Exploring Display Factors that Influence Co-Located Collaboration: Angle, Size, Number, and User Arrangement

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Abstract

With recent advances in display technologies, co-located collaborators now have a number of viable options when choosing technology to incorporate into their face-to-face work activities. Co-located CSCW solutions have been explored for desktop computers, wall displays, tabletop displays, and networked devices including laptops and PDAs. Deciding which display technology is appropriate for a given situation requires an understanding of the impact of the underlying dimensions of the display technologies on co-located collaborative interactions. This paper presents a series of exploratory field studies that explore four factors of physical display technology: display angle, user arrangement, display size, and number of displays. The results from this work provide insights into the strengths and weaknesses of these various display factors, which can help system designers make informed choices regarding display technology.

1 Introduction

Researchers have investigated a variety of computational media to better support people when they want to work or play together in a co-located collaborative (CLC) environment. The key question is not whether the electronic whiteboard is better than the desktop computer. Rather, we need to know when each medium is appropriate and how its associated strengths and weaknesses impact CLC. Choosing appropriate technology depends on a variety of factors, including the task people are trying to accomplish, the environment in which they are interacting, the technology available, the style of the collaboration, and the individuals involved. A better understanding of the underlying dimensions of our media will enable us to provide better support for the desired interactions.

Previous work has identified several display factors that influence CLC (Mandryk, Scott & Inkpen, 2002). These display factors included angle of the display; arrangement of users; size of the display; proximity to the display; privacy of the display; superimposition of display space on the input space; and number of displays. This paper is part of ongoing work to investigate these display factors and develop a framework for CLC. This paper describes an exploratory study conducted to gain additional insight into four of these display factors. Based on the results of this work, we describe strengths and weaknesses of the various options provided by each factor as they relate to CLC.

2 Related work

A number of possible approaches have been proposed for integrating computer support into traditional co-located collaboration. This section presents several approaches that have been explored in the research community.

2.1 Collaboration at a single display

Stewart, Bederson, and Druin (1999) proposed the collaborative interaction model Single Display Groupware (SDG), in which each user at a shared display is provided with their own interaction channel. This notion of supporting multi-user interaction at a shared display has been explored in a variety of collaborative settings, such as a desktop PC, a large vertical surface, and a tabletop work surface.

On a typical PC, both the physical hardware and the software interfaces have been built upon the underlying assumption that only one user is interacting with the system, making CLC awkward. Consequently, researchers have explored modifications of the PC setup to accommodate simultaneous users, such as adding support for multiple input devices (Scott, Mandryk & Inkpen, 2003; Stewart et al., 1999). These desktop SDG systems have been used quite successfully for children's collaboration; however, interacting in such close proximity can be socially uncomfortable for adults. As a result, larger displays are often preferred when adults collaborate in co-located settings.

Electronic whiteboard displays (Pedersen et al., 1993) and tiled wall displays (Fox et al., 2000) have enabled new methods of supporting collaboration. Large displays have been shown to facilitate collaborative activities (Mynatt et al., 1999; Pederson et al., 1993) as well as ad hoc collaboration (Russell, 2002). Wall displays have also been used to help colleagues maintain awareness of each others' activities (Buxton et al., 2000).

Tabletop displays enable users to access digital information via a self-illuminated display or an image projected on a horizontal surface. Tabletop display systems have been developed for various types of collaborative activities, including urban and landscape design, data exploration, and casual activities such as photo sharing (see Scott, Grant & Mandryk, 2003 for a detailed review).

2.2 Collaboration with multiple displays

Another method of supporting co-located collaboration is to provide a group with multiple displays. Some of the first attempts at supporting CLC involved installing personal and public displays into dedicated meeting rooms (Stefik et al., 1987). These systems consisted of electronic whiteboards installed at the front of the meeting room and smaller displays embedded into large meeting tables. Newer collaboration "rooms" have focused on enabling flexible collaboration by providing a variety of tabletop and wall displays (Fox et al., 2000; Streitz et al, 1999). In some instances, multiple adjacent displays have been combined to create a continuous physical and virtual work surface (Rekimoto & Saitoh, 1999). Another approach has been to use proximal displays for different aspects of the collaborative activity. Rodden et al. (2003) have explored the presentation of related information across multiple flat-panel displays (one vertical and two horizontal) embedded in a travel office kiosk to support side-by-side trip planning. Collaborative work often occurs outside of dedicated meeting rooms and can involve people bringing their own mobile devices. A number of researchers have explored tools to facilitate this type of collaborative interaction (Myers, Stiel & Gargiulo, 1998, Booth et al., 2002, Want et al., 2002).

2.3 Display factors

Four display factors were investigated in this research: display angle; user arrangement; display size; and number of display. This section briefly describes each of these factors in the context of the related literature.

2.3.1 Display angle

The angle of a display surface has a strong impact on user interaction. A horizontal display allows several possibilities for user arrangement, providing users with diverse perspectives, and providing a flat surface for placing objects. A vertical display gives all viewers the same perspective on the task and provides a holistic view of the data by allowing users to stand farther back from the display and adjust their position. A tilted display, such as a drafting table, can provide a better viewing angle, but does not afford people gathering around it (Buxton et al., 2000).

2.3.2 User arrangement

Users are constrained to position themselves in front of a vertical display; however, they may gather in myriad arrangements around a horizontal display. Side-by-side arrangements allow users to view the display from the same perspective, but face-to-face or right-angle arrangements allow people to more easily view facial expressions and make eye-contact. Early research on collaboration around physical tables determined that face-to-face or right-angled seating was preferred for conversations due to support for visual contact (Sommer, 1969). Previous work on collaboration around a tabletop display found that a face-to-face arrangement better supported non-verbal communication than sitting side-by-side (Whalen et al., 2004). Rodden et al. (2003) noted that a side-by-side arrangement helped ease social awkwardness of strangers, as there was less expectation for direct eye contact.

2.3.3 Display size

Display size can range from small screen devices to desktop monitors to large wall displays. Previous work has noted that as the size of a display increases, it "becomes qualitatively different" (Swaminathan & Sato, 1997). Large displays are often used to magnify an image, enabling easier viewing or interaction (Buxton et al., 2000; Streitz et al., 1999) or to show additional detail that would not be clearly visible on a smaller display. Work by Tan et al. (2003), reported that users were more effective in spatial tasks when working on a large display. Large, public displays have been shown to promote activity and social awareness (Greenberg & Rounding, 2001; Huang & Mynatt, 2003), while smaller displays are commonly used as individual, private workspaces. Display size can also have an impact on ergonomics. When working with a large horizontal display, artifacts or input may be out of reach forcing users to stand up in order to reach far-away objects (Elliott & Hearst, 2002). Conversely, when working on a smaller display, people may crowd around the display, interfering with each other as they reach across the display.

2.3.4 Number of displays

Many factors influence the choice of how many displays to utilize in a CLC activity and how to configure those displays. Multiple displays can permit a clear partitioning of ownership, allowing users to have effective control over their own personal display, while a shared display allows people to gather around it to collaborate. Previous research suggests that a shared artifact can increase attention and involvement during collaborative tasks (Bly, 1988) and can help foster a better shared understanding than separate displays (Scott, Mandryk et al., 2003; Stefik et al., 1987); however, there is a trade-off between promoting a shared understanding and providing individual flexibility.

3 Exploratory study

3.1 Method

Previous work in the area of CLC has primarily examined either a single display configuration or examined multiple display configurations where a number of factors may have changed. To better understand how various display factors can impact CLC, we conducted a set of coordinated studies to investigate the four display factors in isolation. This approach enables us to more directly attribute observations to a specific display factor.

In each study, a single display factor (display angle, user arrangement, display size, number of displays) was manipulated while all other factors were kept consistent with default values. Values represent common configurations for each factor. Table 1 shows the experimental values used.

3.2 Experimental task

The tasks chosen involved route planning with a subway map. These included activities such as planning a sightseeing route to visit as many sites as possible, including required sites. Problem solving tasks were chosen to be sufficiently realistic and encourage collaboration, yet allow for all four factors to be investigated with minimal constraints. For example, a subway map can be wall-mounted, varied in number and size, and made orientation-independent to support the various user arrangements.

Table 1. Experimental values for each display factor studied.

Display Factor \ Manipulation	Display Angle	User Arrangement	Display Size	Number of Displays
Display Angle	**Horizontal Vertical**	Horizontal	Horizontal	Horizontal
User Arrangement	Side-by-side	**Side-by-side Face-to-face Right angles**	Side-by-side	Side-by-side
Display Size	Large (33″)	Large (33″)	**Small (17″) Large (33″)**	Large (33″)
Number of Displays	Single shared	Single shared	Single shared	**Single shared Multiple (one per user)**

We developed three scenarios for interaction with the map: a tourist activity, an emergency situation, and a courier scenario. A simplified subway schedule was created to make route planning as straightforward as possible. Each scenario involved three sub-tasks: the first involved use of supplemental maps (e.g., city maps), and the second and third subtasks involved more extensive route planning with constraints (e.g., travel to a set of subway stations within a given time). Similar subtasks were chosen for all three scenarios.

The experiment was conducted using a paper prototype that consisted of a vinyl-covered map. Participants could write directly on the map and on a scratch area bordering it. We chose to use a paper prototype because current technological limitations make it difficult to provide rich, natural, multi-user interactions. In addition, display technologies use a variety of interaction styles (e.g. touch sensitive surface or mouse-based input) and we did not want these differences to impact our results.

3.3 Experimental design

Four separate studies were conducted, one for each display factor being manipulated (angle, arrangement, size, and number of displays). Each study had 12 participants (6 pairs), for a total of forty-eight participants (31 male and 17 female). Participants were recruited in pairs with the exception of three pairs who did not have a previous relationship (i.e. friends, colleagues, classmates). No participants took part in multiple studies. The arrangement of scenarios and experimental conditions were counterbalanced in all studies to minimize learning effects. Each study used a within subjects design with each pair completing a scenario for each condition.

Each participant filled out a background questionnaire that asked about experience with collaboration and computers. They were given an introduction to the subway map and the simplified schedule, and were encouraged to collaborate. For each task, written instructions were provided. Each task was videotaped, and coding sheets were used to record observations. At the end of each scenario (about 30 minutes, consisting of three subtasks), participants were given a questionnaire asking them to rate their satisfaction and enjoyment of the task on a five-point Likert scale. At the end of the experimental session, participants were given a final questionnaire that asked for a comparison of the experimental conditions, ranking them in terms of suitability, enjoyment, and perceived effectiveness. Post-session interviews were also conducted to gather information about the participants' experiences.

Following the study, all video data were coded for the number of pointing gestures, amount of writing, instances where participants looked at their partner (partner gaze), amount and type of physical movement during a session, and verbal communication. Pointing gestures included participants touching the table, indicating a location on the table and making large sweeping gestures (e.g. tracing a path). Writing included any characters or marks drawn on the map and on the area bordering the map. Partner gaze included glances and gazes at their partner as well as mutual eye contact. Physical movements were coded into seven different categories: the closeness between partners; whole body shifts; torso movements (leaning/bending); large reaching movements; physical interference (bumping, crossing arms), and difficulty using inside arm or writing hand. Verbal communication was classified using a simplified version of the DAMSL dialogue annotation scheme (Core & Allen, 1997).

4 Results

The nature of this experiment was exploratory and as such, our goal was to uncover interesting trends that could be attributed to individual display factors. The results are presented as general observations, descriptive statistics, and ANOVAs. Table 2 presents the quantitative results from the video coding analyses of pointing gestures, writing, gaze, communication, and physical activity. For all ANOVAs an alpha of .10 was chosen to help minimize Type II errors, but this increased the likelihood of Type I errors (Huck, 2000). Therefore, significant results need further, more focused investigation to fully understand their importance. Cohen's f-value measure was utilized to qualify the effect sizes of these results and provide some measure of practical significance (Kotrlik & Williams, 2003).

Given that all of the studies used the same default condition (horizontal display angle; side-by-side user arrangement; large size; single shared display) there was data from 24 pairs of participants interacting in this configuration. Analyses of these data determined that there were no significant differences based on scenario, condition order, or which individual study the users participated in.

Table 2. Means and standard deviations of video coding results for gestures, verbal and non-verbal communication and physical movements.

	ANGLE		ARRANGEMENT			SIZE		NUMBER	
	Horizontal	Vertical	Side-by-Side	Right-Angle	Face-to-Face	Large	Small	One Display	Two Displays
Pointing gestures	115 (36)	70 (51)	101 (16)	107 (39)	87 (36)	132 (74)	75 (32)	126 (58)	101 (29)
Writing	33 (11)	30 (17)	34 (19)	26 (16)	32 (17)	30 (19)	20 (13)	28 (8)	28 (14)
Partner gaze	22 (13)	19 (15)	9 (8)	24 (14)	15 (17)	18 (13)	8 (7)	25 (16)	22 (17)
On-task communication	94 (32)	61 (21)	62 (37)	84 (20)	75 (25)	94 (49)	61 (32)	97 (32)	66 (32)
Preparatory communication & clarification	17 (7)	10 (4)	15 (4)	15 (11)	14 (11)	21 (8)	26 (17)	19 (13)	20 (13)
Ratio of physical activity between partners	.46 (.12)	.49 (.15)	.38 (.25)	.33 (.23)	.63 (.23)	.65 (.26)	.46 (.24)	.39 (.18)	.76 (.23)

4.1 Display angle

4.1.1 Communication

Whether the display was horizontal or vertical impacted the amount of pointing interactions exhibited by the participants. Users made significantly more pointing gestures in the horizontal condition than in the vertical condition ($F(1,5)=4.68$ $p=.083$), with a large effect size ($f=.56$). In the vertical display condition, there were significantly fewer preparatory comments, and fewer requests for information from each other or from the facilitator ($F(1,5)=6.13$ $p=.056$, $f=.74$). This coincides with subjective observations and participant comments that indicated participants were more focused on completing tasks when standing in front of the vertical display than when sitting. Users also tended to have more on-task communication in the horizontal condition; however, this difference was not statistically significant ($F(1,5)=3.25$ $p=.131$, $f=.7672$).

4.1.2 Ergonomic observations

Participants tended to write larger on the vertical display than on the horizontal display. Of the ten participants who wrote characters or digits in both orientations, six wrote larger in the vertical condition, and four were unchanged. Of those who wrote larger, three wrote 2-3 times larger. This difference could be attributed to the fact that it is difficult to make fine motor movements on a vertical surface when your arm is unsupported (Pheasant, 1986). Five participants specifically commented that it was more difficult to write on the vertical surface than the horizontal. This difference may also be a result of experience (people are more used to writing on a horizontal surface) or expectation (writing on a vertical surface often suggests writing to provide information to people at a distance).

One observed difference between the horizontal and the vertical display sessions was the physical movement the participants exhibited. In the horizontal condition, participants were fairly stationary, making only torso movements throughout the session. Six of the participants explicitly stated that they enjoyed being able to sit while performing the activity, commenting that it was "more comfortable/familiar". For the vertical display session, people completed the task while standing and exhibited a high degree of full body movement throughout the session. Ten of the twelve participants were recorded as exhibiting more full-body shifts than they had in the horizontal condition (with a corresponding reduction in the amount of leaning). Some participants didn't like the physical effort required to stand at the display: two participants explicitly complained their back was stiff after the vertical session and expressed a concern of potential back pain for longer duration activities, while one mentioned arm fatigue. However, eleven participants expressed that they appreciated the "freedom of movement".

4.1.3 Preferences

No differences were found for users' preferences of display angle for either effectiveness (6-horizontal; 6-vertical) or enjoyment (7-horizontal; 5-vertical). The main (stated) reason why participants preferred the horizontal display angle was because they felt it was "a more natural surface for collaborating" and was relaxing to work at and write on (8 participants made comments related to this). In contrast, six people commented that they preferred the vertical display angle because they felt it was "easier to see everything" and was "good for displaying and sharing ideas".

Participants also appreciated the ability to place objects on the horizontal surface. Two participants complained about the difficulty of managing extra objects when working on the vertical display.

4.2 User arrangement

Given the spatial nature of the task in this study, perspective of the information was important. In the three arrangements, users' individual and group perspectives varied considerably. Side-by-side users had a shared perspective and face-to-face users had opposing perspectives. Right-angled users had a range of perspectives as five of the six pairs shifted their position (3 to side-by-side, 1 to face-to-face, and 1 to both arrangements). As such, interaction in the right-angle condition was highly variable.

4.2.1 Communication

No significant differences were found for the amount of pointing gestures or writing, and the effect sizes were small. A significant difference was found for the amount of partner gaze between participants ($F(2,10)=7.32$, $p=.011$, $f=.51$). Post hoc analyses revealed that users glanced at their partners significantly more (with large effect sizes) in the right-angled condition than in either the side-by-side condition or the face-to-face condition ($F(1,5)=19.41$, $p=.007$, $f=.59$ and $F(1,5)=4.56$ $p=.086$, $f=1.12$ respectively). A large effect size was also found in the post hoc analysis for the amount of partner gaze between the face-to-face and side-by-side configurations ($f=.45$) with more gaze occurring in the face-to-face condition; however, this difference was not statistically significant.

On average, participants had a more equal distribution of activity in the face-to-face condition, with a large effect size ($f=.61$), however this difference was not significant. Further analyses revealed a significant difference for the distribution of activity between partners in the right-angle and face-to-face conditions ($F(1,5)=5.06$, $p=.074$, $f=.93$). For five of the six pairs, the partner who was sitting sideways to the map had a considerably lower level of activity. A large effect size was also found for level of activity between the face-to-face and side-by-side conditions ($f=.76$) although this difference was not statistically significant.

Although we hypothesized that variation in user arrangements would impact dialogue patterns, no differences were observed in the speech interaction between the three user arrangement conditions.

4.2.2 Ergonomic observations

Ergonomic difficulties, particularly with the side-by-side and right-angle arrangements, were evident from the physical movement data. Four out of six pairs exhibited more large reaching movements in the side-by-side arrangement compared to face-to-face. This suggests that the participants may have been in a less effective position to access the necessary information on the display than in the face-to-face arrangement (where participants tended to position themselves in the centre of the map). In addition, four pairs had more instances of interference (bumping each other or crossing arms) when side-by-side than when face-to-face. In the side-by-side condition, the closeness of the participants limited the amount of space each person had available for their inside arm. Our observations indicated that nine participants had difficulty using their writing arm in this condition. Although this was awkward for the participants, in most cases it did not decrease the amount they wrote. The right-angle arrangement similarly constrained users' freedom of movement due to the rectangular shape of the table. The person at the short side of the table had limited arm space at the shared corner and limited table space outside the map. Four of the six people in this position had difficulty using their writing arm, but in most cases this did not decrease the amount they wrote.

4.2.3 Preferences

The majority of participants ranked the face-to-face arrangement as being most effective followed by the right-angle and side-by-side arrangements (8, 4, and 3 participants respectively), while one participant indicated no preference. In terms of enjoyment, most stated a preference for the face-to-face and right-angled arrangements (7 and 6 respectively) while only one participant stated a preference for side-by-side. Participants preferred face-to-face because it enabled an unobstructed view, did not restrict movement, and facilitated conversation. Side-by-side was preferred because both partners had "the same view of the map". Participants preferred right-angle because it was easy to communicate with their partner and had some of the advantages of the other conditions.

4.3 Display size

4.3.1 Communication

On average, participants exhibited more non-verbal interactions (including pointing gestures, writing, and partner gazes) and had a more equal distribution of activities when working with the larger display size. Although none of these differences were statistically significant, large effect sizes were found for pointing (f=.56), partner gaze (f=.51), and equality of distribution (f=.42). In addition, more on-task communication was exhibited, on average, when using the larger display. This difference was not statistically significant; however, a large effect size (f=.43) was revealed.

4.3.2 Ergonomic observations

The size difference between the small and large maps did not create significant differences in the users' physical interactions. Two pairs sat closer together when using the small map, one pair sat closer when using the large map, and the remaining three pairs sat essentially the same distance apart. Despite the smaller size, increased physical interference was not observed. The only noticeable differences were attributed to reaching towards areas on the larger map. Participants exhibited more leaning and large reaching movements in the large display condition.

4.3.3 Preferences

More participants stated a preference for the small display over the large display. For effectiveness, eight participants preferred the small size, three preferred the large size, and one had no preference. For enjoyment, six participants preferred the small size, four preferred the large size, and two had no preference. Participants who preferred the small display size commented it was "easier to find" landmarks because it fit in their field of view (7 participants). Participants who preferred the large display size indicated it was easier for two people, particularly when "splitting up the task" (2 participants).

4.4 Number of displays

The number of displays available can impact the amount of independent and joint work undertaken by a group. In our study, groups who worked on one shared display worked very closely with the shared map. Groups who utilized multiple displays tended to shift their focus between their own map and their partner's map. However, two of the pairs in the multiple display condition chose to work only with one map, essentially emulating the single display condition. As such, we need to be aware of this variability when evaluating the results.

4.4.1 Communication

No significant differences were found for pointing gestures, writing, or partner gaze, and these results revealed only small or medium effect sizes. Not surprisingly, a significant difference was found with degree of distribution of activities; participants demonstrated a more equitable distribution when they were given two displays instead of sharing one display ($F(1,5)=5.09$ $p=.074$, $f=.97$). More on-task conversation was observed, with a large effect size (f=.52) when participants shared a display; however, this difference was not statistically significant. This coincides with participants' comments that the shared display made it easier to discuss and share ideas.

4.4.2 Ergonomic observations

Whether participants were given a single map or a pair of individual maps impacted their physical interactions. Four pairs of participants sat closer together in the single configuration than in the multiple display configuration. This also contributed to a decreased ability to use their inner arm. In the multiple display configuration, participants exhibited more leaning (9 participants) and more large reaching movements (9 participants).

4.4.3 Preferences

For both effectiveness and enjoyment, nine participants preferred a single display and three preferred two displays. Participants who preferred the single display commented that it enabled them to "discuss and share ideas" and that they could complete the task “more efficiently”. Participants who preferred multiple displays indicated that they enjoyed working in their “own space” or that it accommodated “different working styles”.

5 Summary: Impact of the display factors

The results from our user studies provide insights into the display factors by: (i) validating previous results or hypotheses; (ii) failing to show differences in expected areas; and (iii) presenting new observations related to display configurations. The following summary highlights pertinent results and discusses the potential impact on co-located collaboration.

5.1 Display angle

As expected, participants felt that the horizontal angle was natural and comfortable for collaboration. Ten of twelve participants expressed strong satisfaction with the horizontal display, finding it effective and enjoyable. However, tradeoffs existed between horizontal and vertical displays in comfort and perspective.

Participants interacting with the vertical display noted more ergonomic difficulties related to arm fatigue, difficulty writing, and back stiffness. However, strong benefits of vertical displays related to perspective were noted. Users frequently moved towards and away from the display to switch between a focused and holistic view, commenting that the vertical display made it easier to see everything. While these results are intuitive, there has been little empirical research in the area of small group collaboration around vertical displays.

Our results also revealed that people using a vertical display tended to work in a more time-efficient manner than those using a horizontal display. The participants exhibited fewer preparatory comments as well as fewer pointing gestures, and a few explicitly commented that they worked faster in this configuration. The strength or weakness of this aspect depends on the goal of the activity and the people involved. A vertical display may be better for shorter, more focused tasks, while a horizontal display may be better for longer duration tasks that require more discussion.

5.2 User arrangement

Providing users with an appropriate perspective and unrestricted interactions (e.g. freedom of movement, access to information, and personal space) is a constant trade-off. This was clearly evident in our study. The side-by-side arrangement provided users with a shared perspective of the map, which caused many participants to find it more effective and enjoyable. However, this benefit was offset by the fact that users typically had less room and a more obstructed view in the side-by-side configuration.

Our results revealed that users had a less equitable distribution of activity and more ergonomic difficulties when side-by-side than when face-to-face. Several participants preferred face-to-face because it enabled an unobstructed view and did not restrict their movements. Users also felt that face-to-face facilitated conversation (although we found no differences in verbal coding). The right-angle arrangement was typically viewed as a compromise, with partners sharing a similar perspective while still maintaining a better interpersonal angle to facilitate communication. However, most participants shifted from the right angle condition toward one (or both) of the other configurations.

5.3 Display size

Previous research indicated that as the size of a display increases, it “becomes qualitatively different” (Swaminathan & Sato, 1997). Although some differences were noted in our study when the display size changed,the interactions were similar overall and not “qualitatively different”. The earlier research does not provide an indication of how much change is needed or whether other display factors need to change in order to see substantial differences.

It is important to consider whether information can be presented in a size that fits within users’ field of view. Several participants stated they preferred the smaller display size because it fit within their view, making it easier to find things. In addition, display size impacted participants’ interactions. With the large display, participants tended to lean more and make more large reaching movements. Although we expected interpersonal distance to change as display size changed, this was not observed in our study. Most participants chose a distance that was comfortable for them regardless of display size.

Our results also revealed a more even distribution of activities and more pointing gestures with the larger display. Whether these interactions positively or negatively impact collaboration depends on the amount of information to present, its format, the interaction requirements of the activity, and the number of people working together. Further research is needed to fully understand these underlying factors and their relation to display size.

5.4 Number of displays

Our results related to the number of displays closely match observations in previous work. When participants shared a display, they generally sat closer together, exhibited more on-task communication, and demonstrated less leaning and reaching. Overall, participants felt that they were more efficient with the single display. Our observations supporting the use of multiple displays, such as more equitable interactions, the ability to work independently, and users' preference for personal workspaces, were also as expected. It is important to consider these issues when determining the number of displays for a collaborative activity. For some activities (and some personality types), highly integrated work is important while in other instances, the ability to work both jointly and in parallel, and move seamlessly between these interaction styles, is important.

6 Conclusions and future work

Innovative display technologies provide opportunities for the design of new co-located collaboration (CLC) workspaces. We have presented results related to how display angle, display size, number of displays, and arrangement of users can impact CLC. Detailed insights into these display factors provide researchers and practitioners with insight into appropriate selection of display technology and an understanding of the tradeoffs involved in choosing one display type over another.

This research examined four display factors. The next stage of this research will examine two additional display factors: direct input and display proximity. In addition, focused research is needed to further explore the relationship between each display factor and the various types of collaborative activities. For example, a visual search task can be difficult on a large screen display because important information can be outside of a user's field of view. Both the task and the required types of interaction impact the appropriateness of a given display configuration. Further insights into such issues would contribute to our understanding of the impact of display choice.

7 Acknowledgments

We would like to thank NSERC, Mitsubishi Electric Research Labs (MERL), and Dalhousie University for supporting this research. Thanks also to H. Tanta-ngai, B. Biggs, J. Satel, and the EDGE Lab for their assistance.

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