long and contains 13 discrete sections separated by subheadings. Depending on experimental group, participants either read this text in a single, unitary page that scrolled (complete with subheadings) or read the same exact text divided by subheading into discrete pages, which resulted in 13 separate pages. This decision to keep the text under subheadings intact in the nonscrolling condition was based on previous work in text processing showing the importance of preserving text units under headings for understanding (Lorch & Lorch, 1996). Because readers were able to read the complete sections under their headings in the scrolling condition, this feature was preserved in the nonscrolling condition. In the nonscrolling condition, participants navigated between pages using "Next" and "Back" links embedded at the bottom of each page. This allowed participants to read either the immediately preceding or the immediately proceeding page by clicking on a single link. Additionally, in both conditions, the text was also illustrated with conceptually relevant illustrations (Figure 1).

*Comprehension task.* After reading, participants were asked to write a short argumentative essay response to the question, "What causes ice ages?" This essay response was evaluated for the presence of five critical concepts that were identified a priori. These concepts were the cyclical nature of earth's climate change, the effect of the tilt of the earth on the amount of solar radiation received by different areas, the effect of reduced solar energy received on the surface of earth, the effect of reduced carbon dioxide in the atmosphere, and finally, that changes in weather systems can affect climate.

All essays were evaluated by two independent coders, who produced a high level of interrater reliability (Cohen's $\alpha = .90$, $p < .05$). Any differences were resolved through discussion. Essays were also evaluated for overall length (number of sentences).

*WMC assessment.* Participants completed a computerized assessment of WMC, Automated Operation Span (AOSPAN), developed by Unsworth, Heitz, Schrock, and Engle (2005). AOSPAN is a computerized version of the original Operation Span task developed by Turner and Engle (1989) and has been shown to be both reliable and diagnostic for assessing differences in WMC (Unsworth et al., 2005). This task requires the simultaneous processing and storage of unrelated information and is thus considered a complex span task (Conway et al., 2005).

In this task, participants evaluate the correctness of a series of simple math equations, which range in set size from three to seven. After evaluating the correctness of each presented equation, participants are given a letter to remember for a later test. After completing each set, participants

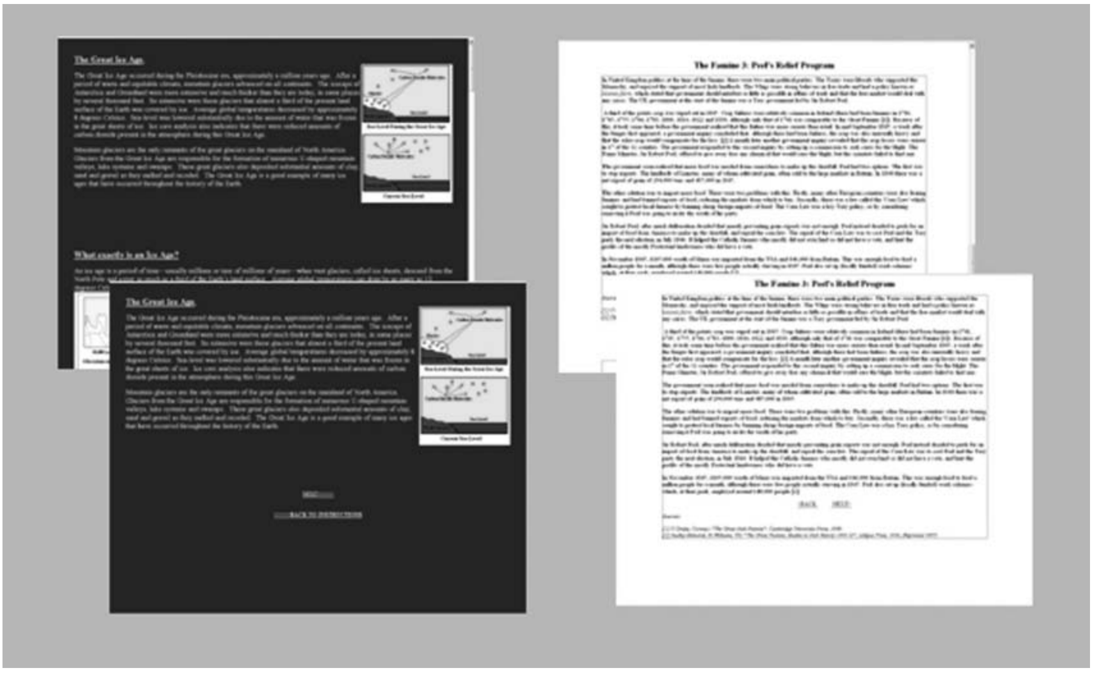

*Figure 1.* Scrolling versus nonscrolling presentations for Experiments 1 and 2.

select the letters that were presented after the equations from a matrix of 12 possible choices. For a response to be considered correct, each letter must be recalled in the correct serial position. Participants completed 3 trials of each set size, which resulted in 75 overall individual trials. Participants were awarded a single point for every correct letter recalled, and these points were then totaled at the end of all trials. Thus, the maximum score on the AOSPAN task is 75. Participants who do not maintain a level of 85% correct on evaluating the math equation are not retained for later analysis.

### Procedure

Experimental sessions were conducted in groups of 2 to 8 participants. All participants were seated at individual computers prior to the beginning of the study. Participants were first given 8 min to complete the initial survey. Participants were then directed to a Web site and were given 15 min to read all available information. Participants were instructed to read the information carefully because they would be tested on the material later, to read all of the text, and to not skip any information. Participants were given no further detail on the nature or quality of the later assessment. Participants were warned when there were only 2 min left to read. After the 15 min had passed, participants left the Web site and were asked to write a short argumentative response to the question, "What causes ice ages?" Participants were allowed as much time as they desired to complete their responses, and participants were instructed to write at least a page in response to the question. The Web page was unavailable to the participants while they were writing.

After completing the essay, participants completed the AOSPAN task. They were then debriefed and dismissed. The entire experiment took no longer than 1 hr.

## Results and Discussion

Descriptive statistics are presented in Table 1. To ensure that both groups were equivalent in terms of WMC, Internet usage, and prior knowledge on the topic of ice ages, independent samples *t* tests were performed between presentation conditions on each of these variables. Results indicated that there was no significant difference between the scrolling and nonscrolling

**TABLE 1:** Descriptive Statistics for Between-Presentation Comparisons in Experiments 1 and 2

| | Experiment 1 | | Experiment 2 | |
|---|---|---|---|---|
| Variable | Scrolling | Nonscrolling | Scrolling | Nonscrolling |
| WMC (AOSPAN) | 59.80 (7.99) | 61.15 (6.70) | 58.55 (9.80) | 57.53 (9.88) |
| Time spent on Internet | 3.45 (1.15) | 3.40 (1.14) | 3.50 (1.10) | 3.94 (1.03) |
| Pretest essay | 0.30 (0.47) | 0.45 (0.51) | 0.50 (0.51) | 0.58 (0.51) |
| Final essay length | 7.20 (2.55) | 8.55 (2.01) | 6.94 (2.13) | 8.32 (2.75) |

*Note.* WMC = working memory capacity, number of correct items recalled; AOSPAN = Automated Operation Span (Unsworth, Heitz, Schrock, & Engle, 2005); Time on internet = scale of 1-5, 1 being lowest; Pretest = number of correct concepts recalled.

conditions on any of the variables, $ts(38) < 1$, $p > .05$. Thus, the two conditions were well matched on their general ability, overall computer usage, and prior knowledge of the content.

### Effects of Text Presentation on the Comprehension Task

We evaluated the comprehension results using hierarchical linear regression. Presentation condition was dummy coded (scrolling = 0 and nonscrolling = 1) and entered in the first block of the analysis along with WMC score. Prior to analysis, WMC score was centered by subtracting the mean score from each data point. An interaction term was also computed between presentation condition and WMC and entered in the second block of the analysis.

In terms of essay length, neither presentation condition nor WMC significantly predicted essay length ($R^2 = .04$, $p > .05$). The Presentation Condition × WMC interaction also did not predict essay length ($R^2$ change = .00, $p > .05$). These results suggest that there was no difference in the length of essay responses for either presentation condition or WMC, and these variables did not interact to influence essay length. This finding is important, as it ensures that any subsequent effects are not attributable to one group's simply having more opportunity to include information in their response.

In terms of the number of correct causes included in the essay response, in the first block of analysis ($R^2 = .31$, $p < .01$), only presentation condition was a significant predictor of essay performance ($\beta = .52$, $p < .01$). As shown in Table 2, nonscrolling interfaces produced significantly better comprehension overall than did scrolling interfaces. Although comprehension tended to increase with WMC, this effect was not statistically reliable ($\beta = .23$, $p > .05$) in the first block.

However, results from the second block of analysis indicated that the addition of the interaction term between WMC and presentation condition did account for a significant portion of additional variance ($R^2$ change = .07, $p < .05$). WMC did interact with presentation condition to affect overall comprehension ($\beta = -2.52$, $p < .05$). As shown in Figure 2, WMC was especially relevant in the scrolling condition.

Whereas scrolling did lead to worse performance overall, there was a more pronounced effect for those individuals who had lower WMC. Performance was the worst for lower-WMC individuals in the scrolling condition, whereas there was little disparity between individuals who differed in WMC in the nonscrolling condition. To further solidify this assertion, separate linear regressions were conducted for each presentation condition in which WMC alone was used to predict learning. For the nonscrolling condition, WMC ($\beta = -.12$, $p > .05$) was not significantly related to comprehension ($R^2 = .01$, $p > .05$). However, in the scrolling condition, WMC ($\beta = .54$, $p < .05$) was significantly and positively related to essay performance. This suggests again that lower-WMC individuals were especially sensitive to the manipulation.

Overall scores were low; the frequency of recall for each concept is presented in Table 2. Concepts appear from top to bottom in their

**TABLE 2:** Frequency of Concepts Included in Essays and Average Correct in Experiments 1 and 2 (by order of first mention, top to bottom)

| | Experiment 1 | | Experiment 2 | |
|---|---|---|---|---|
| Concept | Scrolling | Nonscrolling | Scrolling | Nonscrolling |
| Concept 1 | 9 | 8 | 3 | 7 |
| Concept 2 | 5 | 10 | 13 | 18 |
| Concept 3 | 5 | 11 | 2 | 0 |
| Concept 4 | 8 | 13 | 7 | 6 |
| Concept 5 | 1 | 8 | 17 | 19 |
| Concept 6 | — | — | 9 | 11 |
| Concept 7 | — | — | 7 | 4 |
| Concept 8 | — | — | 2 | 3 |
| Average concepts per essay *M* (*SD*) | 1.40 (0.99) | 2.50 (0.76) | 3.33 (1.08) | 3.58 (0.84) |

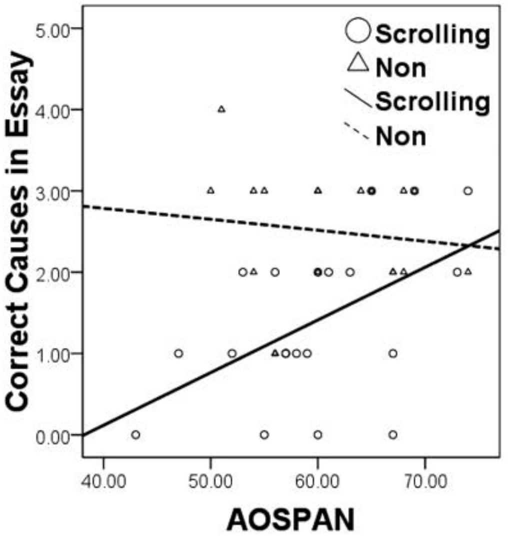


*Figure 2.* Regression lines for the number of correct causes included in essays by scrolling condition and working memory capacity in Experiment 1. AOSPAN = Automated Operation Span.

order of first appearance in the text. A repeated-measures ANOVA indicated there was no effect of concept order, $F(4, 152) = 1.97$, $p > .05$, nor was there a significant interaction between concept order and condition, $F(4, 152) = 1.03$, $p > .05$.

Thus, the results of Experiment 1 suggest that a scrolling format had an effect on comprehension, and this effect was most pronounced in low-WMC participants. To ensure that this effect of scrolling is not isolated to this specific text, a second experiment was conducted, in which we kept the methodology as consistent as possible but used a different complex text and content area (e.g., the causes and consequences of the Irish potato famine).

## EXPERIMENT 2

### Method

#### Participants

Participants in this study were 37 undergraduates ($N = 37$) from a large, public Southwestern university who had not participated in Experiment 1 (18 in the scrolling condition and 19 in the nonscrolling condition). An additional 14 participants were not retained in the final analysis (2 participants were omitted for failure to maintain 85% accuracy on the WMC task; 12 were omitted for high prior knowledge). Participants were compensated with course credit in an Introductory Psychology class.

#### Design and Materials

The design was identical to Experiment 1, except participants now read a text developed by Wiley (2001) about the Irish potato famine. This text is approximately 3,500 words long and contains information about the causes of the famine, the impact both economically and in terms of population, and attempted relief efforts. This text contained eight main concepts derived from an a priori causal model of the phenomena and was illustrated with conceptually relevant images. Sample interfaces are presented in Figure 1.

### Procedure

The procedure was also identical to Experiment 1, except participants were now given only 5 min for the pretest response and were allowed to read the Web site for 17 min. Time adjustments were made because of the slightly longer text. After reading, participants completed an essay response to the question, "What caused the significant changes in Ireland's population between 1841 and 1851?" All essays were again evaluated by two independent coders, who produced a high level of interrater reliability (Cohen's $\alpha = .74$, $p < .05$).

## Results and Discussion

Descriptive statistics are presented in Table 1. The scrolling and nonscrolling conditions were not significantly different (*t*s < 1.28, $p > .05$) in either WMC, hours spent on the Internet, or pretest responses. This demonstrates that the groups were well matched on relevant demographic variables.

As in Experiment 1, hierarchical linear regressions were conducted to test for the effects of WMC and presentation condition on learning. Dummy coding, centering, and the method of analysis were identical to Experiment 1.

In terms of final essay length, both WMC and presentation condition failed to significantly predict essay length ($R^2 = .04$, $p > .05$). Similarly, WMC and presentation condition did not interact to affect essay length ($R^2$ change = .00, $p > .05$).

In terms of the number of correct causes included in the essay response, results from the first block indicated that there were no significant effects of either WMC or presentation condition on essay performance ($R^2 = .11$, $p > .05$). However, addition of the interaction term in the second block accounted for a significant portion of additional variance ($R^2$ change = .10, $p < .05$) and produced a significant overall model ($R^2 = .21$, $p < .05$). The differential effects of WMC in each presentation condition are shown in Figure 3.

To further evaluate the influence of WMC in each presentation condition, separate linear

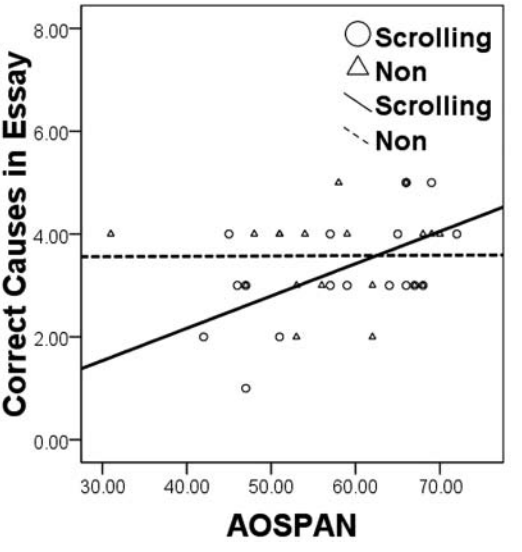


*Figure 3.* Regression lines for the number of correct causes included in essays by scrolling condition and working memory capacity in Experiment 2. AOSPAN = Automated Operation Span.

regressions were again conducted. For the nonscrolling condition, WMC was found to not be significantly related to comprehension ($R^2 = .00$, $p > .05$). However, in the scrolling condition, WMC ($\beta = .57$, $p < .01$) was found to be significantly related to comprehension ($R^2 = .28$, $p < .01$), such that higher WMC led to better comprehension, equivalent in level to that in the nonscrolling condition. This result corroborates the findings of Experiment 1 with a completely different text and again suggests that scrolling may negatively affect the learning of lower-WMC readers.

Again, the frequency of recall for the individual concepts was tabulated and appear in Table 2 in order of first appearance in the text. A repeated-measures ANOVA did show a significant effect for concept, $F(7, 245) = 24.54$, $p < .05$, which suggests that certain concepts (e.g., the potato blight) were recalled much more frequently than others. However, and most importantly, there was not a significant Concept Order × Condition interaction, $F(7, 245) = 1.19$, $p > .05$. Thus, although some concepts were easier to recall than others, the *pattern* of concept recall was consistent across both conditions.

## GENERAL DISCUSSION

Despite the prevalence of scrolling in online environments, more research is needed on how this feature affects the comprehension of text. Our results indicated that scrolling negatively affects learning from text, and this effect is most pronounced in learners who have lower WMC. Across two studies, these learners were less able to develop a causal understanding of a complex topic when presented with a scrolling interface than when presented the same information units in discrete pages. On the other hand, scrolling had little impact on higher-WMC learners.

The fact that the same result was obtained across two studies with different texts and topics supports interpreting this between-subjects finding as being attributable to the manipulation. Future studies may consider a within-subjects design as another means of replication, although order effects should be considered. Indeed, even in the current design, the WMC task always followed the comprehension task. Administering these assessments in separate sessions to guarantee their independence would be a useful change to consider in future studies.

Moreover, beyond providing a replication, the second set of results also allays concerns that the findings of Experiment 1 may have been driven by a functional ceiling on performance on the comprehension task. However, this is clearly not the case in Experiment 2. As is visible in Figure 3, at very high levels of WMC, performance in the scrolling condition actually exceeds that in the nonscrolling condition. If this interaction were driven by a limit on the number of concepts that could be learned in the given time frame, one would expect performance in both conditions to plateau at the same level, which was not the case.

One possible reason scrolling had a negative effect on comprehension may be the fact that it requires readers to both maintain a surface representation of a text and engage in comprehension processes. Consistent with this explanation, scrolling can be thought of as exacerbating the cognitive demands or load on readers, which especially affects lower-WMC readers. Another possibility is that lower-WMC readers may have difficulty controlling their attention while reading scrolling texts and may be more likely to become disoriented or lost during reading. A third possibility is that when faced with scrolling texts, lower-WMC readers may fail to engage in consolidation or integration processes regularly. Without the prompt offered by page breaks, low-WMC readers may fail to engage in wrap-up processes critical for comprehension. All of these are interesting hypotheses that will require detailed trace data to decide which of them may apply.

Relating these findings to Piolat et al. (1997) suggests a few critical points. First, the ability to detect a significant effect on comprehension may be attributable to the choice of learning measure. As noted previously, summaries can be generated either from surface memory or from understanding, whereas the essays used here are more distinctly measures of comprehension. A second important factor may have been the structure of the pages in the nonscrolling condition. Piolat et al. used a paged condition in which all pages were matched in length (number of lines of text). Presumably, important sections were disrupted in this format. Thus, any advantage of nonscrolling pages may have been offset by the introduction of these disruptions. Using pages that preserve sections of text may be critical for better understanding in paginated format. Future investigations could contrast these two nonscrolling conditions.

The implications of this study are that basic design features, such as whether text scrolls, can have a significant effect on understanding. Specifically, this result suggests to designers that if comprehension is important, they should likely present information in meaningfully paginated form, as doing so appears to provide optimal learning for all individuals. This study also highlights the need to investigate not only the effects of such features of interfaces but also the potential interactions that these characteristics might have with the cognitive abilities and preferences of the learner (Wiley, Sanchez, & Moher, 2005).

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