

The Proximity Factor: Impact of Distance on Co-located Collaboration

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ABSTRACT

Groups collaborating around a large wall display can do so in a variety of arrangements, positioning themselves at different distances from the display and from each other. We examined the impact of proximity on the effectiveness and enjoyment of co-located collaboration. Our results revealed collaborative benefits when participants were positioned close together, and interaction with the display was felt to be more effective when participants were close to the display. However, clear tradeoffs were evident for these configurations. When at a distance to the display, the choice of direct versus indirect interaction revealed that interactions were easier when using direct input but the effectiveness of the collaboration was compromised.

Categories and Subject Descriptors

H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces - *Computer-supported cooperative work.*

General Terms

Human Factors, Performance, Experimentation

Keywords

Co-located collaboration, wall display, large displays, single-display groupware (SDG), proximity, direct input, indirect input.

1. INTRODUCTION

People working together in a co-located collaborative setting require appropriate technological support and a suitable environment for carrying out their tasks. A large wall-mounted display is a useful tool for group interaction, as it provides a large surface to gather around and can be viewed from a distance, if desired. However, collaboration is affected by many factors, and it is important to understand how the dimensions of this medium impact co-located collaborative interactions.

Proximity is an important factor related to collaboration around a large, shared display. The distance from the screen can affect aspects such as comfort, the ease of resolving gestures, and the ability to view the entire screen. Proximity to others is also a vital element of collaboration, as it affects ease of communication and

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the establishment of shared understanding. The choice of direct or indirect input methods also impacts collaboration. This factor is closely tied to display proximity: generally, a person can use direct input only on a display that is within reach. In order to utilize direct input methods to interact with a screen at a distance, users can either use a remote pointer or interact with a secondary display close to them. In addition, the choice of input device affects the ease of interaction with the display, including the ability to create freeform annotations and to gesture fluidly without fatigue. These elements influence how people engage in computer-supported collaboration.

This paper presents results from a study that investigated how co-located collaboration between pairs of participants was affected by their proximity to a shared large screen display and to each other. We also examined how the method of input (direct, indirect) affected collaboration when users were at a distance to the display. We first present related work in the area. We then outline the experimental methodology of our study including the task used to study collaboration. In the results section, we present each display proximity condition and describe how it affected the way that participants collaborated with each other and interacted with the display. We then provide a synopsis of the results, outlining the strengths and weaknesses of different user and display proximities and input strategies. We conclude with our future work in this area.

2. RELATED LITERATURE

There is a vast amount of literature in psychology considering the impact of proximity (to both objects and other people) on perception, communication and collaboration (see [15] for a survey). The CSCW research community has long recognized, however, that large screens and other collaborative computing tools may not directly reflect results from studies considering proximal collaboration in non-virtual spaces [6, 15, 21, 31]. CSCW research involving large screen displays has generally focused on specific interaction techniques [2, 13, 16] and perceptual phenomena [26, 27], or examined situated use of more complete prototypes [14, 18, 25]; each of these focuses is briefly explored in this section. While projects such as Continuum [17] have conducted comparative evaluations of complex input and display configurations for mixed co-located and distributed collaboration, there is less published research considering the impact on collaboration of basic configurations of display, input modality, and user arrangement, which is the focus of the study presented in this paper.

2.1 Co-located Collaboration

Evaluation of large display technology in applied domains provides practical insights and guidelines, often while suggesting more general usage patterns. Large display technology has been shown to facilitate co-located collaborative activities such as writing, sketching, and webpage design, for instance [11, 14, 18]. Other research has explored ad hoc collaboration facilitated by strategically placing large “public” displays in work environments [3, 4, 7, 8]. Among the observations of such work are the ways in which protocols develop for using the displays [1, 20] and the conceptual distinction between personal and public displays [4, 7].

Much of the early research involving large displays has involved the creation of completely realized systems and their evaluation in simulated or real settings. In the early 1990s, the Tivoli project [18] examined appropriate contexts of use and interaction modalities for large public displays. Tivoli attempted to extend existing whiteboard practices, supporting simultaneous direct input and considering issues of stylus operation and ownership. Flatland [14] was another electronic whiteboard project, intended to support “long term, informal” use. The design was motivated by observing “everyday” practices of whiteboard use in office environments, emphasizing the fact that writing on a whiteboard is ergonomically and contextually different from using a personal paper notebook.

Other early projects supporting co-located collaboration involved installing personal and public displays into a dedicated meeting room. The Colab [23] and DOLPHIN [24] systems included electronic whiteboards at the front of a meeting room as public displays, along with personal displays embedded into large tables. Other collaboration “rooms”, such as i-LAND [25] and iRoom [10], have focused on providing users with flexibility and choice during collaborative activities, by providing configurable environments and multiple display options including tables, personal displays and wall displays.

2.2 Display Proximity

Other research has focused more specifically on the impact of display size and proximity on perception and interaction. When choosing a display size, it is important to consider the size of the objects that will be viewed on the display and whether or not these objects will be visible within a user’s field of view [24]. Research involving non-interactive screens has consistently indicated a preferred viewing distance which appears at odds with direct interaction with larger screens by touch [12]. However, large displays within physical reach can provide a sense of immersion [12] and facilitate gesturing to objects on the display [19]. Gestures can also be used by group members to coordinate their collaborative activities when close to the display [28]. In contrast, users farther from the display must rely on indirect or remote methods to gesture to digital artefacts.

Social factors can also impact collaboration at large displays. A user study involving BlueBoard [20] indicated a strong social aspect to its use, which influenced work practices. The researchers observed a variety of interaction styles (e.g. dominated by a single person, or fluid exchanges with no obvious leader), and no obvious “etiquette” for display use. Turn taking appeared natural, but was also enforced by a limitation in the hardware that precluded simultaneous use. When one person

dominated, others in the group tended to pull away from the board to form an audience. Several experiments [26, 27] show that distance from a public display does not detract from its perception as being public. This research found that public displays elicited different cognitive and social responses than desktop displays, even when the dimensions relative to an individual’s visual field were the same.

2.3 Interaction Techniques

Whether or not input occurs in the same physical space as the display can impact collaboration. Users reaching with their arms to interact with a touch sensitive display can obscure the view for others. However, collaborators are more likely to notice the action, leading to a greater awareness than with indirect input [21, 30]. The choice of input can also affect users’ comfort and performance. For example, reaching across a wall display to select an artefact may be fatiguing [24] and socially awkward [20], while a non-superimposed, relative input device (e.g. a mouse) will require less physical movement. Remote pointers provide direct interaction from a distance, potentially allowing users to take in the entire screen and interact easily with objects beyond arm’s length. However, previous work has demonstrated that remote pointing is problematic when acquiring small targets [13].

Relatively few studies have focused on remote interaction with a large public display via indirect input. i-LAND’s CommChairs provide a facility for remote interaction using tablet computers, but the impact of this capability was not directly reported [25]. Vogel and Balakrishnan [29] describe a large display system with four distinct proximity modalities, each providing interaction opportunities suiting the distance and the activities appropriate at that distance. Intended for environments where users are standing, indirect input using mice or other devices was not considered. Brignull et al. [1] describe a longitudinal study, in which they equipped a student common room with a non-interactive public wall display and three “interaction points” (wireless keyboard and mouse). They observed a tendency for the students to choose the interaction point closest to the display, but note that others would intermittently join in from other interaction points, and that “this became a critical factor in the interplay of [the system] and the room”.

3. PROXIMITY STUDY

An experiment was conducted to investigate the effects of display proximity and input methods when interacting in pairs with a large wall display. Twenty-four participants (15 male, 9 female) took part in this study. Participants were recruited in pairs in order to observe collaboration between people who were familiar with each other. These participants were drawn primarily from within the student population at Dalhousie University.

3.1 Experimental Design

We utilized a mixed within-subjects design. Display proximity was the within-subjects factor which included three different experimental conditions (Figure 1):

1. *Both Near*: Both users near the display
2. *Both Far*: Both users far from the display

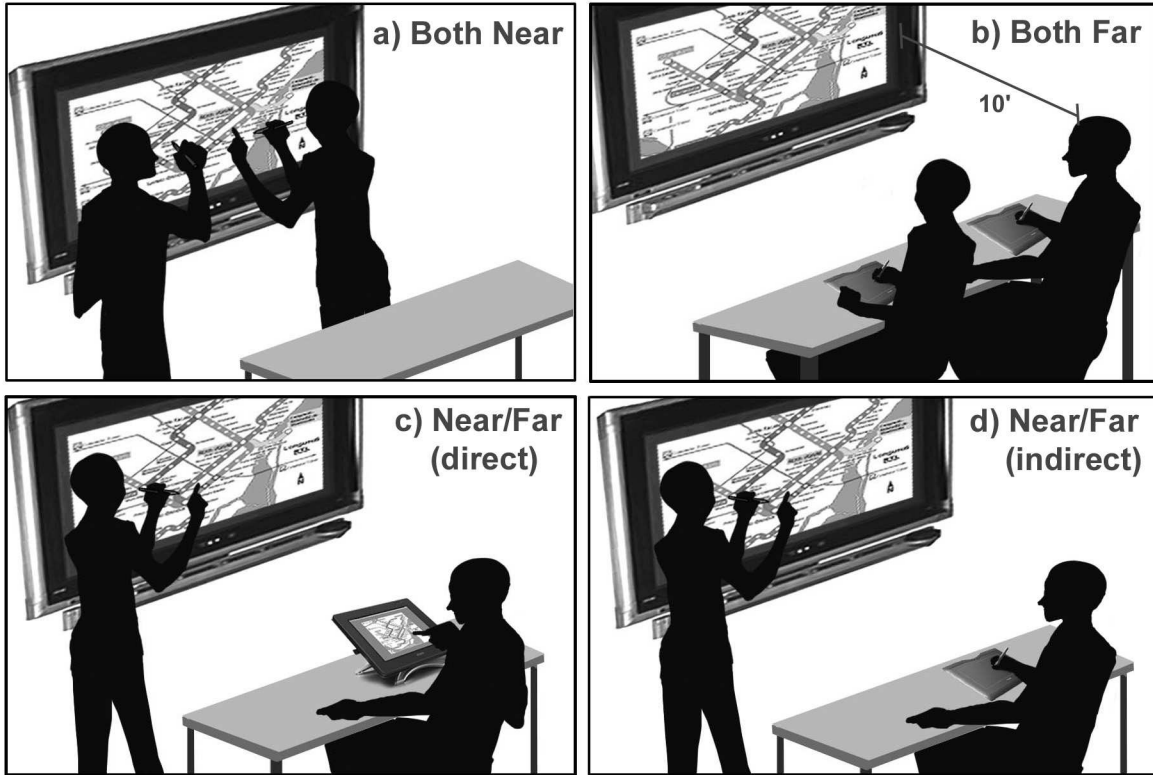


Figure 1. Experimental conditions: both near (a), both far (b), and near/far with direct input (c) and indirect input (d). Stylus-based interaction was used across all conditions. Far participants were seated 10' from the display.

3. *Near/Far*: One user near the display while their partner was far from the display

Users in the “near” condition stood within arm’s reach of the display, so that they could interact directly with it. Users in the “far” condition were seated at a table 10 feet from the display, within the suggested distance range for optimal viewing of displays of this size and were seated to approximate typical meeting room collaboration scenarios. The third condition (*near/far*) was repeated so that each participant had an opportunity to perform in both the near and far positions, resulting in a total of four different arrangements for each pair of participants. It was important to investigate the *near/far* condition with each participant getting an opportunity to perform in both the near and far position to expose any relationship dynamics or individual differences that could affect their behaviour. For example, prior work [9] indicates that people with experience writing on vertical surfaces such as whiteboards are more comfortable using interactive vertical displays.

When users interact with a large shared display at a distance, a choice must be made between a direct or indirect method of input. Input type can have a significant impact on interactions at a distance. Therefore, we explored two input modes as a between-subjects factor when participants were in the *Near/Far* condition:

1. *Near/Far Direct*: The partner far from the display used direct input on an LCD tablet.
2. *Near/Far Indirect*: The partner far from the display used indirect input on a tablet with no display.

Half of our participants (6 pairs) used direct input on the LCD tablet when they were far from the screen (Figure 1c), while the other half (6 pairs) used a tablet with no display for indirect input (Figure 1d). Each modality was stylus-based in order to focus on direct/indirect input and not on differences between input methods.

The three experimental conditions (both near, both far, *near/far*) were counterbalanced to minimize learning effects, although the two *near/far* arrangements were always completed one after the other. The tasks were not counterbalanced as they were very similar to each other and no learning effects were anticipated (i.e. all pairs performed the same tasks, in the same order).

3.2 Task

A set of four route-planning activities were developed based on subway travel. Participants were provided with a subway map on a large display and were asked to complete a series of four activities. A simplified set of subway travel times were provided on the map and allowed participants to gauge the duration of a chosen route. The subway map used in this study was easy to understand and did not require specialized technical knowledge for interaction. Participants could annotate the map (e.g. circling stations, tracing paths, making jot notes) while planning their routes.

The activities consisted of simulated errands and event-planning required during a conference in Montreal, using the four subway lines (yellow, orange, blue, green) to navigate the city. In addition to the general instructions described below, each activity included

other pertinent details such as the required starting and ending locations, nearest subway station to a task location, and time estimates both for walking to the task locations and for completing the actual task. The four activities were completed in the following order:

Activity 1: *You are both attending a conference in Montreal and will have 2 hours to explore the city between talks. One of you wants to see the Botanical Gardens and the other insists on seeing the Expo Dome. Determine if both attractions can be visited during the conference break.*

Activity 2: *You are organizing a dinner for colleagues attending the conference. The conference ends at 5:00pm and the dinner will be held at Schwartz’s Deli. Determine at what time to make dinner reservations if people have to first return to their hotels to freshen up. Your colleagues are staying at hotels near the following three subway stations: the University of Montreal, the Bonaventure, and Vendome.*

Activity 3: *You are both giving a workshop and must pick up items for the workshop from a copy shop at Square Victoria, a novelty shop close to Parc, and a stationary store near the Rosemount station. Plan your route and determine if there will be time for one of you to run the errands during a 90-minute break or if both of you need to go so you can split the tasks.*

Activity 4: *You both would like to drop off your CV in person at three local universities: Concordia, McGill University, and the University of Montreal. Plan your route and determine if you can do this over one 90-minute lunch break or whether the visits must be broken up over 2 days.*

These experimental tasks were similar to those used in previous co-located collaboration studies [9]. Route planning is a realistic task that participants find enjoyable and engaging and requires no specialized knowledge or skills. Participants were encouraged to collaborate as they normally would and no roles in the collaboration were assigned. These activities permitted participants to partition the problem-solving task as they wished. For example, they could use a “divide-and-conquer” strategy, with partners computing different portions of the route or computing travel times in parallel, or they could work together to complete each step.

3.3 Experimental Equipment

A simplified Montreal subway map (see Figure 2) was shown on a 61" plasma display at the front of the room. The display was equipped with a SmartBoard touch sensitive overlay that allowed annotations to be drawn on top of the map. In the “near” condition, participants interacted directly with the large display. Participants in the “far” proximity condition used graphics tablets with styluses: for indirect input, they used Wacom Graphire 4x6" pressure-sensitive tablets; and for direct input, they used a Wacom Cintiq 12x12" pressure-sensitive tablet with built-in LCD display. The Cintiq tablet display was synchronized with the large display, such that all cursor movements and annotations from one screen were shown on the other. In the “Both Near” condition, due to the limitations of the SmartBoard overlay, participants had to coordinate their input on the large display, as only one could interact with the overlay at a time. In the case of the Both Far and the Near/Far conditions, participants could draw simultaneously.

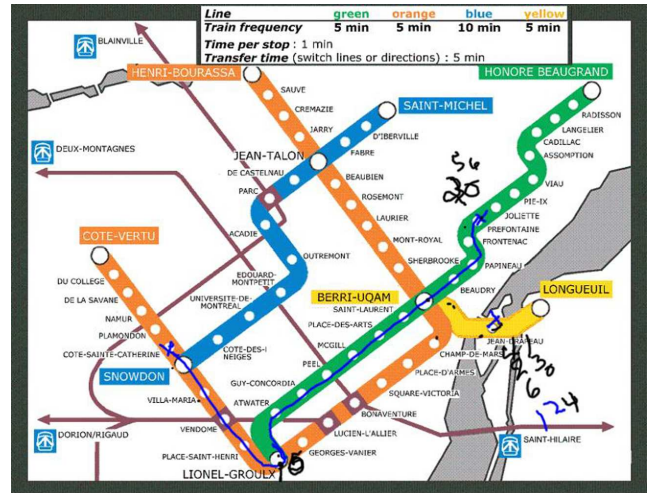


Figure 2. Example of map annotations (made with both partners near).

For indirect input in the far condition, we chose to continue to use tablets rather than mice. This choice was due to the nature of our task. Participants needed to be able to create freeform annotations, which are difficult to generate when using a mouse. This also enabled us to compare stylus-based interactions in all conditions. We also provided pens and paper notepads in all conditions, in case participants preferred to write on paper rather than the display or tablet.

3.4 Procedure and Data Collection

Each participant completed a consent form and background questionnaire that asked about their experiences with computer-based collaboration, with various input devices (direct and indirect), and with large displays. Written instructions were provided for each activity, beginning with a short warm-up task to familiarize participants with the subway rules and the input configuration for that particular condition. After the warm-up, participants began the main activity, which involved answering questions by calculating travel times and routes (the four activities used are described in section 3.2).

Each task was both video- and audio-taped. Coding sheets were used to record observations, including how participant pairs coordinated activities, and the nature of their communication. The map image was saved at the end of each activity so that annotations created during the collaboration process could be examined. Annotations typically consisted of traced routes, calculations, and symbols denoting metro stations of interest to the activity (see Figure 2). During analysis, all four maps (there was one map per activity) belonging to a participant pair were evaluated jointly by two researchers. The maps were ranked on a scale of 1 to 4, where 1 had the most annotations and 4 had the fewest annotations. In the case of disagreement between the researchers, consensus was reached through discussion.

At the end of each activity, participants were given a questionnaire, which included a series of questions on a 5-point Likert scale to rate the enjoyment and effectiveness of the collaboration and map interaction for the proximity condition just completed. After all tasks were completed, participants were given a final questionnaire that asked them to rank the four

arrangements (both near; both far; near/far (with me near); near/far (with me far)) in terms of effectiveness and enjoyment for both interactions with the map and collaboration with their partner. The questionnaires also asked participants to explain their reasoning behind each of their ratings and rankings. The questionnaire results are presented in a descriptive format. No statistical analyses were performed on these data given the small sample size, as well as the fact that the data points were not completely independent (i.e. participants completed the activities in pairs but answered questions individually).

4. RESULTS

In the discussion below, we describe each display proximity condition in terms of its associated strengths and weaknesses related to collaborative interactions, map interactions, and input device issues. We refer throughout this discussion to three tables of results. Table 1 shows the participant rankings of each condition in terms of effectiveness and enjoyment for *collaboration*. Table 2 shows similar data in terms of effectiveness and enjoyment of *map interactions* for each condition. The rankings used a scale from 1 (best) to 4 (worst). Table 3 shows the researcher rankings for quantity of map annotations by condition using a scale from 1 (most) to 4 (least). For each table, the top-ranked condition is highlighted.

4.1 Both Users Near

4.1.1 Collaboration

The majority of participants ranked this condition as being the most effective and the most enjoyable for collaboration (see Table 1). Overall, participants felt this condition allowed them to communicate and share information more easily. In terms of enjoyment, participants felt it was easier and less stressful to collaborate with their partner when they were working side-by-side. These perceptions were validated in our observations; users tended to collaborate fluidly and exhibited very few communication breakdowns (e.g. resolving physical gestures,

Table 1. Participant rankings of each condition in terms of effective and enjoyable collaboration. Note: one participant gave a tied ranking of 3 for the ‘me near’ and ‘me far’ conditions for both measures.

Ranking	1	2	3	4
Effective Collaboration				
Both near	11	5	3	5
Both far	8	8	2	6
Near/Far (me near)	4	4	12	4
Near/Far (me far)	1	7	8	8
Enjoyable Collaboration				
Both near	13	6	0	5
Both far	6	7	5	6
Near/Far (me near)	4	7	6	7
Near/Far (me far)	1	4	14	5

understanding partner’s actions) when they were both working near the display. Although the majority of participants ranked the *Both Near* condition highly, five participants indicated that they felt this condition was the least effective and least enjoyable for collaboration. This demonstrates the individual variability that was evident across participant rankings. This coincides with Brignull et al.’s [1] observation that groups tended to come together around the “interaction point” closest to the display, however the lack of direct input with the display itself in their study makes comparison difficult.

4.1.2 Map Interaction

The majority of participants also ranked this condition as being the most *effective* and the most *enjoyable* for map interactions (see Table 2). These rankings were attributed to the better view users felt they had being close to the map and the ease of direct interaction. However, others felt that the display was harder to see when close and one user explicitly commented that “the board is too big when you stand near, it is hard to recognize everything”. This variation reflects the findings of other work considering field of view when using large displays [12, 24]. Prior to our study, only informal testing was done to ensure that participants would be able to comfortably interact with the map interface when close to the display. When designing interfaces for collaborating with others, a variety of viewing angles and distances need to be considered. Observations also revealed that only seven pairs made use of scratch pads for extra notes and figures in this condition.

4.1.3 Impact of Device

Many participants enjoyed interacting directly with the shared display through the touch-sensitive overlay. Although the novelty of the device may have influenced users’ preferences, the other input devices were also novel to the majority of participants. Furthermore, the rankings for collaboration and map interaction were high despite the need for coordination of input in this condition. Indeed, six participants commented that the lack of simultaneous input caused them to give this condition a lower ranking than they would have done otherwise. For all pairs, we

Table 2. Participant rankings of each condition in terms of effective and enjoyable map interactions.

Ranking	1	2	3	4
Effective Map Interaction				
Both near	12	4	4	4
Both far	3	6	7	8
Near/Far (me near)	5	8	6	5
Near/Far (me far)	4	6	7	7
Enjoyable Map Interaction				
Both near	12	5	3	4
Both far	5	4	5	10
Near/Far (me near)	4	9	6	5
Near/Far (me far)	3	6	10	5

observed that the coordination of input was accomplished without explicit discussion, something that was also observed with the BlueBoard [20].

Despite users' positive perceptions of working close to the large display, several ergonomic issues arose. Some participants had difficulty accessing all areas of the screen and sometimes had to bend down to interact with the lower portion of the map. Others felt crowded standing at the large display with their partner. We often observed that participants' arms got in the way of each other. Participants also had difficulty using the scratch pads and juggling instruction sheets and pens while standing at the display. Observations revealed that participants frequently bent over and wrote against their legs, or kneeled on the floor.

4.2 Both Users Far

4.2.1 Collaboration

Eight (out of 24) participants ranked this condition as being the most *effective* while six ranked it as being the most *enjoyable* (see Table 1). Being close to their partner was reported to be of benefit for collaboration. Others felt that this configuration better supported simultaneous interactions (which was not possible in the both near condition), and that there was more room to plan and discuss strategies when sitting at the table.

Despite these positive responses, we observed some participants having difficulty resolving the physical gestures made by their partner in this condition, an issue previously raised by Rogers and Lindley [18]. For example, participants in one group elected not to use the cursors to gesture, relying solely on physical gestures (i.e. pointing to locations on the wall display). After comparing individual counts of stations, they discovered that they had miscommunicated the route they were following and each had calculated times for a different route.

4.2.2 Map Interaction

Having both participants positioned far from the display was not perceived to be the most *effective* condition for map interactions by the majority of participants (see Table 2). However, the rankings for this condition were spread fairly evenly across the 2nd, 3rd, and 4th positions. The main concern raised with this condition was the ease of interacting with the indirect input device. Analysis of the map annotations supported this notion, with this condition having the fewest map annotations (see Table 3). In fact, two groups did not annotate the map at all in this condition. In contrast, scratch pads were used frequently, with

Table 3. Researcher rankings for the quantity of map annotations by condition. Note: There are 24 instances of the Near/Far condition and 12 each for Both Near and Both Far

Ranking	Map Annotations			
	1	2	3	4
Both near	2	4	6	0
(/12)	(17%)	(33%)	(50%)	(0%)
Both far	1	0	2	9
(/12)	(8%)	(0%)	(17%)	(75%)
Near/ Far	9	8	4	3
(/24)	(38%)	(33%)	(17%)	(12%)

almost all groups (11/12) utilizing scratch pads at some point during the session. Those participants who did find this condition effective felt it was easier to view the map. The participants ranking for *enjoyment* of map interactions was highly variable in this configuration (see Table 2). Benefits expressed included the suitability of the distance from the display, the ability to sit down and relax, and the fact that annotations on the map could be made concurrently (unlike the *Both Near* condition).

4.2.3 Impact of Device

Participants in this condition used Graphire tablets as indirect input devices. Although the tablets were beneficial because they provided users with the ability to point and gesture using the cursor, observations revealed that participants had difficulty writing words and numbers with the tablets. As a result, they relied more heavily on the scratch pads than in other conditions. For example, in one group, after a participant struggled to write "17" on the display using the tablet, his partner said "why don't you just write on the paper." In another group, one participant preferred drawing a smaller version of the map on the scratch paper and used that to show her partner the locations of the stations of interest, rather than indicating them on the large map. This group did not use the tablets for either gesturing or writing on the display. In their next activity, the partner near to the display said, "this is better".

4.3 Near User / Far User

Having partners separated with one near the display and one far from the display significantly changed the dynamics of the collaboration. We first present general observations about collaboration and map interactions with partners separated, followed by a discussion of issues for the participant in the near and the far positions.

4.3.1 Collaboration

More communication problems were observed when participants were separated from each other. For example, in one group (a dating couple), the near participant had started interacting with the display and his partner (with indirect input) was having difficulty understanding his actions. She said "can you talk to me?" Her partner did not respond. She tried again, "ok... why are you circling it?" Her partner tried to explain and then said, "just read the thing". After some bickering back and forth, the far partner commented, "I don't like sitting down here."

One barrier to effective communication was the difficulty of resolving physical gestures made by the far participant. In one group, the far participant tried to physically point out where a station was on the map and his partner reminded him that he could point using the tablet. In another group, the far participant was pointing at the screen to resolve a misunderstanding but eventually gave up and used the stylus to gesture with the cursor instead.

The difficulty in communicating at a distance was felt so strongly by two groups that they did not stay separated. In one group, the far participant joined their partner near the display. In the other group, the near participant joined their partner at the back. These participants were unwilling or unable to discuss strategy and figure out routes when separated. In each group, one of the participants was not a native English speaker and appeared to

have been embarrassed to speak loudly in front of the researchers. Because of this potential confound, these two groups were excluded from the analysis and two additional groups were recruited.

4.3.2 Map Interaction

Analysis of the map annotations revealed that this condition had the heaviest use of annotations (see Table 3). For eighteen (out of 24) maps, the participant situated near the large display was responsible for most of the annotations. Furthermore, when the far participant used indirect input, in every case (12/12) the partner near to the display contributed most of the annotations. Interestingly, when the far participant used direct input, the partner near the display contributed the most annotations in only half the cases, with four pairs having similar levels of annotations and two pairs where the far participants were responsible for most of the annotations. Scratch pads were also heavily utilized with fifteen (out of 24) participants making extra notes on the scratch pads. Further analysis revealed that the far participant with indirect input made the majority of notes in almost all cases (11/12 pairs).

4.3.3 The Near User

Participants did not consider this condition to be very *effective* for collaboration (see Table 1). In addition, the results were mixed for the *effectiveness* and *enjoyment* of map interactions (see Table 2). Those that did feel the condition was effective indicated their preference for not having to share the display, the ability to maintain control of the display, and the ability for both partners to annotate the display simultaneously. Although some participants felt this configuration afforded them more control, it did not override the overall leadership roles observed in each group. In half of the instances, participants near to the display had an increase in their level of coordination of the activity; however, in only one group did a person that clearly played a more passive role in other conditions switch to an active role when near to the display.

4.3.4 The Far User

Participants ranked this condition as being least *effective* and least *enjoyable* for collaboration (see Table 1). The lone participant who found this arrangement effective indicated that he preferred to take a more passive role. Again, participants gave mixed evaluations of effectiveness and enjoyment of map interactions (see Table 2). Contrasting benefits expressed by the participants included the ability to be more authoritative (directing their partner at the large display) and the ability to take a more passive role (observing their partner at the large display). Other benefits related to the use of direct input (LCD Cintiq tablet), including the ability to have two views of the screen, one of which was smaller and easier to take in.

When the far participants utilized the indirect input device, the strengths and weaknesses of the device were similar to those reported in the *both far* condition. That is, the participants could easily point and gesture to regions on the map using the tablet, but found it difficult to annotate the map. For the pairs who utilized direct input, several instances were observed where the number of displays affected communication. For example, the far participant would sometimes point or trace a route on their personal display using their finger instead of the cursor. This would confuse their partner at the large display who was unable to view the gesture.

Participants were also concerned about having to divide their attention between multiple displays. During the warm-up activity, one participant stated "I can tell now that this is going to be bad for working together because I'll be looking at my screen and not at the other one." During the activity, he told his partner they needed to talk more: "You have to tell me what you're doing... it does [show], but I don't know what you're doing." In other cases we observed participants in the far position who were very engrossed in their individual display and needed to be prompted verbally by their partner on several occasions to look up from their display.

5. DISCUSSION

Our results provide insight into how physical proximity to a shared display and the style of input device used (direct or indirect) can impact collaborative interactions. It is important to understand, however, that assessing the "effectiveness" of co-located collaboration is challenging. Co-located interactions are extremely rich and complex, individual differences significantly impact collaboration, and the choice of task and types interactions required are important factors. As a result, there is no "best" display configuration. We must instead try to understand the various configurations possible and their associated strengths and weaknesses in order to make appropriate choices.

Based on our results, we have identified three key issues that impact technology choices related to proximity: 1) proximity between partners; 2) proximity to the shared display; and 3) interaction at a distance. Concerns related to direct/indirect input observed in our study are interdependent with display proximity and are considered jointly.

5.1 Proximity between partners

The majority of participants felt that having both people close together was more effective (19/24) and more enjoyable (19/24) for collaboration (see Table 4 for combined rankings according to distance from partner). We attribute this to the fact that communication was easier when participants were close together. Several instances of "communication breakdown" were observed in the *near/far* condition. The map was consistently used for gestural communication when both participants were at the shared display. However, map annotation was less frequent when participants were close to each other. This may have been influenced by technological limitations: lack of simultaneous interactions when both participants were near the display and indirect input when both participants were far from the display. Alternatively, participants may have naturally used pointing and gesture more often to communicate when close to each other.

Table 4. Participant rankings in terms of effective and enjoyable collaboration according to proximity between partners.

Ranking	1	2	3	4
Effective Collaboration				
Close to partner	19	13	5	11
Far from partner	5	11	20	12
Enjoyable Collaboration				
Close to partner	19	13	5	11
Far partner	5	11	20	12

These findings suggest that the degree and nature of communication desired for specific tasks is important to consider when deciding where to position partners for a collaborative task.

5.2 Proximity to the shared display

Interacting while close to the shared display was perceived by a majority of participants as being more effective (17/24) and enjoyable (16/24) for map interactions (see Table 5 for combined rankings according to distance from the display). Superimposed pen-based interactions were natural for participants accustomed to whiteboard interactions. However, our activities were relatively short and did not require very complex or repetitive interaction with the display. When deciding on such a configuration, there are important ergonomic issues to consider. First, standing at a display can be tiring for long period of use. Even if chairs are provided, most wall displays are mounted at a height that supports interaction while standing in front of the display. Second, depending on the size of the display, users may need to reach or crouch to interact with areas of the display. Finally, large arm movements are often required, which can be fatiguing.

Being close to the display was preferred for map-based interactions; however, interactions with other artefacts were compromised. We chose to not have any extra tables or chairs near the display to ensure that participants could freely move around in front of the display (noted as a benefit of working at a vertical display in previous research [9]). Without a table, however, it was difficult for participants to write on scratch paper. This reflects a common tradeoff related to physical configurations with large shared displays.

5.3 Interaction at a Distance

Some of the participants in our study felt that interacting at a distance was more comfortable since they were seated and had a broad view of the display. However, if users want to interact with a shared display at a distance, deciding on direct or indirect input

Table 5. Participant rankings in terms of effective and enjoyable map interactions according to proximity to the shared display. Subtotals shown for direct/indirect input when far.

Ranking	1	2	3	4
Effective Map Interaction				
Close to display	17	12	10	9
Far from display	7	12	14	15
*direct input	4	3	2	3
(/12)	(33%)	(25%)	(17%)	(25%)
*indirect input	3	9	12	12
(/36)	(8%)	(25%)	(33%)	(33%)
Enjoyable Map Interaction				
Close to display	16	14	9	9
Far from display	8	10	15	15
*direct input	4	3	2	3
(/12)	(33%)	(25%)	(17%)	(25%)
*indirect input	4	7	13	12
(/36)	(11%)	(19%)	(36%)	(33%)

is an important consideration. Very little research has been conducted to examine the associated strengths and weaknesses of either approach.

5.3.1 Direct Input

Direct input at a distance can only be provided with a secondary visual display or by remote pointing. There are significant interaction benefits to using direct input with a secondary display since it enables users to interact up-close, leveraging their experience with desktop environments. One third of the twelve participants who used direct input when interacting at a distance ranked that condition as most enjoyable and effective overall for interacting with the main display (see Table 5). The text annotations on the map were smaller and more legible when participants utilized direct input at a distance rather than the indirect input device or direct input on the large shared display.

Interaction with a secondary display however is problematic from the perspective of collaboration. When users focus their attention completely on the secondary display, they no longer have a shared visual reference with their partner. This can compromise users' ability to establish a shared understanding [5] and can cause communication problems [22]. In our study, participants often gestured at the secondary display, which was not visible to their partner. If users divide their attention between the two displays, their individual and collaborative interactions may suffer. In our study, we observed that participants who used direct input (at a distance) exhibited less verbal communication than participants in the other configurations. Participants also felt it was difficult to continually switch their view between the two displays.

5.3.2 Indirect Input

Indirect input at a distance is beneficial from a collaborative perspective because it necessitates that both partners attend to the same visual surface. In our study, this resulted in more verbal communication between the partners than in the "direct input at a distance" condition.

Although many users are proficient with a mouse (an indirect input device), it is not well suited for interactions such as creating annotations. However, even with stylus interactions, anything beyond simple pointing can be difficult to perform from a distance. In our study, participants who used the indirect input device (Graphire tablet) at a distance interacted less with the map than their partner who was close to the map. Similarly, when both people used indirect input devices at a distance, they created fewer map annotations overall. This suggests that indirect interaction from a distance using the Graphire tablet may have been more challenging than direct interaction using either the wall display or the peripheral display. Indeed, only 8% (3/36) of participants ranked this condition as most effective for map interactions and 11% (4/36) ranked it as most enjoyable, compared with 33% (4/12) for both measures for participants with direct input (see Table 5).

6. CONCLUSIONS AND FUTURE WORK

Co-located collaboration on a large display is affected by many factors, including proximity between partners and distance from the display. Although research in other domains has explored issues such as proximity and collaboration, we cannot make the assumption that collaborative behaviour will remain constant with

the introduction of technology. Evaluation of complex collaborative infrastructures [10, 17, 23-25] can provide rich observations that contribute to our overall knowledge of such systems. Contextual evaluations also shed light on interesting patterns of perception and behaviour [1, 3, 4, 7, 8, 11, 14, 18, 20]. In both kinds of research, however, it can be difficult to extrapolate general principles. By focusing on basic configurations of input modality and proximity, our study revealed some interesting effects of input devices and display proximity on collaboration that can aid practitioners in choosing appropriate configurations for co-located collaboration.

Results demonstrated people's strong preference for working closely together, regardless of how far they were situated from the display. In terms of display interaction, most of our participants preferred to be close to the display, finding it both enjoyable and effective. However, this arrangement may require horizontal surfaces to be made available to place artefacts on when working; as well, interacting directly with the entire surface of the large display can be difficult for users. While being seated farther from the display can be comfortable and allow for an overview of the whole screen, this mode of interaction may be more difficult for annotations. When investigating the effects of input methods for interaction at a distance, we observed that having a secondary display for the purposes of direct input interfered with the establishment of shared understanding in the near/far condition, as there was no single shared point of reference.

Because this was a preliminary investigation, we did not explore all aspects of input modes at this stage. The choice of task also influences the appropriateness of a given device. While the map task was well suited for stylus interaction, for a task that requires substantial textual input (e.g. document editing) a keyboard and mouse would be more appropriate. We wish to delve more deeply into these issues in future studies. As well, we intend to study in more detail how multiple displays, with direct input, affect interaction at a distance. These studies will provide valuable information about the creation of shared understanding with multiple displays in a co-located setting.

7. ACKNOWLEDGMENTS

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