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Turning to learn: Screen orientation and reasoning with small devices

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ABSTRACT

While the prevalence and use of mobile devices to gather important information is increasing rapidly, a critical question is whether information gathering and reasoning with these devices produces acceptable levels of performance, especially relative to more traditional desktop environments? Across two studies, participants were evaluated on their ability to not only remember information conveyed on small devices, but also reason with said information in complex ways. Results indicated that, when compared to a full-size display, there is a reasoning deficit when using a small device. However, changing the small device to landscape orientation effectively eliminated this performance decrement. Further, this orientation manipulation appears to most support individuals who are lower in working memory capacity, as these individuals have been shown previously to struggle with learning from scrolling interfaces. This suggests that consideration of learner differences, through adaptive design, can promote optimal use of small technologies.

1. Introduction

Recent advances in the cost and efficiency of consumer electronics have resulted in small technologies becoming increasingly integrated into our everyday lives. Smartphones, personal data assistants (PDAs), netbooks and tablet computers are now all becoming common features of our daily routine, and in some cases nearly replace our dependence on traditional desktop (or even laptop) computing hardware. Smartphones alone represent a huge surge in consumer electronics, with annual smartphone sales already approximating fifty-four million units annually worldwide (Gartner, 2010).

The portability of these technologies provides benefits in many domains. For example, small devices are now frequently used in medicine (Garritty & Emam, 2006), and provide the opportunity to read and edit patient records anywhere within the medical facility (Luo, 2004). In education, students can have access to their lessons (Motiwalla, 2007; Reimers & Stewart, 2009; Waycott & Kukulska-Hulme, 2003), and also their community of schoolmates, anytime and anywhere (Vogel, Kennedy, Kuan, Kwok, & Lai, 2007). In business enterprise sectors, they permit users to work from anywhere, while simultaneously enabling them to stay in communication with the rest of the organization (Kirschner & Powell, 2005). Users are able to access e-mails, documents, and the web from their portable device (Cui & Roto, 2008); tasks that as few as 10 years ago would require users to have access to a dedicated personal computer to accomplish. Further, in many developing countries, people have limited access to desktop computers (Joshi & Avasthi, 2007), and as such users rely entirely on their small screen devices to provide a window of access to online resources.

It is clear, however, that people use these small devices differently than they use their desktop computers. For example, people do not usually use their small devices to create or edit long documents, because of the small screen size and limited input affordances (Cui & Roto, 2008). Given the invasion of these devices into our social consciousness, an important question is whether these small devices indeed provide an equivalent experience to (or replacement of) more traditional full-size displays (e.g., displays normally packaged with desktop computers, approximately 15″ and larger)? Specifically, are these devices useful and appropriate platforms for gathering factual information, and do they permit adequate reasoning with said information?

Some evidence suggests that they do not. For example, small screens have been shown to make reading more difficult and slower (Dillon, Richardson, & McKnight, 1990; Findlater & McGrenere, 2008). Also, web search can be more difficult on small screens than on larger screens (Jones, Buchanan, & Thimbleby, 2003).

1.1. Small devices and scrolling

Nearly half of the time spent using mobile devices is dedicated to communication-related, text-centric activities; primarily e-mail (Gartner, 2010). However, an obvious tradeoff that occurs when reading textual information like e-mails on small devices is that, due to the small physical size of the screen itself, text often

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overflows onto multiple screens and thus requires the user to scroll down to read the entire communication (e.g., ‘web clipping’; Albers & Kim, 2002). Even when information sources are explicitly designed to better portray information on mobile devices (e.g., mobile webpages), oftentimes even these tailored interfaces struggle to portray all information on a single screen.

This need to scroll has been shown previously to negatively impact subsequent performance. Scrolling has produced negative effects on information search and information gathering (Brooke & Duncan, 1983; Morrison & Duncan, 1988). Scrolling has also been shown to reduce reading performance and comprehension (Piolat, Roussey, & Thunin, 1997; Sanchez & Goolsbee, 2010; Sanchez & Wiley, 2009). It has been suggested that this result is likely because of the added difficulty in locating information within a text that scrolls.

Scrolling may produce these problems by one or more mechanisms. Perhaps it becomes more difficult to locate information once it has been scrolled. This could be due to a reduction in spatial memory. That is, because the text has scrolled, one no longer has a static reference point with which to orient oneself within the text. Another possibility is that scrolling may make it difficult to integrate information across screens. A third possibility is that the scrolling itself attracts attention. Movement in the visual periphery has been demonstrated to be an obligatory cue (Hoffman & Subramaniam, 1995). As a result, when movement happens on the screen, the user may dedicate attention to the movement rather than to the meaning of the text.

While current consumer technology permits the adaptive resizing of text via multi-touch gesturing, or even changing the orientation of the display (e.g., landscape viewing), these options still struggle against the limitations of the display size, and in fact might place more demand on the user to constantly resize and adapt their reading behavior to the specific device. As such, it is critical to explore whether such adaptive behavior does provide a quantifiable benefit for use on small displays.

1.2. Current study and hypotheses

In this set of studies, remembering and reasoning performance are compared across different types of displays. In the first experiment, performance on a small display is directly contrasted with a full-size counterpart. The results of the first experiment are then expanded with a second experiment which manipulates screen orientation on a small-device in an attempt to ameliorate any differences in reasoning performance.

If small devices are more difficult to understand because of the scrolling nature of the interface, it is expected that performance on a small device will be significantly impaired relative to a full-size display. However, if small displays do not affect reasoning performance, there should be no difference between display sizes. Further, if scrolling does indeed impact subsequent performance, reducing the need to scroll should also reduce any discrepancies in performance when reading from a small device.

2. Experiment 1 methods

2.1. Participants

Thirty-four ($N = 34$) undergraduates from a large public university were solicited for participation in this experiment. All participants were Native English speakers and were compensated with course credit in an Introductory Psychology class. This experiment was conducted entirely within subjects.

2.2. Materials

2.2.1. Reasoning problems

All participants read two short analytical reasoning scenarios. Each scenario contained three rules which ultimately influenced the final solution space. In one scenario, participants were asked to schedule a series of visits to six historical sites, and the rules influenced the order in which the sites could be visited. The remaining scenario was similar; however the overall context was different. In this second scenario, participants were instead asked to organize a series of six presentations for an invited conference, and were tasked with setting the presentation order. The rules in this case also limited the order the presenters could be scheduled. These scenarios were nearly identical in length ($M(\text{sd}) = 288(1.41)$ words).

Participants read each of these scenarios through a series of five emails from either their history professor (historical sites) or employer (conference). The first email always articulated the basic conditions of the scenario, for example the number and names of the speakers and the relevant background story. Emails 2–4 each presented a single discrete rule which constrained the ultimate solution of the problem. Finally, the fifth email simply stated that there were no other constraints on the scenario. Participants were given 5 min to read all five emails, and were allowed to re-read the emails as they desired during the time period.

2.2.2. Display

For the small screen device, participants read the emails on a de-branded virtual device which utilized a 208×276 presentation area at 96 ppi, analogous in size to several common consumer electronics. The full-size display presented the information as a generic email interface with emails appearing below the ‘Inbox’. In both presentation conditions, 12 pt Times New Roman font was used to present the textual information. Scenario and display type were completely counterbalanced across participants.

2.2.3. Rule recall

To test for the successful recall of the basic rules used in each scenario, participants completed a rule recall questionnaire (RRQ), which consisted of three multiple choice questions, one for each corresponding rule. In the RRQ, participants were asked to select which of five possible options represented the actual rule conveyed in the email communication (e.g., Dr. M must present after which presenter?). Participants received a single point for correctly answering each of these questions, and participants were allowed 2 min to answer these three questions. While completing the RRQ, the original emails were unavailable to the participants.

2.2.4. Rule application

To evaluate how well participants reason with information gathered from either a small display or full-size display, all participants also completed a Rule Application Test (RAT). For each scenario, participants were asked to answer six multiple choice questions which queried how well participants could apply the learned rules. For example, “Which could be the correct order in which you visit the sites?”. Participants were asked to choose only one answer per question, and were given up to 8 min to answer all six questions. Participants were allowed to access the emails as needed when answering these questions. The RAT was evaluated for the number of correct responses, and overall solution time. In this population, both measures produced normally distributed patterns of data in terms of both skew and kurtosis ($zs < 1.7$, $p > .05$).

2.3. Procedure

Participants were run in groups of 2–5 individuals. After completing informed consent, participants read one of the two scenarios on either a small-display device or full display (based on counterbalancing condition) for 5 min. Participants then completed the corresponding RRQ, which took an additional 2 min. Finally, participants then completed the RAT and were allowed up to 8 min to complete the RAT. If the participants finished before the 8 min had expired, they were told to wait quietly until all participants in the group had finished. Participants then repeated the above procedure except with the other scenario and display. The entire experiment took approximately 30 min.

3. Results and discussion

3.1. Rule recall

In terms of simple recall of the three corresponding rules for each display, a simple within-groups ANOVA revealed no differences in how well the basic rules were learned across the different display sizes. The problem rules were learned equally well in the small-display condition ($M(sd) = 2.76(.55)$) as in the full-size condition ($M(sd) = 2.79(.54)$, $F < 1$). This suggests that simple recall of facts or rules does not vary across the different display sizes. Importantly, this also suggests that any subsequent reasoning results are not a result of reduced rule recall in either condition, which could naturally impact this reasoning performance.

3.2. Rule application and time to solve

In terms of performance on the RAT, it appears that overall reasoning performance did vary based on display condition. Performance in the small-display condition ($M(sd) = 4.29(1.61)$) was significantly lower than performance in the full-size condition ($M(sd) = 4.76(1.16)$; $F(1, 33) = 6.81$, $MSe = .55$, $\eta_p^2 = .17$, $p < .01$).

Similarly, in time required to solve the RAT, there was also a significant difference across display conditions. In the small-display condition, participants took significantly longer to solve the RAT ($M(sd) = 297.30(71.57)$ seconds), than in the full-size condition ($M(sd)=256.78(90.13)$ seconds; $F(1, 33) = 7.38$, $MSe = 3781.28$, $\eta_p^2 = .18$, $p < .01$).

These results suggest that while small mobile devices like smartphones and PDAs are convenient and useful for seeking out basic facts or information, there does appear to be a significant tradeoff regarding how well this information can be used in relevant and complex ways. While basic factual recall is unaffected by display size, reasoning performance (or applying factual rules) is significantly decreased when users gather information from small screens. Small displays not only reduce overall correctness of reasoning solutions, but also require participants to take longer to reach these solutions, thus exposing consumers of such technology to a twofold disadvantage.

However, what causes this small device deficit? It is highly likely that this reduction in performance is in fact a result of the need for users to scroll through each email on the small screen in order to access all the information. While simple, this intuition is consistent with prior work which has found similar deficits as a result of scrolling in full-size interfaces, for both visual search (Brooke & Duncan, 1983; Morrison & Duncan, 1988) and reading for comprehension tasks (Sanchez & Wiley, 2009). It is likely that the scrolling increases demands on working memory (Sanchez & Wiley, 2009), making it more difficult to integrate information between screens. It may also be the case that the movement created on the screen by scrolling tends to attract user attention to stimuli that are not related to the actual information.

Can these deficits be attenuated by minimizing the need to scroll? In a second experiment, a new group of participants read the same scenarios on the small-display devices, however, rather than also reading on a full-size display, they instead read on the same small screen device that was instead rotated 90′ to a landscape orientation. As this landscape orientation effectively eliminates the need to scroll, it is an important question whether this simple change reduces or eliminates the reasoning deficits on small screen devices found in the first experiment. Finally, as learning demands from scrolling interfaces have been shown to interact with user characteristics (Sanchez & Wiley, 2009), a measure of working memory capacity was added in this second experiment.

4. Experiment 2 methods

4.1. Participants and design

In this second experiment, thirty-three ($N = 33$) undergraduates who had not participated in the first experiment were solicited for participation. All participants were again Native English speakers, and were compensated with credit in an Introductory Psychology course at a large public university. This experiment was also conducted entirely within subjects.

4.2. Materials and procedure

The materials and procedure were identical for this second experiment, except that the full-size display was instead replaced with a 90′ rotated version of the small-display device used in E1. In addition, a measure of working memory capacity was included in the experiment, and completed in a separate half-hour session.

4.3. Working memory capacity (WMC)

Working memory capacity represents a stable cognitive ability that has previously demonstrated high correlations with measures of reading comprehension (Daneman & Carpenter, 1980), science learning (Geiger & Litwiller, 2005; Sanchez & Wiley, 2006), attentional control (Conway & Engle, 1994), and also measures of fluid intelligence (Unsworth, Heitz, Schrock, & Engle, 2005). Importantly, WMC has also been related to learning from small devices, and other scrolling interfaces (Sanchez & Goolsbee, 2010; Sanchez & Wiley, 2009) Thus, in order to control for any potential differences in general cognitive ability in this experiment (Conway, Kane, & Engle, 2003), participants completed an assessment of working memory capacity (WMC). All participants completed Automated Operation Span (OSpan) which requires participants to verify simple mathematical operations while also trying to remember unrelated letters (Unsworth et al., 2005). OSpan represents a complex span task, where participants engage in the simultaneous processing and storage of information, which is fundamentally different from simple span tasks (e.g., list-learning) that only require storage of information.

In OSpan, operation–letter strings (e.g., IS $(8/2) - 1 = 1$? K) were presented in sets comprised of two to seven individual strings. Three trials of each set size were presented, and set sizes were presented in a random order. In this task, participants are required to evaluate the correctness of the math equation (e.g., ‘Yes’ or ‘No’), and are then presented the letter, which they are asked to remember for a later test. Responses are considered correct only if the letter is recalled correctly, in the correct serial position. In order to ensure that participants were attending to the processing task, an 85% accuracy criterion on the math operations was required. Administration and scoring followed the recommendations in Conway et al. (2005).

5. Results and discussion

In order to evaluate the change in performance across displays, a repeated-measures ANOVA was conducted. To statistically control for WMC, WMC was entered simultaneously as a covariate in the analyses. Again, measures of reasoning performance and time to solve produced approximately normal distributions in terms of both skew and kurtosis ($zs < 1.65$, $p > .05$).

5.1. Rule recall

Across both the landscape and portrait orientations, there was no difference in learning the three basic rules for each scenario, and this difference did not interact with WMC ($Fs < 1$). Rule recall in the landscape presentation ($M(sd) = 2.64(.60)$) was equivalent to rule recall in the portrait orientation ($M(sd) = 2.61(.56)$). This again suggests that presentation format does not impede the successful learning of basic factual information, and that users can successfully recall information from small displays.

5.2. Rule application and time to solve

For performance on the RAT, there was significant difference between presentation orientation ($F(1, 31) = 8.73$, $MSe = 1.15$, $\eta_p^2 = .22$, $p < .01$). The landscape orientation produced significantly better reasoning performance ($M(sd) = 4.58(.97)$) than did the portrait orientation ($M(sd) = 3.85(1.62)$). Further, this difference also interacted with WMC ($F(1, 31) = 5.77$, $MSe = 1.15$, $\eta_p^2 = .16$, $p < .05$). As is visible in Fig. 1, higher WMC individuals showed very little difference in overall performance across the presentations. However, lower WMC individuals showed a significant performance benefit when reading from a landscape display.

In terms of solution time, there was no difference between orientations, and this difference in solution time did not interact with WMC ($Fs < 1$). When reading a portrait display ($M(sd) = 237.75(56.76)$, participants solved the problems just as quickly as when they read in the landscape orientation ($M(sd) = 247.14(54.44)$. While the landscape orientation did improve reasoning performance, it did not reduce overall solution time.

This pattern of results suggests again that factual information recall is not affected when information is presented in a small display (regardless of orientation). However, it does suggest that by simply changing the orientation of the device, appropriate use of this information can be increased, and users engage in more correct reasoning based on the learned facts. Specifically, this benefit appears most pronounced for lower WMC individuals, who have been shown previously to struggle with applying information from interfaces that scroll (Sanchez & Wiley, 2009). Higher WMC individuals were relatively unaffected by the change in orientation, however by simply rotating the display 90', lower WMC individuals were able to significantly increase their reasoning performance.

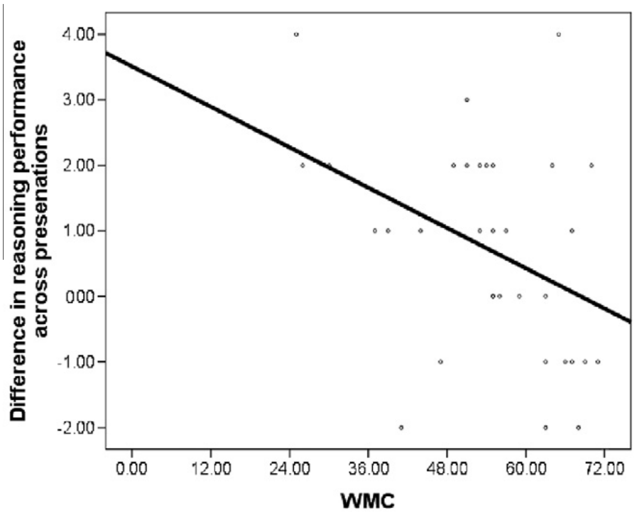

Fig. 1. Difference in reasoning performance between the landscape and vertical views by WMC in Section 4. A positive difference represents better performance in the landscape orientation, while a negative difference equals better performance in the vertical orientation. A difference of 0 indicates equivalent performance across orientation conditions.

6. General discussion

This set of studies was designed to explore whether reasoning or factual recall was inhibited by information gathering from small devices. Across two studies, results suggest that factual recall is relatively unaffected when learning from a small device. Learners were able to successfully recall critical factual information when prompted, and this recall was at a level equivalent to normal displays. Thus, there appears to be little detriment for information gathering on small devices.

However, when it comes to using this factual information to make appropriate decisions or otherwise reason about a given situation, there was a significant decrease in performance for small displays. Small displays produced lower overall reasoning performance, and also increased the amount of time it took to solve the problems relative to a full-size display. This suggests that while factual information gathering is unaffected when done a small device, reasoning performance is negatively affected when done on a small device. This performance decrement could likely be a result of the need to scroll to read all information on the small device screen. Scrolling has previously been shown to impact performance (Sanchez & Goolsbee, 2010; Sanchez & Wiley, 2009), and the current finding is consistent with these results.

Further, results of the second experiment suggest that this performance issue can be addressed through a simple manipulation of the orientation of the small device. By simply rotating the device 90′, and thus minimizing the need to scroll, reasoning was significantly improved. Importantly, this improvement was localized primarily to those participants who were lower in WMC. High WMC individuals were relatively unaffected by the change in orientation, however lower WMC individuals significantly improved their reasoning when the need to scroll was minimized. Again, this corroborates previous research which has suggested that low WMC individuals in particular struggle with reading and using scrolling interfaces, and reducing scrolling increases performance for these individuals (Sanchez & Wiley, 2009).

7. Conclusion and future research

In conclusion, this study suggests that using small devices does come with an explicit tradeoff, most notably in the time and correctness of reasoning on information gathered from a small device. However, it also does suggest that this detriment can be easily remedied through manipulation of the interface, in this case by increasing the amount of text presented on a single screen by adjusting the device to landscape orientation. Future research should explore other adaptive means of conforming the learning environment to best fit the needs of the user, to thus capitalize on the utility of these small devices for everyday use.

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