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Usability in Multiple Monitor Displays

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USABILITY IN MULTIPLE MONITOR DISPLAYS

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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.

Introduction

Rationale

In the last twenty years accessible information has grown dramatically. Computer displays, however, 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 cost-effective means of increasing display space is through the use of multiple monitors linked to act as one screen. This "multimon" solution is already taking hold in some fields of work; 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). As LCD prices continue to fall, and software support improves, multiple monitors have the potential for exponentially greater use.

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. 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.

The ultimate 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.

Multiple Monitor & Large Display Benefits

In the past multiple-monitor evaluation has focused on qualitative analysis, and primarily of dual monitor setups. While studies have indicated that multiple monitor systems have drawbacks, the bulk of findings were very positive (Czerwinski et al., 2003). Czerwinski et al. suggest that the extensive windows management inherent in single monitor systems is detrimental to both productivity and user acceptance (2003).

Another suggested benefit of multimon systems is that they facilitate peripheral awareness. Simple single-monitor interfaces cause the user to minimize or cover information that could be displayed in the periphery of multimon systems. These minimized windows need to be stored in memory while they are out of sight. Finding features in deeply nested menus is also problematic. 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 from storing data in memory. Navigating through multiple windows to locate, retrieve, and edit information is inherently disruptive to mental processes. People generally consider it a relief not to have to switch so frequently (Grudin, 2001).

Other disruptions may also be reduced by multiple monitor use. Applications that interrupt the user, such as instant messengers, may block the user's field of view, and otherwise redirect the user's attention away from their primary task. With multimon it is suggested that these interruptions are far less disrupting when they appear in a secondary monitor (Grudin, 2001).

Benefits of Multiple Monitors vs. Large Displays

While the aforementioned benefits of multiple monitor systems may be most beneficial to multimon, they can also be linked to any large display. One benefit, however, that currently can be connected only to multimon 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).

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 (Grudin, 2001). Grudin contends that the increasing amount of information available to users demands partitioning, which is already conveniently accomplished by multi-monitor bezel areas (2001).

Multiple Monitor Drawbacks

While multiple monitor systems appear to have potential, research indicates that there is also a great need for improvement.

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. 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).

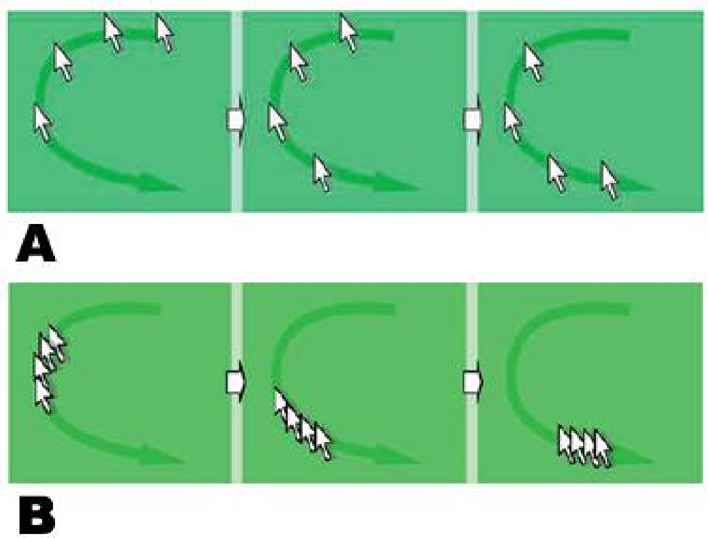

Figure 1. (A) Regular density cursor (B) High density cursor (Robertson et al., 2005)

While bezels may benefit organization and encourage task diversity, usability problems can 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 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 optimal (Robertson et al., 2005).

Figure 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).

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.

Multitasking

The considerable amount of information reaching users has also made computer multitasking commonplace. 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).

One difficulty with examining the multitasking phenomenon is that 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 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 of complementary tasks.

Figure 3 shows the difference in multitasking between working spheres and multitasking within a working sphere. Working spheres are represented by the large dark circles, indicating a higher level of multitasking than the encompassed tasks, which are represented by the smaller white circles. Figure 3.A illustrates the typical multitasking study, where users are tested multitasking between working spheres. Lower level tasks, and therefore instances of multitasking, exist within each working sphere, but are not evaluated in terms of multitasking success.

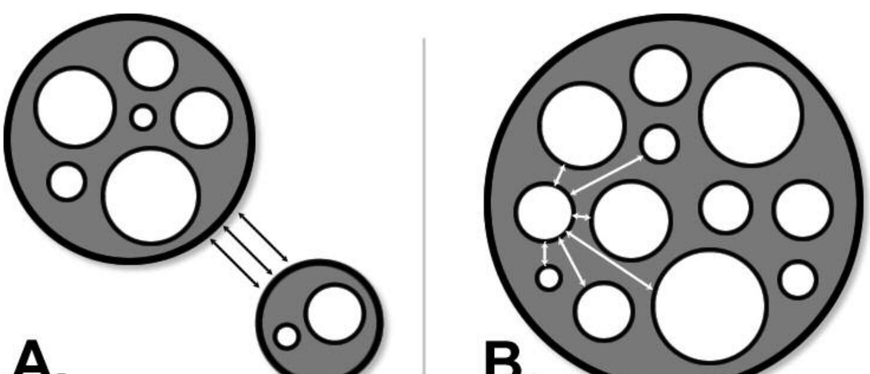

Figure 3. Multitasking between (A) and within (B) working spheres

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).

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 follow-up by Spector & Biederman (1976), had participants perform arithmetic operations on two columns of numbers. After each operation the participant would verbally report his or her result. Half of the participants performed these operations sequentially, and the other half switched after each verbal response (Rubinstein et al., 2001). This method of testing allows for highly quantifiable results by removing cross correlations, but does not necessarily simulate natural multitasking.

Due to the artificial nature of these studies, researchers are really only evaluating one form of multitasking – forced multitasking, due to interrupt. This is of limited applicability. In some settings multitasking occurs because of interrupts, but presumably the bulk of multitasking occurs when users themselves opt to switch tasks. One study that did take this limitation into account was done by Kushleyeva, Salvucci, and Lee. They 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).

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 ideal for determining the effectiveness of multitasking, as users were pressured to multitask using time constraints and penalties for not switching tasks (Kushleyeva et al. 2005).

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 commonplace computer use. Where most studies have evaluated multitasking at a high level (between working spheres) this study attempted to evaluate multitasking at a lower level (within a working sphere). Moreover, the tasks used allowed users to practice internally-driven task switching. Scientific conditions were also maintained, and sufficient users were tested to allow for the use of inferential statistics.

Method

Participants

24 students recruited from the University of Missouri - Rolla served as participants, 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.

Materials and Equipment

Those in the multiple monitor group used a quadruple screen display from MASS Engineered Design, arranged two monitors high and two wide for testing (Figure 4). 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 single 17-inch monitor. Twelve participants were randomly assigned to each group.

Figure 4. MassMultiples 17” Quadruple Screen Display

The quad-panel and single monitor groups both interacted with Macromedia’s Dreamweaver. Since the goal of this study was to analyze multiple monitor systems, and not Dreamweaver, participants were asked to follow simple video tutorials to accomplish tasks. Four tutorials were used, all of which can be found at: http://richardhhall.org/dreamweaver. The “Add Text to Page” tutorial was used for acclimation, where “Create Page Layers,” “Add Graphics to Page,” and “Add Links to A Page” were used in the main task.

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

Procedure

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

Participants were then introduced to either the multiple or single monitor testing setup. The participating student was directed to the task document and the first video tutorial. The files to use were explained, recording devices were started, and participants were asked to begin.

This period of testing was to be completed in ten minutes, and was meant only to familiarize participants with the system, so 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, which was to be completed in 30 minutes. For this period, the experimenter was not available to the participant. Fifteen minutes into the 30-minute testing period, however, the experimenter sent an instant message to the participant. This contact was initiated only to test the impact of an online interruption, and communication was ended immediately after the interrupt 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 an exit questionnaire was presented.

Results

Scoring

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 to default settings, use of special functionality such as alt-tab for windows switching, and any evidence relating to the usability issues previously discussed. 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. 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.

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 visual space (Ex: Figure 5).

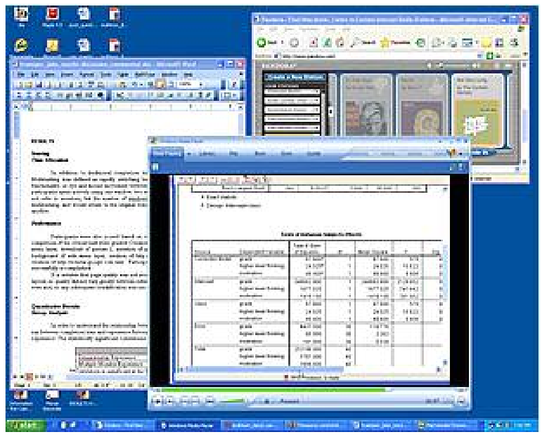

Figure 5. Three Windows open on a monitor

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 1.

Table 1. Pearson correlations between completion time & 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

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 6 illustrates the focus of each of these ten tasks. Participants were given a score out of ten for the number of mini-tasks that were successfully accomplished.

Figure 6. Ten mini-tasks

Quantitative Results

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 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.

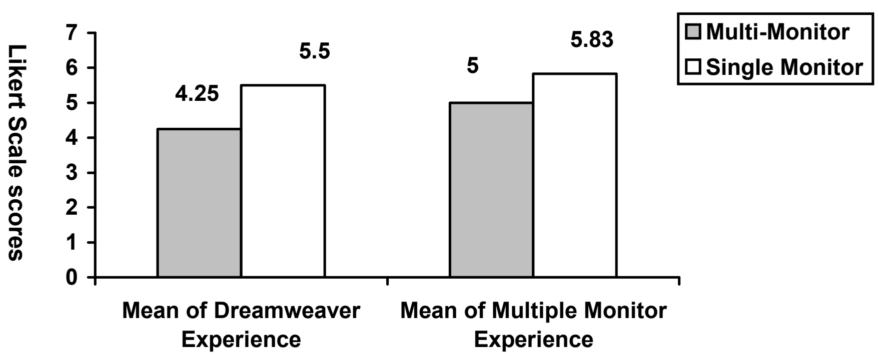

Figure 7. Means for prior participant experience

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 8, 9, and 10.

Figure 8. 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-large effect size (Cohen, 1969)

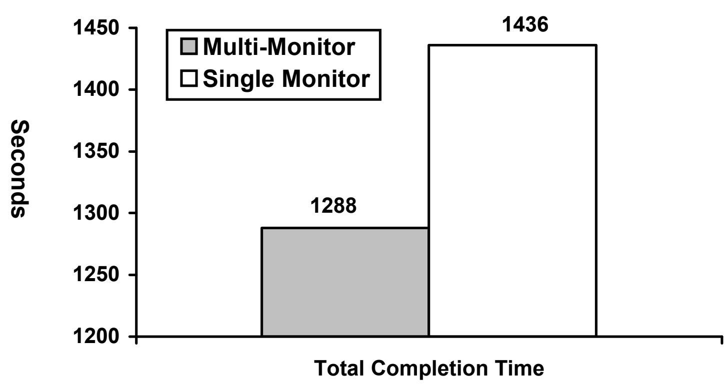

Figure 9. Means for total completion time

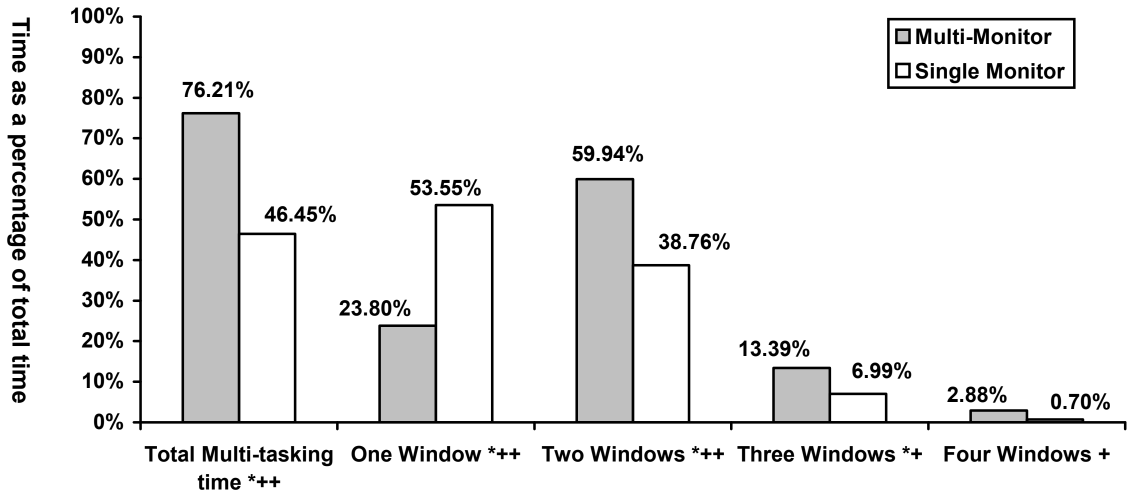

Figure 10. Percent scores & significance of ANOVA multitasking analysis
(*)p < .10, *p < .05, +medium-large effect size, ++Large effect size
$\eta^2 > .09$, medium-large effect size (Cohen, 1969)

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 11. Fourteen participants were categorized as Multitasking and ten were categorized as Sequential.

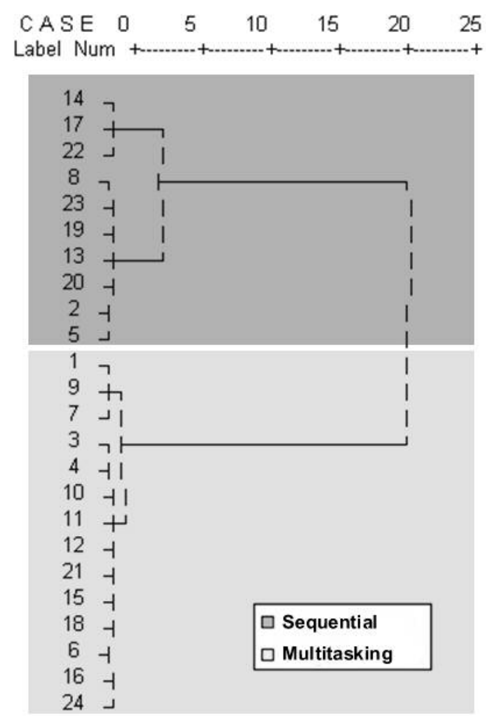

Figure 11. Participant grouping using Ward Method cluster analysis

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 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 3: Mean responses & significance of ANOVA analysis
+medium-large effect size
$\eta^2 > .09$, medium-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, $\eta^2 = .065$

Qualitative Results

Survey Analysis

Participant responses to open-ended survey questions were 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"

Video Analysis

Observations from video recordings were also broken into individual concepts and subsequently pooled to find themes. 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 unnoticed
    - Single: Checked off interrupt / Interrupt recognized an checked off / Too busy with tasks – did not 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
3. **Single monitor users prone to error**
    - Had trouble following the task list – Incorrect link, missing image. Very rarely looked at the task list

- Used a link from a tutorial, not from the task list
- Used the wrong link. 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: Constantly had to drag tutorial out of the way to work within Dreamweaver or read the task list
   - Single: All windows were partially hidden, requiring frequent switching of windows and constant repositioning
5. **Poor OS / Software support of display**
   - Multi: 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 – frustrated expression
   - 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: 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)

Discussion & Conclusions

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 users were given a ten minute pre-task to familiarize themselves with the setup. It is possible however, 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 hindered multiple monitor user performance.

Usability Issues

In addition to productivity, it was suggested that multiple monitor systems benefited users though peripheral awareness (Czerwinski et al., 2003). This seems to be 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.

Regarding the minimization of disruptions suggested as inherent in multiple monitor systems, this was not supported by testing as was hypothesized. Participants met an instant messenger interrupt with varying reactions not dependant on the user group.

Drawbacks were also recognized in testing, and lack of operating system support was revealed in user complaints. Icon arrangement and traveling large distances were among weaknesses that caused irritation, as was observed in video analysis. In addition to distance problems some participants complained about visual discontinuity, specifically in menu navigation.

Software support was an issue as well, though instances were also observed where software better facilitated the multimon setup than the single display.

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. The 2 x 2 monitor 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. Many of the quad-panel users only utilized two of the four screens, citing discomfort with both vertical and horizontal head movement. 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.

References

1. Cohen, J. (1969). *Statistical Power Analysis for The Behavioral Sciences*. London: Academic Press.
2. Czerwinski, M., Smith, M., Regan, T., Meyers, B., Robertson, G., Starkweather, G. (2003). *Toward Characterizing the Productivity Benefits of Very Large Displays*. IOS Press, © IFIP, 2003, 9-16
3. Gonzláez, V., Mark, G. (2004). *"Constant, Constant, Multi-tasking Craziness": Managing Multiple Working Spheres*. 2004 CHI Conference, Volume 6, Issue 1. 113-220
4. Grudin, J. (2001). *Partitioning Digital Worlds: Focal and Peripheral Awareness in Multiple Monitor Use*. 2001 CHI Conference, Volume 3, Issue 1. 458-465
5. Harada, Y., Nosu, K., Okude, N. (1999). *Interactive and Collaborative Learning Environment Using 3D Virtual Reality Content, Multi-Screen Displays and PCs*. Infrastructure for Collaborative Enterprises, 1999.
6. Harrison, S., Dourish, P. (1996). *Re-Place-ing Space: The Roles of Space and Place in Collaborative Systems*. Proc. ACM Conf. Computer-Supported Cooperative Work CSCW, 1996.
7. Hembrooke, H., Gay, G. (2003). *The Laptop and the Lecture: The Effects of Multitasking in Learning Environments*. Journal of Computing in Higher Education, 2003, Volume 15, Issue 1.
8. Jersild, A. (1927). *Mental Set and Shift*. Archives of Psychology (Whole No. 89).
9. König, C., Bühner, M., Mürling, G. (2005). *Working Memory, Fluid Intelligence, and Attention are Predictors of Multitasking Performance, but Polychronicity and Extraversion are Not.* Human Performance, Lawrence Erlbaum Associates, Inc., 2005, Volume 18, Issue 3. 243-266
10. Kuehl, R. (1994). *Statistical Principals of Research Design and Analysis.* Wadsworth Publishing Company.
11. Kuniavsky, M. (2003). *Observing the User Experience: A Practitioner's Guide to User Research.* Elsevier Science (USA). 196-200
12. Kushleyeva, Y., Salvucci, D., Lee, F. (2005). *Deciding When to Switch Tasks in Time-Critical multitasking.* Cognitive Systems Research, 2005, Volume 6. 41-49
13. Lee, F., Taatgen, N. (2002). *Multitasking as Skill Acquisition.* 24^{th} Annual Conference of the Cognitive Science Society.
14. Logan, G. (2003). *Executive Control of Thought and Action: In Search of the Wild Homunculus*. American Psychology Society, 2003, Volume 12, Issue 2. 45-48
15. Mark, G., Gonzláez, V., Harris, J. (2005). *No Task Left Behind? Examining the Nature of Fragmented Work*. 2005 CHI Conference. Portland, Oregon. 321-330
16. Meiran, N. (1996). *Reconfiguration of Processing Mode Prior to Task Performance.* Journal of Experimental Psychology: Learning, Memory, and Cognition. 1423-1442
17. Robertson, G., Czerwinski, M., Baudisch, P., Meyers, B., Robbins, D., Smith, G., Tan, D. (2005). *The Large-Display User Experience*. IEEE Computer Society, 2005. 44-51
18. Rogers, R., Monsell, S. (1995). *Costs of a Predictable Switch Between Simple Cognitive Tasks.* Journal of Experimental Psychology: General. 207-231
19. Rubinstein, J., Meyer, D., Evans, J. (2001). *Executive Control of Cognitive Process in Task Switching*. Journal of Experimental Psychology: Human Perception and Performance, 2001, Volume 27, Issue 4. 763-797
20. Seven, R. (2004). *Life Interrupted*. The Seattle Times Magazine, November, 2004.
21. Spector, A., Biederman, I. (1976). *Mental Set and Mental Shift Revisited*. American Journal of Psychology. 669-679