A Field Study of Knowledge Workers' Use of Interactive Horizontal Displays

Meredith Ringel Morris, A.J. Bernheim Brush, Brian R. Meyers
Microsoft Research
{merrie, ajbrush, brianme}@microsoft.com

Abstract

To better understand the potential for horizontal surfaces in day-to-day work, we conducted a field study. We collected and analyzed over a month of use data from eight participants who used horizontal displays in conjunction with their existing office computer setups. Our analysis of the system logs, observations, and interview data from the study reveals clear differences in preference and use patterns for horizontal and vertical display configurations. Based on these findings, we formulate hardware and software design guidelines that would increase the utility of interactive horizontal displays for office scenarios.

1. Introduction

Many people have recognized the potential for interactive surfaces to augment a typical knowledge worker's office. Concepts for the "office of the future," such as Vannevar Bush's Memex [1] and Tognazzini's Starfire [20], include augmenting the desk, the focal point of much traditional office work. Wellner's DigitalDesk project [21] prototyped the concept of turning a traditional desk into a digital input and display medium, via the use of a camera and projector. More recently, advances in display and sensing technologies have led to an explosion of research into interactive horizontal displays.

Surface computing technologies are still relatively expensive and experimental, thus limiting their study to laboratory, rather than in situ, settings. However, field studies are critical to better understand the potential of surface computing for the types of day-to-day interaction that would occur in the "office of the future." To gather data about in situ use of horizontal displays, we conducted a field study where a Wacom Cintiq 21UX was added to the existing office setups of eight participants for one month.

By moving horizontal surfaces out of the laboratory and into peoples' daily work environments, we contribute findings on issues surrounding sustained use of horizontal displays. Based on these use trends, we present findings on the utility of horizontal surfaces for office productivity tasks. Our study design also allowed a systematic investigation of the differences in how people use horizontal and vertical interactive display surfaces, and on the combined use of these two surface types in real office settings. We found that although all our participants were enthusiastic about acquiring extra screen real estate, they experienced significant challenges using the display in the horizontal configuration, including ergonomic discomfort and visibility problems. Consequently, only one participant preferred using the interactive display horizontally compared to vertically. We have identified several improvements and directions for future research that could allow horizontal surfaces to fit more naturally into office environments.

2. Related Work

Advances in sensing and display technologies have led to a proliferation of surface computing devices, such as DiamondTouch [2] and FTIR [7]. Research on horizontal surfaces can be broadly classified into two areas: tables (multi-user horizontal surfaces, such as [2, 4, 15, 16, and 17]), and desks (single-user horizontal surfaces such as [12, 19, 21, and 23]). This paper focuses on the use of horizontal surfaces as desks.

Most research on interactive tables and desks has studied such systems in isolation, with the goal of developing design guidelines and interaction techniques for this emerging form-factor. However, the vision of augmented office environments includes the integration of a variety of disparate devices to create a unified computing experience. The value of this multi-device vision is reinforced by Morris *et al.*'s study showing the limitations of horizontal displays for data-entry and reading tasks [12], which suggests that isolated use of these devices in offices is not realistic. Thus, we focused our study on a multi-device, multi-display scenario: the use of an interactive surface device in conjunction with each participant's existing office PC. A few other projects have explored the use

of interactive horizontal surfaces in conjunction with a larger device ecology. Augmented meeting rooms, such as the iRoom [9] and i-Land [18] contain a mixture of tabletop displays, wall displays, and mobile devices. The UbiTable [16] enables two users' laptops to exchange data with an interactive table. MultiSpace [4] enables people to use a "portals" metaphor to transfer digital content between interactive table and wall displays. ConnecTables [19] enable digital content to move between two physically proximate digital desks. However, none of these multi-device horizontal systems have been studied in a non-laboratory setting; in contrast, we studied the use of a mixed PC + surface system over a period of several weeks in participants' own offices.

Due to the challenges in studying horizontal systems in situ, there are only a few longitudinal studies of surface use. Ziola *et al.* [23] present a study of in situ use of DeskJockey over a two-week period. However, DeskJockey is a projected display designed for ambient peripheral awareness, rather than an interactive surface; our study focuses on the use of interactive surfaces. Wigdor *et al.* [22] report on the experiences of an individual who used a DiamondTouch table for several months in his office. They focused on analyzing potential effects of the table's touch interface on email message length and the use of its on-screen keyboard. Mazalek *et al.* [11] also describe a case study of a single individual, who used the TViews table in his home for several weeks. In contrast, we report on adding a horizontal computing surface to eight knowledge workers' offices, using an experimental design that enables comparing use across conditions and observing trends across several participants.

Although researchers have enumerated the interesting affordances of horizontal surfaces [15, 17], such as their utility for face-to-face collaboration and ability to support tangible objects, there has been little systematic comparison of the differences in usability and utility between vertical and horizontal displays for various task scenarios. Rogers and Lindley [14] observed groups collaborating around both tabletop and wall displays, finding that face-to-face collaboration around tables encouraged more equitable participation than shoulder-to-shoulder collaboration in front of display walls. Elliot and Hearst [3] compared the use of a horizontal surface versus a tablet computer for architectural drawing tasks. Morris *et al.* [12] compared a digital desk to standard displays for active reading tasks. We compare knowledge workers' in situ use of a stylus-enabled horizontal display to that of a stylus-enabled vertical display based on log and interview data.

3. Field Study

In order to gather data on in situ use trends of mixed-surface setups, we employed a within-subjects field experiment methodology. We recruited eight paid participants (half female) from within a large corporation. Participants volunteered for the opportunity to participate, likely motivated by some belief they would benefit from an interactive surface; from this pool, we explicitly choose people with diverse job roles (Table 1) to better understand how interactive surfaces might augment everyday tasks for a variety of knowledge workers.

All participants used a personal computer as a key part of their daily activities and each used a desktop PC running Windows Vista Enterprise Edition as their primary office computer. Half of the participants had a single monitor connected to their computer, and half had dual-monitor systems. Participants' monitors were each running in landscape mode at a resolution of 1600 x 1200 pixels, and measured 20'' - 21'' diagonally.

We began the study with three hypotheses:

H1: An interactive horizontal display will be a useful addition to knowledge workers' offices.

H2: Participants will use an additional display differently depending on its orientation.

H3: Having a variety of display types will be more desirable than having several homogeneous displays, so participants who already have lots of vertical display space (*i.e.*, those who already have two monitors) will appreciate the addition of a horizontal surface more than the an extra vertical surface, and more than participants who initially had one monitor.

3.1. Study Method

During the six week study period, each participant experienced three two-week-long conditions: an initial condition, followed by the vertical and horizontal conditions. The order of the latter conditions was counterbalanced across participants.

First we photographed each participant's computer and desk and installed in-house logging software on their computer, but otherwise did not change their

User	Occupation	Gender	# of Monitors
P1	administrative assistant	F	2
P2	software developer	M	2
P3	project coordinator	F	1
P4	engineering manager	M	1
P5	educational director	F	2
P6	researcher	M	2
P7	intern	F	1
P8	researcher	M	1

Table 1. Overview of study design and demographics

Figure 1. Study conditions: (a,d) initial, (b,e) vertical, (c,f) horizontal. (a-c) 1 initial monitor, (d-f) 2 initial monitors.

normal computing setup (Figure 1a,d). Our logger stored information on the position, size, title, and input activity history of all open windows. The initial condition served as a baseline for understanding the applications and methods participants typically used to perform their work.

In the vertical condition, the Cintiq was added as an additional monitor (Figure1b,e). It was placed either to the right or left of the participants' original monitor(s), depending on each user's preference. In the vertical condition, the Cintiq was mounted on a Peerless LCT-101 articulated mounting arm, which enabled the height, angle, and depth of the monitor to be interactively modified. We chose this mounting arm to make it simple for participants to move the monitor nearer to themselves if they wished to interact with it using the stylus. The vertical condition served as an additional baseline against which to compare use patterns of the horizontal surface.

For the horizontal condition, we added the Cintiq to each participant's computing setup as an additional monitor. The Cintiq was placed flat upon the participant's desk, in front of their other monitor(s) (Figure 1c,f). During the study, participants could customize the Cintiq's position.

At the conclusion of each condition, we observed each participant working at their computer for thirty minutes, taking notes about the number, type, and spatial arrangement of applications, as well as about participants' interactions with other objects on their desks. After each observation session, we conducted a structured interview, including questions about any interesting behaviors noted during the observation, as well as condition-specific questions. The observations and the interviews were video recorded. At both the halfway point and end-point of each condition, we photographed participants' offices and collected logs.

In the interview after the initial condition, we asked questions about the types of applications and tasks typical of the participant's job and the participant's computer window management techniques. In the horizontal and vertical conditions, the end-of-condition interviews asked about application use, window management, and use of the new display. In our final interview, we also asked each participant to make comparisons between the horizontal and vertical experiences.

3.2. Hardware

Both experimental conditions involved augmenting the initial setup by adding a Wacom Cintiq 21UX as an additional display (Figure 1). The Cintiq is a 21.3'' diagonal, 1600 x 1200 monitor capable of sensing stylus input. The stylus functions as a direct pointing device, a source of digital ink, and as input to automatic handwriting recognition functions. Cintiqs have been established by several researchers (*e.g.*, [8] and [12]) as a valuable horizontal-surface research platform. We chose to use the Cintiq as our interactive surface for several reasons:

Resolution: Many surface computing technologies, such as [2] or [7], use projected light to create a display. Standard consumer-grade projectors offer XGA (1024 x 768) resolution. However, we wanted a display similar to the high-resolution displays already in use in participants' offices, so that differential use of the surface could be attributed to properties other than its size and/or resolution.

Readability: Projected surface technologies also suffer from visibility problems, often requiring special lighting conditions (such as dark rooms) for optimal visibility. We wanted to use a display that would function well under participants' existing office lighting conditions.

Stylus Input: A variety of interaction techniques, including touch [2] [7], stylus [13] [19], and tangible objects [11], have been proposed for use with interactive horizontal displays. The pros and cons of different input techniques for horizontal form-factors are still being debated [6]; thus, we sought a stylus-enabled surface for our study, since they offer more precise input than touch systems, which is important in office settings where tasks such as writing, sketching, and precise pointing are commonplace.

Compatibility: Multi-touch surface hardware is not yet compatible with commercial systems, which generally accept only a single point of input. Stylus input, however, is accepted by common operating systems (such as Windows Vista) and applications (such as the Microsoft Office suite). Also, because the Cintiq is not a standalone system, it can run in a multi-monitor configuration with users' existing PCs, allowing participants to easily move content onto and off of it.

In both the horizontal and vertical conditions, we also provided participants with a stylus, a wireless

keyboard and wireless mouse (to allow flexible placement), the Cintiq's instruction manual, and a printed tutorial on stylus, ink, and handwriting recognition features of a variety of common office applications. In the horizontal condition, we also provided a 1/16" acrylic sheet that could optionally be used to protect the Cintiq's surface from spills or scratches (while not interfering with the stylus) and a set of wooden risers the same thickness as the Cintiq (see Figure 1f). We explained that these risers could be optionally used to make surrounding regions of the participants' desks level with the horizontal display. We left all of these materials in the participants' offices so that they could choose to use them at any point.

4. Findings

In this section, we present the quantitative and qualitative findings of our field study, gathered from analysis of the logs from each participant's computer and the observations and interviews we conducted. To account for variations in system use time across our participants, all log data has been normalized as percentages of each user's activities in each condition. Table 2 provides details on the log data we discuss.

After the final condition, we asked each participant whether they had preferred the horizontal or vertical condition. Six of eight (P1, P2, P3, P4, P6, P8) preferred the vertical condition, with only one preferring horizontal (P7) and one undecided (P5). Our analysis revealed several themes that help explain these preferences, as discussed in the following sections.

4.1. Physical Setup

In the vertical condition, half of the participants (P1, P2, P3, and P8) adjusted the Cintiq's position. P1 and P3 moved the Cintiq monitor to be slightly closer to them along the z-axis than their other monitor(s), and P2 and P8 lowered the Cintiq so its bottom edge rested against the top of the table and tilted it slightly. Three of these users (P1, P3, and P8) mentioned that they actively repositioned the Cintiq based on their current task, such as by pulling it closer and tilting it slightly when using the stylus, or swinging it outward to share a view with collaborators. One drawback to the vertical condition's configuration, pointed out by P2, was the feeling that having three vertical displays created a "wall" between him and visitors in his office.

In contrast, in the horizontal condition every participant adjusted the Cintiq in one or more ways. All eight participants propped books or other objects under the rear of the Cintiq in order to tilt it "drafting table" style. Glare from both artificial and natural light was a motivating factor for this for five participants. They reported that the tilting reduced but did not eliminate the glare problems. Three participants (P1, P6, P7) also felt that the display was hard to see when it was horizontal, not only due to glare but also due to the fact that the topmost portions of the screen were more distant from the user than were the lower portions.

In addition to tilting the surface, participants made a variety of other changes in the horizontal condition, including lowering the height of their desk and/or raising their chair in order to view the Cintiq better (P1, P5), placing the wooden risers next to the Cintiq so that their arms rested on the desk flush with the surface (P2), pushing the Cintiq farther toward the back of the desk (P6), or rotating the Cintiq to be at an angle (P7). Five participants (P1, P4, P6, P7, and P8) moved the Cintiq to the left or right, rather than keeping it directly in front of them, so as to use the central desk area for their mouse and keyboard.

Six participants complained of ergonomic discomfort when using the horizontal surface. P2 commented that the horizontal display position didn't feel "natural." P3 and P8 mentioned that it was uncomfortable to lean over and read long documents on the horizontal surface. P3 felt that even propped up with a book, the surface was still at an uncomfortable angle. P4 and P5 mentioned problems with the large body movements needed to use or glance at the horizontal surface while working with the other, vertical screens. P7 turned the entire display to a more comfortable angle for writing, but then found that reading at the rotated angle was uncomfortable.

In the horizontal condition, seven participants reported that finding space on their desk to locate other objects was difficult. For example, P6 moved the Cintiq to the rear of his desk since he liked to use the space closest to him for resting his arms. However, this location made the Cintiq more difficult to view, and P6 complained "I don't have any place [on my desk] to put it that's appropriate." P2 felt that he had to move his normal monitors further away from him than he liked in order to fit the Cintiq directly in front of them. Finding space for the mouse and keyboard was difficult, and prompted most participants to locate the Cintiq to the side rather than directly in front of themselves.

4.2. Tasks and Applications

Of all the applications they used in each condition, participants placed the widest variety on their primary monitors; the vertical Cintiq hosted only a subset of the users' applications, similar to a secondary monitor. The

horizontal Cintiq hosted an even smaller proportion of applications (Table 2, 1st row).

Two participants described how they found the horizontal surface useful for tasks involving reflective thought. P2, for example, said he put his e-mail on his horizontal Cintiq since he liked to use the surface for reading for understanding because it "feels like a book." P7 told us that she preferred to use the horizontal surface rather than her normal monitors when composing word processor documents, using the stylus to hand write them and then convert to text; she felt the process of hand-writing a document allowed her to reflect on it carefully, while the automatic conversion of the ink to text then created a product she could share with others.

In the vertical condition, we observed that the Cintiq was often used as a peripheral display. This is similar to what Grudin [5] observed for dual-monitor users, who had one display that was peripheral to the other and used mostly for reference purposes. We noticed that the horizontally-oriented Cintiq also was treated as peripheral, with participants often using it to display their email inboxes or other reference materials. For instance, P4 described writing code in a development environment on his primary monitor, and placing associated API documentation on his horizontal Cintiq. P5 arranged calendar appointment reminders to appear on the horizontal Cintiq, noting that they were "less obnoxious" there and it was "easier to ignore them."

The peripheral nature of the Cintiq in both conditions is reinforced by the log data on the proportion of all of the windows participants opened that appeared on each display (Table 2, 2nd row). While primary monitors hosted over half of the windows opened in each condition, the vertical Cintiq hosted fewer, and the horizontal Cintiq held fewer still. The low amounts of input directed at the Cintiq, particularly when horizontal, further highlight its role as a display for reference, rather than activity. Over half of the input time in each condition was directed toward participants' primary monitors, while the vertical Cintiq received less, and the horizontal Cintiq was the focus of only a tiny amount of input (Table 2, 3rd row).

4.3. Space and Window Management

Participants were enthusiastic about acquiring extra screen real estate, regardless of whether they initially had one or two monitors. P5 summed up this attitude, noting that she would be sad to return to two monitors when the study was over, because "[I] just can't have enough", and "The more space I have, the more I'll take." However, the addition of display space in the form of the horizontal surface complicated window management. When users' attention was directed at their normal monitors, the horizontal display was not in their main or peripheral field of view, sometimes causing participants to "lose" windows because they

		Primary Monitor			Secondary Monitor			Cintiq Monitor	
		I	V	H	I	V	H	V	H
% of unique applications used during the condition that appeared on the display	1M	100 (0)	82 (35)	98 (2)	NA	NA	NA	49 (36)	33 (19)
	2M	83 (31)	70 (31)	82 (25)	53 (29)	35 (14)	44 (5)	62 (33)	45 (30)
% of windows opened during the condition that appeared on the display	1M	100 (0)	60 (38)	87 (4)	NA	NA	NA	40 (38)	13 (4)
	2M	67 (14)	50 (17)	54 (12)	33 (14)	20 (15)	28 (14)	31 (26)	17 (13)
% of all input time during the condition focused on the display	1M	100 (0)	53 (35)	90 (2)	NA	NA	NA	47 (35)	10 (2)
	2M	64 (5)	51 (17)	55 (8)	36 (5)	21 (21)	32 (15)	27 (29)	13 (13)
% of input time on each display in each condition attributed to the keyboard, mouse, and stylus [K | M | S (Cintiq only)]	1M	39 | 61 (6 | 6)	36 | 64 (9 | 9)	38 | 61 (7 | 7)	NA	NA	NA	40 | 55 | 5 (11 | 7 | 9)	22 | 49 | 30 (13 | 24 | 31)
	2M	40|60 (5 | 5)	38 | 62 (4 | 4)	40 | 60 (2 | 3)	34 | 66 (6 | 6)	32 | 68 (3 | 4)	34 | 66 (6 | 6)	30 | 68 | 2 (8 | 9 | 4)	22 | 58 | 20 (11 | 23 | 21)

Table 2. Mean use statistics based on log data for participants with one (1M) or two (2M) initial monitors. I = initial condition, V = vertical, H = horizontal condition. For participants who had two initial monitors, the primary monitor was calculated as the non-Cintiq monitor that received the most input events. All numbers are percentages. Standard deviations are in parentheses.

didn't notice items appearing on the horizontal surface.

P8 said he thought of the horizontal and vertical display areas as being two disparate, "isolated spaces." P2 also commented that he felt the horizontal and vertical screens felt like two separate working areas, rather than a unified workspace.

4.4. Input Devices

The addition of the Cintiq meant participants could use the stylus to write digital ink or perform mouse-like interactions on that display. However, the log data shows our participants typically used the mouse, rather than the stylus, to interact with applications on the Cintiq (Table 2, 4th row). More input time on the vertical Cintiq was from the mouse than the stylus; the horizontal Cintiq received a higher proportion of stylus input than when vertical, but was still dominated by mouse use.

The high overhead of switching input devices seemed to play a large role in the choice to use the mouse, rather than the stylus, on the Cintiq. Half of the participants mentioned that they found switching between the mouse and stylus irritating. P5 captured this sentiment when she explained she used "whatever is in [my] hand so [I] can make the fewest changes back and forth." P4 articulated a more subtle annoyance of device switching – the cursor's inability to remember its most recent per-device location; for example, if the mouse cursor was on his primary monitor and he used the stylus on the Cintiq, when he returned to using the mouse he was annoyed that he now had to move the cursor a long way to return it to the primary monitor.

Although participants often used the mouse on the horizontal surface, they complained about the challenges of doing so, such as needing to move the mouse a long distance to reach the surface (P2), losing track of the cursor due to screen size and glare (P4), and difficulty in mentally mapping what direction a mouse motion would cause the cursor to move when the display was horizontal (P6).

5. Discussion

H1 was not confirmed by our findings. P7 was the only participant who preferred the horizontal condition, since it assisted her with reflective composition tasks and "to do" organization more than her vertical surfaces. The other participants either did not find the horizontal surface useful, or else found it no more useful than having the same surface available vertically. P3 captured this with her remark on the horizontal Cintiq; "I'm struggling to find good uses for the kind of work I do." It is also important to consider that our participants may not have found the horizontal surface useful due to many of the usability challenges described in the prior sections, such as ergonomic problems and irritation with device switching; future horizontal technologies that surmount these issues may yet prove themselves useful to office workers.

H2 was confirmed by our findings, which showed differential use patterns of the Cintiq in each condition. In particular, the Cintiq had more windows placed on it, and a wider variety of application types placed on it, when it was vertical than when it was horizontal. The Cintiq was also used more actively (received more input events) when it was vertical than when it was horizontal.

H3 was not confirmed by our findings. Indeed, none of the four participants who had two initial monitors preferred the horizontal condition. However, participants' comments indicating their eagerness to acquire more display space suggest that our assumption that two 1600 x 1200 monitors would saturate users' need for vertical display space was incorrect. It may still be the case that there is some, albeit higher, saturation point beyond which users would prefer different types of displays rather than additional vertical pixels; this issue is left to future investigation.

5.1. Design Recommendations

Although our participants faced many challenges in integrating the horizontal surface into their work routines, given the preference of one participant for the horizontal condition and the "tied" preference of another, we remain optimistic about the potential for horizontal surfaces to play an important role in next-generation offices. However, our findings suggest that there are many changes that must be made to hardware and software before office workers can benefit from having horizontal interactive displays as part of their work environment.

Horizontal surfaces should fit into users' ecology of objects. For example, they must be durable. Participants in our study were concerned with the risk of damaging their surface in the course of normal use. This made users resent the desk space devoted to the display, since they felt it was lost to "normal" functions. Also, the design of interactive horizontal displays must accommodate the positioning of traditional input devices; this might involve encouraging users to adopt keyboard trays, or making a digital surface large enough that users don't mind "wasting" a portion of the surface by covering it with other devices. Additionally, horizontal surfaces need to be viewable under standard office lighting conditions.

This may require investigation of different display hardware or special coatings for glare reduction.

Horizontal surfaces should afford tilting. All participants in our study tilted their horizontal surface, both to reduce glare and to increase comfort. The long-term DiamondTouch user studied in [22] was also reported to have tilted his table. Several of our participants indicated that an even more flexible positioning scheme might be desirable – the ability to dynamically change the surface's orientation from horizontal to vertical (and anywhere in-between) depending on the current task. For example, P3 commented "Ideally it [the Cintiq] would be less heavy and you could switch between horizontal and vertical positions depending on what you're doing." P5 and P8 also commented on the desirability of moving the surface between orientations as needed.

Horizontal surfaces integrated with standard displays need intelligent cursor management. This would ease the pain of switching between horizontal interaction using direct input (such as styli or touch) and traditional, indirect interactions with vertical displays (such as with the mouse). In particular, the system should remember the last cursor location for each input device, so that input device switching does not require moving the cursor across a large area to return it to its prior location. Additionally, because having surfaces in two planes further complicates the pointer-loss problem that users already have on large vertical displays, a cursor management systems should enlarge, animate, or otherwise visually emphasize the cursor at the moment of device switching, in order to assist users in locating it.

Horizontal display designers must account for the difficulty users have observing two different planes simultaneously. For example, our study participants had difficulty noticing windows that appeared on the horizontal surface when they were attending to a vertical display, because the surface was not within their peripheral vision. Providing subtle notifications on the vertical surface that a window on the horizontal display requires attention (and vice versa) might alleviate this problem. Providing multiple task bars, one for the vertical surface that contains representations of the windows located there, and one for the horizontal surface containing those windows' representations, would also assist with the "dual plane" challenge, by not requiring users to switch their focus of attention between planes in order to manage the windows on the surface they are actively using.

Horizontal displays for office workers should support arbitrary rotation of individual windows. While prior surface research, such as the DiamondSpin toolkit [17], proposed the importance of rotatable UI components, the emphasis has been on providing rotation in multi-user scenarios, in order to facilitate communication and comprehension among users seated around different edges of a table [10]. However, rotation would also benefit single-user surface scenarios, by allowing users who are writing with a stylus to rotate the target window in the same manner in which they would rotate a piece of paper.

5.2. Limitations

When considering the lessons learned from our field study, it is worth bearing in mind possible limitations of our methods. Although we derived our design guidelines based on findings that were relatively consistent among all our participants, their experiences may not be representative of all knowledge workers – users with different job roles may have utilized the displays differently. We hope that our findings inspire others to investigate the value of adding horizontal displays in a variety of settings.

It is also worth noting that it can be difficult to separate out the changes caused by the Cintiq's orientation from those attributable to its inking capabilities. We attempted to control for this by using a stylus-enabled surface in the vertical, as well as the horizontal, condition. However, some conflation of the effects of the orientation and the novel input functionality is unavoidable when studying surface technologies, as the novel form-factor of such devices is inherently tied to novel input mechanisms such as styli and touch.

Finally, although our study contributes data on longer-term use patterns of horizontal surfaces than prior work, it may not have been sufficiently long-term for participants to incorporate the horizontal surface into their routines. P5 commented that two weeks was not enough time for her to "get used to" having the horizontal Cintiq and P7 said she did not want to invest in changing her current article-reading practices because she would have to give up the Cintiq in two weeks. Investigating whether more permanent introduction of horizontal surfaces into an office environment would result in increased use would be a valuable avenue for future exploration.

6. Conclusion

In this paper, we described a field study comparing how office workers utilized a stylus-enabled display, positioned either vertically or horizontally, in conjunction with their current work environments. This work provides findings relevant to researchers interested in scenarios wherein horizontal displays, such as interactive desks, are a key part of a

computationally-augmented office. We contributed findings on in situ use of horizontal surfaces, presenting results on the suitability of horizontal surfaces for office productivity tasks, and presenting results on the differential use patterns of horizontal and vertical displays in this setting. Additionally, based on our study's findings, we contributed a set of design guidelines to improve the experience of using digital horizontal surfaces in office settings. We hope this work will enable designers to improve the utility of horizontal systems, moving us one step closer to the vision of "the office of the future."

7. References

[1] Bush, V. As We May Think. *The Atlantic Monthly*, 1945.

[2] Dietz, P. and Leigh, D. DiamondTouch. *UIST 2001*, 219-226.

[3] Elliot, A. and Hearst, M. A Comparison of the Affordances of a Digital Desk and Tablet for Architectural Image Tasks. *International Journal of Human-Computer Studies*, 56(2), February 2002, 173-197.

[4] Everitt, K., Shen, C., Ryall, K., and Forlines, C. MultiSpace: Enabling Electronic Document Micro-mobility in Table-Centric, Multi-Device Environments. *IEEE Tabletop 2006*, 27-34.

[5] Grudin, J. Partitioning Digital Worlds: Focal and Peripheral Awareness in Multiple Monitor Use. *CHI 2001*, 458-465.

[6] Ha, V., Inkpen, K., Whalen, T., and Mandryk, R. Direct Intentions: The Effects of Input Devices on Collaboration around a Tabletop Display. *IEEE Tabletop 2006*, 177-184.

[7] Han, J. Low-Cost Multi-Touch Sensing through Frustrated Total Internal Reflection. *UIST 2005*, 115-118.

[8] Izadi, S., Agarwal, A., Criminisi, A., Winn, J., Blake, A., and Fitzgibbon, A. C-Slate: A Multi-Touch and Object Recognition System for Remote Collaboration using Horizontal Surfaces. *IEEE Tabletop 2007*, 3-10.

[9] Johanson, B., Fox, A., and Winograd, T. The Interactive Workspaces Project: Experiences with Ubiquitous Computing Rooms. *IEEE Pervasive Computing* 1:2.

[10] Kruger, R., Carpendale, S., Scott, S., and Greenberg, S. *JCSCW*, 13(5-6):501-537, 2004.

[11] Mazalek, A., Reynolds, M., Davenport, G. The TViews Table in the Home. *IEEE Tabletop 2007*, 52-59.

[12] Morris, M.R., Brush, A.J.B., and Meyers, B. Reading Revisited: Evaluating the Usability of Digital Display Surfaces for Active Reading Tasks. *IEEE TableTop 2007*, 79-86.

[13] Parker, J.K., Mandryk, R., and Inkpen, K. TractorBeam: Seamless Integration of Local and Remote Pointing for Tabletop Displays. *Graphics Interface 2005*, 33-40.

[14] Rogers, Y. and Lindley, S. Collaborating Around Large Interactive Displays: Which Way is Best to Meet? *Interacting with Computers*, 2004.

[15] Scott, S.D., Grant, K.D., and Mandryk, R.L. System Guidelines for Co-located collaborative Work on a Tabletop Display. *ECSCW 2003*, 159-178.

[16] Shen, C., Everitt, K., and Ryall, K. UbiTable: Impromptu Face-to-Face Collaboration on Horizontal Interactive Surfaces. *UbiComp 2003*, 281-288.

[17] Shen, C., Vernier, F., Forlines, C., and Ringel, M. DiamondSpin: An Extensible Toolkit for Around-the-Table Interaction. *CHI 2004*, 167-174.

[18] Streitz, N., Geißler, J., Homer, T., Konomi,S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, P., and Steinmetz, R. i-Land: An Interactive Landscape for Creativity and Innovation. *CHI 1999*, 120-127.

[19] Tandler, P., Prante, T. Müller-Tomfelde, C., Streitz, N., and Steinmetz, R. ConnecTables: Dynamic Coupling of Displays for the Flexible Creation of Shared Workspaces. *UIST 2001*, 11-19.

[20] Tognazzini, B. The "Starfire" Video Prototype Project: A Case History. *CHI 1994*, 99-105.

[21] Wellner, P. Interacting with Paper on the DigitalDesk. *Communications of the ACM*, July 1993, 36(7), 87-96.

[22] Wigdor, D., Penn, G., Ryall, K., Esenther, A., and Shen, C. Living with a Tabletop: Analysis and Observations of Long Term Office Use of a Multi-Touch Table. *IEEE Tabletop 2007*, 60 - 67.

[23] Ziola, R., Kellar, M., and Inkpen, K. DeskJockey: Exploiting Passive Surfaces to Display Peripheral Information. *Interact 2007*, 447 - 460.