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Effects of Visual Separation and Physical Discontinuities when Distributing Information across Multiple Displays

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Abstract: Systems that include multiple integrated displays distributed throughout the working environment are becoming prevalent. Compared to traditional desktop displays, information presented on such systems is typically separated at much wider visual angles. Additionally, since displays are often placed at different depths or are framed by physical bezels, they introduce physical discontinuities in the presentation of information. In this paper, we describe a study that utilizes a divided attention paradigm to explore the effects of visual separation and physical discontinuities when distributing information across multiple displays. Results show reliable, though small, detrimental effects when information is separated within the visual field, but only when coupled with an offset in depth. Surprisingly, physical discontinuities such as monitor bezels and even separation in depth alone do not seem to affect performance on the set of tasks tested. Following the findings, we provide recommendations for the design of hardware and software in multiple display environments.

Keywords: Multiple displays, large displays, physical separation, physical discontinuities, bezels, user study

1 Introduction

There is a trend towards multiple integrated displays that provide abundant display space distributed throughout the workplace. Having multiple displays allows the system to present information across much wider visual angles than before. Also, since displays are often placed at different depths or are framed by physical bezels, physical discontinuities are introduced in the presentation of information. Yet, relatively little is known about how to best present information to the user in such systems. In this paper, we describe a study exploring our hypotheses, that:

- Separating information by wider visual angles hurts performance on divided attention tasks.
- Even at equal visual angles, dividing information by physical discontinuities such as depth or monitor bezels also hurts task performance.

Results from our study demonstrated a reliable, but small, detrimental effect on performance from separating information within the visual field, but only when it is further separated by depth. We found that physical discontinuities introduced by bezels or depth alone had no effect of performance for our set of tasks. We conclude with design recommendations.

2 Related Work

2.1 Multiple Display Systems

Many researchers are building multiple display workplaces as well as designing interfaces that exploit affordances offered by these systems. For example, Raskar et al. (1998), in their *Office of the Future*, envision a workplace in which every surface may serve as a high-resolution projected display. Tan et al. (2003) have studied performance benefits on various tasks in the *Display Garden*, a rapidly configurable collection of physical displays. In our work, we explore the effects of visual separation and physical discontinuities when distributing information across multiple displays in such systems.

2.2 Human Vision and Peripheral Information

In their work, Carrasco & Naegele (1995) present the *eccentricity effect*, which shows that targets presented near the point of visual fixation are noticed much more easily than targets further away. Grudin (2001) asserted that the division of space afforded by multiple non-contiguous displays helps users assign specific functions to each subspace. We expect the division of a task across subspaces to add cognitive load and hurt task performance.

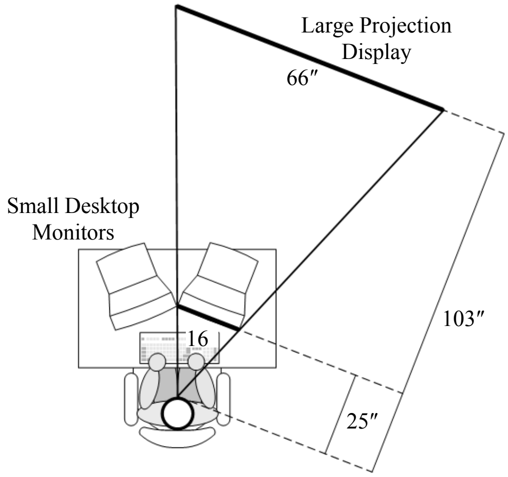


Figure 1: Experiment setup. Visual angle held constant between the small display and large display conditions.

Recognizing that the eye has to rapidly refocus when working at multiple depths, early ergonomics recommendations called for displays and documents to exist at a single depth (Ankrum, 1999). We explore the effects of working on information on displays separated at different depths in physical space.

2.3 Notifications

There have been a series of studies on the effects of notifications and other kinds of interruptions during computing tasks (for a review, see McFarlane & Latorella, 2002). Most of these studies have shown disruptive effects of notifications while multitasking (Czerwinski et al, 2000; Maglio & Campbell, 2000). Other studies have examined the location of notifications for optimal detection while minimizing disruption (e.g. Hess et al, 1999). Unfortunately, most studies have utilized standard desktop displays, and have not explored larger or multiple display surfaces.

3 Experiment

3.1 Experiment and Setup

We used two NEC MultiSync FE1250 22" monitors and a Sanyo PLC-XP30 LCD projector. All displays ran at a resolution of 1024 x 768 and were calibrated to be of roughly equivalent brightness and contrast. The image on each monitor was 16" wide by 12.5" tall. The image projected on a wall-mounted screen was 66" wide by 49.5" tall. One of the monitors was always the *left display*. Either the second monitor or projection screen was the *right display*. In order to get identical visual angles on both right displays, the monitor was placed 25" away from the user, while the large projection display was 103" away (Figure 1). The centers of all displays were set to be at eye-height, 60" above the ground. The position of the right monitor was carefully marked so that it could be moved in and out accurately for each condition.

We ran the study on an 800 MHz Dell computer equipped with a dual-headed nVidia GeForce2 MX graphics card. Only one of the right displays was used at any given time. The user used a standard keyboard and Microsoft IntelliMouse. Twenty-four (12 female) intermediate to advanced Windows users with normal or corrected-to-normal eyesight took part in the study. They ranged from 18 to 55 years of age (mean: 36.9). The experiment took an hour and users received software gratuity for participating.

3.2 Tasks and Procedure

For this study, users performed a primary task in conjunction with a secondary and tertiary task. In the primary task, *proofreading*, users had to identify as many grammatical errors as they could within a set of text articles, marking each by double clicking on the word in question. They did not have to suggest corrections to the errors. This task was chosen to be both visually and cognitively demanding.

For this task, we chose seven articles of similar length and readability from the New York Times. We introduced errors into the articles using the following rules: (a) each sentence had at most one error; (b) errors were fairly evenly spaced throughout the article; (c) errors included only subject-verb agreement, inconsistent verb tense, and word order (ie. two words flipped).

The secondary task is one we call *notification detection*. In this task, users had to detect visual changes outside the focal region of the primary task, a scenario common in peripheral awareness systems. In our task, users had to detect a pop-up MSN instant messenger notification, and respond by hitting the space bar as quickly as possible.

Properly detecting a notification brought up the tertiary task, *text comparison*. Text comparison is representative of tasks in which the user must cross reference and compare content displayed in multiple locations. In this task, we highlighted a random set of 4 contiguous lines in the proofreading text. We also replicated either a verbatim representation of the highlighted text or the text with a single word order change in a dialog box on the opposite display. Users had to indicate whether or not there was a difference between the two passages by clicking on one of two buttons, labeled ‘same’ or ‘different’ above the article. After doing this, they resumed proofreading.

In each trial, we gave users 4 minutes for the proofreading task. Six notifications were randomly distributed with the constraint that they were at least 20 seconds apart. The clock that showed users how

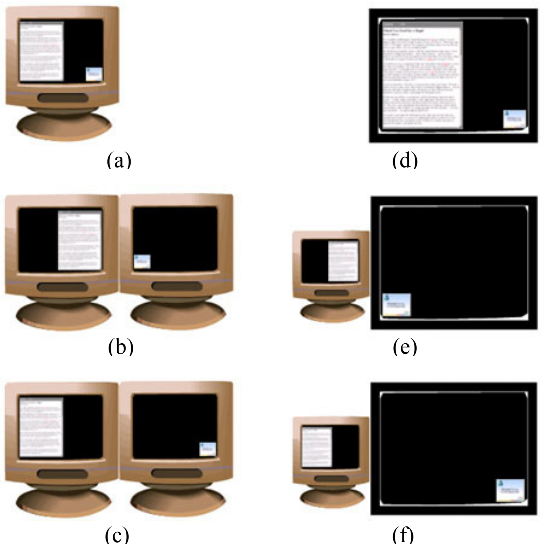


Figure 2: Display conditions used.
(a-c) Monitor: near-within, near-across, far-across.
(d-f) Projector: near-within, near-across, far-across

much time remained for proofreading halted when a notification was detected. It restarted after the user completed the text comparison task.

3.3 Design

We used a within subjects design. Each user performed 1 practice and 6 test trials, one in each of the 6 conditions, created using a 2 (display: monitor v. projector) x 3 (distance: near-within v. near-across v. far-across) design (Figure 2).

The visual angle between the primary task and the secondary and tertiary tasks in the near-within condition was kept exactly the same as in the near-across condition (~27 degrees). The only difference was that the near-across condition had the monitor bezels or a bezel and depth discontinuity between the tasks. In the far-across condition, tasks were separated by ~55 degrees. We counterbalanced the order of conditions with a Latin Square design. After the experiment, users filled out a preference survey.

3.4 Results and Discussion

Overall MANOVA

We performed a 2 (display: monitor v. projector) x 3 (distance: near-within v. near-across v. far-across) repeated measures multivariate analysis of variance.

We observed no significant effects or interactions for the average reaction time to detect a notification or the average reaction time for the text comparison task. For the number of correct text comparisons, we observed a significant interaction between display and distance, $F(2,46)=3.05$, $p=.05$. Post-hoc analyses showed that the near-within and far-across conditions were borderline significantly different, $p=.06$. The interaction reached significance because this difference between the near-within and far-across conditions was reliable for the projector (means: 5.167 and 4.625 respectively), though not the monitor condition (means: 5.042 and 4.875), seen in Figure 3. Although the result reaches statistical significance, the effect is small, practically speaking.

For the number of correct typos found in the proofreading task, the interaction between display and distance reached borderline significance, $F(2,46)=2.6$, $p=.085$. Again this was driven by a larger difference between the near-within and far-across conditions on the projection display (means: 7.875 and 7.000 respectively) but not the monitor (means: 7.667 and 8.000), seen in Figure 4. These effects are also small.

These performance results ran counter to our initial hypotheses. For the time to detect notifications and for the text comparison times, we observed no effects of separation, bezel, or depth. In fact, we did not observe a significant main effect of visual separation in the performance data for any dependent measure. Instead, we observed a small but reliable

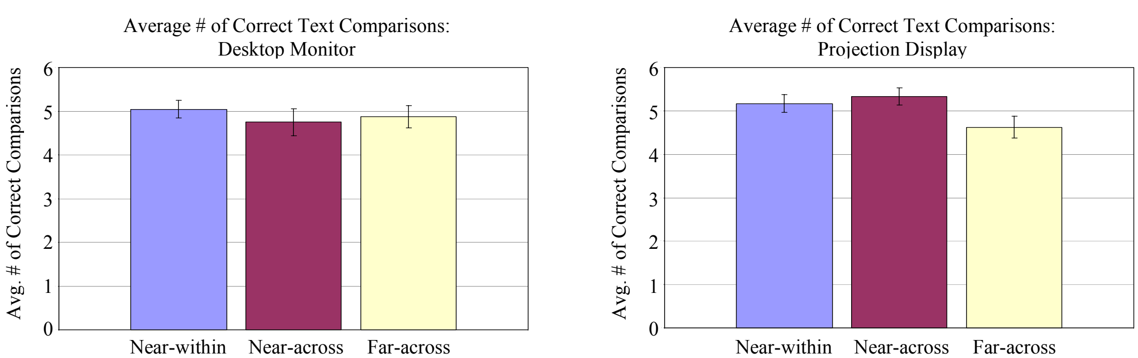
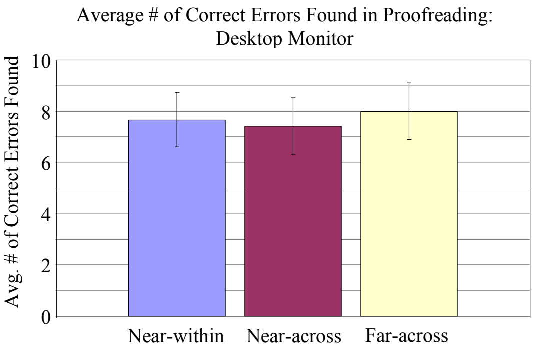


Figure 3: Though we saw no significant differences for the monitors (*left*) for average number of correct text comparisons, there was a significant difference between near-within and far-across conditions for the projector conditions (*right*).



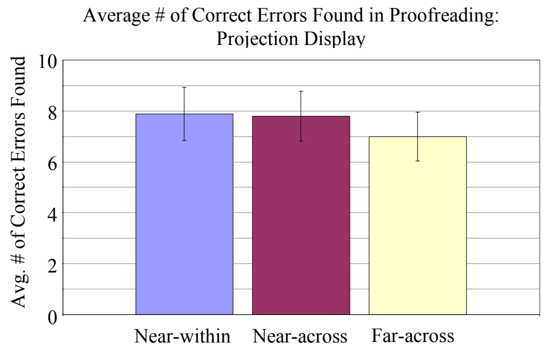


Figure 4: Though we saw no significant differences for the monitors (*left*) for average number of errors correctly found, there was a significant difference between near-within and far-across for the projector conditions (*right*).

interaction between display and the distance variable for the overall proofreading correct and text comparison correct measures. This interaction could be best described as resulting from the differences between the near-within and far-across conditions being stronger for the projector condition.

Satisfaction Data

Surprisingly, 14 out of 24 participants preferred the smaller display for their primary task, significant by binomial test, p=.006. Also, 10 preferred the tasks on the same screen and 11 preferred them on split screens. This result is quite interesting, and converges nicely with some of the performance-based results we observed during the experiment.

4 Conclusion and Future Work

We examined the effects of visual separation and physical discontinuities when distributing information across multiple displays. The study we conducted demonstrated a detrimental effect on performance from separating information within the visual field when it is further separated by depth. However, for our tasks, effects were relatively small (about a 10% performance decrement), and designers, aware of the small differences present, can weigh the importance of the information to be displayed with this trade-off in mind. Also, physical discontinuities introduced by bezels as well as by differences in depth alone do not seem to have an effect on performance on our set of tasks. This was surprising, but implies that designers might have more freedom than anticipated when splitting information across boundaries.

To add further ecological validity to this work we plan to introduce distractions with unrelated content. Previous research has shown that this makes visual search and detection tasks harder, but we do not know the effects our manipulations would have. More work also needs to be done to explore different tasks within the same experimental framework. Results from this work have critical implications both on the design of workplaces, but also on software operating in these new display configurations.

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