Usability in Multiple Monitor Displays

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Abstract

An experimental study was conducted to examine the impact of multiple monitors on user performance and multitasking. Forty-three participants were assigned to two groups—a multi-monitor group and a single-monitor group—to carry out a series of tasks. Both quantitative and qualitative data were collected and analyzed. Results indicated that those who used the multi-monitor display were more inclined to multitask and scored higher on performance measures than those using the single monitor. Interviews from the participants validated the quantitative results and provided additional insights on usability issues of multi-monitor displays.

ACM Categories: B.4.2, H.1.2, I.4.0

Keywords: Multiple monitors, multitasking, large display monitor, user performance, usability

Introduction

Computing power has increased exponentially in the last twenty years. The increasing speed of Internet connections has made it possible for ordinary users to access a vast amount of information quickly. However, display technologies have not been developed at the same pace (Grudin, 2001). Research has suggested that even a large computer monitor fills only about 10% of visual space of a user. Furthermore, restrictions in neck movements can shrink that to 1% utilization (Czerwinski et al., 2003).

One way of increasing display space is to use multiple monitors that are linked to act as one screen; this is sometimes called "multimon" (Czerwinski et al., 2003; Grudin, 2001; Robertson et al., 2005). Although there has been little software developed to capitalize upon multi-monitor setups and manufacturers are not promoting multiple monitor systems, information workers—professionals dealing with significant amounts of information—are seeking out the multi-monitor option. A Harris poll commissioned by Microsoft of 1197 Windows users found that nearly twenty percent of information workers were using multiple monitor systems (Robertson et al., 2005). Moreover, once they start to use multi-monitor systems, users claim that they would never return to a single monitor (Czerwinski et al., 2003).

Research suggested that price and limited desk space are the main reasons for not using multiple monitor systems (Czerwinski et al., 2003; Grudin, 2001). However, it is predicated that the cost of liquid crystal displays will decrease radically in the next few years (Robertson et al., 2005). The dramatic reduction in cost, along with the smaller desktop footprint of LCD monitors, has the potential to significantly increase the use of multiple monitor setups. Moreover, laptop manufacturers are also now supporting multi-monitor set ups. Therefore, Czerwinski foresees a potential explosion in multiple monitor use (Czerwinski et al., 2003).

With the grassroots use of multiple monitor systems and the potential for future growth, it is important to understand the impact of multiple monitors on productivity. However, to our best knowledge, there is very little empirical data available to assess the effectiveness of multiple monitor systems. Also, when users cross display spaces they are also very likely switching between applications, indicating that multiple monitor systems may support multitasking more than traditional single-monitor displays do. The effect of multiple monitors on multitasking, however, needs to be further examined and empirically evaluated.

The goal of this study is to better understand the relationship between multiple monitors and multitasking, as well as the effect of multiple monitors on user performance. This study aims to address the following research questions: (1) what are the effects of multi-monitors on user performance and multitasking? (2) what are the usability issues in multi-monitor displays?

The rest of the paper is organized as the follows: In section 2, we review prior literature related to multi-monitors and multitasking, and discuss usability issues in multi-monitors. Section 3 presents the theoretical foundation of this study—peripheral awareness and cognitive load theory—and proposes hypotheses for this study. Section 4 describes the research model, research design, and data collection procedures. Section 5 presents the results of data analysis, which is followed by the discussion section— Section 6. Section 7 concludes the paper and discusses the directions for future research.

Literature Review

Multiple Monitors

Multiple monitor displays have been possible for approximately fifteen years for Macintosh systems and for Windows operating systems since 1998 (Grudin, 2001). Frequent use, however, has been primarily limited to financial traders, graphic artists, and CAD developers (Czerwinski et al., 2003). We have seen significant growth in the number of information workers who are using multiple monitor systems in the last few years (Robertson et al., 2005).

While cursory studies do indicate that there is a significant increase in the productivity of users of extra large screen users when compared to those using moderately sized screens (15-17 inches)—tested with common Windows XP Office tasks —few empirical studies have focused on multiple monitors.

Among the few studies that have evaluated multiple monitors, they primarily tested dual-monitor setups and focused on qualitative analysis. Overall, the findings of these studies were positive, although they did indicate that multiple monitor systems have drawbacks (Czerwinski et al., 2003). This is encouraging, particularly considering that operating system support for multi-monitor setups was deficient. Prior research also suggests that the extensive windows management inherent in a single monitor system is detrimental to both productivity and user acceptance (Czerwinski et al., 2003).

Multiple Monitors vs. Large Displays

It may seem logical to assume that multiple monitor displays are the same or even inferior to a single monitor of equal screen area. Multiple monitor systems, however, can better facilitate the logical organization of processes.

Grudin favors a “house with many rooms” analogy, in which he suggests that “just as houses have several rooms… [so] our digital worlds can benefit from partitioning” (2001, p. 458). Grudin expands on this analogy:

> People generally value large rooms —and they value more rooms. A house with one large bedroom is not the same as a house with two bedrooms of moderate size. In the two-bedroom house, the second room is used for different purposes —perhaps as a guest room and office. One could use the master bedroom for these purposes, but we usually don’t, even if it is large. The wall makes a difference (Grudin, 2001, p. 464).

Following Grudin’s logic, having additional monitors, partitioned by bezels (which refer to the areas between screens), promotes diversity of use. People could stretch one window across multiple monitors, but they generally don’t (Grudin, 2001).

A complementary concept is brought forward by Harrison and Dourish (1996). They believe that there is an important difference between space and place. The main tenet of their contention is, “Space is the opportunity; place is the understood reality” (Harrison and Dourish, 1996). So in the context of multiple monitor displays, space refers to physical monitor area, where place refers to the virtual tasks that satisfy that region. Grudin (2001) contends that the increasing amount of information available to users demands partitioning, which is already conveniently accomplished by multi-monitor bezel areas.

Usability Issues in Multiple Monitors

While there is strong potential for multiple monitor systems, research also indicates that there is need for improvement (e.g., Robertson et al., 2005). There are some usability issues inherent in multi-monitors or large displays. One obvious problem is the distance users have to cover to traverse the virtual screen. For the Windows operating systems, the start menu is located at the bottom left-hand corner, so a great deal of motion is required to return to the start menu from most places on the screen. One possible solution is the "start anywhere" feature that is being developed by Microsoft, which allows the user to call up the start menu anywhere on screen through a keyboard input. This of course only solves the problem for use of the start menu, but not the traversal problem in general. Microsoft is also working on other solutions, such as a mouse that you can "launch" across the screen (Robertson et al., 2005).

Another problem consequential to the large screen size is that users tend to lose their cursor. Not only is there more area in which the cursor may be lost, but the larger scale also involves higher cursor velocities. Since a cursor is only visible once per frame, this quick movement makes it virtually invisible for significant stretches. Hence, cursor loss is very common. Potential solutions include higher density cursors, shown in Figure 1, and use of a cursor auto-locator that is already commonly available (Robertson et al., 2005).

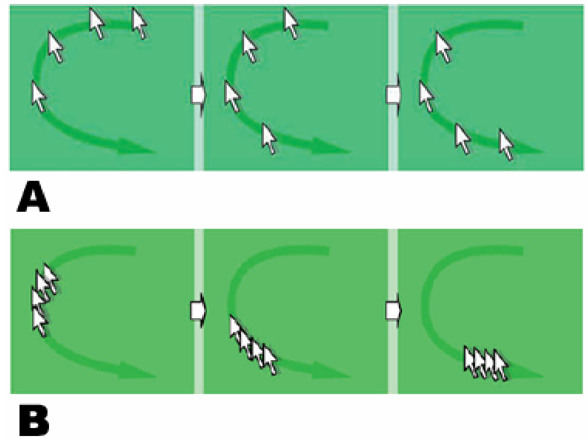

Figure 1. (A) Regular density cursor (B) High density cursor (Robertson et al., 2005)

While it is suggested that bezels—the areas between screens—can support task diversity, usability problems may occur when a user crosses a bezel with the cursor. Although it may not be common for users to stretch windows across monitors, in the cases where they do, it leads to a visual discontinuity that makes information absorption uncomfortable, if not impossible. Another significant problem occurs in crossing a bezel with a mouse. As is shown in Figure 2, the path appears "deflected" rather than following the shortest visual path to a point.
One suggestion is to use calibration to make a user's apparent shortest path a reality. The problem, however, is that in order to do this, the visual space "behind" the bezels is lost, so there is a tradeoff between options, with neither being entirely optimal (Robertson et al., 2005).

The "maximize" option can also be troublesome (Robertson et al., 2005), although it is straightforward when dealing with a single monitor. With a multi-monitor system, should the maximize command fill all screens, or just the screen in which it currently resides? Furthermore, when an application is maximized to a screen, does it lose its drag and drop functionality?

Figure 2. (A) Deflected cursor path (B) Shortest path calibration (Robertson et al., 2005)

At the moment, operating system support seems to be the primary limitation for multi-monitor systems (Grudin, 2001). As the demand for greater display landscape is likely to increase the number of multi-monitor users over the next several years, developing better support is paramount.

Software application problems may not be quite as fundamental as operating system flaws, but are still significant. The vast majority of software doesn't sufficiently support multiple monitor systems (Grudin, 2001). In order to better support multi-monitor systems, applications need sound window management. In some cases, pop-up alerts appear across bezels. In others, windows appear in places that the user would not expect, and ultimately go unnoticed. Moreover, information is often displayed in the primary monitor, obscuring the user's primary task (Robertson et al., 2005). For example, help information should be displayed on a secondary monitor for easy consulting, rather than overlaying the main work screen. At the very least software needs to recognize and remember where users relocate windows (Grudin, 2001).

Multitasking

According to Richard Seven, multitasking is simply "doing, or trying to do, more than one thing at once" (2004). Other authors have defined multitasking as "the ability to accomplish multiple task goals in the same general time period by engaging in frequent switches between individual tasks" (König et al., 2005, p. 244), and as "the ability to handle the demands of multiple tasks simultaneously" (Lee and Taatgen, 2002, p. 1).

The considerable amount of information available to the users has made computer multitasking commonplace, to the extent that it is not unusual to see a user with a dozen applications and browser windows open at a time. This is especially true with users of multi-monitors as the bezels support task diversity and, therefore, facilitate multi-tasking.

Prior research on multi-tasking focused on switching between disjoint, unrelated tasks. The majority of studies do not differentiate between mutually exclusive tasks, and complementary tasks in multitasking. As a result, the bulk of multitasking studies only evaluate multitasking where the task objectives are independent and even mutually exclusive. However, this is rarely the case in "real life" window management. González and Mark see "higher levels of units of work or activities that people divide their work into on a daily basis," which they term "working spheres" (2004, p. 117). Using González and Mark's terminology, previous research has examined multitasking between separate working spheres, rather than multitasking within a single working sphere full of complementary tasks.

Figure 3 depicts the difference in multitasking between working spheres and multitasking within a single working sphere. Working spheres are represented by the large dark circles, indicating a higher level of multitasking than the encompassed tasks, which are represented as smaller white circles within the body of each working sphere.

Figure 3.A illustrates the typical multitasking study, where users are tested multitasking between working spheres, such as a software developer talking about one project over the phone, while attempting to work on a separate project on his or her computer. Lower level tasks, and therefore instances of multitasking, exist within each working sphere, but are not evaluated in terms of multitasking success. In the case of the software developer working on his or her computer, this lower level multitasking might occur between the main software development tool, a list of user requirements, an application for checking in and out files, online supplemental resources, and so forth. Even talking on the phone may fall within the same working sphere if it pertains to the developer's onscreen work.

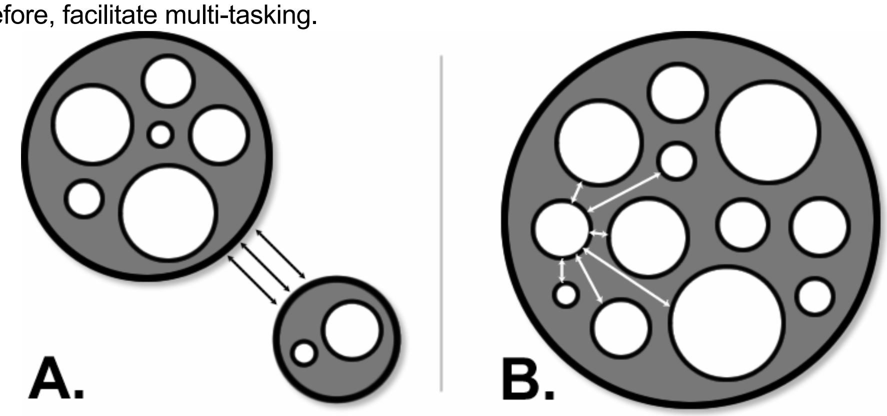

Figure 3. Multitasking between (A) and within (B) working spheres

While lower level multitasking may be productive if the tasks are "virtually automatic," such as walking and chewing gum, "true, effective, efficient, meaningful multitasking is akin to jamming two TV signals down the same cable wire. You get static, not high-definition" (Seven, 2004).

Where most studies evaluate multitasking at a high level—between working spheres (Figure 3.A)—this study will attempt to evaluate multitasking at a lower level—within a working sphere (Figure 3.B). Tasks, however, will not be automatic, and users will be tested multitasking in meaningful situations.

Another limitation of previous multitasking research is that there is little emphasis on evaluating multitasking in complex situations, as one might encounter in an office environment. For example, one study by Jersild (1927) and the subsequent follow-up by Spector & Biederman (1976) had participants perform arithmetic operations on two columns of numbers. After each operation was performed the participant would verbally report his or her result. A participant might be asked, for instance, to add three to each of the digits in the first column and subtract three from digits in the second column, responding verbally after each action. Half of the participants performed these operations sequentially, completing one entire column before starting on the other, and the other half alternated between columns, switching tasks after each verbal response (Rubinstein et al., 2001). This method of testing allows for easily quantifiable results by removing cross correlations, but does not necessarily simulate natural multitasking.

The artificial nature of multitasking studied in laboratory settings has limited applicability in real life. As Kushleyeva et al. (2005) stated,

> While cognitive modeling has begun to make good progress in accounting for human multitasking behavior, current models focus on externally-driven task switching in laboratory-task settings. In contrast, many real-world complex tasks, particularly time-critical ones, involve internally-driven multitasking in which people themselves decide when to switch between tasks (2005, p. 41).

This "internally-driven" multitasking is what is lacking in most multitasking studies. The current research attempts to evaluate multitasking within the context of commonplace information technology tasks, while maintaining the participant's freedom to multitask via internally-driven task switching.

Hypothesis Development

One of the purported benefits of multiple monitor systems is that they facilitate peripheral awareness. Simple single-monitor interfaces cause the user to minimize or cover up information that can be displayed in the periphery of multiple monitor systems. Windows that are minimized need to be remembered while they are out of sight, which can be challenging. Finding features in deeply nested menus can also be problematic—even experienced users may struggle to locate the desired feature among complex menu choices. By keeping all advanced toolbars open on a secondary monitor, users can take advantage of peripheral awareness (Grudin, 2001) and improve the users' capability of finding relevant information. It is therefore much easier and faster to find relevant information to complete a task using a multiple monitor display. Therefore, multiple monitors can help to improve user performance by increasing the speed and accuracy of their task performance.

H1: Users' performance is better when using multi-monitor display as compared to single monitor display.

As multitasking is becoming more and more commonplace, it also increases the users' cognitive burden by forcing users to switch between various applications and remembering functions/features on those applications. Navigating through multiple windows to locate, retrieve, and edit information disrupts users' mental processes on primary tasks. Even functions designed to ease the process, like Windows' "Alt-tab" functionality, can become tedious when users are working with several windows. People generally consider it a relief not to have to use buttons so frequently (Grudin, 2001).

Grudin (2001) suggested that multiple monitors are partitioned by bezels which promote task diversity. Users can divide their tasks and multi-task on different monitors. Increased working space on multiple monitors provides more opportunities for users to multi-task. Multiple monitors decrease the user's cognitive burden by allowing rapid glances to check information and aiding user recognition memory (Robertson et al., 2005).

Therefore, we hypothesized that multiple monitors facilitate more multitasking compared to single monitor display.

H2: Users are more likely to do multi-tasking when using multi-monitor display than when they are using single monitor display.

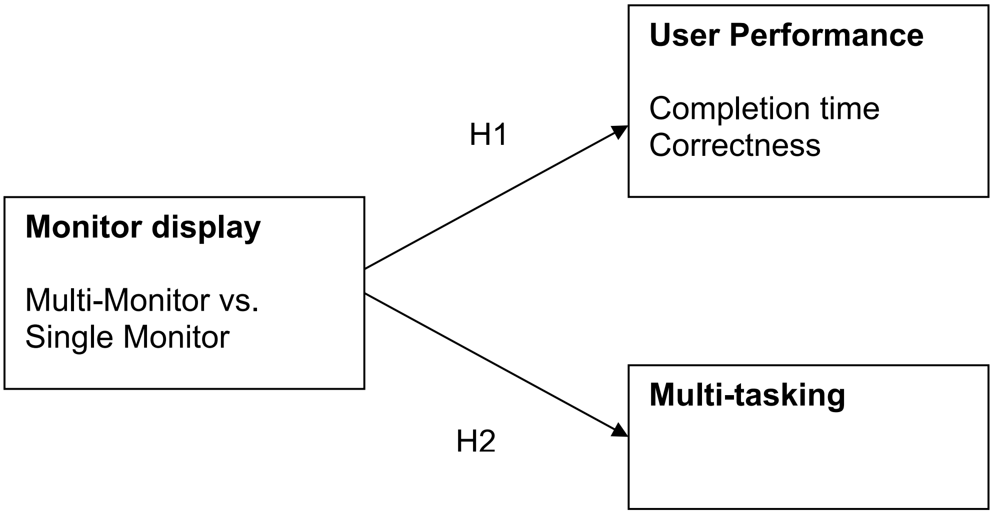

Figure 4. Research Model

Research Method

In this section, we present the research model, research design, and research procedures.

Research Model

In this research, we are interested in examining the effect of monitor display on user performance and multi-tasking. The research model for this study is depicted in Figure 4. In this model, we propose that monitor display influences user performance and multi-tasking; that is, users are more likely to multi-task and have better performance when using multi-monitor display as compared to single monitor display.

Research Design

We conducted an experimental design because it allows for the manipulation of variables and the testing of causal relationships. For the multi-monitor display, we adopted a quadruple panel workstation from MASS Engineered Design Inc., two monitors high and two wide (see Figure 5). Each of the four monitors spanned 17 inches diagonally for a total of 34 inches of display space, minus bezels. We used a 17-inch single monitor for single monitor display.

Figure 5. Mass Multiples 17" Quadruple Monitor Display

The quadruple monitor display adopted in this study is an established system that is commercially available. Therefore, it overcomes the problems of operating systems and software applications many other multi-monitors may have, and allows us to focus on comparing the effect of multi-monitor display and single monitor display on user performance and multi-tasking. The quadruple monitor is only one of many ways of assembling and arranging multi-monitors, which may limit the generalizability of the results of this study. However, we believe that the choice of a quadruple monitor display is suitable for the purpose of this study. On one hand, quadruple monitor display allows for the display of information in all four monitors, which could possibly support task diversity and facilitate multitasking; on the other hand, the usability issues in multi-monitor displays are more evident in quadruple monitor display given the increased bezel areas.

Participants

Forty-three participants were recruited from a medium-sized Midwestern technological research university in the United States. Among the 43 participants, 33 were male and 10 were female. Participants were between the ages of 17 and 40. All participants were majors in either Information Systems or Business. Participants were compensated for their involvement with class credit.

Tasks

The participants were asked to create a web page using Macromedia's (now Adobe's) web development tool, Dreamweaver©. This task can be divided into ten mini-tasks, including:

1. Creation of a top banner layer
2. Creation of a main content layer
3. Creation of a side menu layer
4. Download of picture 1
5. Insertion of picture 1 into content layer
6. Download of picture 2
7. Use of picture 2 as background of side menu layer
8. Creation of a link to http://www.umr.edu
9. Creation of a link to http://campus.umr.edu/lite link
10. Creation of a link to http://scholar.google.com link

The tasks are illustrated in Figure 6.

Since the focus of this study was on multiple monitor systems, and not the Dreamweaver© software, participants were asked to follow simple video tutorials to accomplish the task. The tutorials gave participants the expertise necessary to complete the task, therefore controlling participants' knowledge/skill with the assigned task.

Four tutorials were provided to each participant, including "Create Page Layers," "Add Text to Page," "Add Graphics to Page," and "Add Links to a Page." The descriptions of the tutorials can be found in Appendix A, and the video tutorials are available at http://richardhhall.org/
dreamweaver.

Participants viewed these tutorials in Windows Media Player Classic and also interacted with Internet Explorer, MSN Instant Messenger, and Microsoft Word. Folder navigation within the Windows operating system was also necessary.

The task was chosen for this study for the following reasons: 1) the task was designed to simulate commonplace computer tasks to information workers; 2) the mini-tasks embedded in this web development task were within a working sphere (see Figure 3), which allowed users to practice internally-driven task switching. As internally-driven multitasking is of more interest to the researchers in this study, the task adopted in this study is appropriate.

Experimental Procedures

Participants were randomly assigned to one of two treatment groups in this study: multi-monitor (21 participants) or single monitor (22 participants)

Figure 6. Ten Mini-tasks

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Each participant completed the experiment in an hour-long session. When a participant arrived at the testing location, he/she was asked to sign a consent form. The experimenter then gave the participant a brief description of the testing procedure and the underlying rationale behind the experiment. The experimenter also informed the participant that the experiment would be recorded, and that he or she may withdraw from the experiment at any time.

The participant was then introduced to either the multiple monitor equipped testing computer or the single monitor setup. At this point the participant was directed to the Task 1 folder containing the task document (Appendix B) and the first video tutorial. The contents of the folder were explained, recording devices were started, and the participant was asked to open the Task 1 document and begin.

This initial test was to be completed in ten minutes and was designed only to familiarize participants with the system. As such, for this phase of testing, the experimenter was available to answer questions and assist the user where necessary. Recordings were not used in data analysis. After ten minutes, testing was stopped, and participants were informally interviewed regarding comfort level.

The participant was then given the primary task (Appendix C), which was to be completed in 30 minutes. For this period, the experimenter was not available for questions or assistance. At the end of thirty minutes the experimenter returned to inform the participant that the testing session had concluded. Recording was stopped. The participants were asked to complete a questionnaire with open-ended questions about the strengths and weakness of the monitor display that they have used (multi-monitor or single monitor).

Measurement

User performance was measured in terms of overall completion time and correctness of completed tasks. This information was derived from the recordings. Overall completion time was defined as the total time spent working on task objectives. Timing was started when the participant first opened the task list and concluded when all task objectives had been successfully completed. If all objectives were not successfully met, then timing ended when the testing period ended or when the participant stopped working on the objectives, whichever came first.

Multitasking was characterized by rapidly switching between windows either through minimization and maximization, alt-tab functionality, or eye-and-mouse movement between open windows. For this study, window switches that occurred within ten seconds were considered sufficient to be measured as multitasking. The time a participant spent actively using one window, two windows, three windows, or four or more were recorded. Note that windows do not refer to monitors, but the number of windows opened within the visual space (an example is provided in Figure 7).

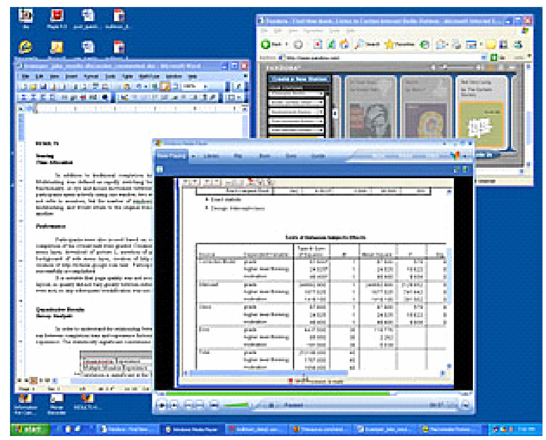

Figure 7. Three windows open on a monitor

In order to establish the reliability of the reviewer's multitasking times, eight videos were randomly chosen to be analyzed by a second scorer. Total completion time was evaluated in seconds, and single window use, double window use, triple window use, and quadruple or greater window use were evaluated as a percentage of the total time. The results from the two scorers were analyzed using Pearson's correlation. According to Stemler (2004), Pearson's correlation is the most popular measurement for consistency. The results are shown in Table 1, which suggest that there is a high inter-rater reliability.

Table 1. Pearson's correlations - completion time & prior experience – Reliability

	2 Evaluator Correlations
Total completion time – Seconds	.999
One window used only - % of total	.979
Two windows used - % of total	.907
Three windows used - % of total	.890
Four or more windows used – % of total	.887

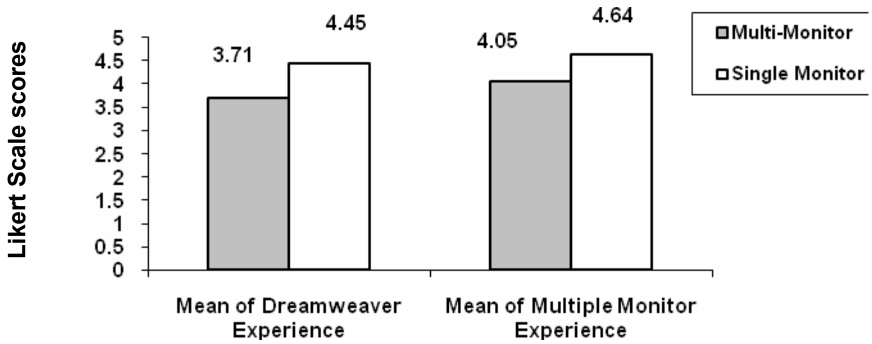

Figure 8. Means for prior participant experience.

Qualitative data collected in this study include the participants' answers to the open-ended questions on the questionnaire at the end of the experiment, as well as the video recordings of the experimental sessions. The collection of both qualitative and quantitative data not only enables us to validate our results from multiple resources but also provides additional insights on the usability issues related to multi-monitor display.

Research Results

Control Variables

This study controls for the effect of the participants' prior knowledge/experience on the task by offering a tutorial to each participant at the beginning of the experimental session.

We also captured the participants' experience on Dreamweaver and multi-monitor in two, 10-point Likert scale questions.

Paired-sample t-tests were conducted to determine if the two experimental groups differed regarding the participants' previous experience on Dreamweaver and multiple monitors (Kuehl, 1994). The results are depicted in Figure 8. Although the groups did not significantly differ on experience scores, the means were higher for both experience factors in one group. Since both experience factors correlated strongly with productivity, these factors were used as covariates in subsequent analyses.

The Effect of Multi-monitors on User Performance and Multitasking

In order to compare the effect of experimental conditions on performance, a series of univariate analyses of co-variance (ANCOVAs) were performed with group (i.e. multiple monitor vs. single monitor) as the categorical independent variable in each analysis, and one of the following seven measures as dependent variables: total completion time; time spent actively using one window only; time spent actively using two windows; time spent actively using three windows; time spent actively using four windows; number of successfully completed mini-tasks, and time spent actively using two or more windows (all multitasking). Dreamweaver and multi-monitor experience served as covariates in each analysis.

To ensure that multitasking scores were not biased by completion times, multitasking times were evaluated as a percentage of total time.

The results of the data analysis related to the hypotheses were presented in Table 2.

Table 2. Results of ANCOVAs for User Performance and Multi-tasking

Hypothesis	Measurement	Monitor display (Mean)		P value	
		Single monitor display	Multi-monitor display		
H1	Total completion time	1431	1397	0.730	Not supported
	Correctness of the task	8.19	9.47	0.036 *	Supported
H2	Time spent multi-tasking	43.06%	62.76%	0.010 *	Supported

The results from ANCOVA suggest that the multi-monitor group took less time to complete the task than the single-monitor group, but the difference is not statistically significant. However, the correctness of the task in the multi-monitor group is significantly higher than the single monitor group. Figures 9 and 10 illustrate the effect of monitor display on user performance. Therefore, H1 is partially supported.

In terms of multi-tasking, the results from ANCOVA suggest that multi-monitor group spent 62.76% of their time multitasking (which is defined as the percentage of time users spent actively using two or more windows), while the single-monitor group spent 43.06% of their time multi-tasking. The results suggest that there is significant difference between the two groups. Therefore, H2 is supported.

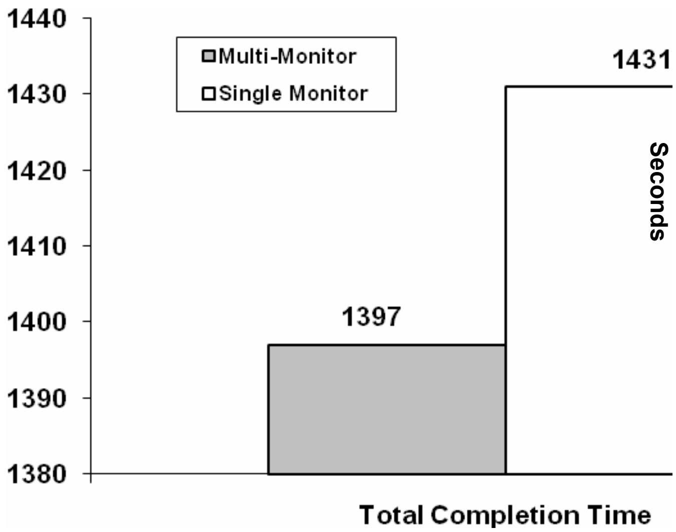

Figure 9. Means for total completion time in seconds
P>0.05

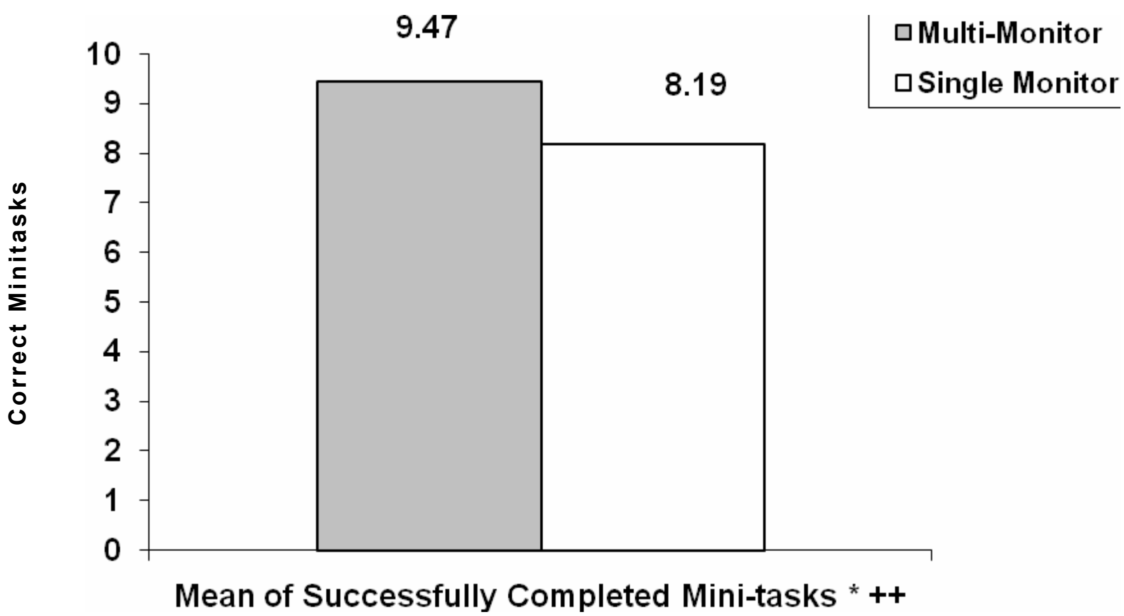

Figure 10. Means for portions of successfully completed task, out of ten possible
*p < .05, ++Large effect size

Table 3. Effect size

Dependent Variable	Effect size
Total multi-tasking time	0.160
One window only	0.160
Two windows used	0.125
Three windows used	0.073
Four windows used	0.065

To further analyze the effect of monitor display on multi-tasking, we examined the difference between the single monitor group and multi-monitor group in terms of the time users spent with "One window used only," "Two windows used," "Three windows used" and "Four windows used." Table 3 summarizes the effect size of each test. Note that an η2 over .09 is a medium to large effect size based on Cohen's criteria (Cohen, 1969). Figure 11 summarizes the results of ANCOVA tests. '

Qualitative Analysis of Usability Issues in Multi-monitors

To analyze the participants' answers to the open-ended questions, the researchers followed an approach that is similar to open coding in the grounded theory approach (Strauss and Corbin, 1998). The researchers reviewed the transcripts and looked for "discrete incidents, ideas, events, and acts" (Strauss and Corbin, 1998, p. 105) from the transcripts, and performed constant "comparative analysis" by grouping similar concepts into a category which captures their shared characteristics.

The following are the key categories generated from the participants' answers to the open ended questions. These categories describe the major differences between single monitor display and multiple monitor display.

Multi-tasking. The participants from the multiple monitors groups found that the use of multi-monitors enabled multitasking, where participants from the single monitor group found that single monitors detracted from multitasking. For example, one participant mentioned that "[Multi-monitors] allows [a person] to do multiple things at once such as editing code and then watching the results in another display." Whereas another participant mentioned "[There is] not enough room [in a single monitor]. Couldn't watch video, edit HTML and preview in browser at the same time."

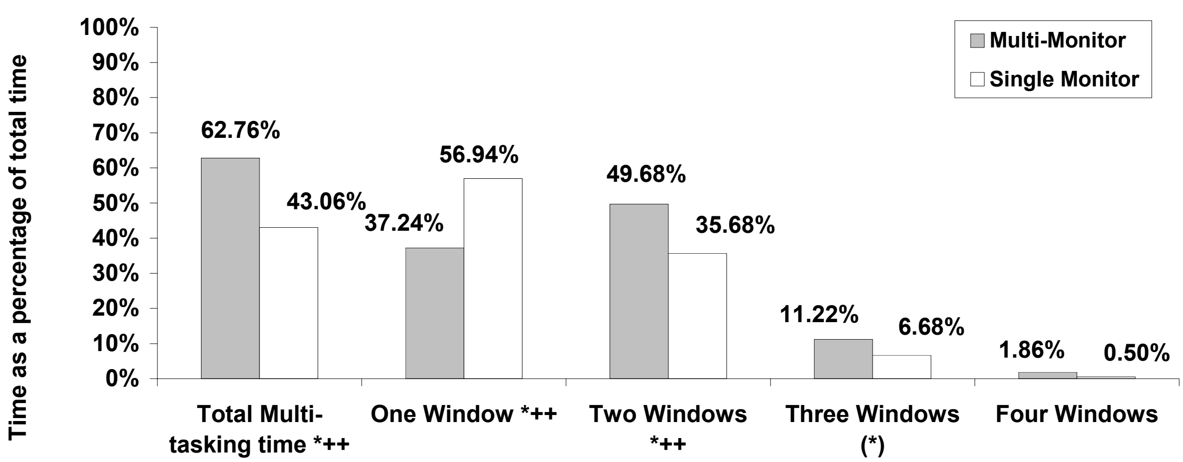

Figure 11. Percent scores & significance of ANCOVA multitasking analysis
(*)p < .10, *p < .05, +medium-large effect size, ++Large effect size

Working space. Multiple monitor users enjoyed having extra space so that they are able to "*see* all you need at once" or have "more space to organize windows." However, single monitor users were frustrated by limited space and found it "too constricting" and "overlapping windows obscures some parts."

Switching between windows. Multiple monitor users found that the use of multiple monitors "eliminates the constant clicking to get from file to file" and they can "simply leave all necessary files open for easy maneuvering." On the other hand, single monitor users felt that using one monitor only "was very cluttered and had to alt-tab to see them all." Overall, "it's a pain to switch between applications" using single monitor display.

However, the multiple monitor display is not without problems. The participants also identified some usability issues with the multiple monitor display, especially with the 2 x 2 quad-panel display. For example, the participants found that "cross section is right in the center…," and "none of the screens were at eye level," which forces them to "look up and down the whole time."

Also, some participants found that four monitors were too much. Having too many monitors caused them to become easily distracted by trying to do too many things at once, which affected their performance. This is in line with prior literature in which multi-tasking is found to be negatively associated with user performance (e.g., González and Mark, 2004; Hembrooke and Gay, 2003; Jersild, 1927; Meiran, 1996; Rogers and Monsell, 1995; Rubinstein et al., 2001; Seven, 2004; Spector and Biederman, 1976). As suggested by Hembrooke and Gay, "there is a long tradition of psychological and media communication research that indicates that our ability to engage in simultaneous task is, at best, limited, and at worst, virtually impossible" (2003, p. 2).

Video recordings were reviewed and analyzed qualitatively, noting facial expression, gestures, posture, and user comments. Any pause or task that consumed more than a few seconds of the user's overall time was documented, as was the participant's windows management and monitor usage. Other noteworthy events included: changes to default settings; use of special functionality such as alt-tab for windows switching; and any evidence relating to the usability issues previously discussed.

The analysis of video recordings found that 2 x 2 quad-panel display was poorly utilized. Some participants used the two left panels only; some participants primarily used the top two screens. This indicates that 2 x 2 quad-panel display may not be the optimal arrangement of multiple monitors.

The video recordings also indicate that multiple monitor users benefited from peripheral awareness, whereas single monitor users struggled with window placement. The users of multiple monitors didn't need to re-adjust windows after opening a secondary window, whereas the single monitor users constantly had to drag the tutorial out of the way to work within Dreamweaver or read the task list. Also, in single monitor display, all windows were partially hidden, requiring frequent switching of windows and constant repositioning. The results from video recording analysis provide additional evidence that multiple monitors support task diversity and facilitate multitasking.

Discussion

While there was no statistically significant relationship between overall task completion time and display type, there does appear to be evidence to suggest that there is a productivity increase for multiple monitor users. There is a statistically significant relationship between experimental condition and time spent multitasking, where users of the quad-panel display system multitasked more frequently than users of the single panel display; this is also supported by qualitative analysis of user feedback.

The results of this study suggested that multiple monitor systems benefited users through peripheral awareness (Czerwinski et al., 2003). This was supported by user comments as well as qualitative observations. Users from the single monitor group complained about the discomfort of switching between too many windows, and users from the quad-panel group frequently expressed satisfaction at not having the need to switch between windows. By keeping all relevant information on the monitors, multiple monitor users are able to access and find relevant information more easily and accurately, thus increase the accuracy of there task performance.

Although multiple monitors facilitate multi-tasking, there is no significant difference in task completion time between the multiple monitor group and single monitor group. Multiple monitors are partitioned by bezels, which allow the users the divide their tasks and multi-task on multiple monitors, thus, promote multi-tasking. On one hand, the results of this study validate statements from prior research (e.g., Grudin, 2001) that bezels promote task diversity, thus enabling multi-tasking. On the other hand, they also provide evidence that multi-tasking does not necessary leads to increased productivity. As indicated by the participants in the open-ended questions, multiple monitors sometimes can distract them from their primary tasks as they are trying too many things at once. This is in line with prior literature which suggest that multiple tasking is negatively associated with user performance as multitasking increases users' cognitive burdens with the challenges of remembering and switching between multiple tasks (e.g., González and Mark, 2004; Hembrooke and Gay, 2003; Jersild, 1927; Meiran, 1996; Rogers and Monsell, 1995; Rubinstein et al., 2001; Seven, 2004; Spector and Biederman, 1976).

The negative effect of multiple monitors on user performance could also be possibly explained by the bezels available in the multiple monitors, which is considered to be one of the major usability issues in multiple monitor set up. Although bezels promote task diversity, they increase the distance users have to traverse the screens and make cursor loss more common (Robertson et al., 2005). This is evident in the qualitative results from the observation. In addition to distance problems, some participants complained about visual discontinuity, specifically in menu navigation. With traditional Windows dropdown menus, it was common during testing for a menu to fall across a bezel, making selection of the right option difficult. Had Microsoft's calibration technique been used in this study, some menu options may not have been visible at all. A more detail oriented task than what was used in this research would likely illuminate how critical this problem is.

Drawbacks of the multi-monitor setup were also recognized in the experiment and lack of operating system support was one of the complaints users had. One participant, for example, was bothered by the organization of icons on the desktop—the default organization of icons on a Windows desktop is top to bottom, which on a large 2 x 2 multiple monitor desktop leaves a long vertical string of icons on the left side of the screens. This icon string was uncomfortable for the user when searching for applications needed for successful task completion. This irritation was observed on multiple occasions in video analysis. Another instance of lacking software support, this time related to multiple monitor use, was the fact that at least one user wanted to be able to move Dreamweaver's menus to another screen, leaving the full body of one screen for Dreamweaver's content pane. This functionality was either not available to the user or not easily accessible.

By far the most commented flaw, however, was not in the operating system or in any specific software, but in the quad-panel setup itself. Participants often didn't like aspects of the 2 x 2 monitor arrangement. This arrangement puts the largest bezel area, where the four corners meet, directly in the center of the desktop space, which participants found uncomfortable. They also didn't like the fact that there was no 'primary' screen, and since there was no central screen at eye level, users had to always be looking up and down, as well as left and right. In fact, it was commonly observed that multiple monitor users arranged their windows so that there was only vertical scanning, or only horizontal scanning, but not both, only utilizing two of the four screens. Some users also indicated that four screens of information were more than they wanted to handle at once.

Despite drawbacks, the response to the multiple monitor setup was clearly positive. The majority of participants indicated strongly on post-questionnaires that they enjoyed the multiple monitor experience, and believed that it enhanced their performance. Users also indicated that they saw great potential for multiple monitor use in every day tasks, and would strongly consider getting a multiple monitor setup for their own home computer.

Conclusions and Future Research

The use of multiple monitors is becoming more commonplace among information workers these days. However, there is a lack of empirical research to examine the effect of multiple monitors on user performance and multitasking. This research fills this void by conducting an experimental study to compare user performance and multitasking using multiple monitor display vs. single monitor display. The results of this study suggest that those who used the multi-monitor display were more inclined to multitask and scored higher on performance measures than those using the single monitor. The qualitative data collected in this study including video recording and answers to open-ended questions support the quantitative results. The analysis of qualitative data also offers additional insights on usability issues on multi-monitor display.

There are also some limitations in the study that warrant further discussion and should be taken into account when interpreting the results. First, this study focuses on examining the difference between quad-panel setup and single monitor setup. The quad-panel is only one of many ways of setting up multiple monitors. Therefore, caution must be taken in generalizing the results of this study to other multiple monitor arrangements. For example, some usability issues have been identified in using the 2 x 2 monitor arrangement in this study, such as bezels, visual discontinuity, and limited use of screens, which have affected users' performance (e.g., time spent to complete the task). These issues may not be as critical in other multi-monitor arrangements (e.g., bezels may be reduced in a double monitor set up).

Future research can extend this study by examining the effects of different multiple monitor set ups on user performance and multi-tasking, identify usability issues in each multiple monitor setup, and recommend optimal set-ups for multiple monitors. This will not only enhance our understanding in multiple monitors in academic research, but also have practical implications to the industry.

Another possible limitation relates to the task used in the experimental study. We asked the participants to create a web page using Macromedia's (now Adobe's) web development tool, Dreamweaver. The mini-tasks embedded in this task were within the same working sphere; therefore, allow the users to practice internally-driven multitasking. Hence, the results of this study only apply to tasks within the same working sphere and internally-driven multi-tasking.

As multitasking can take place between working spheres or within a single working sphere, future research can extend this study in the context of multi-tasking between working spheres, and examine the effects of monitor display on user performance. Task may also influence the users' choice of monitor display and willingness to multitask. Therefore, future research can also examine the moderating effect of task on multitasking using different multiple monitor arrangements.

The qualitative results of this study have identified some usability issues related to the use of multiple monitors, such as bezels and multiple monitor arrangement. Future research can focus on investigating the usability issues in multiple monitors, as moving across brands of monitors, the range of bezels as well as the size and shape of the monitor differ. Therefore, it is possible that the appearance of the monitors, and/or the arrangements of monitors may affect users' attitude towards multiple monitor setup, and affect their task performance.

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Appendix A. Description of the Tutorials

The following are the descriptions of the four tutorials used in this study.

Add Text to Page: This simple tutorial was used to help participants acclimate to Dreamweaver and the physical interface that they would be using. The tutorial covers how to use Dreamweaver to manipulate text spacing and alignment, as well as text font, weight, and color. How to create numbered lists and bullet points, including sublevels, is also addressed, as well as basic operations such as cut and paste, and simple layer functionality. The total runtime of this tutorial is 4 minutes 21 seconds (4:21, for brevity).

Create Page Layers: This tutorial was used in the main testing period and was meant to assist participants with basic page layout. The video elaborates on the operation of layers, including basic layer placement, size and shape manipulation, adding text or image content within a layer, and the use of background colors and images within layers. More advanced layer operations such as overlap (z-index) and overflow properties are also covered. Additionally, the tutorial illustrates how to preview work within a browser, and the basics of a traditional three part web design: banner, menu, and content. The total video runtime is 9:03.

Add Graphics to Page: This tutorial was also used in the main testing period. It simply shows how to add images to a basic webpage. Layers are once again used; this time to manipulate image placement. The resizing of images in Dreamweaver is shown but not recommended. Also included in the tutorial is the use of a copyright-free graphics site, http:/pics4learning.com, which is required for the completion of the participant's main task as well. Total runtime is 3:31.

Add Links to A Page: This tutorial is the third and final video used in the main testing period. The tutorial shows how to add links to text or an image. Specifically, the tutorial uses three URLs as examples; the main task in this study also requires the creation of three links. Two of these URLs are identical between the main task and the tutorial. The third link, however, does not match, and was a common source of error for single monitor users. This tutorial's total runtime is 3:29

Appendix B. Familiarization Task

Your task for the first 10-minute period of testing is to create a table with 5 rows and 2 columns, filling each cell with a differently formatted text. Follow the "text" tutorial to complete this task. "Text" tutorial is available in the "Tutorials 1" folder on your desktop.

Format the text in the ten cells as follows:

Tables can be created through the main menu: *Insert -> Table*

Results may be previewed in the browser from the main menu: *File -> Preview in browser* or by pressing the *F12* button on your keyboard.

You are allowed to consult the test facilitator for this period of testing. The facilitator will inform you when the 10-minute time period has concluded.

Appendix C. Main Task

Your task for this 30-minute phase of testing is to build a simple web page complete with images and menu links by following the available tutorials. You will not be allowed to ask the experimenter for help.

To get started, open Dreamweaver (link on the desktop), and follow the "layers" tutorial for creating a simple page with layers. Tutorials are available in the "Tutorials 2" folder on your desktop. Model your page after the same traditional design that the tutorial uses, with a left-menu, top-banner, and main content area.

To fully complete this task you will need to download images to your desktop. Open a browser window to http://pics4learning.com/ and find an image to use as a background for your menu. Save the image to your desktop and set it as your menu's background in Dreamweaver. The "layers" tutorial contained information on setting images as a background to a layer.

The site http://pics4learning.com/ will also be needed to find an image to insert in the main content area (NOT as a background). Save this image to your desktop as well and insert it by following the "image" tutorial.

Finally, you will need to create real links in your menu by using the "links" tutorial. Create three links to the external sites: http://www.umr.edu, http://campus.umr.edu/lite, and http://scholar.google.com.

The test facilitator will inform you when the 30-minute time period has concluded.