

A USABILITY AND PERFORMANCE ANALYSIS
OF MULTIPLE MONITOR DISPLAYS AND MULTITASKING

by

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ABSTRACT

This study was designed to examine the impact of multiple monitor use on user performance. Additionally, multitasking was evaluated as a mediational factor in performance. Twenty four students were tasked to create a web page using Macromedia's Dreamweaver©, as well as several video tutorials, Microsoft Office applications, and a web browser. Twelve participants interacted with a four-monitor display, and twelve used a traditional single-monitor setup. Those who used the quad-panel display were more inclined to multitask, where multitasking was evaluated between application windows, not between monitors – i.e. not exclusive to the multiple monitor setup. Participants of the multiple monitor group also scored more favorably on performance measures than those using the single monitor. In addition, users who multitasked finished objectives more quickly than those who used a sequential approach. Qualitative analysis also revealed usability issues within each setup.

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1. INTRODUCTION

1.1. RATIONALE

In the last twenty years computing power has increased exponentially. The Internet has matured, and improved connection speeds have made immense amounts of information quickly available to common users. While accessible information has grown dramatically, displays have not developed at the same pace (Grudin, 2001). Even a large computer monitor fills only about 10% of our visual space. Furthermore, restricting neck movements can shrink that to 1% utilization (Czerwinski et al., 2003).

One means of increasing display space is through the use of multiple monitors linked to act as one screen, also sometimes called “multimon” (Czerwinski et al., 2003; Grudin, 2001; Robertson et al., 2005). To date, there is very little software developed to capitalize upon multi-panel setups. Furthermore, manufacturers are not promoting multiple monitor systems. With that said, a Harris poll commissioned by Microsoft of 1197 Windows users found that nearly twenty percent of information workers used multiple monitor systems (Robertson et al., 2005). Even without a marketing push towards multiple monitor use, professionals dealing with significant amounts of information are seeking out this option. More over, multimon users claim that they would never return to a single monitor (Czerwinski et al., 2003).

Investigators claim that the main reasons for not using multiple monitor systems were concerns about price and limited desk space (Czerwinski et al., 2003; Grudin, 2001). However, these environmental factors are rapidly evolving. Display

manufacturers, however, are predicting that the cost of liquid crystal displays will decrease radically in the next few years (Robertson et al., 2005). This dramatic reduction in costs and the smaller desktop footprint of LCD monitors has the potential to significantly increase the use of multiple monitor setups. Laptop manufacturers are also all now supporting multimon, and since many users own both a laptop and a home computer, Czerwinski sees a potential explosion in multiple monitor use (Czerwinski et al., 2003).

1.2. RESEARCH APPROACH

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. Although multiple monitor work stations are becoming more common in the business place, a corporation cannot fully embrace their use without evidence of return on investment. At present, however, there is very little empirical data available to assess the effectiveness of multiple monitor systems.

The concept of multitasking is also relevant in considering multiple monitor effectiveness. When users cross display spaces they are also very likely switching between applications – linking multitasking to multiple monitor use. This link, however, requires further evaluation.

1.2.1. Research Questions. The goal of this study is to better understand the effect of multiple monitors and multitasking on user productivity. This paper compares a four-monitor desktop to a single-monitor setup with respect to performance and usability. The mediational impact of multitasking on these factors is also examined.

The specific experimental questions addressed are as follows:

1. What is the effect of monitor display on performance?
2. What is the effect of monitor display on usability?
3. How does multi-tasking mediate questions 1 and 2?

Qualitative and quantitative data is compiled in an effort to triangulate the relationship between multiple monitors and performance, as well as identify or confirm usability issues related to the multiple monitor system.

1.2.2. Thesis Overview. This thesis is organized as follows:

- Section I – Introduction: This section covers the findings of previous studies regarding multiple monitors and multitasking.
- Section II – Method: This section describes the approach taken and materials used in the study.
- Section III – Procedure: This section details the exact procedure followed in conducting this study.
- Section IV – Results: This section shows and explains the findings of qualitative and quantitative data analysis.

- Section V – Discussion & Conclusions: This section summarizes findings and uses both qualitative and quantitative results to arrive at conclusions relating to research questions.

1.3. MULTIPLE MONITOR & LARGE DISPLAY BENEFITS

Multiple monitor displays have been possible for approximately fifteen years now on Macintosh systems, and since 1998 for Windows operating systems (Grudin, 2001). Frequent use, however, has been primarily confined to financial traders, graphic artists, and CAD developers (Czerwinski et al., 2003). While cursory studies do indicate that there is a significant increase in the productivity of extra large screen users when compared to those using moderately sized screens (15"-17") – tested with common Windows XP Office tasks – few empirical studies have been run with multiple monitors as the concentration. Where multiple monitors *have* been tested the focus has been on qualitative analysis, and primarily of dual monitor setups. While these studies did indicate that multiple monitor systems have drawbacks, the bulk of findings were very positive (Czerwinski et al., 2003). This is encouraging particularly considering that the users tested didn't have experience with multi-monitor systems, and operating system support was deficient. Their study suggests that the extensive windows management inherent in a single monitor system is detrimental to both productivity and user acceptance (Czerwinski et al., 2003).

Another suggested benefit 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 multimon systems. Minimized windows need to be stored in memory while they are out of sight, and are

easily forgotten. Finding features in deeply nested menus is also problematic. Even sophisticated users may struggle to locate the desired feature among complex menu choices. By keeping all advanced toolbars opened on a secondary monitor users can take advantage of peripheral awareness and lessen their cognitive load (Grudin, 2001).

Larger displays further lessen the user's cognitive burden by aiding user recognition memory (Robertson et al., 2005). Allowing rapid glances to check information keeps the user storing data in memory. Navigating through multiple windows to locate, retrieve, and edit information is inherently disruptive to mental processes. 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).

Other disruptions may also be reduced by multiple monitor use. Applications that interrupt the user, such as instant messengers or email alerts, may block the user's field of view, and otherwise redirect the user's attention away from their primary task. With multimonitor it is suggested that these interruptions are far less disrupting when they appear in a secondary monitor (Grudin, 2001). Once again peripheral awareness becomes beneficial as users can acknowledge the interrupt without being disrupted. The biggest problem here, however, is that there is no telling where that interrupt window will appear, though more often than not it is on the primary monitor, which will be addressed later in multiple monitor drawbacks.

1.4. BENEFITS OF MULTIPLE MONITORS VS LARGE DISPLAYS

While the aforementioned benefits of multiple monitor systems may be most beneficial to multimons, they can also be linked to any large display. One benefit, however, that currently can be connected only to multimons systems – with the possible exception of projection displays – is that of cost. A 21” LCD monitor has the same display space as two 15” LCD’s, but at a dramatically greater cost.

Most users initially assume that having a second monitor is inferior to a single monitor of equal screen area. Multiple monitor systems, however, can also be exclusively linked to a benefit in 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 furthers the 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).

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

A complementary concept is brought forward by Harrison and Dourish. Their belief is that there is an important difference between *space* and *place*. The main tenet of their contention is that, “Space is the opportunity; place is the understood reality” (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 contends that the increasing amount of information available to users demands partitioning, which is already conveniently accomplished by multi-monitor bezel areas (2001).

1.5. MULTIPLE MONITOR DRAWBACKS

While there does appear to be sizeable potential for multiple monitor systems, research indicates that there is also a great need for improvement. As suggested above, the demand for greater display landscape is likely to increase the number of multimonitor users over the next several years. As such, developing better support is paramount.

At the moment, operating system support seems to be the primary limitation (Grudin, 2001). One of the more obvious problems is the vast 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. For this particular example, Microsoft is working on something they’ve called “Start Anywhere” 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 button, and 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 operating system 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 involves higher cursor velocities. Since a cursor is only visible once per frame, this quick movement renders it virtually invisible for significant stretches. Hence, cursor loss is very common. Potential solutions include higher density cursors, shown in Figure 1.1, and use of a cursor auto-locator that is already commonly available (Robertson et al., 2005).

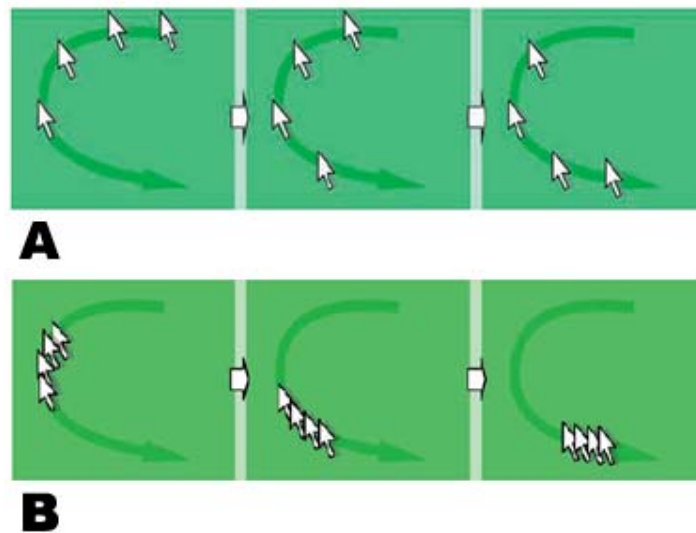


Figure 1.1. (A) Regular density cursor (B) High density cursor (Robertson et al., 2005)

While bezels are suggested to benefit organization and encourage task diversity, usability problems may occur when the user crosses a bezel. It may not be common for users to stretch windows across monitors, but, 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 1.2, the path appears “deflected” rather than following the shortest visual path to a point. The suggested solution here is to use a calibration step to make the 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).



Figure 1.2. (A) Deflected cursor path (B) Shortest path calibration (Robertson et al., 2005)

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). Help information, for example, should show up 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).

The “maximize” option can also be troublesome (Robertson et al., 2005). When dealing with a single monitor, the use is exceedingly simple, but 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?

Finally, regarding quadruple monitor displays, we can only speculate as to the negative effects, given the dearth of research. There is greater real-estate and more bezel areas than on a simple dual monitor display, potentially amplifying the issues discussed above. The addition of windows, and increased screen space, may similarly increase the potential effectiveness of multiple monitor displays as discussed. It could also, however, cause information overload, merely allowing users a greater opportunity for distraction. From this perspective multiple monitors may allow users to view more information than can be handled productively, impairing, rather than improving, user performance.

1.6. MULTITASKING

The considerable amount of information reaching users has also made computer multitasking commonplace – to the extent that it’s not unusual to see a user with a dozen applications and browser windows open at a time. The majority of the psychological community, however, believes that multitasking hinders user performance (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). Hembrooke and Gay summarize this: “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).

There are two major competing theories posed to explain the negative effect of multitasking, the resource allocation theory, and the bottleneck theory (König et al., 2005). According to König et al., “resource allocation theorists... argue that during multitasking a person’s mental resources are shared by the different tasks”, whereas “bottleneck theorists argue that interference occurs because certain mental operations cannot be divided, resulting in a bottleneck that allows only one task to pass through at a time” (2005, p. 244). A secondary goal of this study is to examine the multitasking phenomenon, which would presumably be an important component of multi-monitor use, with the aim of better elucidating the phenomenon with the context of these two theories.

One difficulty with examining the multitasking phenomenon is that the definitions are inconsistent among different researchers and theorists. 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’” (Delbridge in König et al., 2005, p.244), and as “The ability to handle the demands of multiple tasks simultaneously” (Lee and Taatgen, 2002, p. 1).

Another difficulty with applying multitasking research to display design is that studies address multitasking in its most extreme setting. Namely, they focus on switching between disjoint, unrelated tasks. This is rarely the case in ordinary 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 coin: “working spheres” (2004, p. 117). The majority of theorists, however, don’t 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 totally unrelated, and even mutually exclusive. Using González and Mark's terminology, this is multitasking *between* separate working spheres, rather than multitasking within a single working sphere full of complementary tasks.

Figure 1.3 graphically shows 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 1.3.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.

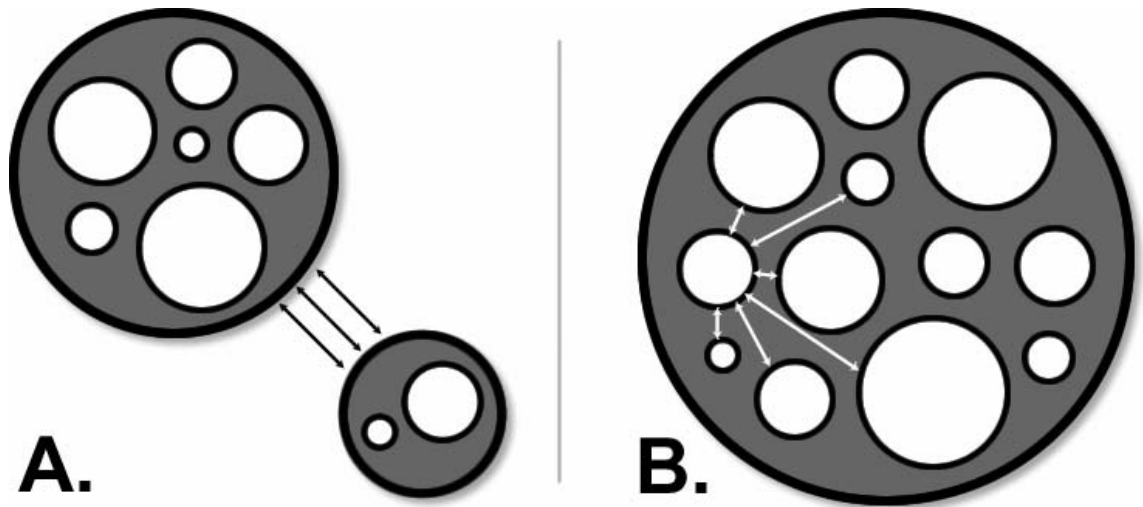


Figure 1.3. Multitasking between (A) and within (B) working spheres

David Meyer, as is quoted by Richard Seven, suggests that lower level multitasking may be productive if the tasks are “virtually automatic,” such as walking and chewing gum, “but true, effective, efficient, meaningful multitasking is akin to jamming two TV signals down the same cable wire. You get static, not high-definition” (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. One study by Arthur 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.

Due to the artificial nature of these studies, researchers are actually only evaluating one form of multitasking – forced multitasking, due to interrupt. This is of limited applicability. In some settings multitasking occurs because of interrupts, such as a phone call, but presumably the bulk of multitasking occurs when users themselves choose to switch tasks. One study that did take this limitation into account was done by Kushleyeva, Salvucci, and Lee. Kushleyeva et al. state:

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 exactly what is lacking in the vast majority of multitasking studies. Kushleyeva et al. unfortunately do not attempt to apply

this reasoning to the analysis of multitasking efficacy, but rather attempt to determine when users decide to switch between tasks.

The testing method used by Kushleyeva et al. is also not optimal for determining the effectiveness of multitasking. Test participants were asked to respond “yes” or “no” a series of questions regarding whether or not a given letter was present in a random letter string. Similar to the two column approach, users interacted with two separate frames, one containing 20 letter strings, the other containing 5 or 9 letter strings. Participants could stay within one frame or switch at their discretion, provided they did so before an imposed time limit expired. Test subjects who remained on one frame for an extended period of time would feel pressured by the dwindling timer to switch tasks. Those who failed to switch before the timer expired were penalized with a loss of twenty-five points, which is substantial in comparison to the single point awarded for each correct answer (Kushleyeva et al. 2005). While this method does allow for some flexibility in task switching, participants are still externally pressured to switch between tasks. In contrast, the present research attempted to evaluate multitasking in an office setting performing commonplace information technology tasks, while wholly maintaining the participant’s freedom to multitask via internally-driven task switching.

1.7. PRESENT EXPERIMENT

This experiment attempted to evaluate multiple monitor systems in terms of usability and performance, and also endeavored to understand the mediational impact of multitasking on these factors. A quadruple panel display work station was compared to a single monitor system, and participants were given tasks intended to simulate realistic, commonplace computer use. Moreover, these tasks allowed users to practice internally-

driven task switching and were also designed to fall *within* one working sphere. Scientific conditions were maintained, and sufficient users were tested to allow for the use of inferential statistics.

2. METHOD

2.1. PARTICIPANTS

24 students recruited from the University of Missouri at Rolla served as participants in this study, including Information Science & Technology and Business Management majors. Participants were between the ages of 17 and 40, and included 19 male students, and 5 female. All students were recruited from undergraduate courses, and were compensated for their involvement with class credit.

2.2. MATERIALS AND EQUIPMENT

2.2.1. Equipment. Those in the multiple monitor group used a quadruple screen display from MASS Engineered Design Inc. arranged two monitors high and two wide for testing (Figure 2.1). Each of the four monitors spanned 17 inches diagonally for a total of 34 inches of display space, minus bezels. Those in the single-monitor group used a 17-inch single monitor. Twelve participants were randomly assigned to each group.



Figure 2.1. MassMultiples 17” Quadruple Screen Display

2.2.2. Software and Electronic Materials. The quad-panel and single monitor groups both interacted with Macromedia’s web development tool, Dreamweaver. Since the goal of this study was to analyze multiple monitor systems, and not the Dreamweaver software, participants were asked to follow simple video tutorials to accomplish tasks.

Four such tutorials were used, all of which can be found at:

<http://richardhhall.org/dreamweaver>. The titles of the tutorials used are: “Create Page Layers,” “Add Text to Page,” “Add Graphics to Page,” and “Add Links to A Page.”

Basic descriptions of each tutorial are offered below.

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 shows 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

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.

3. PROCEDURE

Participants completed the experiment one at a time in hour-long sessions. Upon arrival at the testing location the participating students were asked to sign a consent form and fill out the pre-questionnaire. While this was done, the experimenter deleted any saved files left over from previous testing sessions, and restored system and software settings to their defaults. On completion of the questionnaire, the experimenter gave the participant a brief description of the testing procedure and the underlying rationale behind the experiment. Students were also informed that they would be recorded, and that they may withdraw from testing at any time.

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

This period of testing was to be completed in ten minutes, and was meant 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 statistical analysis. After ten minutes, testing was stopped and students were informally interviewed regarding comfort level.

The participant was then given the primary task (Appendix D), which was to be completed in 30 minutes. For this period, the experimenter was not available for questions or assistance. Fifteen minutes into the 30-minute testing period, however, the

experimenter sent an instant message to the participant. This contact was not initiated to assist the user, but rather to test the impact of an online interruption. As such, the experimenter ended communication immediately after the interruption was accomplished.

At the end of thirty minutes the experimenter returned to inform the participant that the testing session had concluded. Recording was stopped, and the exit questionnaire was presented.

4. RESULTS

4.1. SCORING

4.1.1. Overview. Video recordings were reviewed 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 participants' windows management and monitor usage. Other noteworthy events included: changes in default settings, use of special functionality such as alt-tab for windows switching, and any evidence relating to the usability issues highlighted in outside research and discussed in Section I. Open-ended questions on the post-questionnaire were also included in qualitative analysis.

Quantitative measures included overall completion time, multitasking times, 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 – either at the end of 30 minutes or when the participants stopped working, whichever came first.

4.1.2. Multitasking Scores. In addition to recording traditional completion times, degree of multitasking was also considered. *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, a window switch that occurred within ten seconds was considered sufficiently rapid to be measured as multitasking. The time participants 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 monitor space (Ex: Figure 4.1).

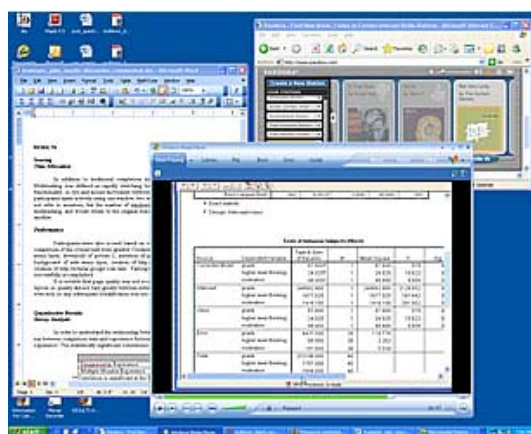


Figure 4.1. Three windows open on a monitor

In order to establish the reliability of the reviewer's multitasking times, eight videos were randomly chosen to be analyzed by a second scorer. These new times were correlated with the original scores using Pearson's correlation method. Total completion time was evaluated in seconds, and single window use, double window use, triple window use, and quadruple or greater window use was evaluated as a percentage of the total time. The resulting correlation scores are shown in Table 4.1.

Table 4.1. Pearson correlations between completion time and prior experience - Reliability

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

4.1.3. Performance. Participants were also scored on successful task completion.

Ten relatively simple mini-tasks essential to the completion of the overall task were graded. Figure 4.2 illustrates each of these ten tasks:

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 <http://www.umr.edu> link
9. Creation of <http://campus.umr.edu/lite> link
10. Creation of <http://scholar.google.com> link

Participants were given a score out of ten for the number of mini-tasks that were successfully accomplished.



Figure 4.2. Ten mini-tasks

4.2. QUANTITATIVE RESULTS

4.2.1. Survey Analysis. In order to understand the relationship between prior experience and completion time, Pearson's correlations were performed between overall time and the following experience factors: Dreamweaver Experience, Instant Messenger Experience, Web Browsing Experience, Multiple Monitor Experience, and Quadruple Monitor Experience. Two statistically significant relationships were found, and are displayed in Table 2.

Table 4.2. Pearson correlations between completion time and prior experience
 **Significant at the 0.01 level, *Significant where $p < .05$, ++Large effect size

	Completion Time	Significance
Dreamweaver Experience	-.512 ++	.011 *
Multiple Monitor Experience	-.579 ++	.003 **

To determine if the two experimental groups differed regarding previous experience two, *within-subject T-tests* were computed (Kuehl, 1994). Neither was statistically significant. The resulting means are displayed in Figure 7. Despite the fact the groups did not significantly differ on experience scores, the means were higher for both experience factors for one group, and since both experience factors correlated strongly with productivity, these factors were used as covariates in subsequent analyses.

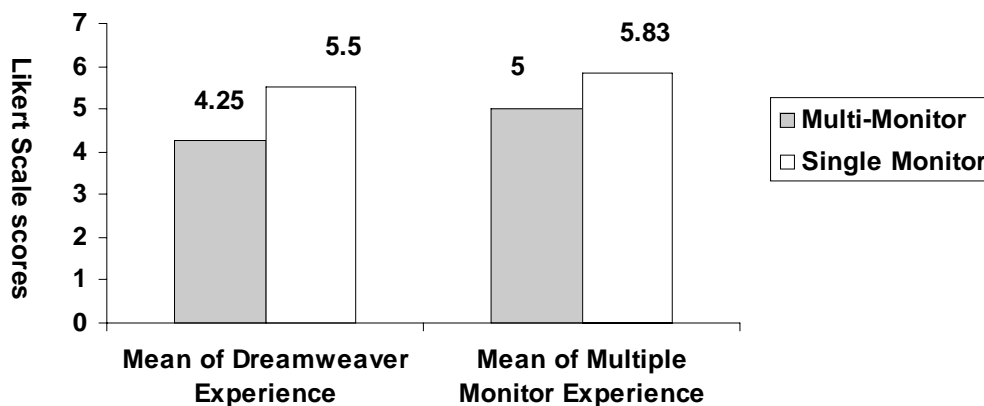


Figure 4.3. Means for prior participant experience

4.2.2. Time & Performance Analysis. In order to compare the effect of experimental conditions on performance a series of univariate analyses' of variance (ANOVAs) were performed with group (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). To ensure that multitasking significance was not biased by longer completion times in one of the groups, multitasking times were evaluated as a percentage of total time. Dreamweaver experience and prior multiple monitor experience were used as covariates. The analysis of variance was found to be significant for "Total multi-tasking time," "One window used only," "Two windows used," and "Successfully completed mini-tasks," and marginally significant for "Three windows used." Note that an η^2 over .09 is a medium to large effect size based on Cohen's criteria (Cohen, 1969). The statistics associated with this analysis are displayed in Figures 4.4, 4.5, and 4.6.

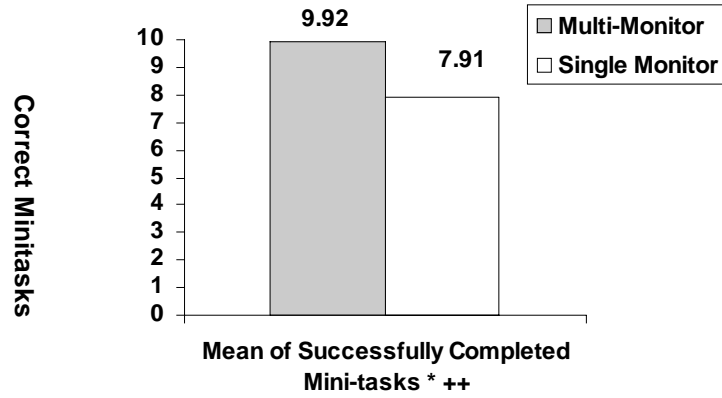


Figure 4.4. Means for portions of completed task, out of ten possible

(*) $p < .10$, * $p < .05$, +medium-large effect size, ++Large effect size

$\eta^2 > .09$, medium to large effect size (Cohen, 1969)

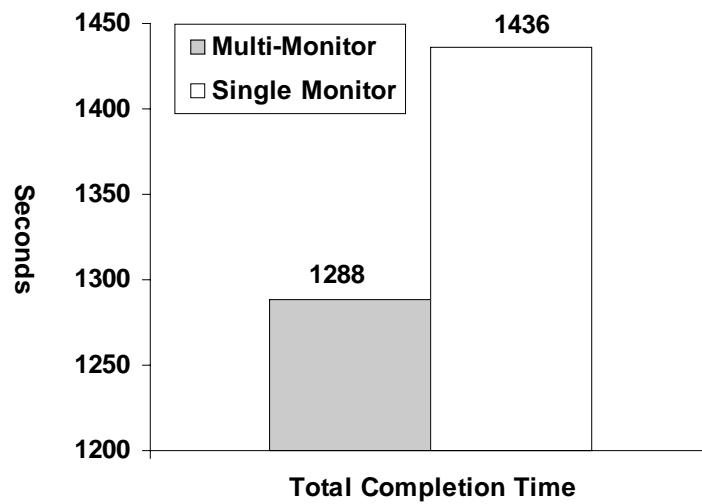


Figure 4.5. Means for total completion time

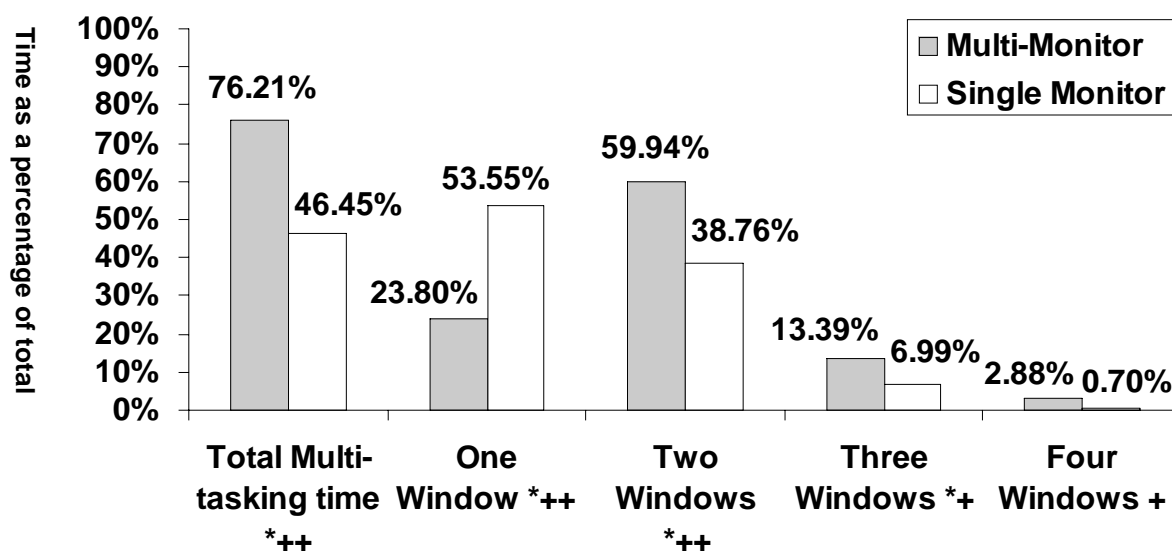


Figure 4.6. Percent scores & significance of ANOVA multitasking analysis

(*) $p < .10$, * $p < .05$, +medium-large effect size, ++Large effect size

$\eta^2 > .09$, medium to large effect size (Cohen, 1969)

To further understand the relationship between multitasking and proficiency, participants were re-categorized as either multitasking or sequentially operating users. This was accomplished using a Ward method cluster analysis. A cluster analysis is defined as: “A branch of statistics that measures the ‘distance’ between items in a multivariate environment and attempts to find groupings that are close together in a variable space” (Kuniavsky, 2003 p.196). In this case, the “distance” between participants was based on their *total multitasking time* scores, as a percentage of total time. The cluster analysis resulted in two clear groupings, as can be seen in Figure 4.7. Fourteen participants were categorized as Multitasking and ten were categorized as Sequential.

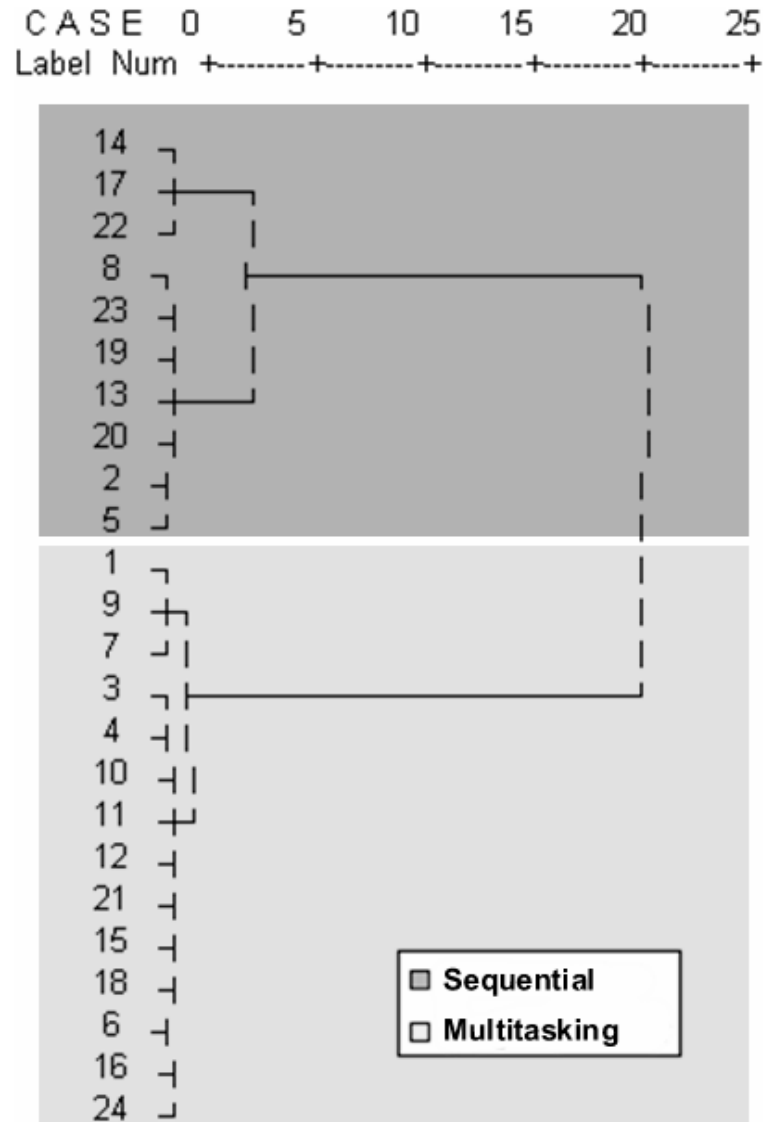


Figure 4.7. Participant grouping using Ward Method cluster analysis

Because of the new participant groupings, the influence of prior user experience between groups had to be readdressed. As was shown previously in Table 4.2, Dreamweaver Experience and Multiple Monitor Experience significantly impacted user's completion times. Dreamweaver Experience and multiple monitor experience, when evaluated in an independent sample T-test, resulted in the means shown in Figure 4.8. No significant difference was found between the two groups, but since the means are

unbalanced, and because prior experience significantly impacts user performance, as illustrated in Table 4.2, prior Dreamweaver experience and Multiple Monitor experience are used as a covariates in the following analysis.

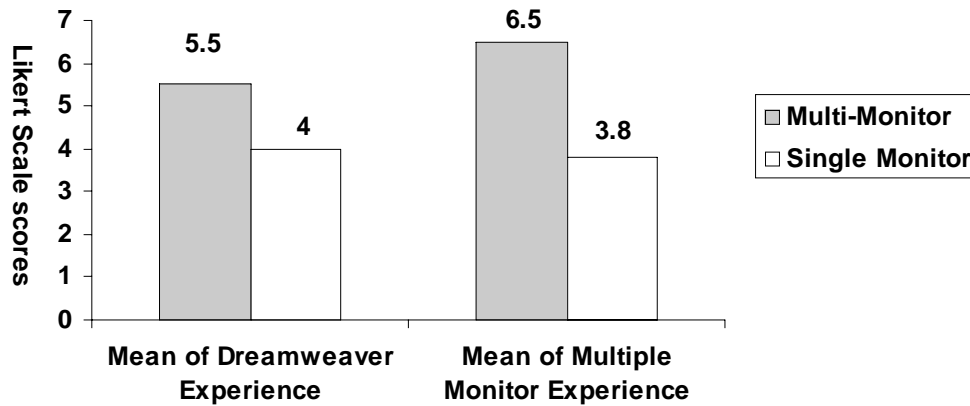


Figure 4.8. Means for prior participant experience

Using the two new participant groups, two, one-way analyses of variance were computed where the new categorizations (multitasking vs sequential) acted as the independent variables, completion time and successfully completed mini-tasks were used as dependant variables. Dreamweaver experience and Multiple Monitor experience were again used as covariates. The statistics associated with this analysis are displayed in Table 4.3. The new multitasking grouping included five participants from the single monitor group, and nine from the quad-panel display. The sequential group included seven participants from the single monitor group, and three from the quad-panel display.

Table 4.3: Mean responses & significance of ANOVA analysis

+medium-large effect size

 $\eta^2 > .09$, medium to large effect size (Cohen, 1969)

	Experimental Condition		Significance
	Multitasking	Sequential	
Total completion time +	1278.64sec	1479.01sec	P = .147, $\eta^2 = .102$
Successfully completed mini-tasks	9.37/10	8.28/10	P = .252, $\eta^2 = .065$

4.3. QUALITATIVE RESULTS

4.3.1. Survey Analysis. Participant responses to open-ended survey questions were also broken into individual concepts and pooled to find overarching themes. The exposed themes and representative quotes are listed below:

1. Multiple monitors enabled multitasking, where single monitors detracted from multitasking

- Multi: “Could do multiple tasks at once”
- Multi: “Allows to do multiple things at once such as editing code and then watching the results in another display”
- Single: “Can’t do two things at once”
- Single: “Not enough room. Couldn’t watch video, edit HTML, and preview in browser at the same time”

2. Multiple monitor users enjoyed having extra space, where single monitor users were frustrated by limited space

- Multi: “Able to see all you need at once”

- Multi: “More space to organize windows”
- Single: “Too constricting!”
- Single: “Overlapping windows obscures some parts”

3. Multiple monitor users enjoyed not having to switch between windows, where single monitor users became frustrated by frequent switching

- Multi: “Eliminates the constant clicking to get from file to file. You can simply leave all necessary files open for easy maneuvering”
- Multi: “I didn’t have to switch between applications to see what needed to be done”
- Single: “It’s a pain to switch between applications”
- Single: “Was very cluttered. Had to alt-tab to see them all”

4. Multiple monitor operating system drawbacks

- “Icons placed along the left side were too far apart”
- “Hampered my performance navigating the menu”
- “No easy utility for managing windows”

5. Multiple monitors led to some information overload

- “Having too many monitors to look between caused me to become easily distracted by trying to do too many things at once.
- “Hampered my performance to have that much on my screen at once”
- “4 was too much”

6. 2 x 2 Quad-panel display setup bothered some users

- “Cross section is right in the center...”

- “None of the screens were at eye level, so I was looking up and down the whole time”
- “I didn’t like looking ‘up,’ I’m not used to it”

4.3.2. Video Analysis. Observations from video recordings were also broken into individual concepts and subsequently pooled to find general themes. The overarching themes and representative observations are listed below:

1. No recognizable minimization of disruption for Quad-panel display as opposed to single monitor setup

- Multi: Acknowledged Instant Messenger popup, but did not slow task / Interrupt halted activity / Interrupt was unnoticed
- Single: Checked off interrupt / IM popup recognized and checked off / Too busy with tasks – did not even see IM interrupt

2. 2 x 2 Quad-panel display poorly utilized

- Participant used the two left panels only
- Primarily used top two screens
- No vertical head/eye movement – Participant confined to top two screens

3. Single monitor users prone to error

- User had trouble following the task list – Incorrect link, missing image. Very rarely looked at the task list
- Used a link from a tutorial, and not from the task list
- Participant used the wrong link, but corrected the mistake after re-reading the task list some time later

4. Single monitor users struggled with window placement – Multimon benefited from peripheral awareness

- Multi: Didn't need to re-adjust windows after opened in secondary window
- Single: User constantly had to drag the tutorial out of the way to work within Dreamweaver or read the task list
- Single: All windows were partially hidden, requiring the participant to frequently switch between windows and constantly reposition windows

5. Poor OS / Software support of display

- Multi: User could not find the Dreamweaver icon within the long stretch of icons across the left side of the screen – a great deal of vertical head/eye movement – furrowed brow
- Multi: Attempt to drag menu icons outside of main Dreamweaver window failed, user unhappy
- Single: Video player set to “always on top” caused the user to reposition it frequently

6. Users with multiple monitor experience instantly spread out, regardless of experimental group

- Multi: Immediately filled all four panels with equally sized windows (multi-monitor use rated at 10)
- Multi: Spread several windows across four panels, but not defined by monitor space (multi-monitor use rated at 7)
- Single: User resized windows to have several open windows with no overlap (multi-monitor use rated at 10)
- Single: Squeezed all windows into the display space (multi-monitor use rated at 10)

5. DISCUSSION & CONCLUSIONS

5.1. PERFORMANCE

While there isn't a direct 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 four panel display system multitasked more frequently than users of the single panel display – this data is supported by qualitative analysis of user feedback. Furthermore, when users were categorized by their tendency to multitask, rather than by the experimental groups, multitasking users completed the required tasks faster than users who approached tasks sequentially. The number of correctly completed tasks was also significant when comparing the two experimental conditions, where participants in the four panel display group completed the tasks correctly more often than those of the single monitor group. It is notable that the multitasking group did not have the same significantly higher scores than the sequential group (Table 4.3) that the multiple monitor group had over the single-monitor group (Figure 4.4). This may be attributed to recognition memory as put forward by Robertson et al. – multiple monitor users could multitask by arranging windows side by side for quick checking, where multitasking single monitor users spent more time multitasking through window switching.

Since the four panel display promotes multitasking, and the cluster analysis, and subsequent ANOVAs, indicate that those who did multitask had better completion times, there is likely a mediating factor slowing the multiple monitor group's overall times. A

learning curve was an expected issue going into testing, and as was noted in Section II, users were given a ten minute pre-task to familiarize themselves with the setup. It is possible then that the ten minute familiarization task was not sufficient for acclimating new users to the 2 x 2 quad-panel display. Another possibility is that the usability issues inherent in multiple monitor use, as was discussed in Section 1, hindered multiple monitor user performance.

5.2. USABILITY ISSUES

In addition to productivity, it was suggested that multiple monitor systems benefited users through peripheral awareness (Czerwinski et al., 2003). This seems to be supported by user comments regarding windows tabbing, 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.

Regarding the minimization of disruptions, suggested in Section I to be inherent in multiple monitor systems, this was not supported by testing as was hypothesized. Participants met an instant messenger interrupt with varying reactions – some users stopped all work the instant the interrupt occurred, while others checked off the interrupt and went about their business, still others made no acknowledgement of the interrupt what-so-ever. No trend was noticed between the groups. So online interrupts had varying impacts on participants, regardless of the experimental condition – Level of disruptiveness appeared entirely dependant on the individual.

Drawbacks were also recognized in testing, and lack of operating system support was one of the complaints users had. One participant 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 in searching for the applications needed to complete tasks. This irritation was observed on several occasions in video analysis.

In addition to distance problems, some participants complained about visual discontinuity, specifically in menu navigation. With traditional Windows dropdown menu's, 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.

Software support was also an issue, though ironically one of the most common software problems occurred exclusively with the users of the single monitor setup. The problematic software was the video application that participants used to watch tutorials for completing tasks. The video player's default setting positioned it "always on top" of other applications, which was a necessity for multitasking if users intended to watch the video while working in Dreamweaver (otherwise the video player would fall 'behind' Dreamweaver when the user clicked within the application – assuming Dreamweaver was maximized to fill the entire screen). Participants did not always like having the video "on top" though, especially when attempting to read the task list, where most users proceeded to drag the video player partly off screen to get a full view of the list.

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 menu's 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 common flaw, however, was not in the operating system or in any specific software. The drawback that was most often commented on by users was the quad-panel setup itself. Participants often didn't like aspects of the 2 x 2 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 the previously mentioned drawbacks, the response to the multiple monitor setup was overwhelmingly 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.

APPENDIX A.
PRE-QUESTIONNAIRE

Please fill out this brief questionnaire as accurately as possible. You are given a series of statements, please respond to each by circling a number ranging from 1 to 10 (strongly disagree – strongly agree)

I am a frequent computer user

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I am very experienced with Dreamweaver

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I am very experienced with a web development tool other than Dreamweaver

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I am very experienced with Instant Messaging software

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I am very experienced with MSN Instant Messenger

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I am very experienced with web browsing software (Internet Explorer or Firefox)

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I am very aware of multiple monitor use in personal computing

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
-------------------	---	---	---	---	---	---	---	---	---	----	----------------

I have a great deal of experience using multiple monitor systems

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
----------------------	---	---	---	---	---	---	---	---	---	----	-------------------

I have a great deal of experience using four monitor systems

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
----------------------	---	---	---	---	---	---	---	---	---	----	-------------------

APPENDIX B.
POST-QUESTIONNAIRE

Please fill out this brief questionnaire as accurately as possible. You are given a series of statements, please respond to each by circling a number ranging from 1 to 10 (strongly disagree – strongly agree). You will also be asked to respond to two open ended questions – if you need more writing room feel free to use the back of this paper.

I see great potential for multiple monitor use in everyday tasks

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
----------------------	---	---	---	---	---	---	---	---	---	----	-------------------

I thoroughly enjoyed using the multiple monitor system

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
----------------------	---	---	---	---	---	---	---	---	---	----	-------------------

I found that the multi-monitor setup greatly enhanced my performance

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
----------------------	---	---	---	---	---	---	---	---	---	----	-------------------

I would strongly consider getting a multiple monitor setup for my home computer

Strongly Disagree	1	2	3	4	5	6	7	8	9	10	Strongly Agree
----------------------	---	---	---	---	---	---	---	---	---	----	-------------------

What strengths did you find in using the multiple monitor system?

What weaknesses did you find in using the multiple monitor system?

APPENDIX C.
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:

Turn text color to red	Decrease text size to -3
Change font to Arial	Center align font
Make text bold	Right justify text
Make text italic	<ul style="list-style-type: none"> • Add bullet points • To text
Increase text size to +3	<ol style="list-style-type: none"> 1. Add numeric bullet points 2. To text

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 D.
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.umn.edu>, <http://campus.umn.edu/lite>, and <http://scholar.google.com>.

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

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VITA

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