Scrolling Behaviour with Single- and Multi-column Layout

Cameron Braganza, Kim Marriott, Peter Moulder, Michael Wybrow and Tim Dwyer*
Clayton School of Information Technology, Monash University, Australia
FirstName.LastName@infotech.monash.edu.au

ABSTRACT

The standard layout model used by web browsers is to lay text out in a vertical scroll using a single column. The horizontal-scroll layout model—in which text is laid out in columns whose height is set to that of the browser window and the viewer scrolls horizontally—seems well-suited to multi-column layout on electronic devices. We describe a study that examines how people read and, in particular, the strategies they use for scrolling with these two models when reading large textual documents on a standard computer monitor. We compare usability of the models and evaluate both user preferences and the effect of the model on performance. Also interesting is the description of the browser and its user interface which we used for the study.

Categories and Subject Descriptors

H.4.3 [**Information Systems Applications**]:
Communications Applications—*Information browsers*;
H.5.2 [**Information Interfaces and Presentation**]:
User Interfaces;
I.7.2 [**Document and Text Processing**]:
Document Preparation—*Photocomposition/typesetting*

General Terms

Experimentation, Human Factors

Keywords

Web-browser, Multi-column layout, Scrolling, Reading

1. INTRODUCTION

Increasingly, large, primarily textual documents are being read on a variety of electronic devices including traditional desktop monitors, laptops, mobile phones and e-books. One of most basic decisions when presenting such documents is the choice of *layout model*.

The standard layout model used in web-browsers is the *vertical scroll* in which (conceptually) the document is laid out in a single page whose width is equal to the viewing window's width and whose height expands to fit the document

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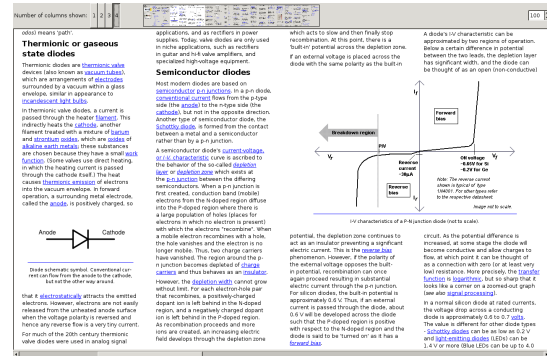[1]Tim Dwyer is currently a visiting researcher at Microsoft Research.

Figure 1: Example of horizontal-scroll layout using our browsing tool.

content. Scrolling moves the viewing window up and down the page. While popular, this model is only suited to single column layout unless the entire document can fit in the viewing window (since if the whole page doesn't fit on the screen, then one needs to scroll backwards to find the start of the second column). Unfortunately, on many devices single column layout leads to uncomfortably long lines of text when the viewing window size is maximized to make use of the available display.

The next most common layout model, *paged layout*, does support multi-column layout. In this model the document is laid out on consecutive fixed-size pages. This model is, of course, intended for print media and typically the page size is chosen by the document author, e.g. as a PDF file. However, in our view it is not well-suited to electronic viewing unless the page size is chosen at display time and layout is performed dynamically so that some reasonable multiple of pages are fully visible in the viewing window. This is especially true when pages have multiple columns.

A third (much less common) layout model is the *horizontal scroll*, illustrated in Figure 1. Two recent applications that provide horizontal scrolling are Tofu[1] and the Times Reader[2] for reading newspaper articles. In the horizontal-scroll layout model the document is laid out in fixed-width columns on a single page whose height is set to the viewing window height and whose width expands to fit the document content. Scrolling moves the viewing window across the

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[1]Tofu 2.0 is available from http://amarsagoo.info/tofu/
[2]Available from https://timesreader.nytimes.com/

page. In our view, horizontal scrolling is the natural model for multi-column layout on electronic devices because, since the layout is dynamic, it overcomes inappropriate page size problems associated with paged layout.[3] We will therefore focus on the vertical- and horizontal-scroll layout models.

Another key component of the user interface for reading on electronic devices is the *scrolling mechanism* used to control which part of the document is visible on-screen. A variety of techniques are used, including: keyboard (both page-at-a-time movement, finer movement with arrow keys and keys to go to the beginning or end of the document); the scroll wheel and its extension the scroll ball; on-screen widgets such as scrollbars and other (often more visual) representations of the whole document where one can select which part to be displayed; and allowing the document to be "dragged" through the viewport (this mechanism is common on hand-held touchscreen devices and also provided in many PDF readers).

We are interested in the *scrolling strategy* used to read the document. This determines when scrolling is performed and by how much. Examples of different strategies are scrolling a line, a column or an entire screenful at a time.

We describe a user study investigating the vertical- and horizontal-scroll layout models and their effect on scrolling strategy and scrolling mechanism when reading large textual documents electronically. The main contributions are:

- It is the first user study to compare usability of the horizontal-scroll and vertical-scroll layout models. We evaluate both user preferences and performance.

- As part of the study, we evaluate user preferences for scrolling mechanisms and its relationship with reading performance. This is done for both layout models.

- We investigate the scrolling strategies used with each layout model. There has been little work on identifying scrolling strategies used for reading large textual documents electronically.

- In order to perform the user study, we implemented a browsing tool that provided both vertical and horizontal scrolling for a substantial subset of HTML and allowed a variety of scrolling mechanisms. A fourth contribution of this paper is to describe this tool and the design of the user interface for horizontal-scroll layout.

In our study 24 participants read two short stories from a standard computer monitor and answered questions about each. The questions typically required them to go back and check details in the text. One story was presented with multi-column layout on a horizontal scroll, the other with single-column layout on a vertical scroll. Participants were free to use whichever scrolling mechanism they preferred and to customize the layout by, e.g., resizing the browser window or changing the number of columns in horizontal layout. All interaction with the browser was logged and eye-tracking was used to determine the focus of attention on the screen.

Our findings were that one third of participants were more comfortable with horizontal-scroll layout and two thirds with vertical-scroll layout. The most common reason for prefer-

ring vertical-scroll layout was familiarity, while ease of navigation and shorter line length were the main reasons for preferring horizontal-scroll layout. We found that participant scrolling strategy and choice of scrolling mechanism was related to their choice of preferred layout.

The same basic scrolling strategies were used with each kind of layout: scrolling a screenful at a time, scrolling after reading a smaller region in the screen (such as a column) and continuous scrolling. However, continuous scrolling was quite common for vertical-scroll layout but very infrequent with horizontal-scroll layout while scrolling a screenful at a time was much more common with horizontal-scroll layout than with vertical-scroll layout.

We found that participants spent less time scrolling and used fewer scrolling actions with horizontal-scroll layout than with vertical-scroll layout, although the overall time to complete the tasks was not significantly different. The scroll ball and scroll bar were very frequently used when reading with vertical-scroll layout but with horizontal-scroll layout they were used less often, and keys were used more often. These differences accord with the differences in scrolling strategy.

2. RELATED WORK

There has been considerable research into reading printed material and how to best format it, e.g. [13]. There is much less research into on-line reading and many of the results are inconclusive or contradictory. The critical review by Dyson [3] provides a good summary of research in this field.

A relevant area of research is investigations into the effect of line length on readability. Dyson & Kipping [6] found that longer lines (of up to 100 characters) were read more quickly. However, Dyson [3] states that this is partially due to glare (shorter lines lead to more white space on the screen) and the need for more scrolling since the number of lines shown on the screen was constant across different line lengths. Interestingly, long lines are not found to lead to faster reading with print media where a line length of around 50 characters has been deduced to be optimal [3] (which is in accord with typographic guidelines [2]). Dyson & Haselgrove [4] found that comprehension rates were better with medium length lines (55 characters) than with long lines (100 characters). A consistent finding is that readers dislike long lines [6, 15].

User dislike of longer lines, along with the desire to maximize use of the available screen space make the use of multi-column layout appealing. Unfortunately, as Dyson [3] states, few studies have compared single and multi-column layout for on-screen reading. Dyson & Kipping [5] compared one column (80 characters) and three column layout (25 characters per column). They found that with paging, the younger age group read the single column layout more quickly than the three column layout while for older participants (> 25) there was no difference. Baker [1] compared one-, two- and three-column layout—with and without full justification—using paging. The results regarding reading speed and comprehension were, in our view, inconclusive. In both studies users preferred multi-column layout over single column.

There have been studies comparing paging and scrolling for single-column layout. Dyson & Kipping [5] split participants reading one-column layout into two groups: one could use keys to page up or down and the other could use keys to scroll up or down by one line at a time. They found that scrolling was slower than paging. However, at least partly this may be the result of forcing users to scroll with the key-

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[3]Note that paged layout with dynamically chosen page size is quite similar to horizontal-scroll layout. The main differences are that with horizontal-scroll layout there are no page boundaries, so figures can bridge adjacent columns and it is natural to scroll a column at a time rather than a page at a time.

board. They also found that there was substantial variation in the number of scrolling actions (keystrokes within 2 seconds of each other were collapsed into a single action) used by readers and that faster readers tended to scroll more frequently. However this was not explored in detail. We also note the work of Zhai, Smith & Selker [16] who compared the usability of different scrolling devices and also Jones et al.[9] who looked at scrolling use by small-screen users when working with content formatted for larger screens.

Our paper further explores single- and multi-column layout for on-screen reading and scrolling strategies. There are three main differences with previous work. It is the first user study that considers horizontal-scroll layout. The second difference is that this study allowed users to choose how to scroll and their desired browser preferences, such as window dimensions and font size. We feel that while making analysis more difficult, this provides results that will better model real-world performance where users can make these choices. The third difference is our focus on identifying scrolling strategies through the use of eye-tracking data. Eye-tracking has previously been used to identify strategies for browsing, reading and searching web-pages, e.g. [7, 10, 14]. The novelty in our study is that we use it to investigate strategies for reading long textual documents that do not fit on the screen and require the entire document to be read.

There has also been some research into reading with dedicated e-readers. Schcolnik [11] conducted an on-line survey of users of e-readers and a subsequent user study in which participants were asked to read a short article from an e-reader. Both studies collected user preferences but did not investigate performance. Participants were overwhelmingly found to prefer paging to scrolling and portrait mode to landscape mode. It is hard to generalize from these preferences since the very slow refresh rate of many e-readers makes the dislike of scrolling unsurprising. Furthermore, as best we can tell, only single-column layout was provided, in which case the long lines of text resulting in landscape mode may have been the reason for the dislike.

3. BROWSER

We have built a browsing tool to explore the layout and user interaction issues that arise in multi-column layout of documents using horizontal-scroll layout. The browser supports a subset of HTML/CSS: font styling, lists and paragraphs, headings, links, embedded images and floats. One limitation is that it does not yet handle tables or footnotes, though not due to restrictions of the approach. Examples of a layout obtained with the browser are shown in Figures 1 and 2. As with other common web-browsers, the user can resize the browser window and change the font size.

One important interface question for browsers that support multi-column layout is control of column width in the document. One possibility is that this is set by the document author (typically specified as x em of the body font) and only changed by the viewer in exceptional circumstances. A second possibility is for column width to be dynamic and depend on viewer preferences and width of the browser window. This is the approach we have chosen to use in our tool. The user can explicitly set the number of columns visible in the browser using buttons on the main toolbar. This is specified as an integer number of columns so as to enable maximum use of the viewing area. The tool initially displays three columns. Another possible approach would be to de-

a) Vertical-scroll layout

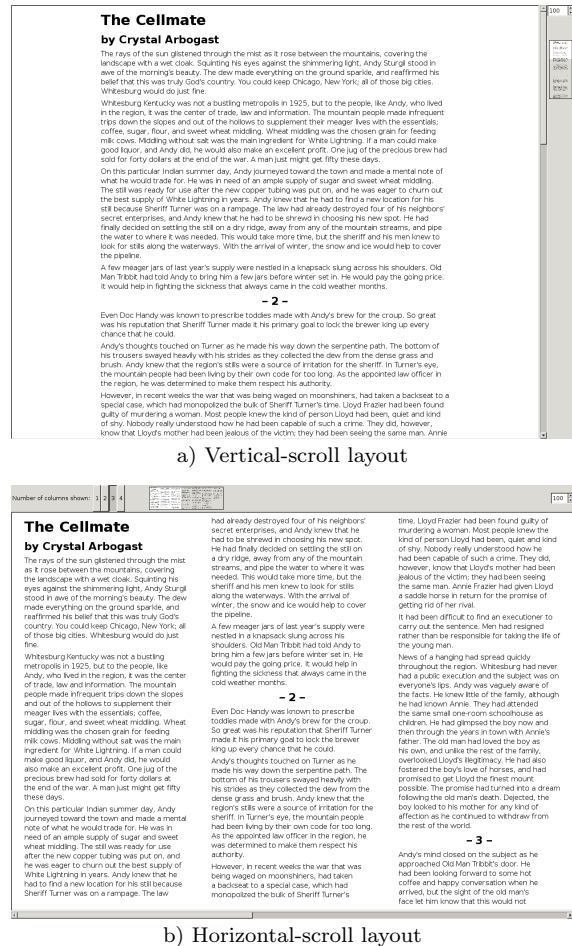b) Horizontal-scroll layout

Figure 2: Screenshots of the browser application displaying one of the short stories used in the experiment. The default settings are used in both layouts.

termine the number and width of columns by dynamically choosing the best template where templates are supplied by the author and may differ in the number of columns [8, 12].

The next question is how the column width should change when the browser width is subsequently modified? One possibility is that the column width remain fixed; this corresponds to a metaphor in which the browser is seen as a window over a previously laid-out document. The other option is that the specified number of columns remains invariant but the column width changes; this corresponds to regarding layout as a dynamic property of the browser window and is what our tool currently does.

Another significant interface design decision was whether or not to provide an overview of the document. An earlier version of the tool did not. However, one participant in a preliminary user study apparently expected the arrow keys to move a whole page when viewing a multi-column layout. We speculated that this might be because they expected the document to be laid out over several screen-sized pages rather than one very wide page of which the screen shows a relatively narrow section; the overview clarifies the situation, and gives immediate visual feedback of viewport position as one scrolls.

The other significant interface decisions were about which scrolling mechanisms to provide and what their exact behaviour should be. We decided to implement all common scrolling mechanisms and allow the user to choose. The mechanisms and their behaviours were:

- *Grab-and-drag:* When the mouse is positioned over the main browser window the user can move the viewable area by holding the left mouse button down. A hand-shaped mouse cursor is used to indicate this interaction.[4]

- *Scroll ball:* The most common mice at the time of writing provide only a vertically aligned wheel that does not fit well with horizontal scrolling. We instead used an Apple mouse with a finger-operated ball that can be rolled in any direction. By moving the ball left or right the user could smoothly scroll the main window left or right.

- *Scrollbar:* The tool provides a scroll bar on the bottom of the window which the user can manipulate either using the arrows at the end of the bar or by dragging the slider.

- *Keys:* The left- and right-arrow keys respectively scroll left or right by one column; or in the case of a partially obscured column, just enough to show one more full column in the desired direction. Page up and page down, respectively, scroll left or right by one screen width (or slightly less if the leftmost/rightmost column is partially obscured). The space bar is equivalent to page down. Home and End keys scroll to the start or end of the document respectively.

- *Overview:* The tool allows the user to left-mouse click directly on the document overview widget. This scrolls to bring the first column in the main window to the column in the overview that is closest to the mouse position.

The main issue when determining the behaviour was whether scrolling should "snap" the left boundary of the main window to column boundaries or not. While we felt that snapping was useful since it is rare for the user to want to display incomplete columns, we also wanted scrolling to behave as similarly to scrolling with vertical-scroll layout as reasonable and this typically does not snap to lines or paragraphs. Thus, we ended up choosing to tailor the snapping behaviour to the particular scrolling mechanism: Scrolling via grab-and-drag, scroll ball and the scrollbar is smooth and does not snap to column boundaries, but snapping does occur with the other methods.

In order to be able to use our tool for the user study, it also provides single-column vertical-scroll layout. For conformity with horizontal-scroll layout, it provides a document-overview window (shown as a vertical strip on the right of the main window) which updates immediately during scrolling. The scrolling mechanisms and behaviour are designed to mimic the behaviour of current web browsers and are similar to horizontal scrolling except that snapping is not performed. The up- and down-arrow keys scroll up and down respectively by 50 pixels while the left- and right-arrow keys have no effect.

4. THE EXPERIMENT

The main contribution of this paper is to describe a study that we conducted to compare usability of the horizontal-

scroll and vertical-scroll layout models and to compare the different scrolling mechanisms and strategies used with each model. The study required participants to read and then answer questions about two short stories laid out with the two different layout models. Participants were allowed to refer back to the story to check their answers. The study investigated both user preferences and performance.

The experiment was designed to investigate the following hypotheses:

- That for reading large, primarily textual documents on electronic devices with moderately wide screens relative to the body-text font size, the horizontal-scroll layout model would be preferred by many users. The rationale for this hypothesis is that this layout model allows more text to be visible on screen at once while maintaining comfortable line lengths.

- We conjectured that it might be easier to navigate with horizontal-scroll layout because the columns would provide additional landmarks. We would expect this to reduce the time spent by participants going back to the story to check their answers to the questions.

- We conjectured that the "natural" scrolling strategy for horizontal scrolling would be to scroll by a column at a time while for vertical scrolling the scrolling strategies would be more varied, ranging from a line at a time to a page at a time.

- As a consequence of this, we expected users would perform fewer scrolling actions and use less time scrolling with horizontal-scroll layout than with vertical-scroll layout since a significant number of users reading the vertical-scroll layout would repeatedly scroll by a few lines while for the horizontal-scroll layout users would scroll by at least one column.

- We conjectured that the choice of scrolling mechanism would be different for the two layouts, with key-based scrolling more common with horizontal scrolling than vertical because scrolling by a column at a time is readily done with the arrow keys.

Participants: The participants were graduate or undergraduate students of Monash University from a variety of courses. All participants were volunteers with normal or corrected-to-normal vision and proficient readers of English. 24 participants completed the experiment; though for 4 participants only their preference data was used: the interaction logs for three of these were truncated due to a software malfunction, and to ensure counter-balancing we needed to discard data from a further participant.

Materials and Design: Two short stories of roughly similar length that would take 10–20 minutes to read were chosen: *Prairie Dogs* by Colin Frizzell (2013 words, Flesch–Kincaid Grade Level 3.9) and *The Cellmate* by Crystal Arbogast (1887 words, Flesch–Kincaid Grade Level 5).[5] For each story five questions were developed. The first was to rate how much they liked the story on a five-point scale. The other questions were designed to require in-depth knowledge of the story and it was expected that participants would need to check their answers by re-reading part of the story. Example questions were "What is the name of the town's Sheriff?" and "Where is the train taking Bill and his friend?"

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[4]While this behaviour interferes with drag-based text selection in non-modal interfaces, we include it since it is a popular interaction method for document and web page scrolling on stylus or touch-based portable devices.

[5]The stories and other materials are available from http://bowman.infotech.monash.edu.au/~pmoulder/scroll-www/

Participants were presented with one story in horizontal-scroll layout and one in vertical-scroll layout. In order not to bias the study, four counterbalanced versions of the experiment were used, varying in the order in which the different stories were presented, and in the layout used.

Short (written) pre- and post-questionnaires were developed. The pre-questionnaire had multiple-choice questions that asked: how many hours the participant spent on average reading from a computer monitor each week (1–2, 2–5, 6–10, >10, unsure/none) and the preferred way to read (online, print or other). The post-questionnaire asked:

1. Which layout were you more comfortable reading text with: a) The vertical scrolling (Up/Down) layout or b) The multi-column horizontal (Sideways) layout?

2. Why do you feel that your preferred layout is better than the other?

3. What, in your opinion, could be implemented to improve the design of the less preferred layout?

4. Is there anything else you would like to add to help our study?

We used the FaceLAB eye tracker developed by Seeing Machines running FaceLAB (version 4.5) to log eye-tracking data during the experiment. Eye-tracking was non-intrusive and did not require the participant to wear head-gear. It did have difficulty tracking some participants, especially those with glasses, astigmatism or very dark eyes.

Procedure: Experiments were performed in a small room. Participants were seated on a standard office chair in front of a 19-inch computer monitor (Dell model #1905FP) on which the browser was viewed.

After reading and signing a consent form which also provided a short description of what the experiment was intended to investigate, the participants completed the pre-questionnaire. The procedure for the first short story was:

1. Instructions for using the browser for vertical-scroll or horizontal-scroll layout as appropriate were read to the participant. The default configuration for the browser was that it was sized to fit the whole screen, with a font-size of 16 pixels ($\simeq 13\frac{1}{3}$ points), and three columns were used in the horizontal-scroll layout. Participants were given time to practise instructions and to familiarize themselves with the appropriate layout type and the different available scrolling methods. They were encouraged change the browser settings (e.g., resize the window or choose a different font size) to make reading as comfortable as possible.

2. Participants were told that they would be reading two short stories with the browser and that they would be asked questions about the story afterwards. They were told that they could go back to the text to double-check their answer.

3. Calibration of the FaceLAB eye-tracker was performed.

4. After checking that the participant was comfortable and understood the instructions, the browser was opened by the research assistant (with layout parameters set to their default value) to show the short story. At the end of the story the participant indicated they had finished and the research assistant pressed a key to log that reading had finished.

5. They were then shown the questions and asked to write their answer on the question sheet.

During both reading and question answering all user interaction with the browser was logged and the participant's gaze was tracked and logged. Once the questions were finished the logging was stopped and the browser was closed.

The procedure for the second short story was the same except that Step 2 was not performed.

Finally, the participants were asked to fill out the post-questionnaire.

5. DATA ANALYSIS AND RESULTS

5.1 Data analysis

The primary data analysis was to extract from the user interaction log file a sequence of user actions and their duration.[6] The actions were:
- browser resizing
- font size change
- changing number of columns (only possible with horizontal scroll layout)
- scrolling by grab-and-drag
- scrolling by scroll ball
- scrolling by scrollbar
- scrolling by using page up, page down or the space bar
- scrolling using other keys
- scrolling using the overview

To account for the fact that quickly dragging a scrollbar or flicking a scroll ball results in multiple scrolling events, consecutive scrolling events within one second of each other were collapsed into a single scrolling action.[7]

A preliminary data analysis showed that there was correlation between the choice of story and the time taken to read the story and the time taken to answer the questions. This is not surprising. To ensure valid analysis we therefore made sure the experiment data was exactly counterbalanced with each story presented the same number of times with both horizontal- and vertical-scroll layout.

5.2 User preferences

Layout model preference: In the post-questionnaire each participant was asked which layout model they were more comfortable reading text with and why they felt that this model was preferable. 8 participants were more comfortable with horizontal-scroll layout and 16 preferred vertical-scroll layout.

Examination of the reasons given by participants who felt more comfortable reading with vertical-scroll layout suggests that their familiarity with vertical scrolling and relative unfamiliarity with horizontal scrolling was a major factor in their choice. For instance, one participant who chose vertical-scroll layout as more comfortable wrote that "It [vertical-scroll layout] is what I am used to" while another wrote "Horizontal scrolling is something new and I

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[6]The minimum duration for a scroll event was 0.3 sec, the time for the smooth scrolling animation to stop.

[7]While the choice of one second is somewhat arbitrary, in the following data analyzes we repeated the analysis using a cut-off for coalescing events ranging from 0.2 seconds to 4 seconds in 0.1-second increments. This resulted in relatively little change and in particular did not change the significance of any results at the 0.01, 0.05 or 0.1 levels except where noted.

	Page keys	Other keys	Scroll ball	Scrollbar	Overview	Grab & drag
Reading						
Horizontal	1 (1)	4 (4)	5 (6)	5 (6)	0 (2)	5 (5)
Vertical	1 (2)	3 (4)	12 (13)	3 (6)	0 (1)	1 (1)
Questions						
Horizontal	0 (0)	3 (4)	6 (7)	7 (9)	1 (1)	3 (4)
Vertical	1 (1)	2 (2)	11 (12)	3 (8)	0 (1)	2 (3)

Table 1: For each scrolling mechanism, the number of people who used that as their primary scrolling method (followed by the number of people who used that mechanism at all) when reading the story in each of the two layouts, and when answering the questions for that story.

wasn't used to it" but also wrote that "LCD screens seem to be more compatible for horizontal scrolling." As some support for the importance of familiarity, two-thirds of the participants (16 out of 24) said that they read >10 hours per week from a computer monitor.

Three participants who preferred vertical-scroll layout said that they disliked that horizontal-scroll layout forced them to move their eyes vertically up and down the full height of the screen. (No participant chose to reduce the height of the window and thus reduce this eye movement.) Such vertical scanning is not required with vertical-scroll layout since repeated scrolling can be used to move lines past the same vertical position on the screen allowing minimal vertical movement of the eyes. This is an interesting physiological difference between the two layouts and it may indeed be easier to move the eyes horizontally than vertically. It also provides support for our hypothesis that different scrolling strategies will be used with the different layout models.

Reasons for being more comfortable with horizontal-scroll layout were shorter line length and that it was easier to keep track of their position in the document when reading.

Participants were also asked how their least preferred layout model could be improved. The most interesting response was from one participant who suggested that page boundaries would help with reading in horizontal scrolling (presumably to aid navigation).

The provision of an overview in the tool seems to have been effective in clarifying the difference between horizontal and vertical-scroll layout since none of the participants expressed confusion between the two different layouts.

Preferred scrolling mechanism: In Table 1, we give for each scrolling mechanism and each layout model and each part (reading the story, and answering questions) the number of participants who used that mechanism during that part. We found that, during reading, the scrollbar and scroll ball are the much preferred mechanism for scrolling with vertical layout but with horizontal layout the preferred mechanisms are grab-and-drag, scroll ball and arrow keys. The difference is less marked in question answering.

To test whether there is a statistically significant difference in what scrolling mechanisms are primarily used for the two layout models, we use a χ^2 test of independence. In the case of reading, we have $\chi^2(df = 4) = 6.2$, $p = 0.18$; for question answering, we have $\chi^2(df = 5) = 5.4$, $p > 0.2$. These χ^2 values are without correcting for continuity; if we use Yates' correction, or if we use a Monte Carlo simulation instead of assuming a χ^2 distribution, then the significance is less still. Thus the study does not find sufficient evidence that different scrolling mechanisms would be used with the two models.

Interestingly, the preferences for scrolling model and for layout model were related. Of the six participants for whom grab-and-drag was the primary scrolling mechanism, only one preferred horizontal-scroll layout; whereas where arrow keys were the primary scrolling mechanism, the situation was reversed, with five of six preferring horizontal-scroll layout! This suggests that layout preference might depend on the scrolling mechanisms typically used with the target device (or software or readership).

Other preferences: We might also expect that scroll layout model might affect the choice of window size or font size. Only two participants chose to change the window size from full-screen. In both cases it was for vertical-scroll layout and just the window width was reduced, presumably to reduce the length of the text lines. Interestingly, both these occurred in cases where vertical scrolling was conducted after horizontal scrolling—perhaps the participants had become accustomed and more comfortable with the shorter line length provided with horizontal-scroll layout. Every participant who changed the font size changed it to about the same font size in each of their two versions. One participant decreased the font size to 70%, one participant increased to 120%, and one participant increased to 160% in one version (VC1) and 170% in the other (HP2). Of the 20 logged participants, 13 kept the default three columns, another four participants briefly tried other numbers of columns before switching back to three columns; two participants used four columns; and one participant used three columns most of the time but tried two columns for $3\frac{1}{2}$ minutes in the middle of their reading. One participant made the comment that they wished they had changed to two columns in the post-questionnaire.

A consequence of this is that while participants were free to vary the browser window size, font size and number of columns, the low number of participants who did so mitigates the possible confounding effect of these factors in the following performance analysis.

5.3 Performance

Number of scrolling actions and total duration:

Figure 3 shows for both the reading and question answering tasks $SA_V - SA_H$ where SA_H is the number of scrolling actions for the horizontal-scroll layout SA_V that for vertical-scroll layout and also $SD_V - SD_H$ where SD_H is the cumulative duration of the scrolling actions for the horizontal-scroll layout and SD_V that for vertical-scroll layout. Symbols indicate the most common scrolling mechanism used by the participant for reading each story: Page keys (Pg), other keys (→), scroll ball (○), scrollbar (⬚), overview (▭), grab-and-drag (✋).

Since we do not know what the underlying distribution is, we use the Wilcoxon matched-pairs signed ranks test to
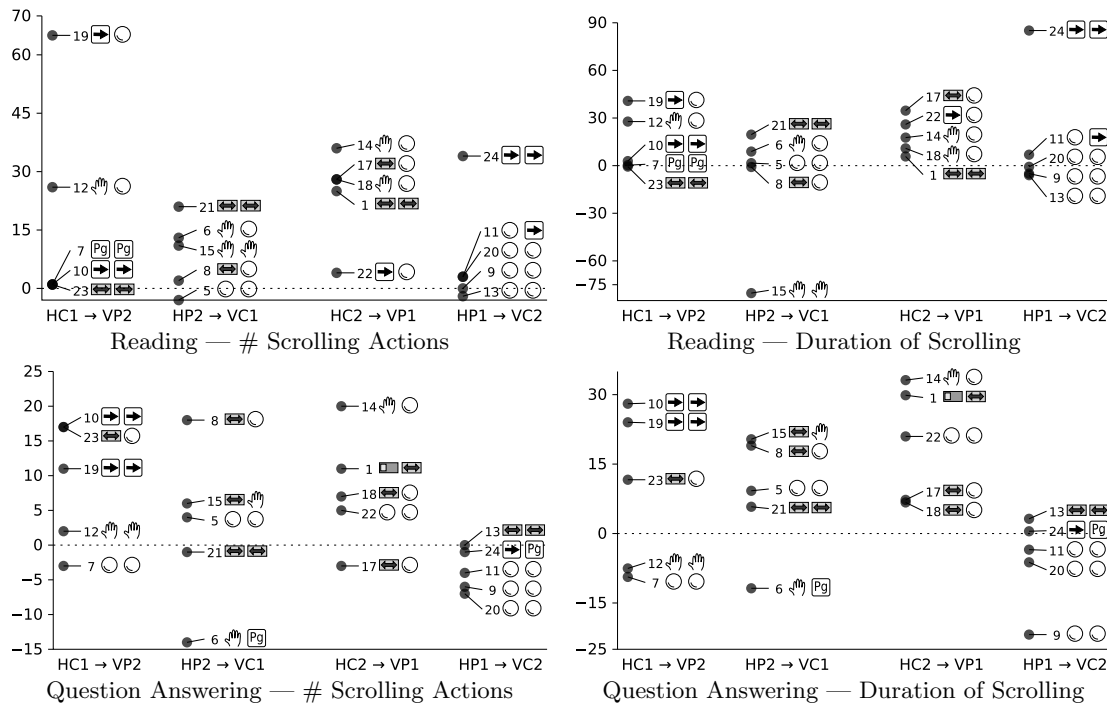
Figure 3: For each participant the difference between the number of scrolling actions and their cumulative duration with vertical- and horizontal-scroll layout. Figures are given for both reading and question answering time. Participants are split into the different versions of the experiment: For instance, $HC1 \rightarrow VP2$ indicates the version in which the first story was *The Cellmate* (C) presented in horizontal-scroll layout (H) followed by *Prairie Dogs* (P) presented in vertical-scroll layout (V). Symbols pairs indicate the most common scrolling mechanism used by the participant for reading the horizontal-scroll layout and vertical-scroll layout, respectively.

check for significance. Our hypothesis was that participants would perform fewer scrolling actions and spend less time scrolling when reading. The study supports this: a one-tailed test for scrolling duration gives $W(N = 20) = 44$, $p = .01$ (p slightly more or less than .01 for different coalesce-cutoff-durations), while a one-tailed test for number of actions gives $W(N = 19) = 11$, $p < .001$ (with slightly weaker significance for cutoff durations less than 500ms, p as high as .012 for 200ms). We also performed a one-tailed test for question answering. The study less strongly supported the hypotheses that horizontal scrolling had less scrolling duration ($W(N = 20) = 54$, $p = .03$), and fewer scroll actions ($W(N = 19) = 54$, $p = .05$, but with p varying from about .03 to over .1 for different coalesce-cutoff-durations) for question answering.

A possible reason for this might be that more scrolling was required with the vertical-scroll model than for horizontal scrolling. We computed for the initial configuration of the browser the minimum distance in pixels that the user needed to scroll to read the entire document, i.e. the amount needed to scroll the initial view to show the last line/column of each story for horizontal and vertical layout. This gave HP : 1697, VP : 2043, HC : 1697 and VC : 2055. Thus there is very little difference between the size of the two stories and while the stories took up slightly more screen space laid out with the vertical scroll the difference is not substantial.

Reading and question answering time: Table 2 gives the average time spent by each participant during reading

and during question answering for each scroll model. Previous studies [6] have suggested that longer line lengths lead to faster reading. In the case of question answering, our initial hypothesis was that columns might aid navigation and so reduce the time required to check answers. However, our study didn't find any evidence ($p > .1$ even for 1-tailed test) of an effect of layout model on total time for either reading or answering questions, whether using t tests or Wilcoxon matched-pairs signed ranks tests, and whether using the difference of the times or the ratio of the times.

We also evaluated the relationship between main scrolling mechanism and performance. Table 2 groups participants by their most frequently used scrolling mechanism (broken down by layout model and task type), and shows the average time spent during that task within that group. There is little difference between the different mechanisms except that page keys have a higher time for reading associated with them than the other mechanisms in both vertical and horizontal layout. However, this should be treated cautiously since we could not establish statistical significance for this as only two participants used page keys for reading.

Since participants could check their answers, there were few errors and these were distributed fairly uniformly between horizontal- and vertical-scroll layout.

5.4 Scrolling strategies

One of the main goals of the study was to identify the kinds of scrolling strategies used during reading. The analy-

(a) Page scrolling (horizontal layout)   (b) Region scrolling (horizontal layout)   (c) Continuous scrolling (horizontal layout)

(d) Page scrolling (vertical layout)   (e) Region scrolling (vertical layout)   (f) Continuous scrolling (vertical layout)
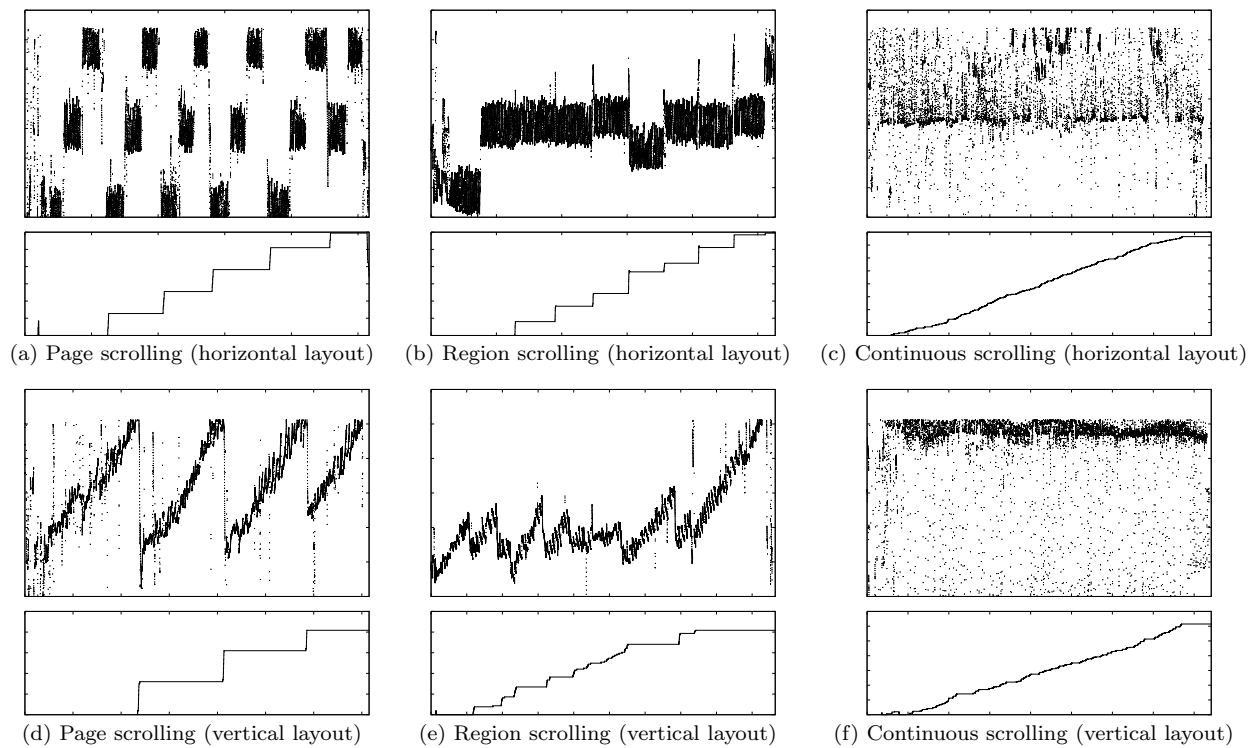
Figure 4: Plots showing example scrolling strategies used by participants. For each example we give two plots. Both show the full reading time (x-axis) in milliseconds. For horizontal layout the top plot gives the participant's gaze location in x-coordinates of the screen and the bottom plot shows the x scroll-offset of the browser window. For vertical layout the top plot shows the participant's gaze location in y-coordinates of the screen and the bottom shows the y scroll-offset of the browser window. In (a), for instance, we can clearly see the participant uses a page scrolling strategy where they read all three columns on the screen, scroll by exactly three columns (a page), and repeat.

sis was qualitative. For each participant and short story for which we had a non-truncated interaction log and calibrated eye tracking data we generated two plots:

- The index of the last word visible in the browser window as a function of time; and
- the x-position of the participant's focus in the browser window as a function of time for horizontal-scroll layout and the y-position (with origin at the top) for vertical-scroll layout.

We then looked at these paired plots and attempted to identify the scrolling strategy used by the participant when reading the short story. Sample plots are shown in Figure 4.

The same basic strategies were shared across both vertical and horizontal scroll layout:

- *Page:* The participant reads a screen at a time, scrolling only when at the end of the screen and scrolling a (nearly) complete screenful.
- *Continuous:* The participant scrolls near continuously, reading the same small area on the screen as they scroll.
- *Region:* This is an intermediate strategy in which the participant reads from the same region on the screen, typically about half of the screen, and scrolls when they reach the end of the region to update the text in the region.

Participants tended to use a fairly consistently strategy when reading the document, apart from at the start and end where they needed to read from the top of the screen and down to the bottom of the screen respectively.

Participants also tended to use a similar strategy in both horizontal- and vertical-scroll layout. For vertical-scroll layout 13% used the page strategy, 46% employed the continuous strategy and 31% read within a fixed region. Interestingly, this means over 75% of people reading vertical scrolling text did not read the entire page before scrolling, but rather chose to scroll more and read within a smaller portion of the display.

For horizontal-scroll layout the participants were less likely to use just a single strategy. Several participants visibly switched between the page and region strategies midway through the exercise. This probably reflects their unfamiliarity with horizontal scrolling. 50% of participants exhibited the page reading strategy and 64% were seen to read and then scroll by a subset of the visible columns (typically the two leftmost columns). We were surprised to see that one participant used a continuous scrolling strategy with horizontal scroll layout (unsurprisingly, this participant preferred vertical scroll layout). Participants who switched between strategies were more likely to start out reading the entire page and switch to reading a region of a couple of columns.
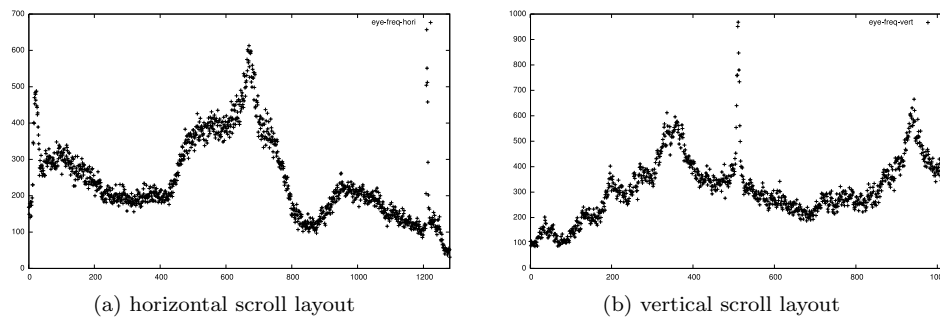
(a) horizontal scroll layout   (b) vertical scroll layout

Figure 5: Plots showing frequency of gaze location. (a) gives the x-coordinate of the participant's gaze location on the screen for horizontal scroll layout and (b) gives the y-coordinate of the participant's gaze location on the screen for vertical scroll layout.

	Reading	Questions
Horizontal		
Page keys	674 ($n = 1$)	— ($n = 0$)
Other keys	489 ($n = 4$)	103 ($n = 3$)
Scroll ball	412 ($n = 4$)	188 ($n = 6$)
Scrollbar	464 ($n = 6$)	180 ($n = 7$)
Overview	— ($n = 0$)	165 ($n = 1$)
Grab-and-drag	457 ($n = 5$)	211 ($n = 3$)
All	462 ($n = 20$)	172 ($n = 20$)
Vertical		
Page keys	753 ($n = 2$)	102 ($n = 1$)
Other keys	423 ($n = 3$)	177 ($n = 2$)
Scroll ball	402 ($n = 11$)	188 ($n = 11$)
Scrollbar	482 ($n = 2$)	110 ($n = 3$)
Overview	— ($n = 0$)	— ($n = 0$)
Grab-and-drag	421 ($n = 2$)	187 ($n = 3$)
All	459 ($n = 20$)	171 ($n = 19$)*

Table 2: Average time taken to read and answer questions for the horizontal- and vertical-scroll layout, broken down by primary scrolling mechanism during that part of the task for that layout model. Note (*) that one participant didn't scroll at all when answering questions for the vertical-scroll layout, so 'most used method' isn't defined for that case.

Another aspect that we investigated was the region of the screen where the participant was most likely to be reading. This is shown in Figure 5. We see that for horizontal-scroll layout reading from the middle of the screen is most common while for vertical-scroll layout the bottom of the screen is most common, though there is another peak about one third of the way down the screen.

We also investigated whether the preferences for scrolling model and for layout model were related. Of the six participants for whom continuous scrolling was the primary scrolling strategy for vertical-scroll layout, only one preferred horizontal-scroll layout. This accords with the dislike of some participants for the need to move their eyes too much vertically in horizontal-scroll layout.

6. DISCUSSION

We have investigated the effect of layout model on how people scroll and read textual documents on computer monitors. The main findings are:

- One third of participants found reading with horizontal-scroll layout more comfortable than reading with the standard vertical-scroll layout model. We found that overall reading and question answering performance was similar with both layouts.

- With vertical-scroll layout many (46%) participants use a scrolling strategy which minimizes vertical eye movement by using frequent scrolling of a few lines. Few (13%) read most of the page before scrolling. Fixation is more likely to be in the bottom part of the page.

- With horizontal scrolling, it was most common for participants to scroll one or two columns at time (64%) but reading a page at a time was also common (50%). Fixation is more likely to be in the middle part of the page.

- Quantitative analysis of the data supported our qualitative identification of differences in scrolling strategy between the two layout models. We found that participants spent less time scrolling and scrolled less often with horizontal-scroll layout than vertical-scroll layout. Preferred scrolling mechanisms for horizontal scrolling are more varied than for vertical scrolling and include more use of keys and less use of the scroll ball and scrollbar.

- Participant comments suggest that familiarity with vertical scroll-layout is one reason for preferring vertical-scroll layout. Our results also suggested that layout model preference was influenced by the choice of scrolling model used in vertical-scroll layout: participants who used continuous scrolling were more likely to prefer vertical scroll layout. Layout model preference also appeared to be influenced by choice of scrolling mechanism: those who used grab-and-drag as the primary scrolling mechanism disproportionately preferred vertical-scroll layout while those who preferred arrow keys disproportionately preferred horizontal-scroll layout.

While the results do not suggest that a majority of readers prefer horizontal-scroll layout, they suggest that if it was more widely available many readers might prefer to use it once they were familiar with it. This provides support for providing horizontal scroll layout in specialized software for reading documents, such as manuals, e-books etc.

Our results suggest that horizontal-scroll layout will be particularly popular on devices such as e-book readers that have slow display refresh and so are not well-suited to continuous scrolling and environments where keys or voice com-

mands are the primary scrolling mechanism. They also suggest that vertical scrolling is well-suited to touchscreen devices where grab-and-drag is the primary scrolling mechanism. Furthermore, we found that, especially for vertical scroll layout, most participants read from a smaller portion of the text than the amount displayed on the screen, preferring to scroll more often than necessary. This suggests that vertical scrolling my be well suited to devices with small screens so long as they have quick display refresh. It also suggests that with larger screens part of the display might be better used to provide contextual information.

Of course, some caution is required when generalizing our findings as they were only for reading short stories on a standard computer monitor by students who generally spend over 10 hours per week reading on a computer. We plan to conduct further studies to see if our findings generalize to other kinds of participants, devices and reading material.

The results also provide some support for the current proposal to extend HTML and CSS to provide multi-column layout.[8] However, the current W3C Working Draft for CSS3 Multi-column layout does not directly support horizontal-scroll layout since it specifies that multi-column elements have their height determined by column properties and the available width for the element. Without using scripting it is not possible to fix the height of a multi-column element and have its width be computed to contain the available content. We feel this to be a deficiency with the draft—especially when display of a large amount of content within this model will cause column heights taller than a single screen, forcing the reader to *vertically* scroll both forward and back within the document to read from one column to the next.

Our finding that participants were more likely to read at the bottom of the screen with vertical-scroll layout is interesting because it provides a guide to floating figure placement: Ideally one wants to place the float so that it will be visible on the screen when a reference to it is encountered in the text. This suggests that figures should be placed just *before* the first reference to the figure.

Acknowledgments

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