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Segmentation of display space interferes with multitasking

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Abstract: Peripheral displays are useful for organizing information and providing additional screen space for managing information. One design issue is whether peripheral displays should be part of a single large contiguous display space or segmented into many dedicated displays. To test this, an experiment was conducted comparing performance for on-screen versus off-screen displays and bordered (i.e., with a bezel) versus borderless displays. To measure multitask performance, participants were tested under dual-task (document editing and headline checking) and single-task (document editing alone) conditions. Distance between peripheral display and workstation display was also varied (near versus far). Results showed that off-screen peripheral displays reduce editing performance more than on-screen peripheral displays, independent of distance. Peripheral displays with borders were also found to reduce editing performance, but only at far distances. Performance on the headline-checking task was reduced by the far display but not by the bordered display. These results suggest that segmenting display space also segments information space.

Keywords: Peripheral displays, multitasking, dual-task, multi-display systems

1 Introduction

The desk surfaces in many offices are piled high with papers and books. Computer screens, each containing different sorts of information, surround us. Email is handled on the laptop to the left; programming is done using the large screen to the right. The physical edges of screens are ringed with many yellow sticky notes, reminding or noting various events, activities, phone numbers (see Figure 1). We are enveloped in information. Some is central to immediate and ongoing tasks, and some is peripheral, for instance, maintaining state of various sorts. In some cases, peripheral information is literally in the periphery of the work area, for instance, on a sticky note around the edge of the screen or on paper lying next to the screen.

As our physical work environments rely on information scattered among available surfaces and objects, perhaps our electronic environments should also be able to capture this natural way of organizing information. One approach to integrating physical and electronic environments is to enable information actions using ordinary physical objects, such as blocks (Fitzmaurice, Iishi, & Buxton, 1995) or paper (Want, Fishkin, Gujar & Harrison, 1999). Another approach is to free the display of electronic information from the confines of the computer screen, allowing information to be distributed across various media in the environment. Display technology advances and cost reductions point to a possible explosion of display space from the current 2 million pixels to over 100 million pixels. Electronic information will soon be able to live outside the small, framed area defined by workstation monitors. As such, we are presented with new opportunities to arrange and distribute electronic information to support tasks and information management needs as never before.

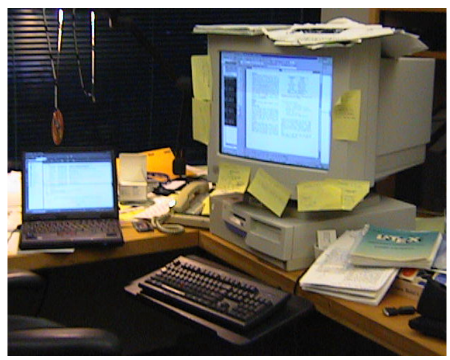

Figure 1: Typical workspace containing both central and peripheral information.

1.1 One Hundred Million Pixels

Display technology continues to advance with high-resolution displays, flexible displays, and video cards that support high resolutions and many monitors. At the same time, CRTs and LCDs have dropped in price. We might soon see end-users with 100 million pixel displays. But what would you do if you had 100 million pixels? How would you arrange these pixels? Would you use multiple screens or one large screen? Would you distribute screens in the environment or collect them around a central area? Though these questions are hypothetical, the issue will soon become important for designers.

The general question is how to design large display spaces to support information needs and multitasking and to minimize information overload, distraction, and interruption (Cutrell, Czerwinski, & Horvitz, 2000; McFarlane, 1999). We assume additional pixels will have benefits but will also impose costs. One benefit of more pixels is that user multitasking can be improved by maintaining the state of multiple tasks, holding information for cross-referencing. This function might reduce the cost of task switching. More pixels may also improve information awareness so that, like paper, electronic information can be posted and organized to support finding and reminding (Barreau & Nardi, 1995; O'Hara & Sellen, 1997). A third benefit is that more display space may provide better connection with and awareness of people and group activities (Dourish & Bly, 1992). Finally, additional display space allows one to better organize information, putting information in its place and reducing clutter (Malone, 1983).

When considering such benefits, it is necessary also to consider potential costs. Simply providing more information is not always helpful and can lead to information overload, a loss of orientation and context in information space resulting in confusion and reduced performance. Distraction from some central task can also result when displays are "noisy" or poorly designed. Display space may also be designed in such a way as to interfere with certain types of tasks, for instance, displaying a phone number on a screen that is far from the phone.

A number of design issues arise from the potential benefits and costs of large display spaces, including contiguity, segmentation, interactivity, distribution, mobility, flexibility, and regularity. *Contiguity* defines the way in which pixels can be grouped together (i.e., displays) and these groups can have various contiguities or distances from one another. What are the costs and benefits of increasing the distance between displays? Are there limits imposed by the user's visual field and the need for head movements? *Segmentation* defines the way pixels are grouped. Should all pixels be in one large continuous display or many separate displays? How many displays does the user need? *Interactivity* defines how easily pixels can be changed or manipulated by the user. Should some of the pixels be harder to change than others so that not all of the display space becomes workspace? *Distribution* defines the degree pixels or displays should be spread throughout the environment. Is there a benefit to putting displays in significant locations or does this just disorient the user? *Mobility* defines how well pixels can be physically moved and carried by the user. Should some of the pixels be mobile and if so, what amount?

Similar to interactivity, *flexibility* defines the extent to which pixels are dedicated to certain types of information. If displays have dedicated functions, users know what to expect and can find information more easily. However, highly configurable displays may allow users to optimize their environments for specific needs. Finally, *regularity* defines the shape of the display, either as a regular form (e.g., rectangle, circle) or an irregular form. For example, a workstation monitor is a regular form (a rectangle), but a monitor with a smaller LCD on the side makes an irregular form. Is information more likely to be lost or ignored with an irregular display space than with a regular one? How does regularity affect expectations of where to find information?

1.2 Peripheral Displays

Display space is currently used as workspace to manage ongoing activities and tasks. Additional display space could be used as workspace, but the majority of new display space will probably be dedicated to organizing and using peripheral information. We call nonessential information *peripheral information* because it is not central to the current task, but might be helpful to it or informative in other ways (Maglio & Campbell, 2000). There are two ways in which information might be considered peripheral, in content and in display. Peripheral displays could present high-priority information as well as peripheral sorts of information, but these displays are always located in the margins or edges of a workspace. Likewise, peripheral information is generally not central to the user's needs but may be displayed in any location.

A primary concern in designing display spaces is how the design influences mental models of information space. Here, we are concerned with how segmentation and contiguity can produce a sense of information isolation (Grudin, 2001). In other words, does segmenting display space necessarily segment information space? If so, what is the cost of segmenting information space? Several display factors might give the perception of non-contiguity, including visible space between displays, distance in depth from one display to another, and relative size of displays. Segmentation can potentially be produced by a large bezel or border, display differences (e.g., different resolution or color depth), and lines or other objects or graphics that signal separation. Which factors produce an attentional barrier that result in islands of information?

Our goal here is to determine the effects of segmenting display space on multitasking performance---i.e., information awareness and multitask interference (distraction). To this end, peripheral displays were presented on-screen and off-screen in the first experiment. The off-screen display was separate from the main workstation monitor, and the on-screen display was a graphical display shown on the workstation monitor. In the second experiment, the effects of the bezel were examined by presenting off-screen displays with and without a bezel. Both experiments also examine the effect of distance between primary and peripheral displays on performance, as well as the information awareness afforded by different display types.

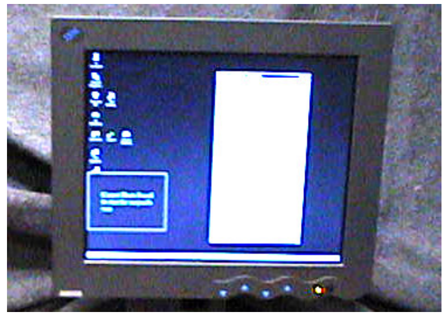

Figure 2: On-screen ticker display is the window on the left. The main editing window is on the right.

Figure 3: Off-screen ticker display is shown in the small screen on the left. Editing window is on the main screen on the right.

2 Experiment 1

The purpose of Experiment 1 was to determine the effects of segmenting display space by comparing multitasking performance across display types (off-screen and on-screen peripheral displays). Display type was crossed with distance (near and far) and the effect on multitasking performance was measured.

2.1 Method

Participants performed two tasks at once: editing a text document on the workstation monitor and remembering headlines from the peripheral display. Performance in this dual-task situation was compared across four peripheral display conditions: (a) near, on-screen; (b) far, on-screen; (c) near, off-screen; and (d) far, off-screen. Information awareness was measured by testing each participant for number of headlines remembered.

Participants. Eight researchers were recruited from our research center and compensated for their time. All had normal or corrected-to-normal vision.

Design. The experiment was constructed as 2 (display type: on-screen vs. off-screen ticker) x 2 (distance: ticker close to editing window vs. ticker far from editing window) within-subjects design. Order of presentation was partially balanced across participants using a Latin square to ensure that each condition occurred in each ordinal position the same number of times. Four different sets of documents to be edited and headlines were assigned to the four conditions also using a Latin square.

Two dependent measures were collected for each participant: number of corrections made and number of headlines correctly recognized.

Equipment and Setup. For the on-screen condition, the text editor and the ticker appeared as two separate windows on a single LCD computer screen (see Figure 2). For the off-screen condition, the text editor appeared on the main LCD computer screen and the ticker display appeared on a small IBM PC-110 screen placed next to the main computer screen (see Figure 3). Both on-screen and off-screen ticker displays were color flat-panel LCD displays driven by the same Java program to display the headlines. The PC-110 screen was 158mm x 91mm in size, and the headlines were displayed in 50

Horse Causes Bus Accident Killing Six
French F-10 Fighter Jet Down Over Turkey
Congressional Staffers Have Alcohol-Free Holiday Party
Nutritionists Tell Americans to Eat Cauliflower
Finland Builds World's First Fusion Power Plant

Table 1: Example headlines.

point Times Roman font. The ticker on the main computer was also 158mm x 91mm in size and the headlines were also displayed in 50 point Times Roman font. For both displays, the headlines were presented in the color cyan on a black background with a gray border. Overall, the two displays were identical in appearance. The text-editing window was placed 5cm to the right of the peripheral display in the near condition and 11cm to the right in the far condition.

Materials. Four documents to be edited---one for each condition---were chosen from popular press articles about software tools or Internet applications. Errors were introduced into the texts by hand according to three rules: (a) between 0 and 2 errors were put in each sentence; (b) errors were evenly spaced throughout the entire document; (c) errors included only subject-verb agreement, word order, and inconsistent verb tense. These error types were chosen (rather than spelling and other typographical errors) so that the editing task would be sufficiently demanding and thus be likely to produce a dual task performance tradeoff.

The tickers displayed thirty two- or three-line headlines, averaging seven words apiece (see Table 1). Four sets of headlines were presented---one for each condition. The headlines were constructed as concise and self-contained summaries of news stories. The topics of the headlines were fictional but plausible and covered the widest possible range of news categories (e.g. world news, local news, sports, entertainment, science, technology, business, and the arts). Each of the thirty headlines was displayed once in random order, and then this sequence repeated so that overall, each headline was displayed twice. Headlines were presented serially, one replacing the other on the display. This ticker was called *serial presentation* or SP in our previous work (Maglio & Campbell, 2000) and *rapid serial presentation* (RSVP) by others (Kang & Muter, 1989). Thus, in this experiment, the headlines did not scroll.

Procedure. Each participant was randomly assigned to one of the condition orderings. Participants were instructed that they would be editing a document and reading a ticker display at the same time. Participants were told about the types of errors that they could expect to find in the document. They were also told to make as many corrections as possible while reading the headlines in a five-minute period. The importance of performing both tasks to the best of their ability was stressed, as well as the fact that they would be tested for their memory of the headlines. During the experiment each headline was on the screen twice for 5 seconds each time. Participants sat directly in front of the main computer at about 1/2 meter from the display. At the end of each five-minute period, the experimenter saved the document that was edited and administered the multiple-choice test. Participants were told to guess on any questions to which they did not know the answers. The entire experiment took between 40 and 55 minutes to complete.

2.2 Results

A 2x2 analysis of variance (ANOVA) was performed on the number of edits made. Results showed a reliable main effect for display type ($F(1,7) = 9.906$, $p < .05$), but no effect of distance (see Figure 4). When the ticker display was on-screen, participants made an average of 8.75 edits, and when the ticker display was off-screen, edits dropped to an average of 6.88.

Another 2x2 ANOVA was performed on scores of the headline recognition test. No reliable main effects were observed (see Figure 5). The average score across all participants was 21 out of 30 headlines correct or 70%. The lowest score was 10, and the highest score was 29. Thus, test performance was within normal range, neither at ceiling or floor.

2.3 Discussion

The results suggest that using an off-screen peripheral display interferes more with multitasking than on-screen even when distance is controlled. In other words, an off-screen display reduces performance more than an on-screen graphical display even with the same distance. Distance, however, had no effect, possibly because the manipulation from 5cm to 11cm was not large enough. In this experiment, the maximum distance was constrained by the size of the workstation monitor. For the on-screen display, the ticker and the editing window could only be moved to the opposite ends of the screen. Even with an 18-inch LCD monitor, the maximum distance between task windows could only be stretched to 11cm.

As with previous work using this method, there was no effect of peripheral display type on information awareness (Maglio & Campbell, 2000).

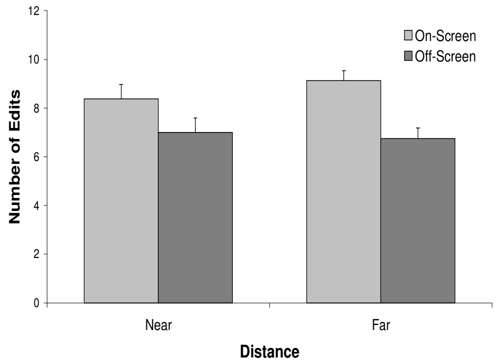

Figure 4: Experiment 1: Off-screen peripheral displays interfere with editing.

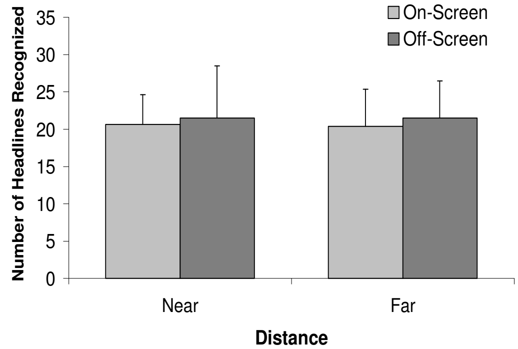

Figure 5: Experiment 1: No effect of distance or display type on headlines remembered.

It is difficult to draw conclusions because the lack of effect could result from an insensitive test or the fact that the display manipulations actually have no influence on information awareness.

The reliable difference observed between on-screen and off-screen displays suggests that off-screen displays promote a sense of information segmentation. But what is it about off-screen displays that lead to this perception? Some differences between these display types include (a) a visible separation between displays, (b) the off-screen display has a bezel or border while the on-screen display did not, (c) the on-screen display was within a regular display space (i.e., in the rectangular area of the workstation monitor) whereas the off-screen display creates an irregular display space.

3 Experiment 2

The purpose of Experiment 2 was to further explore the interference of off-screen displays on multitasking. To do this, we manipulated bezel/border and distance while holding constant screen location and regularity. All peripheral displays were off-screen and in an irregular area (i.e., outside the workstation monitor area).

3.1 Method

Unlike the first experiment, in this one, participants performed a single-task as a baseline to compare with the dual-task condition. The single-task consisted of editing a document alone whereas the dual-task included editing a document and checking whether headlines were world news events. Rather than memorizing headlines, information awareness was measured as ability to identify which headlines described world news versus which described US news. This type of task has been shown to be sensitive to awareness of peripheral information (McCrickard, Catrambone & Stasko, 2001).

In this experiment, a projector was mounted above and behind participants to simulate different types of displays. In this way, a peripheral display without *any* bezel could be presented. The peripheral display was projected onto several small rectangular pieces of foam-core, and the central work area was projected onto the screen of a CRT monitor.

Participants. Twenty-seven participants were recruited from our research center and compensated for their time. Two participants were compensated with a prize (a T-shirt) for being the top performers.

Design. The experiment was constructed as a 2 (border: border vs. no-border) x 2 (distance: near vs. far) within-subjects factorial design. Order of presentation was balanced across participants. The same document was edited in all conditions but participants did not re-edit any portion of it. Headlines were presented in random order.

Stimuli. The workstation monitor display and the peripheral display were simulated with a 1280x1024 pixel resolution projector mounted to the ceiling. The projector created the workstation monitor display by projecting onto the screen of a 15-inch CRT monitor with a white bezel. The screen was covered with opaque white paper to provide a good reflective surface. The peripheral displays were created by projecting a graphical image of a display onto a rigid piece of foam-core board. The foam-core was cut to the appropriate size, and two pieces were placed at two different distances, one far and the other near the workstation monitor display. In the near condition, the foam-core board completely overlapped the CRT bezel. In the far condition, the foam-core board was propped-up using a metal bracket to the right of the main screen. For the border condition, the picture of a black monitor

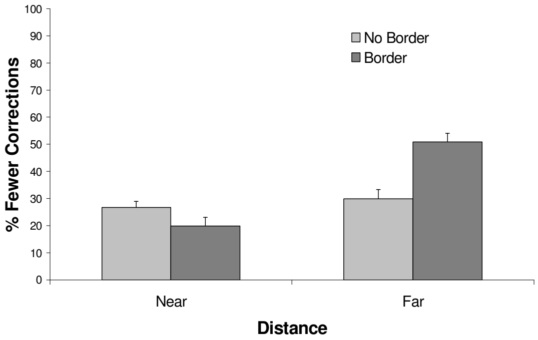

Figure 6: Experiment 2: Fewer corrections or edits are observed for peripheral displays that have a border and are far from the main display.

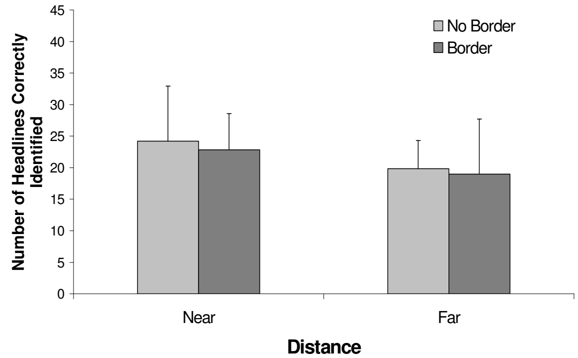

Figure 7: Experiment 2: Number of headlines correctly identified decreases with a far peripheral display, but border has no effect.

bezel was graphically inserted into the projected display.

A projected image was used for the workstation monitor display rather than the CRT screen because the projected image is much brighter than the CRT display. Using a projected image for both displays ensured that they were of the same brightness and resolution. One problem with projecting onto a CRT screen is that the screen is not entirely flat. This caused a small degree of warping of the projected image. On questioning, participants claimed not to notice the warping of the projected image.

The participant sat directly in front of the central display at a distance of 60cm with the peripheral displays to the right. Note that when degree units are reported, they refer to degrees of visual angle based on a distance of 60cm. The peripheral display was 25.5cm (23 degrees) away from the right edge of the editing area in the far condition and 3cm (2.9 degrees) in the near condition. The workstation monitor display was 31cm x 23.5cm (27 degrees x 21 degrees) and the peripheral display was 20.5cm x 15cm (19 degrees x 14 degrees). The editing area was 19.5cm x 11cm (18 degrees x 10 degrees) excluding a vertical scrollbar.

The font for the article text was 14-point Sans Serif, bold, with a black foreground and a white background. The font for the headlines was 30-point Dialog, bold with a white foreground and a black background. The headlines were actual headlines that had occurred within the past four years. Recent headlines within the last six months were not included to minimize familiarity effects. Headlines were 50% US news and 50% world news randomly mixed. The US news headlines spanned many categories, including sports, weather, politics, and entertainment. World news headlines were also highly diverse, including news from 15 different countries and five different continents, dealing with economics, politics, and human-interest subjects. The article used for editing was a magazine article about technology standards for different European countries. Grammatical errors were introduced into the article as in Experiment 1.

Procedure. Participants were told that they were acting as an assistant to a journalist and that as such, they would need to help the journalist with her daily duties. This journalist was a world news reporter for a major newspaper, working on an article under a strict deadline. By helping this journalist with her job, participants were told that they could earn points that contributed to an overall score. Participants with the highest scores would win a special prize.

In the dual-task condition, participants were instructed to perform both tasks---editing and headline checking---concurrently with the goal of maximizing the number of points earned. Participants were informed that they would have only five minutes per session. Editing was performed by evaluating each sentence and pressing a button at the top of the text editing area to indicate whether that sentence was correct or incorrect. The current sentence under evaluation was highlighted with asterisks at the beginning and end of the sentence. When the participant hit one of the buttons---correct or incorrect---the asterisks would automatically move to the next sentence. If the evaluation was correct, the participant earned 25 points. If incorrect, the participant earned 25 points. As soon as the button was pressed, points awarded were displayed and the overall score was updated.

The headline judgment task involved finding headlines that would be relevant to the journalist writing the article, that is, world news headlines. To ensure that the article was timely and fresh, the journalist needed to be informed of breaking world news headlines as quickly as possible. Participants were instructed to press a button on the display when a world news headline appeared. The faster the button was pressed the more points earned up to a maximum of 10. The points were deducted if the headline was not world news. Points earned were shown displayed and the overall score was updated.

At the beginning of the experiment, participants were given instructions based on condition to which they were randomly assigned. Participants were given a five-minute training session to familiarize them with the setup and procedure. Participants were told that there would five sessions of five minutes each. At the end of each session, a break could be taken. Participants were also warned that one session would be a control condition in which the peripheral display would not be present.

3.2 Results

The results were analyzed with a 2x2 repeated measures ANOVA. Information awareness was measured as the number of sentences correctly evaluated. Multitasking interference or distraction was measured as the percent decrease in edits from the single-task condition to the dual-task condition: the greater the percentage, the more interference.

For multitasking interference, there was a reliable effect of distance ($F(1,48) = 12.69$, $p < .05$) with far distance being more distracting than near (far, .38; near, .23), and a reliable effect of border ($F(1,48) = 4.54$, $p < .05$) with border being more distracting than no border (border, .35; no border, .26). There was also a reliable interaction between distance and border ($F(1,48) = 14.06$, $p < .05$) with border being more distracting as distance increased (see Figure 6).

Information awareness of the peripheral displays was analyzed by measuring number of headlines correctly identified as world news headlines (see Figure 7). A two-way repeated measures ANOVA showed a reliable effect of distance ($F(1,48) = 4.29$, $p < .05$), but no effect of borders ($F(1,48) = .32$, NS) and no interaction ($F(1,48) = .02$, NS).

3.3 Discussion

The results show that border has a strong effect on multitasking for off-screen peripheral displays. The effect, however, appears to be dependent on distance in that interference only occurred at the far distance. Why this happened is unclear. Perhaps the overlapping borders of the workstation monitor display and the peripheral display made it appear that the peripheral display had no border, or perhaps the near image of the projected peripheral display may have appeared more like a projection than a real display device when seen up-close.

As predicted, increasing the distance to 25cm from 11cm in the previous experiment produced a reliable effect. Distance was shown to interfere with multitasking and to interact with peripheral display border to produce a very strong effect. Changing the information-awareness task was useful in finding a reliable effect of distance. Greater distances made it harder to get information from the peripheral display. Border, however, had no effect on awareness.

4 General Discussion

Overall, the results show that contiguity and segmentation of display space interferes with multitasking and reduces information awareness. The reason stems partially from two display characteristics—distance between displays and presence of a border. Additional work is needed to determine if similar effects follow from other display characteristics, such as distance in depth, visible space between displays, and peripheral display location. The peripheral display can be located such that the display space forms either a regular or an irregular area. It could be that the interference we observed resulted partly from the irregular location of the off-screen peripheral display. Distance in depth is also an important consideration if future display designs include distributing displays in the environment, such as, on walls or desks.

Because the peripheral display bezel interfered with multitasking, we may expect that the bezel of the workstation monitor may also have this effect. Additional work is needed to determine (a) if the workstation monitor bezel interferes with multitasking, (b) if this interference is additive with the interference from the peripheral display bezel, and (c) if the interference is a function of absolute bezel size or bezel size relative to display size.

The interactive qualities of the displays could also be a factor in the user's mental model of information space. For example, if it is easy to drag information from one display to another, those displays may be conceived as one continuous space. Likewise, if a single large display is segmented into two halves, where moving information between them was time-consuming and complicated, these halves may be viewed as two disconnected spaces.

Learning might also affect mental models of information space. The results observed here were obtained in relatively short periods—less than one hour—with participants who had never used a multi-display system before. Because multitasking performance can improve with practice (Damos & Wickens, 1980), it is possible that users can learn to multitask effectively, reducing interference.

Computer monitors, televisions, and other electronic displays have frames or borders, which suggest information containment. Rarely does one shift attention among many screens or displays to multitask or cross-reference information. The experiments reported here provide empirical support for this notion by showing that off-screen displays can interfere with multitasking. This is because of at least two factors—distance of peripheral display to main monitor and presence of a border or bezel on the peripheral display. These display characteristics act as a kind of attentional barrier that blocks movement of information across display space. In other words, these factors not only segment display space but also segment information space.

The pace of display-space growth presents a challenge for designers and practitioners. Barriers can be added to structure and organize information. Or barriers can be removed to allow information to flow freely. To support multitasking, designers ought to reduce attentional barriers between displays by building peripheral displays with little or no bezel. Alternatively, moving peripheral displays close to workstation monitors will minimize interference of the bezel.

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