# A Comparison between Single and Dual Monitor Productivity and the Effects of Window Management Styles on Performance

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**Abstract.** Several research studies have been published on user opinion and productivity of using dual monitor systems. These studies found that users typically enjoy using multiple monitors, but none found a strong increase in performance and productivity. Other researchers have focused on improving multiple monitor usability, but often without any statistical framework. This study compared single and dual monitor productivity measures: task time, cursor movement, and number of window switches. Additionally, window management styles (WMS) were studied in order to help designers understand user behavior better. WMS were broken into two categories, toggler and resizer, and then compared to the WMS created by Kang and Stasko (2008). The results of the research showed a significant difference between the number of open applications and a significant difference between single and dual monitors for the number of window switches. The only significant difference between the toggler and resizer WMS was the number of window switches, which was an interaction between the styles and the tasks.

**Keywords:** Dual Monitors, Window Management Style, Productivity.

## 1 Introduction

Research on computer monitors varies greatly. Examples of the research topics include monitor size, the benefits of using LCD rather than CRT, and visual fatigue. Research on the use of multiple monitors in a work environment indicates that productivity increases when dual monitors are used in lieu of single monitors. [13]. The present study was performed to describe the differences in the work patterns between single and dual monitor configurations in a controlled experiment simulating an engineering work environment. The study provided a comparison of task time, cursor movement, and the number of toggles between applications for both single and dual monitor configurations. The study also outlined how users with different work patterns designate applications to monitors and how they utilize the virtual workspace.

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## 2 Literature Review

Over the past decade, several important pieces of literature have been authored on using multiple monitors and the associated problems. Productivity continues to be a relevant topic because businesses and people are interested in understanding the possible benefits of using additional monitors. Through a better understanding of this new technology, new operating systems and applications can be designed to take full advantage of the virtual real estate gained when multiple monitors are utilized.

Research has shown that when a person uses a single monitor, they will often use it as a single space; if they were using multiple monitors, they consciously treat the space on each monitor separately. [6]. The author also noted user tasks were split into primary and secondary tasks, and that most of the secondary tasks were for communication, such as instant messaging or email, and personal resources, such as calendars and web browsers. In addition, multiple monitor users often use the secondary monitor(s) in direct support of a primary task on a primary monitor. While increasing display space does not resolve the limitation on information management, such as the placement of windows and task bars, [6] went on to say that it does help by allowing users to spread information out and organize their windows more effectively. However, this study discovered that not all information is treated equally; people prefer to allocate their attention to one task while having additional information readily available.

Research on time saved when using multiple monitors showed no significant difference in the amount of time spent switching between windows or the number of visible windows when comparing single and dual monitor configurations. The research also showed that the participants often hid specific window content that was determined to be distracting or unnecessary. [7]

Researchers and software developers researched multiple monitor usage, tracking who used software to gather data on each participant's work PC over an extended time period. [8] The results of the research showed that single monitor users were nearly twice as likely to have their active window fully visible, and much less likely to have their email fully visible. The researchers also found that the amount of unused space increased as the amount of space and monitors increased, meaning that participants used the space more efficiently. In conclusion, [8] reflected that users often interact with windows simultaneously to complete a task. The authors explained that multiple monitors help users view more windows at any given moment, but they still switch between windows as frequently. They speculate multiple monitor users may use larger window sizes, and believe that this pattern may not actually be related to monitor size. The research done also showed that multiple monitor users do not rely on the taskbar as much as single monitor users, as well information being spread across many monitors. Usage patterns with multiple monitors were more dynamic compared to single monitor usage. The research, however, remained unable to statistically test these patterns because the data were collected from an uncontrolled source.

Focusing more on multiple monitor usage patterns, [9] identified three main usage strategies when interacting with the dialog boxes. They found that each participant used one of the basic strategies, but only a small fraction used the same strategy throughout the entire experiment. These findings indicate that a sole solution to problems encountered when using multiple monitors may not fit all users or fit all types of tasks. Given that participants exercise multiple strategies, software and operation system designers must think of robust solutions. The researchers indicated that further study of multiple monitor usage patterns would be beneficial to designers, but may not provide clear solutions to increase usability.

Research on the effects that multiple monitors have on work performance and patterns for light weight computer tasks was completed by [13]. In a controlled experiment, the researchers compared how the participants performed on both single and dual monitor computers while working with word processors, web browsers, and spreadsheets. During the tasks, cognitive load, task time, and the window operations were recorded. Tracking software also collected the opening and closing of windows, locations of windows, as well as moving and resizing of windows. The cognitive workload measure indicated no significant differences between the single and dual monitors, or the sequence of which they were used. The results, however, did show a trend of multiple monitor users feeling less workload than single monitor users.

An analysis on the different behaviors of single and dual monitor users on window management styles (WMS) was also performed by [13]. The categories were formed based on how the participants accessed windows and for the methods by which they organized their screen space. Participants accessed their windows by either using Alt+tab to switch the window in view, or by moving and resizing their windows. Three additional categories were formed for organizing screen space: “Maximizers”, “Near Maximizers”, and “Careful Coordinators”. Maximizers kept windows at the maximum size, while using Alt+Tab to switch between windows. Near Maximizers resized their windows to occupy most of the screen space, while Careful Coordinators resized their windows so that several windows were visible simultaneously. These categories, however, did not significantly affect task time or workload when compared to the number of monitors being used or the sequence of use. Even though the differences were not significant, when multiple monitors were used during the first session, Alt+Tab users and Move/Resizers both benefited. During the second session, the Alt+Tab users performed faster when using a single monitor, which could have been attributed to the learning curve.

During the two sessions, the researchers observed that Alt+Tab users were less likely to use Alt+Tab with multiple monitors during the first task assignment, and were probably led to act more like Move/Resizers due to unfamiliarity of the task. In contrast, the Move/Resizers were able to coordinate their windows more rapidly and less frequently due to the increased screen space. The workload measures also showed that the Move/Resizers felt less workload during the multiple monitor setting in the second session. A higher workload may have been experienced when multiple monitors where first used, since the user had to manage more screen space and more windows. As the users gained experience using the additional monitors, they were able to develop strategies that allow them to efficiently utilize the increased screen space with less workload.

## 3 Problem Definitions and Hypothesis

The primary objective of the study was to compare the differences in work behaviors and usage patterns when participants used a single monitor and used dual monitors. Differences were examined for three metrics. Task time was measured as the number of seconds it took to complete each individual task. Cursor movement was quantified as the number of pixels the cursor moved during each of the computer tasks that the participant completed. Finally, the total number of switches between windows was recorded as a sum of the number of times a participant switched from one application to activate another application. This metric was chosen because it measures a loss in productivity due to cognitive processes being interrupted when users must seek out information, as well as the time lost in activating windows. An explanation of how productivity is affected by interrupting tasks can be found in [2].

Each of the three metrics was examined with respect to WMSs formulated within this research, as well as for the WMSs developed by [13]. Because the user's WMS and work patterns may vary as the complexity of the task changes, altering the number of open applications may provide insight into how work patterns change when workload varies. Therefore the number of applications used was varied between 2, 3, and 4.

The first set of hypotheses focused on the benefit of using dual monitors over single monitors in terms of time, cursor movement, and how many times participants had to switch between windows. The hypotheses for each of these dependent variables were that dual monitors would allow participants to perform faster with less cursor movement and less window switches. This notion was founded on participants being able to spread the windows across the larger virtual workspace when using dual monitors. Since the participants will have more viewable information, the amount of cursor movement to the task bar, as well as the number of window switches, would decrease as a result.

The second set of hypotheses focused on the effects of different WMSs on performance. Two WMSs were created and tested for differences, toggler (TOG) and resizer (RES). A TOG was defined as a user who primarily sizes their windows to occupy most of the screen, relying on the task bar more heavily when activating windows. A RES was defined as a user who sized multiple windows to allow them to simultaneously view multiple windows. It was hypothesized that RESs would show a decrease for all three dependent variables, based on the thinking that since RESs are able to view more information at once, they would not have to search for windows using the task bar or activate applications by clicking overlapping windows. The RES did not have to activate windows to see pertinent information.

The results of these three TOG and RES hypothesis tests were then compared to the WMS of [13] in order to identify any advantages either set of WMS may have over the other.

## 4 Methodology

The computer tasks used for the experiment were designed to simulate normal engineering computer work that would be completed in a typical office setting while using multiple windows simultaneously on the computer monitor(s). Software packages were chosen to simulate the typical software used in an office environment. These software simulated drafting, data entry, spreadsheet analysis, email, and gathering data. A total of six tasks were designed. Each task was categorized by how many active windows were needed during the task. Three categories of total number active windows were used, two, three, and four, and there were two iterations of each. The task with two active windows used Excel and Outlook. The three active window task added Internet Explorer. Finally, the four active window task added AutoCAD to the suite.

Each participant performed all 6 tasks during the experiment, 3 on both a single monitor and dual monitors. Prior to the experiment, the participants completed a short questionnaire and training. After each monitor setting, the participants completed a questionnaire. Finally, a post completion survey was administered.

Overall, 36 participants were recruited, mostly from the School of Industrial Engineering at University of Oklahoma. The range of participant age was 18 to 39 years, with an average of 23 years of age, and a standard deviation of 3.5 years. The gender distribution of participants in this study was 67% males and 33% females.

The primary equipment used by the participants was a DELL Optiplex 745 PC with two 19 inch monitors. The computer was fit with a standard keyboard and an optical mouse. The dual monitors were placed equidistant from the midsagittal plane.

Three independent variables were studied during the experiment: 1) the number of screens (single or dual), 2) the number of active windows open during the tasks (2, 3, and 4), and the WMSs (TOG and RES). WMS was also researched in [13]; however, the categories have been defined differently in this research. Instead of having multiple categories for both sizing and accessing application windows, the categories used in this research combine the two. "Alt-Tabbing" was prohibited by experimental instruction in order to control the behavior, unlike [13]. This research focused on whether or not users are viewing information simultaneously, with the thought that by simplifying the categories, significant differences between the different WMSs would be found.

## 5 Data Validation, Correlations, and Results

For task time, the fitted value plot showed a troublesome trend, as the fitted value increases the residual value also increases. The residual plots for cursor movement showed that the assumption of normality may have been violated due to the slight curvature of the line and the presence of several outliers. The fitted value plot showed a curve trend and an increasing fitted value. The violation to a zero mean for the error term could clearly be seen in the histogram, where the negative residuals showed a much higher frequency than the positive terms. The plots for window switches showed a violation occurred due to the increasing trend of the residual values as the fitted value increased. The histogram, however, did show a defined bell shaped curve, while the order plot also showed no violation.

A correlation between cursor movement and task time was found ($r^2$=0.7466, $p$ <0.0001) indicating that as cursor movement increases, task time also increases. The correlation between task time and number of window switches showed that as the number of switches increases, task time also increases ($r^2$= 0.5330, $p$<0.0001). Finally, the correlation between cursor movement and the number of window switches showed a positive trend for cursor movement as the number of window switches increases ($r^2$=0.5191, $p$<0.0001). Since cursor movement and number of window switches were correlated to task time, they can both be considered indicators of productivity.

**Table 1.** Means and standard deviations off all data points

| # of Windows | # of Monitors | Sample Size | Mean Task Time | Task Time Standard Deviation | Mean Mouse Movement | Mouse Movement Standard Deviation | Mean # of Window Switches | Window Switches Standard Deviation |
|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 34 | 461.06 | 168.55 | 92806.99 | 39233.39 | 9.59 | 7.21 |
| | 2 | 34 | 484.41 | 154.48 | 101314.65 | 50355.19 | 4.06 | 3.09 |
| 3 | 1 | 34 | 687.91 | 267.78 | 144077.49 | 66694.41 | 34.88 | 10.79 |
| | 2 | 34 | 643.97 | 253.18 | 124435.74 | 63203.57 | 30.79 | 12.49 |
| 4 | 1 | 34 | 1314.82 | 456.51 | 224794.09 | 96363.69 | 32.68 | 8.72 |
| | 2 | 34 | 1310.09 | 414.08 | 225310.30 | 93169.08 | 32.06 | 9.55 |

As the means suggest, there were no significant differences for the number of monitors used or interactions. The number of windows did, however, produce a significant difference ($p$<0.0001). Tukey analysis showed that all three tasks were different from each other, although the two and three window task times were similar.

Despite the mean mouse movement being higher for the 2 and 4 window tasks, no significant results were found. There was a significant difference in mouse movement for number of windows being used ($p$<0.0001). Though there were no significant interactions, the 3 window task exhibited a decreasing trend between the single and dual monitor tasks. Tukey analysis confirmed that all three tasks were different.

There was both a significant difference in the number of windows and in the number of monitors ($p$<0.0001 and p=0.0028, respectively). Unlike task time and mouse movement, the Tukey showed that the 3 and 4 window tasks were similar, while the 2 window task was different from both.

A statistical analysis was performed on the WMS in two ways. The first analysis was performed only on participants that exhibited one style of window management, called pure TOGs (PT) and pure RESs (PR). Of the 34 total participants, three were classified as PRs and 15 were determined to be PTs. The second analysis examined the patterns of all 34 participants.

Task time for PTs and PRs was found to be significantly different ($p$<.0001). Tukey analysis revealed that the 3 window task requires less mouse movement that the 4 window task. Mouse movement only revealed significant differences for the number of windows being used. Tukey analysis revealed that the 3 window task requires less mouse movement than the 4 window task. The number of windows switches did not produce a significant difference ($p$=0.420). Only the interaction between the number of windows and the WMSs was significant for number of window switches ($p$=0.040).

An additional statistical analysis was performed of all of the participants considering their respective WMS for each task. However, the results showed significant results only for the number of windows used for both measures of task time and mouse movement. The means for each type of WMS can be found below in table 2.

**Table 2.** Means of TOGs and RESs with respect to number of monitors, Pure users are identified by bold italics

| # of Monitors | Style | Mean Task Time | | Mean Mouse Movement | | Mean # of Switches | |
|---|---|---|---|---|---|---|---|
| 1 | R | 952.59 | ***1028.83*** | 172859.61 | ***176445.11*** | 35.77 | ***32.00*** |
| 1 | T | 1024.70 | ***939.70*** | 189972.23 | ***182445.29*** | 32.88 | ***31.93*** |
| 2 | R | 845.00 | ***1088.17*** | 164926.70 | ***182445.29*** | 32.88 | ***29.50*** |
| 2 | T | 1021.04 | ***1032.23*** | 178188.46 | ***170398.93*** | 30.94 | ***32.63*** |

## 6 Conclusions, Recommendations, and Future Work

The experiment showed mixed results on the benefit of using dual monitors instead of single monitors. Unlike [13], no significant difference was found between single and dual monitors with respect to task time. It was surprising that despite including more complicated tasks than what was found in the literature, no significant differences for task time were found. Contrary to what the actual task times reveal, participants felt they had performed faster in the dual monitor configuration.

When trying to determine the reasoning behind the results, two logical interpretations were found. Either there truly were no differences in task time due to the lack of operating system and software compatibility with multiple monitors, or problems existed within the experiment obstructing any significant differences from being found. It could have been possible that resizing windows and locating the windows on the additional monitor mitigated the productivity benefits of using dual monitors because of the time spent moving windows. When looking at the results for cursor movement, the differences between the single and dual monitor configurations were minimal, especially for the four window tasks. Cursor movement was a dependent variable that went unexamined by previous research. Even though no significant differences were found in this study, the survey revealed that the participants thought that they were moving the mouse less during the dual monitor configuration.

The benefit of using dual monitors was seen through the decreased number of window switches required to complete a task with the dual monitor. However, time savings associated with reduced switching of windows were most likely mitigated by relocating and positioning windows.

Other possible reasons behind the lack of difference between the single and dual monitor configuration results could have been limitations within the experiment, such as lack of experience with AutoCAD or lack of exposure to dual monitor computers. Drafting software experience was required of each participant in the experiment, but participants were not required to be familiar with AutoCAD. Due to the simple nature of the drafting required, proficiency with just AutoCAD was deemed to be unnecessary. Even though training was provided to each participant on the exact functions that were used during the drafting task, the lack of experience of those participants may have adversely affected their task times, mouse movement, and number of window switches. Also, there was no control for dual monitor experience, thus the results of the study may indeed have been impacted by user experience. When examining these variables no strong differences were seen between inexperienced and experienced AutoCAD users or multiple monitor users.

The third possible explanation of why the experiment did not find differences between single and dual monitors was that the four window task could be completed using three windows at a time. Studying the four window tasks more closely, the tasks closely resemble a set of two separate tasks, rather than one task that requires all four windows to be used simultaneously. Therefore, only three windows were used simultaneously. Had the instructions stated that the user should perform both subtasks simultaneously, the results may have been different. Alternatively, if a between subject experimental design was utilized, equal tasks would not have been required.

Another issue that may have affected the data arose during the design of the experiment. The researchers determined that it was necessary to create varying tasks of the same number of windows with equivalent task times. Using a GOMS analysis, two tasks for each of the 2, 3, and 4 window levels were created. However, during the experimental trials the researchers noticed that the task times for the variations in each of the 2, 3, and 4 window sets were not equal. The researchers determined that the cause of the disparities was due to the varying amounts of reading and comprehension that took place between the tasks. The tasks were then adjusted to equalize the task times, and the GOMS analysis results were adjusted to reflect the changes. It is possible that the adjustments to the tasks could have caused these differences. However, without a formal task analysis that incorporates a key stroke analysis and considers mental activity, it was impossible to form tasks that are truly equivalent. Therefore, it is recommended that future researchers consider developing a formal analysis that can be used to accurately form tasks that are equal in complexity.

In conclusion to the dual monitor analysis, there may still be advantages to having multiple monitors despite the lack of evidence that they increase productivity in terms of time savings. The post-experimental survey revealed that people enjoyed using dual monitors, and believed that they were more productive when using them. If users are more satisfied with using a piece of equipment, job fatigue may be reduced while motivation and work morale may be increased. It would then be logical that providing multiple monitors to a work force would increase productivity for drafting, data mining, programming, and for gathering and recoding large amounts of information. Multiple monitors are especially advantageous when dynamic information, data that requires the user to frequently check, is being displayed by the user. Using a single monitor system would cause the user to allocate prime screen real estate to be able to view the information instantaneously, or cause them to search for the windows more often, thus reducing productivity. With a multiple monitor system, a user is able to designate an area or monitor to view secondary information.

The results for three WMS analyses were surprising, no significant differences were found for any of the WMS. The trends of the means generally showed that there were some differences; therefore, perhaps an additional study with larger sample size would be able to show a statistically different result.

Although, Kang and Stasko's styles showed larger differences in performance for each WMS, compared to the TOG and RES WMS, there was still criticism of their categorization method. Kang and Stasko's styles are based on both window size and how much information can be viewed. While the styles worked for single monitors, it did not effectively categorize dual monitor users. This was due to the fact that the participants could be classified as multiple styles simultaneously since two different styles could be utilized on different monitors. During the analysis, the process of categorizing each participant was difficult, due to the parameters set for each style. This occurrence was largely due to window size being used as a factor in determining what WMS a participant used. For example, during a four window task, a participant may have two maximized windows on one monitor, toggling between them, while on the second monitor having two windows sized so that both are fully visible at one time. Therefore, that user would be a Maximizer on one monitor and a Careful Coordinator on the second. Using the TOG and RES styles, the same participant would be identified as a RES, because they are generally trying to view as many windows as they can simultaneously.

The reason that the TOG and RES categorization method was determined to have an advantage was because it focused on how a participant was gathering information. The most important factor on how windows were managed was how the participant was retrieving information, and how much information they were viewing at one time. Thus, the potential improvement to performance from being able to view more information at once would drive a user to manage their windows differently. While Kang and Stasko's method considered how the windows are positioned, when they considered window size as a factor they confounded the process of categorization. The exact size of the windows does not matter; what actually matters is whether the participant can view multiple sources of information.

In future studies multiple monitor productivity should examine the influence by many different factors such as: monitor size, monitor separation, integration with laptops, software, operating systems, and WMS. From the results of this research, it is recommended that more attention be placed on WMS and the amount of windows being used simultaneously. Alternatively, increasing task complexity by forcing participants to reference windows more often should also be examined. For both methods of increasing task complexity, it is also important to measure how the different styles of window management compare to each other when task complexity is increased. Finally, future research should also place more focus on recruiting an equal sample size of each of the WMS and longer experiment times.

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