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INTERACTION WITH 2D APPLICATIONS ON LARGE AND SMALL DISPLAYS

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ABSTRACT

This paper presents two studies conducted to eliminate possible confounds in previous work (Wallace, Mandryk and Inkpen, 2008). The first evaluates interaction with 2D applications on near and far displays based on performance, perceived workload and subjective measures. A constant field of view and resolution is maintained throughout the evaluation in order to focus purely on the impact of distance on interaction. No difference in performance is found, however participants noted that they felt more rushed in the small display configuration. In the second study, the effect of binding type (static or dynamic) on the time taken to transition between local and remote displays was studied. Our results suggest that binding type does not significantly impact the ability of users to transition between displays.

INTRODUCTION

The growing affordability and availability of large displays has provided an incentive for researchers to investigate their most appropriate uses. In combination with ever-growing network bandwidth and increasingly mobile devices, large displays are providing a fertile ground for multi-display research; the devices are available, the only question is what are they best used for?

While previous research has demonstrated benefits of large, distant displays for spatial tasks, particularly in 3D (Tan, Gergle, Scupelli, & Pausch, 2004), many standard computer applications require standard mouse and keyboard interactions in 2D. Since these 2D office tasks make up a considerable component of day-to-day work performed on computers, it is important to understand how basic factors such as display size can influence a users' performance.

The designers of future multi-display interfaces will need to understand the consequences of moving an application's content to alternate displays – factors such as display size, application, number of users, input method and available hardware may all affect what the "correct" choice is (Hawkey, Kellar, Reilly, Whalen, & Inkpen, 2005). Furthermore, individual users may override these factors with their personal preference; users may prefer to work on a particular display due to poor vision, seating arrangement, privacy or any other number of context-sensitive reasons.

This work presents studies which clarify MDE interface design questions raised in previous work (Wallace, Mandryk and Inkpen, 2008). In particular, we were interested in comparing MDE interfaces which redirect input and/or content across displays. Preliminary findings suggested that input and content redirection were both viable design solutions, however two confounds were identified in our study.

First, content redirection allows users to interact with information on a display which is physically closer to them. The effect of such a difference is not well understood, and could potentially provide a performance benefit. As such, the first presented study explores the influence of display size and proximity on a user's performance in a two dimensional task.

The second confound was introduced specifically in the extended desktop interface; a limitation of our original study design was that spatial relationships were not leveraged in the interface. For example, users sitting with a shared display to their right would move the mouse cursor off the top of their display when transitioning. Investigators observed that many participants tended to move their mice as if these spatial relationships were respected, and that this aspect of the interface may have negatively biased results in the ExD conditions. Our second follow-up study investigates whether providing spatially-oriented interfaces can impact a user's performance when transitioning between displays. In describing these studies, we first present related literature, followed by the two user studies, and a brief discussion of the collected data.

Related Literature

Previous work has primarily reported on the advantages large displays in 3D scenarios (Tan, Gergle, Scupelli, & Pausch, 2004), or in cases where little interaction is required on behalf of the user (Czerwinski, Tan, & Robertson, 2002). While these studies present valid uses for large displays, they fail to address cases where users must interact with a primarily two dimensional environment. Two dimensional environments make up a large percentage of those used by the work force today; tasks such as programming, text editing, database and spreadsheet work, web browsing, email, and instant messaging all fall under this categorization.

Recent developments in multi-display technology provide new opportunities for interaction in environments with multiple displays. Technology such as VNC (RealVNC, 2007) and WinCuts (Tan, Meyers, & Czerwinski, 2004) can enable users to redirect content between displays, and perhaps even more so, application relocation is quickly becoming feasible in real-world use (Biehl & Bailey, 2004). These new technological developments not only provide new opportunities for users, but also bring up design questions for those creating Multi-Display Environments (MDEs).

Swordfish (Wallace, 2006), a project with the goal of studying these design questions, presents the opportunity to closely examine the consequences of these interface choices. The ability to design, implement and evaluate interfaces for MDEs is rapidly gaining importance as these environments come closer to seeing widespread use.

Study 1: Near and Far

Study 1: Procedure

Sixteen right-handed participants were recruited (8 male, 8 female) to participate in the study. Participants ranged in age from under 18 to 35, and had a variety of experience using large displays. Participants were asked to sit at a wooden table positioned 300 cm from a projected display. After completing an informed consent form and an eye-sight and color blindness test, participants completed a brief questionnaire detailing their use of dual monitor configurations and remote desktop software such as VNC.

After participants finished the background questionnaire the investigators described the task and instructed participants to complete it as quickly and accurately as possible. The participant was then asked to perform the task under "near" and "far" conditions which were counterbalanced to account for learning effects.

A multi-dimensional tapping task based on the ISO-9241-9 standard (Douglas, Kirkpatrick, & MacKenzie, 1999) was used for this study. A grey home square was first presented in the centre of the screen. Once the participant moved their cursor into the home square it turned red indicating that they were within the square and should wait for a target to appear. After a short randomly generated delay between 100 and 1000ms a circular target appeared. Participants were instructed to click on this target as quickly and accurately as possible. After clicking on the circular target, participants returned their cursor to the home square to begin a new trial.

Participants completed a short practice block of 10 trials prior to each condition. During each condition participants completed 5 blocks of 72 trials each for a total of 360 target acquisitions. Participants were instructed to take breaks before entering the home square as needed to prevent fatigue.

Targets varied based on three criteria: angle, amplitude and width. Eight angles were used relative to the home square: 0, 45, 90, 135, 180, 225, 270 and 315 degrees. Three amplitudes were used: 75, 150 and 300 pixels. Three different widths were used: 10, 20 and 40 pixels. Figure 1 represents all possible target locations (only one target width is shown per position).

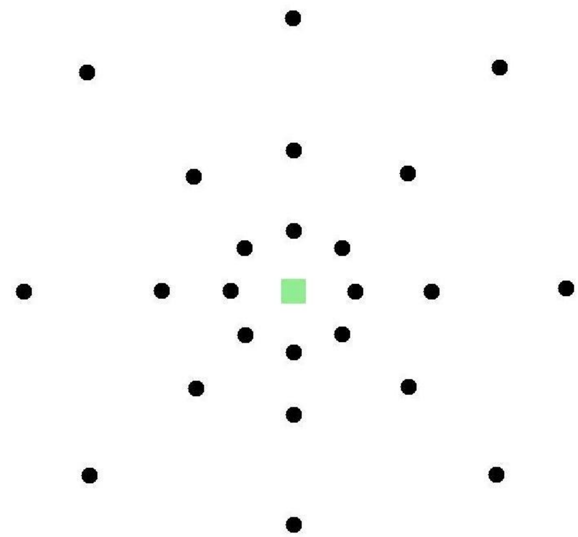

Figure 1. Target locations for the Fitts's Law-based pointing task. Targets were located at 24 different positions based on 3 amplitudes, 3 target widths and 8 angles relative to the origin square.

STUDY 1: PHYSICAL SETUP

Participants completed the study in the Usability Lab in the Computer Science Building on Dalhousie University campus. The Usability Lab is a small room with a wooden table approximately 200cm from a wall which the large display was projected onto. The user sat at the table on an adjustable office chair facing the projected display.

In conditions where the user was using a desktop display, the desktop display was placed on the wooden table approximately 40 cm from the participant's face and the projected display was turned off. In both conditions the room lights were dimmed and the displays were adjusted to be of approximately equal luminance in an attempt to provide an equivalent experience for each participant between conditions and to reduce strain on the participant's eyes. Both displays ran at a resolution of 1024 by 768. The desktop display measured 20" whereas the projected display measured approximately 6'; these dimensions were used to ensure that a constant visual angle was maintained between conditions.

STUDY 1: TASK

The task used was a multi-dimensional tapping task based on the ISO-9241-9 standard. A grey home square was first presented in the centre of the screen. Once the participant moved their cursor into the home square it turned red indicating that they were within the square and should wait for a target to appear. After a short randomly generated delay between 100 and 1000ms a circular target appeared, participants were instructed to click on this target as quickly and accurately as possible. After clicking on the circular target, the participant would return their cursor to the home square for a new trial.

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Targets varied based on three criteria: angle, amplitude and width. 8 angles were used relative to the home square: 0, 45, 90, 135, 180, 225, 270 and 315 degrees. 3 amplitudes were used: 75, 150 and 300 pixels. 3 different widths were used: 10, 20 and 40 pixels. Figure 1 represents all possible target locations (only one target width is shown per position).

Study 1: Data Analyses

Computer logs of mouse events were used to determine movement time (MT). Initial statistical tests showed no main effects for angle or block, and subsequent analyses did not treat angle or block as a factor. A Repeated Measures Analysis of Variance (ANOVA) was performed on the MT data. All main effects and interactions were tested at α=.05. In cases where the sphericity assumption was violated, the degrees of freedom were adjusted using the Huynh-Feldt method. Questionnaire data were analyzed using non-parametric statistical techniques.

Computer logs of mouse events were used to determine movement time (MT). MT data were calculated from the moment the home square changed colour (to green) until the user clicked on the target location. As such, this method of calculating MT includes initial reaction time as well as the time it took the participant to visually acquire the target. Trials were marked as errors if the participant clicked outside of the target any number of times.

Outliers were removed from the analyses by calculating trials where MT was three standard deviations greater than the mean MT for that particular combination of target amplitude and width.

MT data for the six repeated trials at each unique combination of target amplitude and width were averaged within each of the five blocks of trials. The angle at which the target was presented was initially considered within the analyses. No effects for angle were found, and subsequent analyses did not treat angle as a factor. A Repeated Measures Analysis of Variance (ANOVA) was performed on the MT data. All main effects and interactions were tested at α=.05. In cases where the sphericity assumption was violated, the degrees of freedom were adjusted using the Huynh-Feldt method. Questionnaire data were analyzed using non-parametric statistical techniques.

The NASA-TLX was used to assess subjective workload in post-condition questionnaires. A post-experiment questionnaire was used to directly compare each condition in terms of preference, ease of use and mouse movement.

Study 1: Results

No main effect of proximity to the display was found ($F_{1,15}$=1.0, p=.334, η^2=.062), which shows that participants did not aim differently depending on how far away they were seated from the display. This result supports our hypothesis in that MT is dependent on the movement of the mouse in motor space, not the movement of the cursor in display space. The motor space of the task did not change depending on the user's distance from the display.

There were significant interaction effects between display condition and amplitude and display condition and width (see Table 2 for details); however, these effects did not show a differential effect of display condition on MTs for different amplitudes or widths. As such, there were no significant effects of display condition on movement time. Means and standard errors for the study can be found in Table 1.

Table 1: Average MT data (pixels) for each amplitude (pixels) and width (mm), at each distance.

Amp	Width	Near (SE)	Far (SE)
75	10	708 (22)	730 (23)
	20	575 (24)	580 (20)
	40	482 (17)	481 (15)
150	10	813 (27)	821 (24)
	20	688 (24)	691 (21)
	40	577 (24)	571 (22)
300	10	949 (28)	967 (29)
	20	810 (25)	831 (24)
	40	704 (25)	718 (22)

Table 2: Results from the repeated measures ANOVA.

	F	p	η^2	Power
Condition	1.0	.334	.062	.155
Amplitude	708*	.000	.979	1.000
Width	1178*	.000	.987	1.000
Block	1.2*	.330	.073	.305
Condition by Amplitude	7.7	.002	.338	.925
Condition by Width	3.6	.039	.195	.625

STUDY 1: SUBJECTIVE RESULTS

Our subjective results yielded little difference between conditions as one might expect. Small differences in temporal load, preference and ease of use ratings indicate that there may be a difference in how the two conditions are perceived. This difference in temporal load may also account for the lack of preference for content redirection in the input and content redirection study; the higher perceived workload under the near conditions may mitigate some of the benefits of these interfaces. Some participants indicated that they were accustomed to working in single-display systems and did not feel as comfortable working on the large projected display as they did with the desktop which may also account for some of these differences. A summary of the subjective results can be found in Table 3.

These results correspond with other findings in the literature for interaction with large and small displays (Grabe, Lombard, Reich, Bracken, & Ditton, 1999; Swaminatan & Sato, 1997; Tan, Gergle, Scupelli, & Pausch, 2004) and support the idea that content redirection can be applied to MDE interaction without a change in performance.

Only for mental and temporal load did participants indicate any statistically significant difference between subjective workload measures. Results of a Student's T-Test revealed near significant differences in mental effort ($p < .087$) and significant differences in temporal load ($p < .0006$). Results for each of the NASA-TLX subjective workload assessment categories are presented in Table 3.

Table 3: Results from the NASA-TLX subjective workload questionnaire. Each cell represents the mean response, based on a 1-20 scale.

	NASA TLX Measure					
	Mental	Physical	Temporal	Performance	Effort	Frustration
Small Display	5.81	8.13	8.50	14.62	6.81	5.44
Large Display	4.38	7.56	5.56	14.19	6.38	5.06

Other post-condition questionnaire results were not significant. However, a Student's T-test revealed a near significant difference in participant's assessment of the difficulty of working with each interface ($p < .051$). No significant difference was found between comfort, ability to point quickly or amount of mouse movement between conditions (see Table 4). These findings were further echoed in comments collected throughout the questionnaires such as "I feel more comfortable with my eyes when using [the large display]".

Table 4: Results from post-condition questionnaire. Each cell represents the average response, based on a 1-7 scale with a 7 representing high comfort, quick pointing, low difficulty or less mouse movement. Wilcoxen Signed Ranks tests were used for the analysis.

	Comfort	Quick Point	Difficulty	Mouse Movement
Small Display	3.69	3.94	4.06	3.44
Large Display	3.62	3.62	3.81	3.25
p	0.763	0.166	0.102	0.454

Participants were asked to rank the conditions in the post-experiment questionnaire according to preference, ease of use and mouse movement. More than half (9) of the participants indicated that the Large Display condition was their favorite, whereas 9 participants also indicated that the small display condition was easier to use. Comments such as "less glare and eye strain [on the desktop display]" provide some insight into these rankings.

Table 5: Interface preference results from the post-experiment questionnaire. Each cell represents the number of participants who selected the given choice.

	Preference	Ease of Use	Mouse Movement
Large Display	9	5	5
No Preference	3	2	6
Small Display	4	9	5

Study 1: Discussion

As Fitts' Law predicts, MT increased with increases in target amplitude and decreased with increases in target width. In terms of the distance from the display, there was no main effect of display condition, showing that people do not aim differently depending on how far they are seated from the display. The makes sense in that the MT is dependent on the movement of the mouse in motor space, not the movement of the cursor in display space. The motor space of the task did not change depending on the user's distance from the display.

There were significant interaction effects between display condition and amplitude and display condition and width; however, these effects did not show a differential effect of display condition on MTs for different amplitudes or widths. As such, there were no significant effects of display condition on movement time. The display condition by target width interaction effect reveals a trend suggesting that users may take longer to aim to extremely small targets (2-5 pixels) in the far condition than the near condition. At our smallest target width (10 pixels), this difference in MT (16 ms) was not significant. In terms of how display condition affected aiming to different amplitudes, the greatest difference between the near and far conditions (17 ms) was for the longest target amplitude (300 pixels). This difference was not statistically significant, but there is a possibility that for extremely large amplitudes the differences may be significant.

Our subjective results yielded little difference between conditions, as one might expect. Small differences in temporal load, preference and ease of use rankings indicate that there may be a difference in how the two conditions are perceived. Some participants indicated that they were accustomed to working in single-display systems, and therefore did not feel as comfortable working on the large projected display as they did with the desktop. Comments such as:

> "However, the far distance from me to the screen caused me not quite comfortable. The mouse was on the table, which is near to me, and I had to watch a far screen. It is like doing two different jobs not one."

provide some insight into this matter. Another explanation is that the desktop display was more intense than the projected display, as one participant stated that their "eyes began to hurt from focusing on a smaller screen for so long." The displays were adjusted as much as possible to minimize these effects; however it is possible that despite our efforts there was still a configuration difference between displays. Despite these comments, the qualitative and quantitative results provide little reason to suspect that any significant difference exists between conditions.

STUDY 1: CONCLUSIONS

We investigated how distance from a display affects aiming to targets using a multi-dimensional tapping task based on the ISO-9241-9 standard. Participants completed the task in two display conditions, near and far. Targets were presented at three amplitudes, and three widths, defined in pixels. As such, the target sizes were different visual sizes in each display condition (near and far), but were comparable in motor space in each display condition. Our results are consistent with the predictions of Fitts' Law and reveal that there is no significant or systematic difference between aiming to targets on a near display (~40 cm away) or aiming to targets on a far display (~ 300 cm away) when motor space is standardized.

The questionnaire data coincides with the quantitative results collected during the study. Participants did not perceive the two conditions to be significantly different in terms of performance, however did notice a small difference in terms of mental and temporal stress. These findings correspond with other work in the field in showing that for non-spatial tasks, large displays offer no benefit to the end user in terms of performance, but also provide evidence that moving content to a local display may change the user's experience. By moving content down onto a local display the end user may feel more rushed or find the work more taxing than if done on a large display.

STUDY 2: STATIC AND DYNAMIC BINDINGS

In the original input and content redirection study (Wallace, Mandryk and Inkpen, 2008) the Extended Desktop technique had significantly worse transition times when participants were not sitting in the South position. One reason for this could be that the bindings were unnatural; the interface did not leverage the spatial relationships between displays. Investigators noticed that many participants moved their mouse in terms of the spatial relationships between displays, and that this may in turn indicate that there is a potential performance gain in providing spatially correct bindings. This restriction was in place in the original study to reduce the learning curve associated with the interface; participants were already responsible for four different interfaces, further complicating the experimental design would have overwhelmed the participants.

In order to eliminate this factor as a confound, we conducted a follow up study to investigate the role of spatial relationships in interface design. We repeated the docking task at the four seating positions under two binding configurations: static and dynamic bindings. In the *static binding* configuration, participants moved their mouse cursor off the top of their laptop display onto the large, wall mounted display, just as they did in the input and content redirection study. In the *dynamic binding* configuration, the side of the display that the mouse cursor was moved off of changed depending on their seating position. In each case, the binding between the laptop and large display was adjusted to preserve the direction of mouse movement when transitioning. For example, in the East seating position the right side of the laptop display was bound to the right side of the large display such that the large display appeared to extend their laptop's display on the right side. See Figure 2 for each condition's binding configuration.

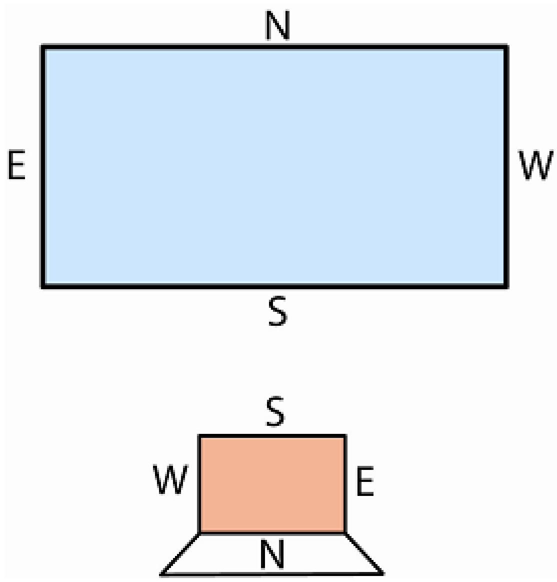

Figure 2. Dynamic bindings can provide a more spatially accurate mapping between displays. In this example, the right ride of the laptop display is mapped to the left side of the shared display in the E condition. In our previous study, static bindings were utilized in all conditions.

STUDY 2: PROCEDURE

Eight right-handed participants (3 male, 5 female), aged between 19 and 44, were recruited to participate in the study. Half (4) of the participants had never used a multi-display system prior to the study but most (5) had used systems with large screens (larger than 20") prior to the study. Five participants had never used remote administration software prior to the study. Participants were paid a small honorarium for their participation in the study.

After completing an informed consent form, participants completed a brief questionnaire detailing their computer use, use of dual monitor configurations, and use of remote desktop software. All computer-based questionnaires were completed on a computer separate from the ones used during the docking task in order to reduce the risk of bias (Reeves & Nass, 1998). Participants were then asked to have a seat at a wooden table positioned approximately 6' from a large projected display. On top of the table was a laptop and connected mouse. The laptop's display measured 15.5" diagonally, whereas the projected display measured 60" diagonally. Both displays were set to a resolution of 1024 by 768.

When participants sat down, they were instructed to adjust the chair such that they were comfortable and able to see both displays clearly. The investigators then described the docking task, and instructed participants to complete the task as quickly and accurately as possible. Participants completed four practice trials to become acquainted with the interface. Following this, each participant completed 10 trials (4 docks + 1 dialog per trial) for each of the 16 conditions (4 seating positions x 4 interfaces).

Starting position and interface order were counterbalanced across participants. For each binding type, participants completed 10 trials in each seating position, shifting clockwise around the table. For example a participant starting in the North seating position performed the task in the same order (North, East, South and then West) for each binding type. After completing trials in all four seating positions for a binding type the participant completed a brief post-condition questionnaire including a modified NASA-TLX subjective workload assessment, questions rating mouse movement and comfort and room for additional comments.

Participants then completed the second condition, followed by a post-condition questionnaire. The four practice trials were repeated prior to each condition in the South seating position to give the participant a chance to adjust to the new interface and ask questions. Finally, after all conditions had been completed, the participant filled out a post-experiment questionnaire directly comparing all conditions in terms of comfort and usability.

STUDY 2: DATA ANALYSIS

Computer logs of mouse events were used to determine timing information throughout the task. We calculated dock time as the time from acquisition of the blue square to a successful dock on the red square. The times for each of the four docks in one trial were summed into a single docking time (DT). Since path length and the logarithm (base 2) of path length were comparable for each trial, we treated the series of 4 docks as one trial.

We calculated the time to transition between the local and the remote display before each trial as the time from which the user clicked on the dialog box on the local display until the user acquired the blue square on the remote display. This was called local_to_remote time (LtoR). We also calculated the time to transition from interaction on the remote display to interaction on the local display after each trial as the time from which the user clicked on the dialog box on the remote display to the time that the user clicked on the dialog box on the local display. This was called remote_to_local time (RtoL). All times were calculated to the nearest millisecond.

To reduce the effects of transitioning between experimental conditions, we separated the data collected into two blocks, the first and last set of five trials, even though no actual break occurred during the study. We only analyzed data from the second block of five trials for each seating position with each interface. We looked for outliers for all timing-based metrics (DT, LtoR, RtoL) by calculating trials where the time spent to dock or transition was greater than three standard deviations above the mean across all participants and conditions. There were no outliers found.

STUDY 2: RESULTS & DISCUSSION

Means and standard errors for all of the time-based measures can be found in Table 6. The subjective workload and preference measures from post-condition and post-experiment questionnaires are presented in Table 7 and Table 8.

Table 6. Means and standard errors for all time-based measures.

Docking Time		Remote to Local		Local to Remote			
Static	Dynamic	Static	Dynamic	Static	Dynamic		Seating Position
3665(195)	3820(313)	2815(381)	2582(340)	2382(237)	2256(258)	North	
3605(190)	3277(149)	2271(97)	2018(124)	1773(97)	1664(105)	East	
3394(190)	3550(230)	1777(78)	1932(143)	1360(100)	1543(149)	South	
3534(172)	3490(202)	2163(176)	2188(123)	1922(104)	1712(91)	West	

Docking Time

Neither binding type ($F_{1,7}$=.033, p=.861, η_2=.005) nor seating position ($F_{3,21}$=2.03, p=.141, η_2=.225) had a significant effect on DT. Docking time should not have been affected by the binding type, thus the result that dynamic vs. static bindings did not affect DT was expected. Although participants were slowest to perform the docking task when seated in the North position, followed by the West, the East and the South seating positions, these differences were not statistically significant.

Transition Time

There was a significant effect of seating position on both LtoR ($F_{3,21}$=.22.9, p≈.000, η_2=.766) and RtoL ($F_{3,21}$=13.2, p≈.000, η_2=.653). Post hoc analysis reveals similar trends to the results from the main experiment: For LtoR, transitioning at the South position was significantly faster than transitioning at the North (p=.003), East (p=.015) or West (p=.003) positions, whereas transitioning at the North position was significantly slower than transitioning at the South (p=.002), East (p=.017) or West (p=.050) positions. For RtoL, transitioning at the South position was significantly faster than transitioning at the North (p=.023) or East (p=.019) positions. These results reinforce those of the main content and input redirection study.

In contrast to what we expected, there was no significant effect of binding type on either transitioning to the remote display (LtoR: $F_{1,7}$=.408, p=.544, η_2=.055) or transitioning back to the local display (RtoL: $F_{1,7}$=.582, p=.470, η_2=.077). There was however an interaction between binding type and seating position on LtoR ($F_{3,21}$=4.00, p=.021, η_2=.363) but not RtoL ($F_{3,21}$=.768, p=.525, η_2=.099). Post hoc analysis revealed that there were no differences in transition time as a result of binding type at the North (p=.494), East (p=.279) or South (p=.311)seating positions but that dynamic bindings provided faster transition times than static bindings at the West seating position (p=.008).

Subjective Results

No statistically significant differences were found in terms of subjective workload, comfort, or ratings of sitting positions. See Table 7 and Table 8 for the means subjective results.

Table 7. Mean subjective workload ratings for each binding type.

	NASA TLX Measure Mental	Physical	Temporal	Performance	Effort	Frustration
Static Bindings	1.6	2.5	2.1	4.8	2.0	1.1
Dynamic Bindings	2.2	2.4	1.8	4.5	2.5	1.8

Table 8. Mean ratings for each sitting potion and binding type.

	Sitting Position North	East	South	West
Static Bindings	1.75	3.00	4.88	3.00
Dynamic Bindings	1.38	3.63	5.00	3.38

We found no differences in transition time between static and dynamic bindings at the North, East or South seating positions. In these positions, users did not take longer to transition between displays under the static binding condition, even though it may have been a less intuitive interface. This finding is somewhat contrary to what investigators observed in the original experiment – many participants were seen “banging” their cursor into the sides of displays. While this behavior may initially seem to be detrimental to performance, we found no significant impact. In our original study, we only included the latter five trials in the analysis. Users are very adept at adapting to different interfaces and likely experienced their difficulties within the first half of the trials. Our findings from this second follow-up study suggest that the Extended Desktop interface was not hindered in our input and content redirection study by utilizing static bindings for the North, East or South seating positions. The difference in transition time found at the West position shows that dynamic bindings prove useful when right-handed participants are seated with the large display to their right.

In the second follow-up study, participants complained about having to remember which side of the screen the current binding existed on; for example, one participant commented that “Once you remembered which direction to move the mouse to get to the other screen, it was easy”. Participants’ confusion over which side to cross over on may have been more of a reflection on their rapid progression through different seating positions than on the interface itself. In a more realistic situation where participants do not move around as quickly, or are able to configure their own bindings, participants may have a stronger preference for dynamic bindings in more than just the West position.

In the static configuration all users rated the South seating position as their favorite; however, in the dynamic condition two participants rated East as their favorite position. Even though the input and content redirection study had similar findings, this change may indicate that dynamic bindings may better suit a user's perceived workspace and in turn lend strength to the argument for an option to adjust bindings dynamically. If this is the case, a longitudinal study would be better suited to exploring users' preferences in realistic scenarios.

Study 2: Implications for Content and Input Redirection

Since no significant differences in performance were found between conditions in this second follow-up study at the North, East and South positions, our results indicate that static bindings did not unfairly bias the Extended Desktop interface in these orientations. While spatial cues may have an effect on the intuitiveness of the system, they appear to have a negligible effect on a user's performance. In the West seating position, the Extended Desktop interface would have likely benefited from dynamic bindings. How dynamic bindings affects the performance, and perception of the Extended Desktop Interface as compared to other interaction techniques remains to be seen.

Our observations of the input and content redirection experiment, along with participants' comments, caused us to wonder whether dynamic bindings would be more appropriate for the Extended Desktop interface. Even though the results from our follow-up study did not support this finding generally, there still may be incentives to provide dynamic bindings as an option. Our results showed that dynamic bindings improved transition time at the West position and did not hinder performance at the other seating positions. It may be that in a natural usage scenario the benefits of dynamic bindings are revealed.

Future work will investigate the role of dynamic bindings further, but our present results show no negative effects of dynamic bindings when utilizing the Extended Desktop interface.

CONCLUSIONS

In order to confirm that the interfaces were responsible for the performance benefits observed in our previous work (Wallace, Mandryk and Inkpen, 2008), we conducted two follow-up studies. The first compared interaction on a local display with interaction on a projected display. The evidence we collected supported our hypothesis, implying that the distance between the user and display was not the primary factor affecting performance. These results strengthen the argument for carefully designing interfaces for multi-display interaction; users working within MDEs face fundamental interaction issues above and beyond those faced by their single-display counterparts. Many MDEs are configured for optimal use of the available hardware rather than for optimal performance as a group.

A second follow-up study investigated the consequences of utilizing static or dynamic bindings in an interface. Our investigators observed that participants had difficulty with the static bindings between displays in the input and content redirection study and hypothesized that an improved Extended Desktop interface would benefit the participants as suggested in previous work (Ha, Wallace, Ziola, & Inkpen, 2006). Our follow-up study found no performance disadvantages for dynamic bindings, with improved performance in the West seating position, indicating that dynamic bindings should be investigated further in future research.

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