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Visual momentum in window management for multiple display environments

Y. T. Janice Tam
San Jose State University

VISUAL MOMENTUM IN WINDOW MANAGEMENT FOR MULTIPLE DISPLAY ENVIRONMENTS

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Y. T. Janice Tam

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APPROVED FOR THE HUMAN FACTORS AND ERGONOMICS PROGAM

Dr. Kevin M. Corker, Professor, Industrial and Systems Engineering

Dr. Kevin Jordan, Professor, Psychology

Samm Starr, SJSU Human Automation Integration Laboratory

APPROVED FOR THE UNIVERSITY

ABSTRACT

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This study determines whether designs intended to preserve visual momentum where appropriate can aid interaction on a computer system attached to two monitors. Participants engaged in multiple tasks including word processing, slide show presentation, and web surfing tasks while performing a computer tracking task. It is believed that interface processes that account for or enhances visual momentum will decrease mental demand. The hypothesis examined whether a multi-display interface designed according to principles of visual momentum may improve multi-tasking performance relative to a baseline (standard) multi-display interface. Results revealed that when cognitive workload was low, a visual momentum-enhanced interface may increase performance in the secondary task well as a perceived reduction in cognitive workload. When the secondary task demanded more cognitive resources, a visual momentum-enhanced interface did not affect performance on either the primary task or secondary task.

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INTRODUCTION

As the cost of desktop computer monitors decreases and graphical processing technology becomes more powerful, assigning more than one monitor to a desktop computer becomes a viable option for many normal computer workstations (Robertson et al., 2005). The virtue of having a second monitor is not difficult to imagine. Similar to working on a large table, additional monitors displaying one continuous desktop enlarge the physical workspace, which is especially helpful for tasks that require information integration from many different sources. Since a great deal of information can be displayed simultaneously, the need to navigate between successive views is reduced. Thus, an increase in screen real estate (i.e., computer workspace) may have an advantage in decreasing workload and cognitive demands (Czerwinski, et al., 2003; Robertson et al., 2005; Simmons, 2001).

Double and sometimes triple monitors operate with software that behaves as if only one display is present (Grundin, 2001). It has been noted that the common windowing system (e.g., Microsoft Windows, which has the ability to layer workspace area containing different information or programs in areas called a "window") utilized by most desktops has encountered a variety of usability problems when running on multiple monitors or larger-sized display (Hutchings & Stasko, 2004). For example, window management is made more complex because users wish to avoid having windows placed across monitor frames (Czerwinski et al., 2006). The varieties of tools available for partitioning the workspace (e.g., windows, frames, icons, menu, and task bars) are considered insufficient for even a single display system for displaying information (Grundin, 2001). An increased physical workspace will likely exaggerate the already cumbersome navigational management currently employed. With the trend toward increased screen real estate by way of multiple monitors, the usability issues of the current window management will increase along with the increase of physical workspace.

Window Management Strategies

To overcome window navigational problems, users have adopted new and interesting ways of arranging their windowed desktops. Windows refer to the frame in which an application appears on a computer desktop. At a given instance, several windows may be visible and may contain different applications or information. In one study, Hutchings and Stasko (2004a) tracked usage patterns of 20 adults at their regular workspaces. Screenshots were captured while the users worked and a structured interview was given afterwards. The authors found that usage patterns could be grouped into three categories. One group of users tends to open all their windows to the size of the display and use a window management system to switch between windows. A second group of users made their windows slightly smaller than the display in order to maintain an area on the display devoted to icon shortcuts. A third group tiled their windows, customized the size to their specific need.

These spontaneous usage patterns users exhibit when organizing their desktop resemble attempts at arranging the workspace to increase "visual momentum." However, it is often implemented as a remedy to counter usability problems as they arise.

Therefore, these attempts are ad hoc and disruptive. If certain visual momentum guidelines were incorporated deliberately into windows management, spatial navigation on a multitasking computer desktop would be more efficient, especially in an extended workspace.

Visual Momentum

The concept of visual momentum is associated with the ability of a human operator to maintain a spatial perceptual process that maintains continuity as they scan among multiple physical displays. As the name implies, when visual momentum is adequate, there is an impetus across successive views that support the rapid comprehension of data following the transition to a new display (Woods, 1984, p.231). In particular, visual momentum should improve the user's ability to extract task-relevant information even when that information is represented in a different form across successive displays (Wickens & Hollands, 2000). In using a multiple display setup, increased visual momentum should decrease the mental effort required to gain situation awareness and extract task relevant information.

Visual momentum can refer to several aspects of interface interaction. In one sense, it can refer to a perceptual phenomenon where a switch in display is almost undetectable by a user engrossed in a task. It can also refer to the characteristic of the interface that manipulates what is shown to the user. Another important facet of visual momentum is the coordination of various displays. In the present study, visual momentum refers to characteristics of the display designed to lead the user from one information source to another. The purpose of this experiment was to apply the tenets of visual momentum to design for the current capabilities of window management in order to improve workflow in a dual display computer workstation.

Problem Statement

The purpose of this study was to determine:

1. Whether the introduction of visual momentum-based design on a computer display affects primary task times.
2. Whether the introduction of visual momentum affects performance on the secondary tracking task accuracy.
3. Whether the introduction of visual momentum will affect subjective workload as measured by the NASA-TLX.

Hypotheses

The following hypotheses were made for the purpose of this study:

1. Introduction of visual momentum will decrease primary task times.
2. Introduction of visual momentum will increase accuracy on the secondary tracking task.
3. Introduction of visual momentum will decrease subjective workload ratings on the NASA-TLX.

Limitations

The study was limited to:

1. Participants who are undergraduate students from the psychology program at a metropolitan university.
2. Participants who are familiar with the Microsoft Windows operating system.

Definition of Terms

The following terms are defined for the purpose of this study:

Multitasking: Multitasking refers to working on two or more computer tasks near simultaneously.

Navigation: Navigation refers to maneuvering through a different programs and windows on a typical desktop computer.

Subjective Workload: The concept of workload is defined by the relationship between resource supply of the user (e.g., attention) and the external task demand (Wickens & Hollands, 2000). The NASA-TLX is a subjective measure of workload that assessed workload on each of five 7-points scales (Hart & Staveland, 1988).

Visual momentum: Visual Momentum refers to the ability to maintain cognitive, spatial and perceptual continuity across multiple displays of the same information.

Summary

Distributed Display Environments either in the form of a single display or multiple-display setup depicting a continuous workspace have been found to increase productivity in a variety of tasks. However, the specific tasks associated with common computer tasks such as word processing, data entry or web surfing have not been studied in detail. Additionally, many studies simply observe users while they complete tasks on their personal workstation, or provide anecdotes on how relieved users feel when given access to more screen real estate. While this provides interesting insights into the habits of multiple and/or large display users, it does not elucidate the exact mechanisms that lead to the documented increase in productivity.

The current study is a controlled experiment incorporating visual momentum techniques to window management and navigation in an attempt to maximize the benefits of a large display area. By manipulating one aspect of navigational burden on the user and varying degrees of distraction through a secondary tracking task, this study documents the precise navigational structures that give multiple monitors such increasingly widespread appeal.

REVIEW OF LITERATURE

Once a luxury only available on high-end workstations, the decrease in cost and footprint of LCD monitors coupled with advances in graphics card technology has made multiple displays a reasonable upgrade for regular computer users. Setting up multiple monitors has purportedly become one the easiest way to increase productivity in a work world that encourages multitasking and attending to a constant stream of interruptions. While the phenomenon is far from ubiquitous, the move towards increased screen real estate is generating much research interest in human-computer interaction.

Studies of multiple monitors for general use are still relatively new; however, the general problems associated with the personal computer interface still apply in this context. This literature review will examine the issues surrounding multiple window management, large screen displays, and how visual momentum may alleviate some of these interaction issues in a multiple monitor set-up.

Multiple Window Management and Multitasking

Regardless of the size of the display, a problem for computer users is balancing the need to consult many sources of information while maintaining concentration on their task. The multiple window interface allows users easy access to many information points simultaneously; however, it also generates an extra step called "window housekeeping", in which the user must manipulate the interface in a way not directly related to the task (Schneiderman, 1998). Multitaskers must often switch between concurrent tasks or activities. Each time a task switch occurs there is an additional cost both in time and cognitive demand to reorienting one's situation awareness due to the extra window housekeeping. To minimize the effect of frequent window switching, many strategies for multiple-window design have been studied. The several that will be addressed through the use of visual momentum in this study are:

- Intent Inference: If the user's tasks are well understood and regular, then the interface can predict the user's need and present the right window at an appropriate time.
- Perimeter Support: Window border decorations can be made informative and useful (Schneiderman, 1998). This allows the user to find the fight window with minimal searching.
- Color/Intensity Coding: Color or intensity coding can effectively separate the visual field without introducing display clutter (Wickens & Yeh, 2001). This may be an effective way of categorizing a workspace with many types of applications running at one time. In this study, internet browsers are coded blue, and office tasks such as word processing and presentation is coded red.

Some of the recommendations have been evaluated by recent research. For example, Oliver, Smith, Thakar, and Surendran (2006) designed a system to facilitate switching between windows. The system, called SWITCH, constantly monitors users' desktop activity, and implements some criteria of window "relatedness" by using semantic similarity of their titles and the temporal closeness in their access patterns. The authors found that despite the appearance of many windows that did not belong to any cluster, processing window titles was highly significant in assigning a window to its proper group. The system was not evaluated in terms of task performance; however, the ability to understand the user's task with algorithms has been demonstrated.

Tiling and Overlapping Windows

Presentation of windows may also affect task performance. Early work indicated that using windows that allow overlapping is beneficial to tiling. Bly and Rosenberg (1986) examined participants' performance of matching graphics with corresponding text. The tasks were presented in an orderly, grid fashion or in an irregular, haphazard fashion. The authors found that information presented in an orderly fashion resulted in better performance with a tiled window display while more irregular presentation of information was carried out more quickly with overlapping windows. However, the tasks involved were relatively simple.

Currently, the amount of information required for any given task has multiplied and the need to integrate different sources of information requires more cognitive burden than mere detection of features would require. Research on interaction techniques for overlapping windows (Beaudouin-Lafon, 2001), as well as a user-defined space that has both overlapping and side-by-side windows (Bell & Feiner, 2000) have focused on decreasing the amount of window housekeeping a user must engage in. Additionally, many users now prefer the ability to tile all running windows on the screen at once (one example is the Exposé function on the Apple Mac OS) in order to quickly scan for necessary information.

Finally, potential interference with task performance is limited by human perceptual characteristics. For example, a cluttered display can cause visual fatigue or interfere with the user's mental model leading users to confuse one activity for another (Reichman, 1986). The limits of human cognitive processing can be made more detrimental with certain displays.

Mori and Hayashi (1995) investigated the potential interference imposed by windows not central to the user's current task displayed in the periphery. Subjects were asked to perform a visual search task (looking for specific words in a block of text) with one foveal window and zero, one, or two peripheral windows. The authors found that, overall, task performance was significantly worse when there was one or more irrelevant windows in the periphery. Specifically, they found that the number of peripheral windows is a significant factor in task interference, as is whether the task window and the irrelevant window were overlapping or not.

Multiple Windows on a Multiple Display System

The same kinds of problems arise when using multiple windows on a multi-display system because the separation between the displays forces the user to center all open windows within the display frame. The workspace, therefore, retains the aforementioned problems associated with a single display plus the additional load of more visible information. When working on one piece of information across multiple displays, the seams in between create gaps in words and divide diagonal lines into non-aligned segments (Mackinlay & Heer, 2004). To mitigate this problem, Mackinlay and

Heer (2004) developed "seam-aware" software that calculates coordinates of the workspace and inserts virtual pixels where the bezels are assumed to be.

There is also a dilemma as to the placement of dialog boxes and toolbars. Dialog boxes usually appear in front of the main application window; this poses a problem when the underlying data must be accessed. Hutchings and Stasko (2005) proposed a novel solution to the problem. In multiple monitor environments, the authors proposed to monitor system-wide window activity. When the application shows a transient window such as a dialog box, the interface replicates the window on each of the monitors. As soon as the user initiates action with one of the copies, the other copies disappear. This is a good way of helping the user maintain visual momentum; however, this may get in the way of the user or task, and may introduce display clutter that can be detrimental to task performance.

The solutions currently available are merely solving a specific subset of problems. All of these solutions are cobbled together into one interface and these patchwork solutions are likely to produce a cumbersome interface.

The windows system has largely remained unchanged since it was first introduced twenty years ago (Hutchings & Stasko, 2004b). However, the use of the windowed desktop has evolved. The type of computer tasks a windowed system supports has diversified, and the set of available operations on a given window (e.g., open, close, resize, iconify, etc.) has become insufficient at managing this diversity (Hutchings & Stasko, 2002).

Hutchings and Staskos (2004a) identified three patterns of window management that users spontaneously develop while engaged in multi-window tasks: *Maximizers*, *Near Maximizers* and *Careful Coordinators*. *Maximizers* maximize all windows and used a separate command, such as the lower taskbar or <alt>+<tab>, to switch between windows. *Near Maximizers* set up frequently used windows in a dedicated space, or leave a bank of icons uncovered. *Careful Coordinators* had many windows opened simultaneously with each window's dimensions arranged as they see fit. These window management styles mimic several visual momentum techniques that aid navigation. It can be inferred that these spontaneous window management styles are meant to increase visual momentum in an otherwise sluggish interface.

Maximizers, for instance, when navigating through their workspace pull up a list (iconic and/or textual) of the currently running windows. Similarly, one of the factors that contribute to visual momentum, the Orienting Function, help users "orient to where they are (the currently visible views) relative to the set of views that they could examine in this context" (Woods & Watts, 1997). This "map" serves as a representational framework for capturing what options are relevant to the current situation and support the user when browsing though potentially relevant views (Woods & Watts, 1997). Although Maximizers can rely on a "map" of the current state of their workspace, the taskbar or <alt> + <tab> fails to represent the structure of information.

Near Maximizers dedicate a small area on their workspace that is exclusively used for their frequently needed icons or program. In the visual momentum sense, "a fixed spatial structure of data serves as a memory aid for users ...when the entire field...is not visible in parallel…" (Woods & Watts, 1997). The need for a memory aid occurs because low visual momentum computer systems create new cognitive burdens for already overloaded users (Woods & Watts, 1997). This kind of user tailoring is limited and brittle because the computer-based system was not explicitly designed to support this kind of behavior. For example, users must move dedicated windows when increased information visibility is needed. Therefore, if the user is provided with an interface with good visual momentum, there should be less reliance on spatially dedicated space. For the present study, however, the increased screen space allows for spatial dedication to be used deliberately to facilitate task performance. Spatial dedication has been found to be beneficial for multitasking when implemented in the periphery (MacIntyre et al., 2001) and therefore will be used to support task completion in this study.

Another technique for supporting navigation through visual momentum is to include salient landmarks that provide information about the interface (Woods & Watts, 1997). Careful Coordinators, who carefully arrange many open windows and applications, often create landmarks on their desktops by having similar widths for similar applications (Hutchings & Stasko, 2004). This allows the user to know at a glance which window contains which type of application.

This kind of user-initiated tailoring demonstrates that the current window management does not meet the needs of current usage of the windowed system. The system was not designed to accommodate this type of behavior, resulting in increased instances of window housekeeping.

Partitioning Multiple Displays

One common way users partition their workspace is to devote one display for their primary focus, while additional displays are used for supporting that focus, such as sources that need to be consulted (Grundin, 2001). Virtual partitions of a single workspace have already been implemented to support discrete activities (for example, virtual desktops are available on the Linux OS). Virtual partitioning is good for organization of tasks. It is, however, only as effective as the user's organizational skills, such as a physical desk organizer is only helpful if the user makes an effort to use it. As Grundin (2001) noted, software has difficulty sensing where on a monitor our attention is focused. But patterns of focusing behavior can be deduced. If this information can be incorporated into windows management software, we may have a better chance at predicting a user's main task versus secondary resource support information on a monitor.

Space Management on Multiple Displays

Ringel (2003) observed virtual desktop users and found a consistency of mapping between desktops within users. That is, for each user the organization of every virtual desktop was consistent through time. The author also found that users grouped all information for one task on one display, or had two displays for one task each devoted to a separate step in the work process. This model of user behavior is different from today's application-based conceptual model, where the same applications, regardless of task, are automatically grouped together.

For this thesis, a multiple monitor setup produced a true periphery where the user must deliberately focus to perceive detail. Due to the nature of human perceptual mechanisms, the periphery is an excellent place to support context awareness in multitasking (MacIntyre et al., 2001), provided not too much movement is implemented that will compete for attention (Grundin, 2001).

Interaction on Large Displays

Research on large display is relevant to this thesis because user interaction in an increased screen real estate environment can be gleaned. Automobile designers often work on large display surfaces in order to design close to scale of the actual product. Grossman and colleagues (2001) presented an alternate interface for 3D modeling on large scale displays. Several of their findings are relevant to a desktop display. For example, multiple views of the same object are available in the periphery. When the user adjusts the object in one view, the other views update in a smooth continuous manner. Large screen displays are also easier to navigate when the user is able to manipulate, explore, and annotate the displayed information (Buxton et al., 2000). While interaction innovations are being explored in automotive design, there is still a dearth of research related to interaction in desktop computing. Hutchings and colleagues (2005) assembled a review of the work that has been done in the area of distributed display environments, that is, computer systems that present output to more than one physical display. The authors noted two major areas that have not been studied by many researchers: understanding and designing for the non-active regions of the display, and the need for recognition of the importance of task relevant interaction beyond static representation of displayed information.

Large Display User Experience

User research in this field has identified six broad areas of usability issues with large displays (Roberson et al., 2005; Czerwinski et al., 2006). They include: losing track of the cursor, increased distance and time needed to access icons and other elements on the desktop, window management problems, task management problems, configuration problems and failure to leverage periphery. As screen size increases users accelerate mouse movements and lose track of the cursor. It also becomes increasingly time-consuming to access icons across larger distances, as well as task and window management problems that hinder task performance. The identified issues that will be addressed in this study are task management problems (minimizing window housekeeping) and failure to leverage periphery (using the information space in a meaningful way).

As discussed previously, window management has been problematic for the complex integrative tasks that users engage in. On a large display, these interface issues are compounded with usability issues of more display area. While the benefits of large displays have been described (Czerwinski et al., 2003; Tan et al., 2004; Czerwinski et al., 2002), there has not been much focus on the increased mental workload and cognitive demand that accompany increases in multitasking behavior that result in productivity differences. This study was designed to address the need for understanding workload and interaction.

Visual Momentum

As discussed in this literature review, displays are used to manage the varying tasks and interruptions that occur throughout a workday. The interface as it currently functions does not support this usage very well. Users must tailor their desktop to work around the limited window management system. This does not have to be – there has been research on different aspects of displayed information that can alleviate some of the navigational burdens imposed onto information workers. The present study is an attempt at implementing the recommendations suggested by the body of research in a practical, task-oriented context.

In addition, the implementation of recommendations will adhere to the tenets of visual momentum. Visual momentum is an information visualization heuristic that is used in some cases to address the problem of displaying large amounts of raw data in a relatively small display (Woods & Watts, 1997). Particularly in the context of the present study, visual momentum refers to the user's ability to use and integrate information across display windows (Woods, 1984). The visual momentum heuristic is most useful when developed in a task-relevant context, which remains the focus of this study.

By understanding the circumstances users encounter while engaged in a task, visual momentum can help users locate the right information when they need it, even when the situation is evolving and changing (Woods & Watts, 1997). By consolidating the many approaches to the problem of information management, this study will hopefully push the initiative to match the desktop interface with user needs.

METHOD

This study looks at whether an introduction of visual momentum will facilitate task performance on a dual-monitor desktop workstation setup. Specifically, this study determines:

1. How the introduction of visual momentum affects task times.
2. How the introduction of visual momentum affects performance on the secondary tracking task.
3. How the introduction of visual momentum affects subjective workload as measured by the NASA-TLX.

Visual momentum refers to the ability to maintain cognitive and perceptual coherence while processing information from multiple sources or displays. The method was developed by using three aspects of visual momentum to produce the visual momentum condition. The dependent variables point to several levels of processing that could be affected by visual momentum. First, the primary task time variable will allow insight into the primary focus of the participant. Secondary task performance will allow insight into whether increased cognitive demand plays a part in visual momentum and its effects on task performance. Finally, subjective workload ratings will give insight in to whether participants consciously acknowledged whether their performance has been affected or not.

Participants

Twenty one participants were recruited for the experiment. Participants were university students from a first-year psychology program. Participants have normal or corrected to normal vision.

Apparatus or Instrumentation

A standard desktop computer attached to two 17 inch desktop LCD monitors was used. See Figure 1 for computer specifications. Task times were recorded as the time between the user initiates the task to when the user clicks the "End" button. The NASA-TLX is a subjective workload measure that assesses workload on each of 5 7-point scales. The dimensions assessed are mental demand, physical demand, temporal demand, performance, effort, and frustration.

Operating System:	Microsoft Windows XP Home Edition
Processor:	AMD Athlon 64 3800+ 2000MHz HyperTransport 939-pin
Memory:	1GB (512 x 2) PC3200 400MHz Dual-channel DDR
Hard Drive:	200GB Serial ATA 7200RPM 8MB Buffer HDD
Graphic Card:	GeForce 6600 GT 128MB DDR3 PCI-E
Mouse / Keyboard:	Logitech UltraX Desktop Optical Mouse and Keyboard
Display:	Two 17 inch LCD Desktop Monitor

Figure 1. Desktop Computer Specifications.

Implementation of Visual Momentum

Three visual momentum aids have been integrated with the default operating system to produce the one visual momentum variable.

Leveraging the Periphery

The far left monitor edge contains a bank of icons that open all the necessary programs in this experiment.

Justification: It has been found (Wickens & Hollands, 2000) that when subjects exhibited a systematic scan for targets, they tend to start at the upper left. By placing all search items on the left-most bezel, the expectancy of the target location will coincide with the natural tendency to search from the left.

Perimeter Support

The color of the frame of the open windows will reflect the type of interaction associated with the application. Applications with the same type of interaction will have the same color frame.

Justification: It has been found that the presence of color was beneficial for some tasks in creating a visual momentum across displays that lacked consistency in their frame of reference (Andre & Wickens, 1991; Harwood et al., 1986). By associating a certain color with a type of interaction, the user will be more easily able to recognize the function of a specific program.

Intent Inference

The <alt>+<tab> command appears on the secondary monitor with the last two windows that the user was working on bolded and highlighted in the color associated with that program.

Justification: Andre and Wickens (1990) used color coding paired with emergent features for the task of perceptual integration in estimating airplane stall danger. They found that emergent features implemented with color coding facilitated integration of three sources of information. By paring color coding (color-coded application) along with an emergent feature (bolding the last two used programs) in this experiment, the user's ability to integrate the information from the <alt>+<tab> command should be facilitated.

All three visual momentum characteristics above will be implemented in the visual momentum condition. None will be present in the no visual momentum condition. This will reinforce the effects of visual momentum during the task trials. See Figure 2 for desktop configuration.

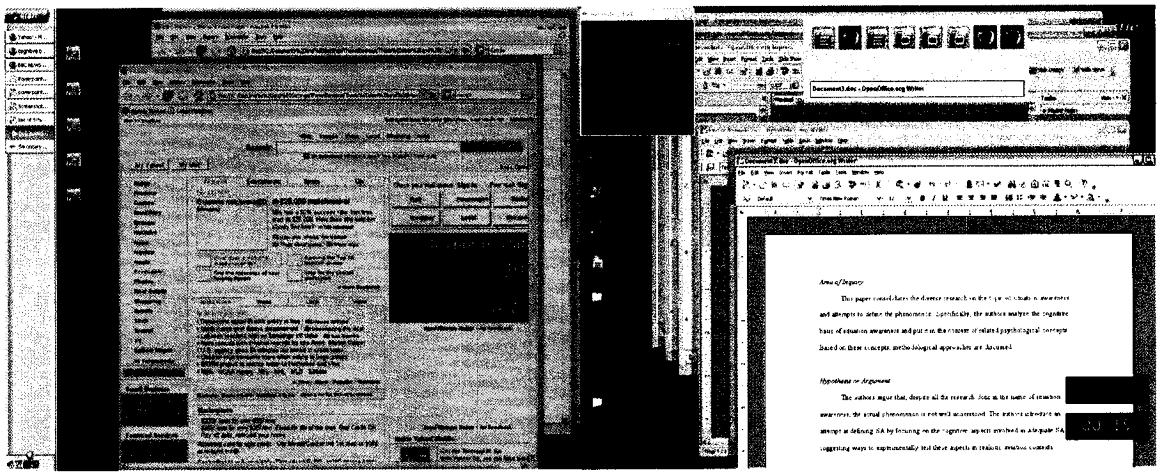

Figure 2. Desktop Configuration. Frame color-coding according to application it represents (browser is blue, word-processor and presentation is red) and <Alt><Tab> modification (upper right).

Procedures

Each participant was exposed to all four interface configurations. These are: 1) No visual momentum with slow tracking, 2) No visual momentum with fast tracking, 3) Visual Momentum with slow tracking, and 4) Visual Momentum with fast tracking. Presentation order of the interface is randomized. After reviewing the task scenario, the participant proceeded through the task sequence several times as practice. Participants were informed they should perform as quickly and accurately as they can, and that their accuracy is recorded and are being timed.

Primary Task Sequence

Each participant carried out 10 repetitions of the task (detailed below) on each interface. Each task involved the following 6-step sequence:

1. A scenario (selecting a university with a cognitive psychology program) was given to the participant.

2. After the participant understands the task scenario, a secondary tracking task was presented that the participant must keep track of throughout the duration of the trial.

3. A search page was presented and the participant had to search for information according to the criteria given in the scenario (Search results will be the same for all participants).

4. The name of the school, the three research foci and a contact person and the contact information was copied and pasted into a Word document.

5. An image of the webpage was captured (using <PrintScreen>) and pasted into an empty PowerPoint slide deck (empty slides already prepared).

6. The participant clicked a button labeled "END" to conclude the task trial.

The dependent variables recorded were:

1. Primary task time-to-completion
2. Secondary task reaction time
3. Ratings of Subjective workload using the NASA-TLX

Scenario

This section outlines the task scenario:

"You are looking for potential colleges to apply to. Your interest is in cognitive psychology or cognitive science, and you start your hunt by searching through a search engine for colleges with an active cognitive psychology or science lab. You soon realize that there are a lot of interesting schools and decide to organize your search results to compare each one."

Secondary Task

The secondary task consists of a "bull's eye" while green dots move towards the red center. The participant must click on the circle before it "falls" into the red area. For slow tracking, a new circle spawned every 2 seconds. For fast tracking, a new circle spawned every 1 second. Hits and Misses were recorded and the percent correct was calculated. The task was performed in the middle of the workspace to avoid the documented performance deficits associated with working near workspace edges. See Figure 3 for secondary tracking task.

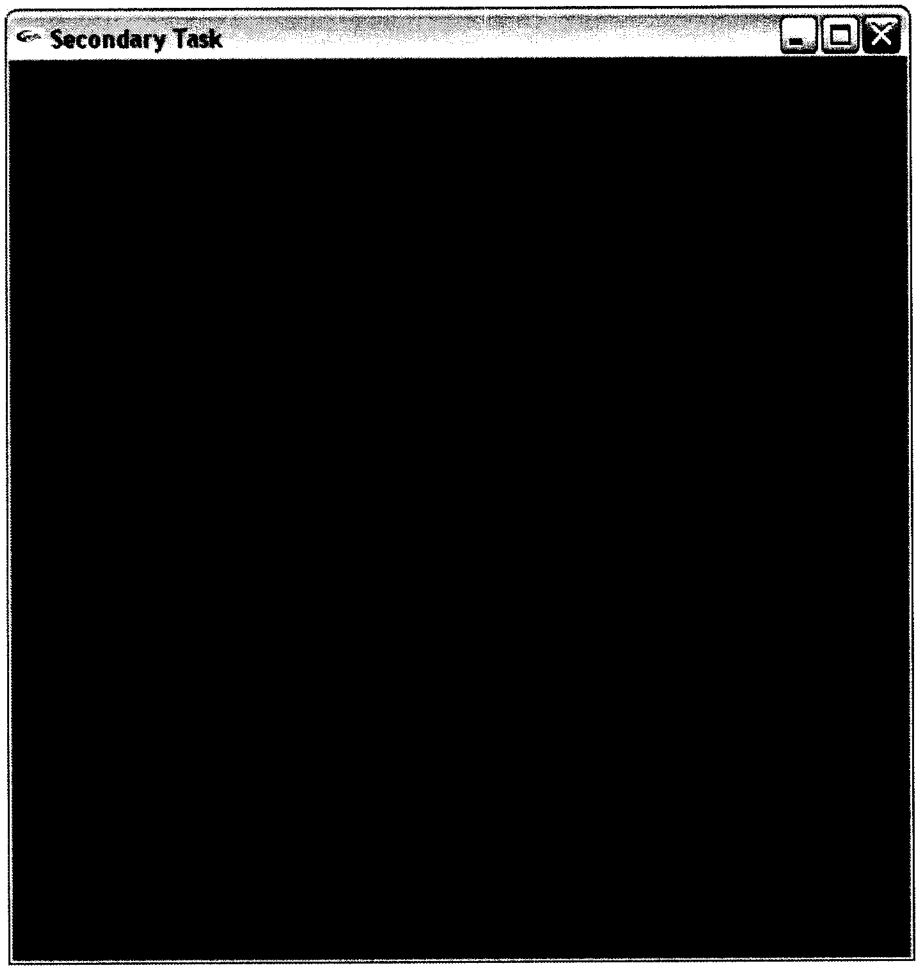

Figure 3. Secondary Tracking Task. Green circle represents the target which moves toward the red center of the "bull's eye" in the background.

Design

This experiment uses a 2 x 2 factorial within subjects design. Each independent variable is defined with two levels. The first variable, interface type, has visual momentum (with visual momentum defined by the 3 characteristics described earlier), and no visual momentum. The second variable is tracking speed (slow/fast) defined above. Each participant was exposed to all interface combinations in a randomized order.

Analysis of Data

Data analysis is a 2 x 2 within-subjects ANOVA. Task performance was analyzed by secondary task level, and is hypothesized to be better with visual momentum display. Task performance is hypothesized to get worse as secondary task got harder. Two measures of display effectiveness were performance time and performance on the secondary task. The specific hypotheses tested are:

1) Primary task times decreases significantly in the visual momentum condition.
2) Accuracy in the tracking task increases significantly in the visual momentum condition.
3) Subjective workload scores decreases significantly in the visual momentum condition.

RESULTS

Three separate analyses were conducted on the following dependent variables to determine if there were main effects of visual momentum and tracking speed on the dependent measures:

- Primary task - Time to completion in milliseconds
- Secondary tracking – Time between hit and spawn in milliseconds
- Subjective workload – NASA-TLX

Primary Task Time - Time to Completion

A two-way analysis of variance yielded a main effect for secondary task speed, $F = 5.67$, $p<.05$, such that the average primary task time to completion was significantly faster for slow tracking speed (M=289579.28 SD=62375.98) than for fast tracking (M=321213.1 SD=99147.66). The main effect of visual momentum and the interaction effect were non-significant, $F=.70$, $p>.05$ and $F=.171$, $p>.05$, respectively. In Figure 4, the graph of means indicate tasks were completed faster when secondary task resource demand is lower (i.e., in the ST slow tracking condition).

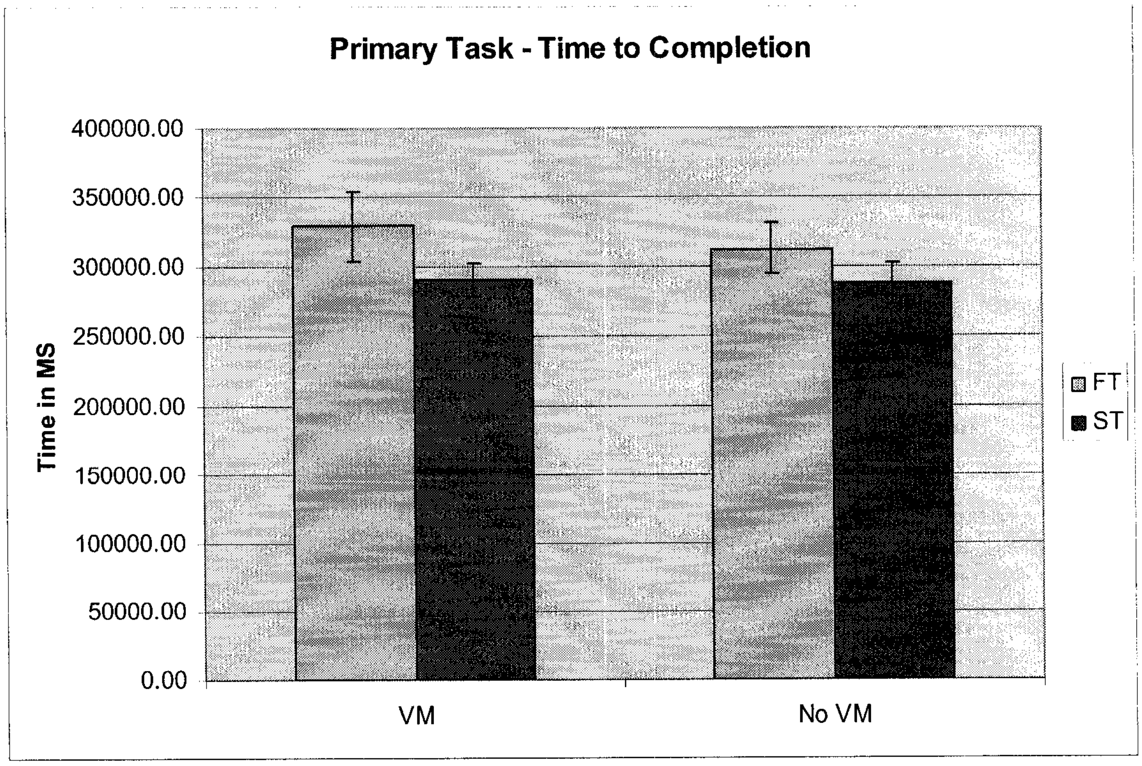

Figure 4. Primary Task – Time to Completion Graph of Means. Bars equal +/- one standard error.

Secondary Tracking - Time Between Hit and Spawn

A two-way analysis of variance on time between hit and spawn on the secondary tracking task yielded non-significant main effects for visual momentum and speed ($F_{[1,21]} = 151676.55$, $p > .05$; $F_{[1,21]} = 4329.11$, $p > .05$, respectively). An interaction effect of visual momentum by secondary task speed $F_{[1, 21]} = 5.682$, $p < .05$, indicating faster reaction to the slow tracking task in the visual momentum condition. In Figure 5, the graph of means indicate that visual momentum may aid on secondary task if resource required are low in the ST slow tracking condition.

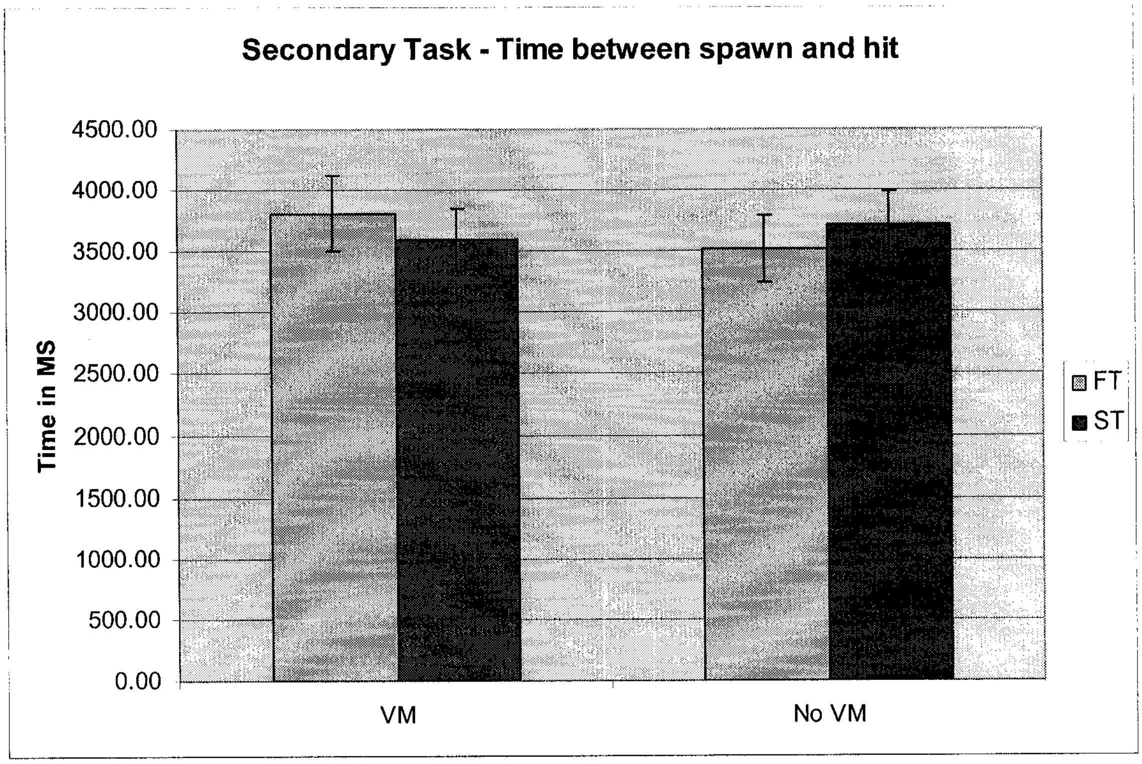

Figure 5. Secondary Task – Time Between Spawn and Hit Graph of Means. Bars equal +/- one standard error.

Subjective Workload – NASA TLX

A two-way analysis of variance on subjective workload task yielded non-significant main effects for visual momentum, speed and non-significant visual momentum by speed interaction ($F[1,21]=1.53$, $p>.05$; $F[1,21]=2.312$, $p>.05$, and $F[1,21]=1.86$, $p>.05$ respectively). A comparison of the means indicate that there is a tendency for perceived lower cognitive load in the visual momentum condition when the secondary tracking is slow. In Figure 6, the graph of means indicate a tendency for lower perceived cognitive workload in the visual momentum condition if secondary tracking resource requirement were low.

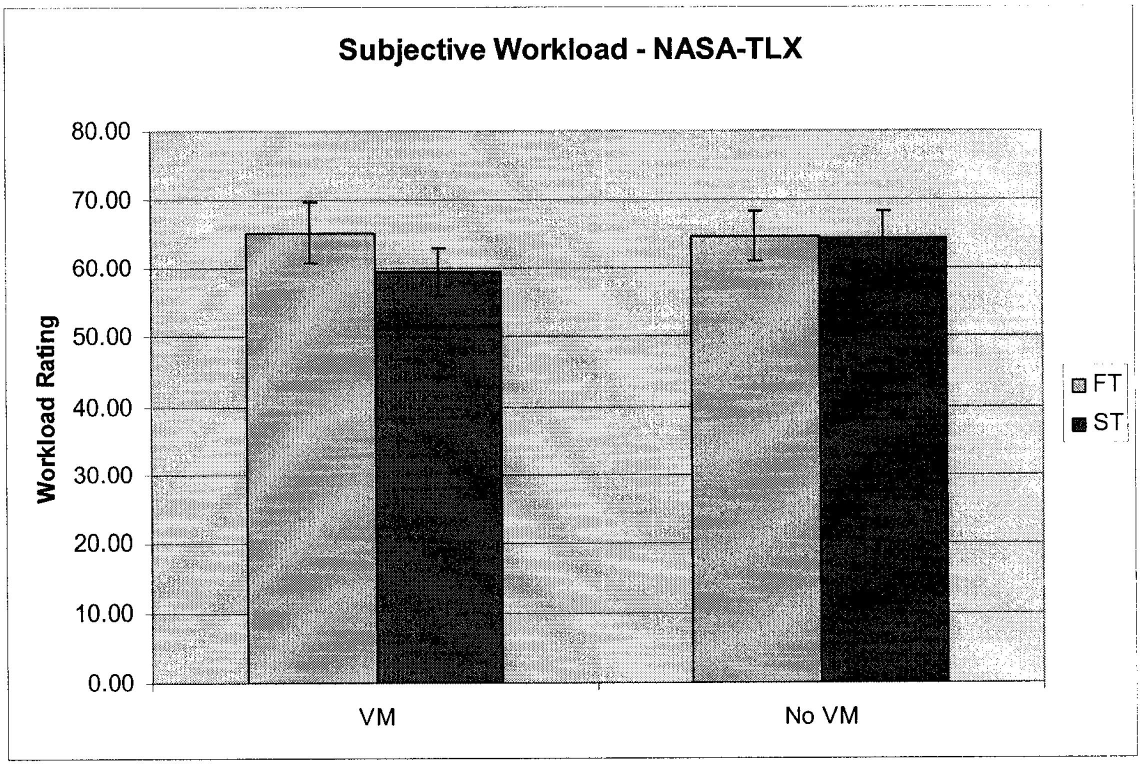

Figure 6. Subjective Workload – NASA-TLX Graph of Means. Bars equal +/- one standard error.

DISCUSSION

The main hypothesis examined is whether a multi-display interface designed according to principles of visual momentum will improve multi-tasking performance relative to a baseline (standard) multi-display interface. The results of this study indicate that while visual momentum appears to have little effect when cognitive workload was high (in this study, workload level was controlled by tracking speed), at low workload level operating through a visual momentum enhanced interface does provide a slight advantage in terms of improved task performance in primary tasks.

Performance on the secondary task benefited slightly from a visual momentum enhanced interface when the cognitive resource demand was low. The opposite effect was found for high-demand cognitive workload task, such that a visual momentum enhanced interface slowed down performance on the secondary task.

While the introduction of visual momentum had an effect on tasks with low-level disruption, this was not the case for trials which required more attention paid to a secondary source. This finding may point to limits on how well visual momentum can aid in everyday computer tasks. For example, for a window-switching task that is the main focus of the user, a visual momentum enhanced interface may be beneficial to performance when a secondary source of cognitive workload does not require too much attention. However, once the secondary task becomes a major disruption to the flow of the primary task, any perceived improvements seen with a visual momentum enhanced interface diminishes. At this point, performance is dominated by the person's ability to switch between two separate tasks, rather than retaining visual momentum across windows on one task. The current study only included two levels of secondary task speed. To fully understand the circumstances of the interaction, it would require a similar experiment through a set range of secondary task speeds.

The non-significant results for subjective workload show a slight trend. As with primary task performance and secondary task performance, a visual momentum enhanced interface had a more prominent effect for the slow workload condition. The weakness may be due to the subconscious nature of cognitive resource allocation. Further research with a larger sample may reveal a stronger effect of decreased subjective workload in the visual momentum condition.

Conclusion

This study is one of the few in the literature that incorporates visual momentum in everyday tasks that is relevant in many fields related to information management. By mimicking the average work environment through the use of increased cognitive workload and multiple points of concentration in one work area, research may be better able to pinpoint characteristics of the workspace that can be recalibrated to improve cognitive workload that may improve productivity.

In this study, visual momentum (VM) was found to have a slight effect when implemented with low workload. A multi-display interface designed according to principles of visual momentum will aid the performance of lower cognitive demand task; however, this study did not explore the type of task and level of demand necessary for the greatest improvement through visual momentum. Further studies using more refined task characteristics will be required to shed light on the specifics of visual momentum's effects on desktop computer tasks.

Additionally, it could be argued that the way the fast tracking task was structured could obstruct the effects of visual momentum of the primary task. Suggestions for future research could focus only on the slow tracking condition to eliminate the fast workload condition made the task less of a "primary task/distraction", or alternatively increase the speed for all tracking condition to increase difficulty level for both conditions to make both tasks a "dual task" process.

Learning effects may also play a role in whether visual momentum has a detectable effect on performance. By separating those who received the visual momentum conditions first (conditions were randomly assigned), time to completion appear to be faster by visual inspection (see Figures 7 and 8).

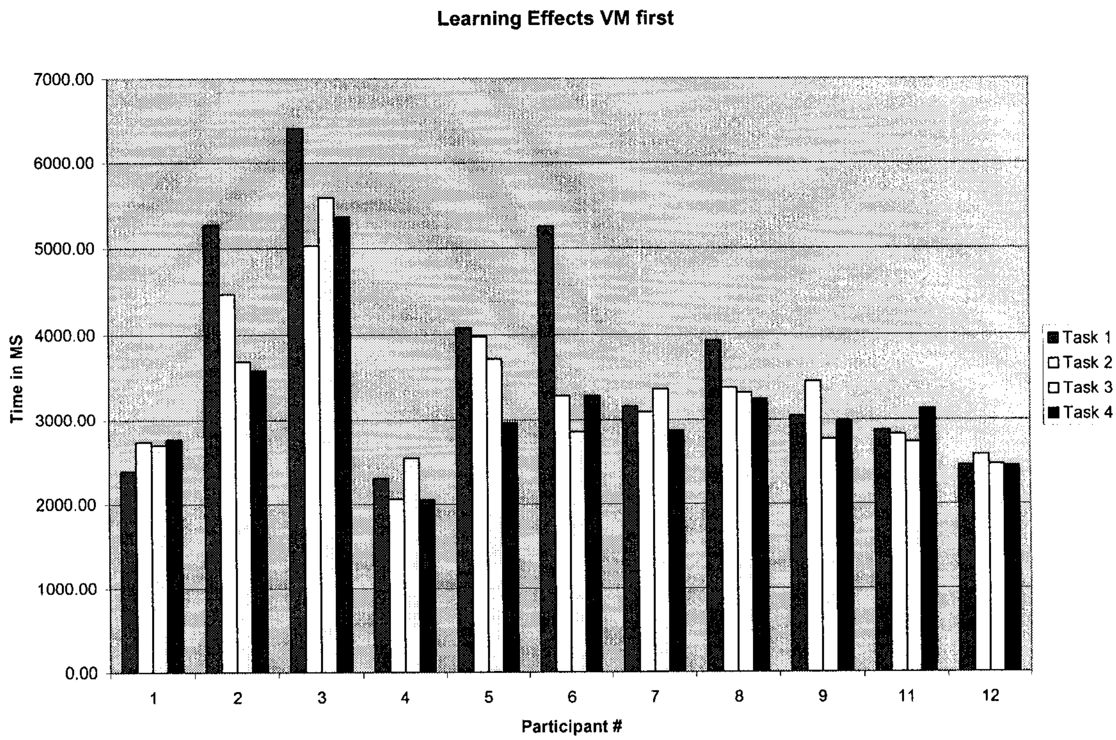

Figure 7. Learning Effects for VM First. This graph shows for those who were exposed to the visual momentum conditions first had a more level learning curve after the first task.

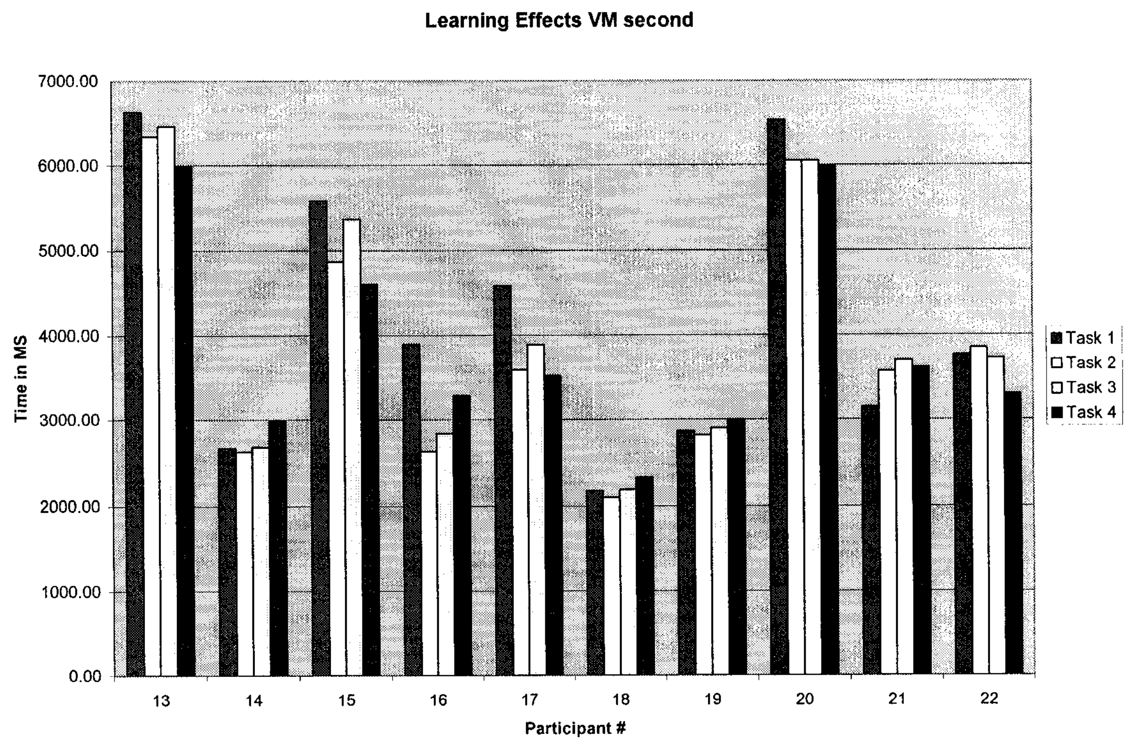

Figure 8. Learning Effects for VM Second. For participants exposed to the visual momentum conditions second had steeper learning curves.

Lastly the interaction paradigm was familiar to all and existing coping mechanisms may have overshadowed the effects of visual momentum. This study used a familiar interface (Microsoft Windows) which may have interfered with any visual momentum effects.

References

Andre A.D., Wickens, C.D. (1991). Display Formatting Techniques for Improving Situation Awareness in the Aircraft Cockpit. *International Journal of Aviation Psychology, 1*(3), 205-218.

Beaudouin-Lafon, M. (2001). Novel Interaction Techniques for Overlapping Windows. *The 14th Annual ACM Symposium User Interface Software and Technology.* (pp.153-154). Netherlands.

Bell, B.A., Feiner, S.K. (2000, November). Dynamic Space Management for User Interfaces, *Proceedings of the 13th annual ACM symposium on User interface software and technology.* (pp. 239-248). San Diego, CA.

Bly, S.A. & Rosenberg, J.K. (1986). A Comparison of Tiled and Overlapping Windows. Conference on Human Factors in Computing Systems at the Proceedings of the SIGCHI conference on Human factors in computing systems (pp.101-106). Boston, MA

Buxton, W., Fitzmaurice, G., Balakrishnan, R., & Kurtenbach, G. (2000, July-August). Large Displays in Automotive Design: *IEEE Computer Graphics and Applications*, 20(4), 68-75.

Czerwinski, M., Smith, G., Regan, T., Meyers, B., Robertson, G.,& Starkweather, G. (2003). Towards Characterizing the Productivity Benefits of Very Large Displays. *Ninth IFIP TC13 International Conference on Human-Computer Interaction.* (pp.9-13), Sweden.

Czerwinski, M., Robertson, G., Meyers, B., Smith, G., Robbins, D., & Tan, D. (2006, April). Large Display Research Overview. *Conference on Human Factors in Computing Systems extended abstracts on Human factors in computing.* Quebec, Canada.

Czerwinski, M., Tan, D.S., & Robertson, G.G. (2002). Women Take a Wider View. *Proceedings of ACM CHI Conference on Human Factors in Computing Systems, (1),* 195-202. Minneapolis, MN.

Grundin, J. (2001). Partitioning Digital Worlds: Focal and Peripheral Awareness in Multiple Monitor Use. *Proceedings of the SIGCHI conference on Human factors in computing systems. 3(1),* 458-465. Seattle, WA.

Grossman, T., Balakrishnan, R., Kurtenbach, G., Fitzmaurice, G., Khan, A., & Buxton, B. (2001). Interaction Technique for 3-D Modeling on Large Displays. *ACM Symposium on Interactive 3D Graphics,* 17-23, Pittsburgh, PA.

Hart, S. G., & Staveland, L.E. (1988). Development of NASA-TLX Score (Task Load Index): Results of empirical and theoretical research. **In P.A. Hancock & N. Meshkati (Eds.).** *Human Mental Workload.* Amsterdam: North Holland.

Harwood, K., Wickens, C., Cramer, A., Clay, D., & Liu, Y. (1986). Effects of display proximity and memory demands on the understanding of dynamic multidimensional information. *Proceedings of the 30th Human Factors Society Annual Meeting.* (pp. 786-789). Dayton: OH.

Hutchings, D.R. & Stasko, J. (2004a). Revisiting Display Space Management: Understanding Current Practices to Inform Next-generation Design. *ACM International Conference Proceeding Series; Proceedings of the conference on graphics interface.* (pp.127-134). Ontario, Canada.

Hutchings, D.R. & Stasko J. (2004b). Shrinking Window Operations for Expanding Display Space. *Proceedings of the working conference on advanced visual interfaces.* (pp.350-353). Gallipoli, Italy.

Hutchings, D.R. & Stasko J. (2002). Quickspace: New Operations for the Desktop Metaphor. *Conference on Human Factors in Computing Systems.* (pp. 802-803). Minneapolis, Minnesota.

Hutchings, D.R. & Stasko J. (2005, April). Mudibo: Multiple Dialog Boxes for Multiple Monitors. Technology, Safety, Community. (pp.1471-1474). Portland Oregon.

Mackinlay, J.D., & Heer, J. (2004, April). Wideband Displays: Mitigating Multiple Monitor Seams. *Conference on Human Factors in Computing Systems.* (pp. 1521-1524). Vienna, Austria.

MacIntyre, B., Mynatt, E.D., Voida, S., Hansen, K.M., Tulio, J., & Corso, G.M. (2001). Support for Multitasking and Background Awareness Using Interactive Peripheral Displays. *Proceedings of the 14th annual ACM symposium on User interface software and technology.* (pp.41-50). Orlando, FL.

Mori, H. & Hayashi, Y. (1995). Visual Interference with Users' Tasks on Multiwindow Systems. *Journal of Human-Computer Interaction.* .7(4), 329-340. New York, NY: Elsevier.

Oliver, N., Smith, G., Thakar, C., & Surendran, A.C. (2006). SWISH: Semantic Analysis of Window Titles and Switching History. *Intelligent User Interfaces Conference.* (pp.194-201). Sydney, Australia.

Ringel, M. (2003). When one isn't enough: an analysis of virtual desktop usage strategies and their implications for design. *Conference on Human Factors in Computing Systems* (pp.762-763). Fort Lauderdale, FL.

Reichman, R. (1986). Communication paradigms for a Windows system. **In D.A.Norman & S. W. Draper (Eds.).** *User-centered system design.* Hillsdale, NJ: Erlbaum.

Robertson, R., Czerwinski, M., Baudisch, P., Meyers, B., Robbins, D., Smith, G., & Tan, D. (2005 July/August). The Large Display User Experience. *The Institute of Electrical and Electronics Engineers Computer Society.* 25, (4), 44-51.

Shneiderman, B. (1998). *Designing the User Interface: Strategies for Effective Human-Computer Interaction.* Reading, MA: Addison-Wesley.

Simmons, T., (2001). What's the Optimum Computer Display Size? *Ergonomics in Design* 9(4), 19-25.

Tan, D., Gergle, D., Scupelli, P.G.,& Pausch, R. (2004). Physically Large Displays Improve Path Integration in 3-D Virtual Navigation Tasks. *Conference on Human Factors in Computing Systems.* 6, (1). 439-446. Vienna: Austria.

Woods, D.D., Watts, J.C., How Not to Navigate Through Too Many Displays. **In M. Helander, T.K. Landauer, P., & Prabhu (Eds.).** *Handbook of Human-Computer Interaction (2nd ed.).* (pp. 617-650). Elsevier.

Woods, D.D. (1984). Visual Momentum : A Concept to Improve the Cognitive Coupling of Person and Computer. *International Journal of Man-Machine Studies, 21,* 229-244.

Wickens, C.D., & Hollands, J.G. (2000). *Engineering Psychology and Human Performance.* Upper Saddle River, NJ: Prentice Hall.

Wickens, C.D., & Andre, A.D. (1990). Proximity compatibility and information display: Effects of color, space, and objectiveness on information integration. *Human Factors,* 32, 61-77.

Yeh, M., Wickens, C.D. (2001). Attentional Filtering in the Design of Electronic Map Displays: A Comparison of Color Coding, Intensity Coding, and Decluttering Techniques. *Human Factors,* 45(4), 543-562.

Appendix

Agreement to Participate in Research and Consent Form

Responsible Investigator: Janice Tam
Title of Protocol: Visual Momentum in Window Management for Multiple Display Environments

I, ________________________________ volunteer to participate in the research project entitled Visual Momentum in Window Management for Multiple Display Environments, to be conducted at San Jose State University under the direction of Kevin M. Corker, Ph.D. The procedures have been explained to me and I understand them. They are as follows: the purpose of the study is to determine whether window management that adheres to the visual momentum principles will affect ability to complete simple tasks on the computer. The task involves navigating through a search engine, copy and paste information on a presentation program and a word processing program while keeping track of a moving circle. Experimental procedures will include one session lasting approximately 60 minutes. The session will consist of 12 trials; the first two trails will be practice and not recorded. The test session will be preceded by an orientation to the laboratory in which all procedures will be explained, and an opportunity to ask questions and to practice will be given. This research poses absolutely no physical or emotional risk to you as a participant.

I understand that I will be given course credit for participation, and there is no other direct benefit I will receive from participating in this research.

I understand that this consent and data may be withdrawn at any time without penalty. My consent is given voluntarily and I may refuse to participate in the entire study or in any part of the study. I understand the data will be reported in group form and individual data will be kept confidential.

Questions about this research may be addressed to Janice Tam at 408/924-3848. Complaints about the research may be presented to Dr. Kevin Corker, Professor, Industrial & Systems Engineering Department, 408/924-3988. Questions about research subjects' rights or research-related injury may be presented to Pamela Stacks, Ph.D., Associate Vice President, Graduate Studies and Research, at 408/924-2480.

Although the results of this study may be published, no information that could identify you will be included.

- At the time that you sign this consent form, you will receive a copy of it for your records, signed and dated by the investigator.

- **The signature of a subject on this document indicates agreement to participate in the study.**

- **The signature of a researcher on this document indicates agreement to include the above named subject in the research and attestation that the subject has been fully informed of his or her rights.**

______________________________	______________________
Subject Signature	Date
______________________________	______________________
Investigator's Signature	Date