Negotiating for Space? Collaborative Work Using a Wall Display with Mouse and Touch Input

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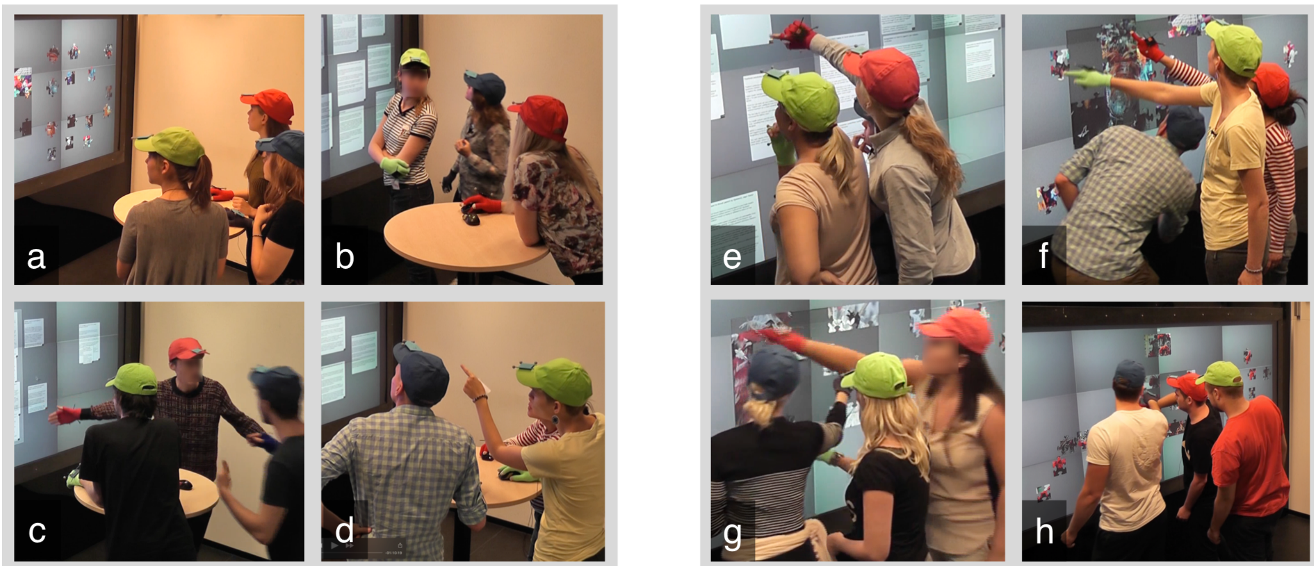

Mouse: (a) most frequent formation, standing by table; (b) some close to display; (c) discussion group formation; (d) gesturing.

Touch: (e) reaching over; (f) moving under; (g) several arms crossing; (h) negotiating the tight space.

Figure 1: Video snapshots from study of groups using wall-display with Mouse (left) and Touch (right) input.

ABSTRACT
Wall-sized displays support group work by allowing several people to work both separately and together. However, whether people interact directly through touch input or indirectly through mouse input can have profound effects on collaboration. We present a study that compares how groups collaborate using either multitouch or multiple mice on a wall-display. Participants used both input methods to work on two tasks: a shared-goal task and a mixed-motive task. Results show differences in participants' awareness in collaborative tasks between the two input methods. The results also help understand the physical constraints touch input set on participants' control of actions in collaborative tasks. We discuss how this influences collaboration. Results also show that touch input did not promote more equal participation than mouse input. We contrast the findings to earlier research on wall-display and tabletop collaboration.

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INTRODUCTION
Wall-sized displays that provide multi-user input can support group work; they allow several people to work both separately and together. However, the way users interact with wall-displays, whether directly through touch or indirectly through mouse input, mid-air pointing, or hand-held devices, may have profound effects on how people collaborate. Unfortunately, the effects that input methods have on group processes around wall-displays are not well understood as they are rarely studied [3]. It is therefore unclear how best to use different input methods in designing for different collaboration scenarios.

This paper compares direct touch input to indirect mouse-based input. Direct touch seems promising for several reasons: it has been shown to improve the user's experience [33] and performance [7] compared to indirect mouse input;

to provide better awareness in group work than indirect input methods [12,24]; and to promote more equal participation [20,28].

Most of the above findings are from research on tabletop displays, however, and may not necessarily transfer to wall-sized displays. For example, direct touch requires up-close interaction (which limits the user's overview of the display) and requires physical movement in order to reach all parts of the display. In contrast, indirect input allows interaction from a distance (i.e., providing better overview) with less physical movement. Indirect input may thus perform better and be preferable to touch for some tasks [15]. Input methods may also impact group processes differently for wall-sized displays than for tabletop displays: Given a much larger surface, people may not as easily see what others are doing; it is unclear if group members need to negotiate for space or might get in each other's way when interacting directly with a wall-display; and touch might not lead to more equal participation among groups using larger display surfaces [20]. More studies are therefore needed to help understand how different forms of input influence group behavior around wall-displays.

We conducted a study of 3-person groups using a 3-meter wide wall-display comparing a multiple-mice condition to a multi-touch condition (see Figure **1**, left and right). We compared conditions on performance and satisfaction, awareness of others, use of movement and physical space, and equality of participation in wall-display interaction. Because group processes are dependent on the task [21], we included both a mixed-motive task and a shared puzzle task (representing different situations where people have shared and/or conflicting goals). This helps understand possible interactions between input method and type of task.

The key contribution is new empirical data on group processes around wall-displays that help understand how using direct touch input or indirect mouse input affects group processes. We present results that contrast findings from earlier comparisons of touch and mouse input in large display collaboration. This work may help understand more broadly how best to use and combine direct touch and indirect input (e.g., mid-air gestures) in large-display interfaces for different scenarios of use.

RELATED WORK

We first discuss input for wall-displays and our rationale for comparing touch and mid-air; then review research on collaboration around large displays that has focused on input method and configuration; and discuss dimensions of group processes that have been related to input.

Input Methods for Wall-Display Interaction

People can interact with wall-sized displays in many ways, including mouse input [3], direct touch [14], laser pointers [23], freehand pointing [32], or handheld devices [4]. We focus on touch and mouse input primarily because they are well known and widespread methods of input, yet fundamentally different: Touch input is *direct* and happens up close, whereas mouse input is *indirect* happens from a distance. We considered comparing touch to mid-air gestures, which also provides indirect input from a distance and may be suitable for large display interaction [15,32]. However, mouse input has been compared to touch in many studies (whereas mid-air gestures have not), including studies of group processes, which is the focus of this work.

For large display interaction, mouse and touch input have known drawbacks: Direct touch requires users to physically move in order to reach all areas of a large display, although alternative techniques have been proposed for interacting with areas that are physically out of reach [2,17]. In contrast, mouse input allows interaction from a distance, but may confine users to a specific location. Also, it can be difficult to keep track of mouse cursors [13], hard to distinguish between multiple cursors, and distracting with the presence of multiple cursors [10].

Many studies have compared touch and mouse input, finding that touch performs better [7,29,33] and is preferred [7,33] over mouse; still, mouse may be best for some tasks [7]. Touch may be preferred by users for improving their experience feeling more competent, more in control, more related to others, and more immersed [33]. Users also seem to prefer touch for collaboration [10,22].

Studies of Input for Wall-Display Collaboration

Research on wall-displays has studied groups seated at a distance using one or more mice for input [3,13] or using touch [1,14]. However, touch and mouse input has not been compared for collaboration on wall displays. Birnholtz et al. studied people working on a negotiation task while seated in front of a 5-meter wide display [3]. They found that groups sharing a single mouse had better discussions, but less parallel work than when each had a mouse; also, single-mouse users could dominate negotiations. They suggested that future work should study other input modalities including freehand pointing and direct pen input.

Few have studied groups using touch input (but see the many studies of public displays [e.g., 1,25]) or freehand pointing for interacting with wall-displays. Jakobsen and Hornbæk found that pairs mixed joint and parallel work on a mixed-focus task using a 3-meter wide multitouch display [14]. Groups shared the display without negotiating for space, whereas tabletop studies have found users to use territories for coordinating group work. However, people may use space and interact with each other differently when they work in larger groups or on tasks where they do not work towards a single shared goal.

Influence of Input Method on Group Processes

The input method that people use influences many dimensions of group processes. We focus on dimensions that have been studied in earlier work on collaboration around large displays.

Awareness

Awareness is a widely used term in the literature on shared workspaces [8]. In this study, we are interested in how the method of input that people use influences their *awareness of others* as defined by Yuill and Rogers [34], p. 4: "the degree to which awareness of users' ongoing actions and intentions is present or made visible moment-to-moment".

Empirical research on tabletop displays suggests that touch input enhances awareness compared to indirect input. Ha et al. studied pairs using a tabletop display for card-matching games and found that participants have a better awareness of the actions of others when they use touch or a stylus rather than when they use a mouse [10]. Nacenta et al. compared five techniques for reaching and manipulating objects in collaborative tasks and found direct touch input (called Drag-and-drop in their study) to have the best all-round performance and user rankings [24]. Last, Hornecker et al. compared mouse and touch input for 3-person groups collaborating on a planning task around a tabletop display and found higher awareness of others' activity in the touch condition [12].

The above studies provide different data to support the view that direct touch interactions are more visible to others than the "virtual user embodiments" (e.g., mouse pointers) with indirect input. Participants in Ha et al.'s study responded significantly faster to their partner's actions in the touch condition (expansive physical gestures were more obvious and noticeable), and 20 out of 24 participants found touch more helpful in communicating what their partner was doing [10]; Nacenta et al. concluded that with indirect input (Telepointers) it was difficult to stay aware of others' actions and, sometimes, in keeping track of their own pointer [24]; and Hornecker stated that the use of mice "provides far fewer visible bodily clues about what each person is doing" [12].

These findings from tabletop research might not hold for wall-sized displays, as one study has shown that horizontal displays provide greater awareness than vertical displays [27]. In particular, direct touch happens up close, which limits the user's overview; with a much larger surface (the largest in the above studies was 125x160cm [24]), people may not as easily see what everyone is doing. In contrast, indirect input from a distance may allow for a better overview.

Interference and collisions

Research mentions problems of interference, collisions, and occlusion when collaborating with touch. Six participants in Ha et al.'s study disliked or were concerned about touch because of physical interference and collisions [10]; participants preferred mouse for interacting in areas in front of their partner, and voiced concerns of invading the other's territory and of bumping hands. Hornecker et al. found that touch caused more actions that interfere with each other, but that interactions were more fluid and interferences were resolved more quickly [12]. Doucette et al. found people to avoid touching or crossing arms over a tabletop [6]; in conditions with different on-screen virtual representations of users' arms, people did no hesitate to reach across. Nacenta et al. found no difference in conflicts (two reaching for the same object) with touch (Drag-and-drop) and indirect input (Telepointers), yet touch was ranked as low-conflict and indirect input as high-conflict [24].

Different interferences and conflicts may show when collaborating around a wall-display than with tabletop displays: users move and may occlude with their entire body. This has not been studied, however. Peltonen et al. describe conflicts between activities on a public multitouch wall-display [25] only for touch and not for indirect input.

Use of space

It is unclear how the method of input, whether direct up close or indirect from a distance, influences groups' use and sharing of space. In a study of pairs collaborating on route-planning tasks by Hawkey et al., participants found it more effective and enjoyable to interact directly with the display through touch and to work closely together [11]. However, people must negotiate use of the shared space when close (which can give rise to interference and collisions); therefore, people sometimes form territories when space is scarce [31]. In a controlled experiment with jigsaw puzzles on a whiteboard, Azad et al. [1] found use of territories similar to those suggested by Scott et al. on tabletop interfaces [31]. They also varied how pieces were laid out (so as to see how participants had to retrieve pieces from areas close to other participants) and found people mostly moved to access pieces instead of asking for help. Other research has found less clear use of territories in wall-display collaboration.

Equality of participation

Research has aimed at promoting equality of participation [5], because it is desirable in many tasks (e.g., negotiations benefit from multiple perspectives; collaborative learning). The method of input also seems to influence equality of participation. In particular, Marshall et al. compared conditions that varied the number (all members can act or only one) and type (touch versus mice) of input device [20]. They found that a multi-touch surface increases physical interaction equality and lowers perceptions of dominance, but does not affect levels of verbal participation.

Display orientation has been found to have little impact on equality of participation [26]. We might thus expect more equal participation with touch on wall-displays. However, this is contrary to our expectation that users would participate more equally using mice because there are no physical constraints for control [34].

Summary

We have discussed several dimensions of group processes that are influenced by the method of input. Our current understanding is mainly informed by empirical research on tabletop displays, however, and results from this research may not hold for wall-sized displays given how vertical and horizontal displays support groups differently [27]. We see several gaps in the literature that we will address:

- Touch has been preferred over mouse in many studies, but not in studies involving wall-displays. Preference for touch or mouse input when collaborating on a wall-display thus remains unclear.
- Touch provides better awareness on tabletops compared to mouse input, but people may not as easily see what others are doing on larger surfaces. It is unclear what people do to maintain awareness using touch and mouse.
- Touch can lead to interference and conflicts (e.g., arms crossing) around tabletops, but it is unclear how users interfere with each other around vertical displays.
- Touch input requires sharing of physical space in a way that mouse input does not; it is unclear how this affects the way users negotiate for space on wall-sized displays.
- Touch can make tabletop users participate more equally, but it is unclear whether touch would lead to more equal participation than mouse for wall-displays.

STUDY

The study aimed at understanding how group processes vary depending on whether users interact directly with a wall-display through touch input or indirectly through mouse-based input. Participants worked in groups of three solving two types of collaborative task.

Experimental conditions

Two conditions varied the method of input as the key independent variable:

Touch. Participants used multi-touch input, allowing them to move freely and interact simultaneously with the display. Participants were restricted to using only one hand.

Mouse. Participants used multiple mice on a table (70cm diameter) placed 1.5m from the center of the display, requiring distant interaction. Each participant had a wireless mouse that controlled their own on-screen cursor, which they could freely place on the table. In contrast to earlier studies of groups using large displays [3,13], participants were not seated and they were free to move.

Participants

Forty-two participants (23 female), 19–33 years (*M* = 24.7), signed up in groups of three. They had known each other between 1 month and 29 years (*Mdn* = 1.7 years), and they were required to have normal or corrected-to-normal eyesight. Participants were paid the equivalent of €27; participants achieving the highest total score on the Newspaper task received an additional €13.

Apparatus

Participants used a multitouch display containing 24.8 megapixels (7,680×3,240). The active display area measures 2.8×1.2m, with the bottom edge 89cm above the floor. The display is back-projected by 12 HD projectors arranged in a 4×3 grid. The display is operated by a single computer with two NVidia Quadro 2000D graphics cards and four hardware extenders.

The display surface detects touch using camera-based tracking with diffused surface illumination. Six cameras, capturing 640×480 pixels at 30 frames per second, are connected by Firewire to a computer, which runs Community Core Vision for tracking touch points. The touch points detected within each camera image are multiplexed by a custom program written in Java.

We tracked participants using an OptiTrack motion capture system. Each participant wore a hat along with a glove on their dominant hand, both with reflective markers attached. We placed a video camera at the back of the room to record the groups while they worked on the tasks.

Tasks

We included two tasks in order to help reveal possible task effects on group processes: a newspaper task adapted from previous work by Birnholtz et al. [3] and a jigsaw puzzle (which has also been studied in related work [1,22]).

Newspaper task: Participants were asked to layout the front page of a newspaper by selecting from among 20 articles shown on the display and placing them in the front page. No more than 10 articles could be selected, articles could not overlap, and large areas of white space were not permitted. Participants were told that they were associate editors for different sections (Politics, Life, Tech). Each participant was assigned three keywords and earned points each time a keyword appeared in an article on the front page (e.g., 3 points for 'election'); articles had to be completely contained within the final front page layout in order to yield points. They knew the others' areas, but not the keywords and point values.

Articles were based on real newspaper articles, but were truncated to comparable length (around 1200 characters) and modified to include the requisite keywords. Articles varied substantially in their value to each participant, but the points were balanced across all articles such that no participant had a built-in advantage. Of the 20 articles, 6 were valuable only to one participant (e.g., 5, 0, 0 points), 2 were equally valuable to all participants (4, 4, 4 points), 3 were valuable to two participants (e.g., 4, 4, 0 points) and 9 were of higher value to one participant (e.g., 6, 2, 2 points).

Groups were given 10 minutes to complete the front page, but if all agreed on the layout they could finish before time.

Puzzle task: Participants solved a jigsaw puzzle consisting of 40 pieces. The puzzles were colorful photos of carnival parades cut into jigsaw pieces placed in random positions on the display. Groups had 5 minutes to solve a puzzle.

The tasks require the same type of interaction and display usage: both involve moving objects to a central area of the display in order to reach a goal. Objects were equally spread out so that participants had to interact with different parts of the display, resembling real-world tasks on wall-displays (e.g., classification tasks or affinity diagramming [16,18]).

Tasks represent opposite ends of the conflict-cooperation dimension in McGrath's group task circumplex [21]. In the Puzzle task, group members share a common goal and are expected to cooperate; in the Newspaper task, group members have conflicting goals: the shared goal of finishing the front page layout and the individual goal of maximizing his or her score in order to receive the monetary reward that we provide as incentive. Participants are thus expected to negotiate in the Newspaper task.

Interfaces
Participants used an interface for each task, which provides different modes for the Mouse and Touch conditions. The two modes support similar interactions for moving articles or puzzle pieces by selecting and dragging (either by mouse clicking or touching) and resizing articles by selecting and dragging a resize handle on the article. Only one user at a time can manipulate a particular article and puzzle piece: as long as one user is engaged with a piece, input from other users is ignored by that piece.

Input modes
In the Touch condition, when a participant's finger touches the surface a touch cursor appears and a "mouse press" event is triggered; a "mouse release" event is triggered when removing the finger from the surface. We restricted participant interactions to touch input from only the hand wearing the glove.

In the Mouse condition, each participant controls their own pointer, as identified by the colors red, green, and blue, and which corresponds to the color of the mouse used. Mouse pointers are large (50×80 pixels) so as to make them easier to keep track of.

Newspaper task interface
The newspaper interface consists of a frame (2000×2400 pixels, 74×89 cm) in the center of the display, which represented the newspaper front page, and articles that can be placed within the front page. Articles are 500×500 pixels; text is in 16pt font determined in pilot tests to be readable from a distance. Articles are placed in random positions and do not overlap nor intersect the front-page frame. Articles can be moved by dragging and can be resized using a handle in the article's bottom-right corner. The content of each article spans the entire width of the article window. If the text of an article does not fit within its window, the text is truncated; the resize handle shows the percentage of the currently visible content. Initially, each article has a black border that turns white if the article is appropriately contained within the front page (this indicates to participants that the keywords contained in it yield points); the border becomes stippled if the article overlaps other articles or intersects the frame.

Puzzle task interface
The puzzle interface contains a frame (2000×1400 pixels, 74×52 cm) in the center of the display for assembling the puzzle, above which a smaller view of the target image is shown, and 40 puzzle pieces randomly placed in a grid so that the pieces do not overlap nor intersect the puzzle frame. Individual puzzle pieces can be dragged.

Design
The study used a within-subjects design with input method (Touch, Mouse) and task type (Newspaper, Puzzle) as independent variables. Groups performed two repetitions of each task for each input method. The order of input method and task type were systematically varied to counter effects of learning and fatigue. In all, participants performed 14 (groups) × 2 (input methods) × 2 (task type) × 2 (trials) = 112 tasks.

Procedure
Participants were first explained the purpose of the study and were required to sign a consent form. Participants were randomly assigned a color, which determined their keywords in the Newspaper task. Participants were then equipped with hat and glove in their color (they used the mouse of the same color). The tasks were explained to participants and they spent about five minutes working on example tasks in order to familiarize themselves with the interfaces; they were encouraged to ask questions. The introduction lasted about 20 minutes.

Participants then completed four tasks with each input method. After completing all tasks with an input method, participants were administered a questionnaire containing questions about perceived task and group performance (3 questions, see Table 2), their awareness (3 questions, see Table 3), participation (3 questions, see Table 7), and 18 questions from a validated measure of social presence [9], all using a 7-point scale. After all tasks had been completed, participants filled out a questionnaire asking about their age and sex; how well they knew each other; whether they preferred mouse or touch; and for comments on using mouse and touch. We summed the Newspaper task scores to identify the winner of the extra €13 reimbursement.

In all, the experiment lasted 75 minutes on average.

Data collection
We combined different types of data for analyzing task performance and group process (see Table 1):

Video. Sessions were recorded on video for analysis of participants' awareness, movement and use of the space.

Interaction data. We instrumented the interface to automatically collect data about participants' interactions.

Tracking. We identified the participant performing each interaction by recognizing only touches with the gloved hand; we quantified participants' movements.

Group work dimension	Related work	Data				Analysis and measures
Performance and satisfaction	Ha et al. [10]		I		S	Task time and progress; subjective satisfaction
Awareness	Ha et al. [10]; Hornecker et al. [12]	V			S	Qualitative analysis; social presence measures
Interference and conflicts	Ha et al. [10]; Doucette et al. [6]; Hornecker et al. [12]; Nacenta [24]	V	I	T	S	Identification of arm-crossing, conflicting actions, and touching
Movement and use of space	Azad et al. [1]; Birnholtz et al. [3]; Jakobsen & Hornbæk [14]	V	I	T		Movement patterns; display-sharing metrics for both off-screen and on-screen space
Equality of participation	Marshall et al. [20]		I		S	Index of inequality

Table 1: Dimension of group work investigated in this paper, related work, data collected (Video, Interaction data, Tracking data, Self-report), analysis methods and measures used in this study.

Self-report. Participants answered questionnaires about subjective satisfaction, awareness, participation, and social presence; benefits and drawbacks with each input, and which input they preferred.

Hypotheses, questions, and analysis measures

Task performance and preference. Although group processes are the focus of this paper, the performance and preference for mouse and touch provides context for the other results. We expected participants to be more effective with Mouse because of lower levels of interference than with Touch when participants work simultaneously; participants can move an item across the entire display with small arm movements using a mouse compared to extensive physical movement dragging items through touch. Based on earlier work, we expected a preference for touch. We logged time on task and the individual score for each group member throughout the Newspaper task. Questionnaires asked participants about their satisfaction and performance with each input method, and their preference.

Awareness. From tabletop studies [10,12,24], we would expect higher awareness for Touch than for Mouse. In the video recordings, we characterized awareness work and indications of awareness [12], but did not analyze them quantitatively. Moreover, the questionnaire asked about participants' perceived awareness of each other's work, how they monitored each other's actions, and social presence [9], for each input condition. Attentional allocation scores did not appear internally consistent (Cronbach's $\alpha = .46$) and were thus discarded.

Interference and conflicts. Tabletop studies have shown more incidents of interference with touch [12], but rated as low-conflict [24]. We analyzed interaction data, tracking data, and the video recordings to identify and characterize instances where participants' actions interfered with others or gave rise to conflicts using each of the input methods.

Movement and physical space. Research has shown varying uses of territories in touch-based wall-display interaction [1,14]. With touch input, participants may physically constrain others' access to parts of the display, while mice should give participants equal access to control of all regions of the display (cf. findings of Birnholtz et al. [3]). We studied how participants used space both in physical space (from the tracking data and the video recordings) and in on-screen behavior (from interaction data). We quantified how participants used and shared the display in terms of time spent and actions performed in nine equally sized regions of the display; the three center regions contained the newspaper front page and the puzzle.

Equality of participation. While earlier work suggests more equal participation with touch [20] we were curious to see more equal participation in the Mouse condition where there are no physical constraints for control [34]. Moreover, we would expect less equal participation in the Newspaper task where group members have an incentive to dominate. To measure how equally participants contributed, we used an index of inequality [20], which has previously been used for evaluating groupware. For each group, we calculated the index I for each task using the following equation [20]:

$$I = \frac{1}{N}\sum_{i=1}^{N}(E_i - O_i) \Big/ \frac{1}{2}(1-\frac{1}{N})$$

N is the size of the group; E_i is the expected cumulative proportion of interaction events if each participant contributes equally; and O_i is the observed cumulative proportion of events, starting with the participant who contributed the least. The index I ranges between 0 and 1; a low index represents greater equality of participation.

RESULTS

Below we report findings for each dimension in Table 1.

Performance and Satisfaction

Task Performance

Participants completed puzzles faster using Mouse ($M = 2.9$ min, $SD = .9$) than Touch ($M = 4.3$, $SD = .7$), indicated by Wilcoxon rank sum $W = 89$, $p < .0001$; 39% of the puzzles for Touch were not finished within the 5-minute time limit, compared to 7% for Mouse. Moreover, participants often agreed on the front-page layout before the time limit; 23% of the Newspaper tasks were completed in less than five minutes. However, there was little difference in time spent on the tasks using Mouse ($M = 7.8$, $SD = 2.5$) and Touch ($M = 7.3$, $SD = 2.9$), W = 445.5, $p = .38$.

Throughout the Newspaper task, we logged the individual score for each group member. The mean individual score is shown for each 30s-interval in Figure 2 for Mouse and Touch. We note that scores appear to increase much faster using Mouse than Touch, and participants' average score after the time limit is lower with Touch. At least one group

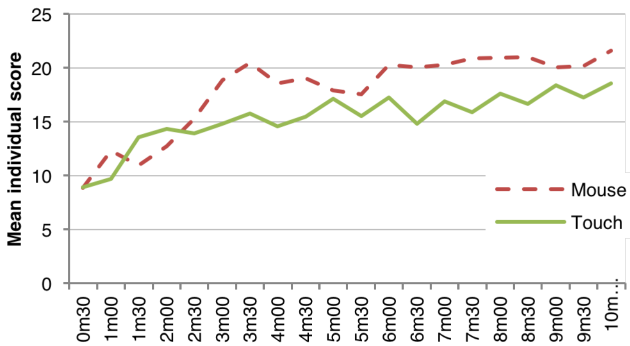

Figure 2: The mean score of individual group members at 30s intervals in the Newspaper task for the two input conditions.

commented that they did not view articles in all areas of the display, which might explain the lower individual score.

Subjective Satisfaction

Participants were more satisfied with their group's performance in solving the tasks with Mouse than with Touch, indicated by Mann-Whitney $U = 1252.5$, $p < .001$. There was no difference between Mouse and Touch for the other two satisfaction questions (see Table 2).

Preference for Input Method

Preference for input was mixed: 23 preferred Mouse, while 18 preferred Touch; one was undecided. Participants' comments give possible reasons for the higher satisfaction with Mouse and the mixed preference:

The main reasons that participants mentioned for liking the Mouse condition were that it gave a better overview (24 participants), was faster (19), easier to use (12), whereas the most often mentioned drawbacks were a lack of attention on partners (12), that it was too far away to see (12), and less collaboration (8).

For Touch, participants mentioned that it was fun (13 participants), better collaboration (10), and noticing and being aware of my partners' actions (10); frequently mentioned drawbacks were bad responsiveness (21), lack of overview (12), and it was slow (9). Irregular touch tracking was a likely cause for some of the feedback about the responsiveness of touch.

Awareness

Qualitative analysis of video helped characterize behavior in the two conditions. First, with respect to awareness work, we saw verbal shadowing for all groups in both conditions. For Mouse, we saw participants in every group gesture with their mouse pointer (e.g., circular motions to draw attention)—this seemed quite effective; few gestured with their hands. For Touch, in contrast, we found frequent use of deictic gestures, for all groups. In both input conditions, participants often relied on consequential communication of moving puzzle pieces or articles. Also in both input conditions, we saw changes in F-formations that allowed participants better awareness of each other while focusing

	Mouse	Touch
I enjoyed working on the tasks using this input method	5.9	5.3
I was satisfied with our performance in solving the tasks	5.9	4.8
I enjoyed working together with my partners using this input method	5.9	5.9

Table 2: Mean ratings in satisfaction with group work for Mouse and Touch.

	Mouse	Touch
I knew what my partners were doing	4.3	4.6
I believe that my partners knew what I was doing	4.4	4.6
Co-presence ($\alpha = .94$)	4.8	5.4
Perceived behav. interdep. ($\alpha = .90$)	4.4	4.8

Table 3: Means of measures of attention and social presence.

on a particular area of the display or signifying intent (to discuss, for example, see Figure 1c); this was, however, much more frequent and fluid for Touch.

Second, as for positive signs of awareness, participants generally worked well in parallel, particularly in the Mouse condition. It seemed quite easy for participants to follow from a distance what others were doing, in the Mouse condition, perhaps because most actions were quite visible (moving pieces or articles).

Third, we saw more negative signs of awareness for Touch than Mouse, which was surprising. Most prominent were interferences, where participants bumped into each other or where one participant inadvertently interrupted work or caused extra work for someone else; typically, when they got in each other's way or when their arms crossed. There were also instances of verbal monitoring, where a participant questioned actions of others' that had happened in other parts of the display, but such cases were not common. For Mouse, in contrast, we saw few instances of participants interfering with the work of partners, mostly when one participant inadvertently blocked another's view, and also only few instances of verbal monitoring.

There does not seem to be much difference in how well participants felt they knew what each were doing for the two input methods, see Table 3. However, input seems to have some influence on social presence: The measure of co-presence [9] was greater for Touch ($M = 5.4$, $SD = 1.3$) than for Mouse ($M = 4.8$, $SD = 1.4$), $U = 633$, $p = .026$. Co-presence is "the degree to which the observer believes he/she is not alone and secluded, their level of peripheral or focal awareness of the other, and their sense of the degree to which the other is peripherally or focally aware of them" [9]. Participants' comments (as described above) also suggest that they felt better aware of others' actions, however, a few wrote that it was hard to sense partner's actions. We found no significant difference for perceived behavioral interdependence, $U = 698$, $p = .14$.

Interference and Conflicts

In the video analysis, we found instances of participants' actions inadvertently interfering with others (sometimes due to lack of awareness of others as described above). This happened most often for puzzles in the Touch condition. We found participants in all groups reaching in front of each other, and crossing arms—quite frequently for some groups. We analyzed tracking data to find that participants' arms crossed (for more than 1s) eight times on average for Puzzle tasks and two times for Newspaper tasks. In most cases, participants reached in front of each other without causing interference. Also, interferences were often easily resolved. However, there were also instances of participants accidentally touching or bumping into each other.

Moreover, we found instances where participants' actions conflicted with the interests of others, albeit almost exclusively in the Newspaper task. For Mouse, we saw conflicts arising in several groups when participants replaced each other's articles on the front page. For instance, the participants of group 1 did so repeatedly; interaction analysis showed that they moved articles on or off the front page 81 times in a single task (M = 26 times per task for Mouse, M = 19 times for Touch). There were also participants in one group that moved articles to occlude articles that other participants were reading, which caused discussion. We think such conflicts were rare for Touch because of the physical constraints imposed by touch input: whereas a mouse pointer can be moved without constraint across the display, touch interactions are constrained by distance of reach and by obstructions from other users.

Participants also made comments that suggested problems: nine participants mentioned as a drawback of Touch that their arms tangled/bumped into each other.

Movement and Use of Space

Participants moved and used the physical space quite differently in the two conditions and with great variation between groups.

Proxemics and Use of Physical Space

Table 4 below summarizes the time participants spent in each other's intimate (0-46cm), personal (46-120cm), and social (120-240cm) proxemic distance zones, as defined by Hall [1963]. Two groups were excluded in this analysis based on tracking data, because of tracking errors.

Altogether, participants spent the majority of time close together with both Mouse and Touch. Data further show that participants spent the most time in front of the center three regions of the display (M = 71%, SD = 18). This is expected, as both tasks to a large extent required working on a shared area (i.e., front page layout or assembled puzzle). There was an association between input type and time spent in different regions, $X^2 = 4565.4$, $df = 2$, $p < .0001$. Participants spent relatively more time (M = 81%, SD = 14) in the center regions with Mouse input than Touch (M = 61%, SD = 15); participants stood mostly around the table. There was also an association with task, $X^2 = 1600.6$, $df = 2$, $p < .0001$. Participants spent more time in the center regions for Puzzle tasks (M = 79%, SD = 13) than for Newspaper tasks (M = 62%, SD = 19), where they spent time reading the articles in the left and right regions.

	Intimate	Personal	Social
Mouse	32%	64%	4%
Touch	26%	55%	19%

Table 4: Time participant spent in different proxemic zones.

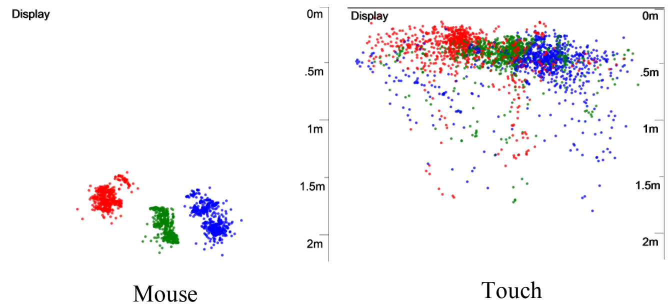

Figure 3: Plots of all positions of each member (Red, Green, Blue) in group 3 for Mouse and Touch conditions.

Sharing of Space in Front of Display

We defined a display-sharing metric of how *equally participants spent time* in different regions of the display. We calculated this on a per-task basis as the mean index of inequality (I) of time spent in different regions, weighted by the relative amount of time spent in each region. Values close to 1 indicate that participants spent time in each their separate regions. A repeated measures analysis of variance (RM-ANOVA) showed a main effect of input, $F(1, 11) = 237.9$, $p < .0001$. As expected, values are higher for Mouse (M = .91, SD = .12) than for Touch (M = .45, SD =.16). There was no effect of task, $F(1, 11) = 3.97$, $p = .071$. We combine the metrics with analyses of videos and of plots of participants' locations (Figure 3 shows plots for group 3) to examine differences in the spatial behavior of the groups.

In the Mouse condition, most groups stood in relatively fixed positions around the table throughout all tasks (Figure 3, left), and mostly facing the display (Figure 1a). However, some groups moved closer to articles in the Newspaper task to read them (groups 5, 6, and 14; see Figure 1b); groups stayed put to solve Puzzle tasks, which seemed to be very efficiently done in parallel using mice.

In the Touch condition, participants moved much (see, Figure 3, right). Groups varied in how they shared the space when using touch input: group 3 seemed to partition the display the most with a metric of .72 (see Figure 3, right); group 4 had a metric of .28 for Touch. Based on informal observations of the groups, we think one reason why some groups did not share the display more evenly with Touch is that they settled into stationary positions, particularly in the Puzzle task.

Movement Patterns: Negotiating for Space

We reviewed the video recordings to better understand how participants moved when sharing the space in front of the display in the Touch condition. Overall, there is great variation in how participants moved and they were seen to fluidly switch between a wealth of different formations. We note some interesting patterns of movement and formation:

First, as already suggested, participants stood close to each other much of the time and we often saw them reaching in front of, over, or under each other's arms (see Figure 1e-h).

Second, group members were sometimes unavoidably obstructed from parts of the display, especially when two participants stood closely together. In some cases, this led to the participant reaching over (e.g., Red in Figure 1e), in particular, when they wanted to grab an article or piece and move it somewhere else.

Third, group members navigated for a position close to the center region. For example, Green in group 4 (see Figure 1h) spent almost all time in one puzzle task in the center region; he occasionally stepped back to let his partners access the puzzle only to step close again; he reached in front of his partners instead of moving around them; looked over the others' shoulders instead of moving around.

Fourth, there was a tendency for some group members to "get stuck" in certain regions; one participant commented that he felt that he did not get to view articles in all parts of the display.

Use and Sharing of the Display Space

To understand how participants' sharing of the display differed between Mouse and Touch, we also calculated the display-sharing metric (described in a previous section) for how equally participants *interacted* in different regions of the display. This is shown in Table 5 for both input methods and task types. RM-ANOVA showed no main effect of input, $F(1, 13) = 1.08$, $p = .11$. This is surprising because Mouse provides participants equal opportunity to interact with all regions of the display, which should lead to even use (cf. Birnholtz et al. [3]). We found a main effect of task, $F(1, 13) = 21.0$, $p < .01$. Participants interacted more equally in Puzzle tasks (see Table 5); we observed some groups forming personal territories in the Newspaper task for grouping articles of relevance to them.

Equality of Participation

There is no difference between the input conditions in the index of inequality (I) based on the number of interactions each group member performed, shown by RM-ANOVA with input and task as factors, $F(1, 13) = 1.70$, $p = .215$. This is contrary to results from research on tabletop collaboration. However, there was a main effect of task, $F(1, 13) = 13.1$, $p < .001$, as we expected: group members did participate more equally in the Puzzle task ($M = .16$, $SD = .09$) than in the Newspaper task ($M = .25$, $SD = .12$). This is interesting: In the Newspaper task, where participants had conflicting goals, some participants interacted more, perhaps to their own advantage. Still, there was no interaction between input method and task, $F(1, 13) = .072$, ns. Table 6 shows the mean index of inequality for each input method and task type.

	Mouse	Touch	M
News	0.50	0.52	0.51
Puzzle	0.41	0.45	0.43
M	**0.45**	**0.49**	**0.47**

Table 5: Display-sharing metric: Weighted mean index of inequality in interactions performed in different regions of the display (0 means each region was evenly use by all).

	Mouse	Touch	M
News	0.23	0.26	0.25
Puzzle	0.14	0.18	0.16
M	**0.19**	**0.22**	**0.21**

Table 6: Mean index of inequality of interaction for each input method and task type.

	Mouse	Touch
We collaborated well on the tasks	5.2	5.4
One partner dominated the tasks	3.0	3.0
One partner was left out of the tasks	1.9	2.2

Table 7: Mean ratings on questions on equality of participation for Mouse and Touch.

We also asked participants questions relating to their group participation (see Table 7). There was no difference in ratings of how well they thought they collaborated on the tasks, whether one partner dominated the tasks, or whether one partner was left out (as shown by Mann-Whitney test).

DISCUSSION

Here we summarize our main findings and relate them to previous work. We also discuss possible implications for designing input for collaborative wall-display interfaces.

Mouse versus Touch

Preference was almost evenly split between the Mouse and Touch conditions, in contrast to earlier studies where touch input has been preferred [7,33]. Each input method seemed to have benefits and drawbacks that require difficult tradeoffs, compared to what earlier work suggests.

Efficient, providing overview, but conflicting actions

Mouse input was found faster and more accurate by participants; puzzles were completed faster and participants seemed to raise their individual scores faster in the Newspaper task. Participants benefited from mouse in several respects: They could reach and move articles and puzzle pieces across far distances with minimal physical movement. They were able to overview the display, which seemed to help in keeping track of their partners' actions. However, some felt they were too far away and moved closer to the display, occasionally blocking the view for other participants. Also, the high level of control over objects anywhere on the display gave rise to conflicts for some groups.

Fun, supporting collaboration, but physical interference

Touch, in contrast, was found to be more fun, although the responsiveness of the touch display was disliked. Dragging objects using touch was slower, required extensive physical movement, and participants had to navigate around each other. Many participants mentioned that touch was best for collaboration. Participants gave ratings that scored higher on a measure of co-presence, which indicates that they had better awareness of others. However, we also saw more instances of participants interfering with each other, inadvertently bumping into each other on occasion. Such incidents were disliked by some, while others found that the physical interaction between participants made the experience more fun and enjoyable.

Our results on preference and performance are limited by the optical touch implementation used: It is possible that people might prefer to use or perform better with other touch systems (e.g., low-latency capacitive sensing). Tasks can also be considered to favor mouse input because text was adjusted to be readable from a distance.

Differences to Earlier Research

An important contribution of this work is to bridge a gap between research on input methods for collaboration on tabletop displays and research on wall-displays:

Awareness of others. Tabletop work has found that people are better at monitoring others' work using touch [10,12]. Our data are less clear, suggesting a different tradeoff between touch and mouse in providing awareness on a wall-display. Participants made few physical gestures in the Mouse condition, resembling results of Ha et al. [10] (1:4 ratio of physical vs. virtual gestures). However, mouse gesturing seemed unproblematic; we saw no signs of and received no comments suggesting the type of difficulties reported in other research of keeping track of others' actions, despite the much larger display. A key difference is that participants worked mostly from a distance where they had a good overview. Also, task actions (moving articles or pieces) and the large pointers were likely more visible.

Negotiating for space. With touch input, people seemed to negotiate for space, moving around and reaching over each other when working in the shared area of the display. This can be contrasted to a recent study of pairs working closely together on a similarly sized wall-display with ample space for working together (although on a different type of task) [14]. Our findings suggest that limitations in the usability of direct touch on wall-displays for collaborative tasks may show when three or more users concentrate on a small shared area. Controlled studies varying group size and task could help understand these physical limitations better.

Interference and conflicts. Similar to tabletop research comparing touch and mouse input [12,24], we found more interference with touch. A key difference from tabletop research concerns the physical movement that is required with a wall-display compared to when users stand around a tabletop (like in [12]). Different types of conflicts seem to arise from the two types of input: touch leads to more unintentional interferences, whereas we saw more conflicts from deliberate actions in the mouse condition (e.g., moving or occluding articles of others) than in the touch condition. We wonder if the physical constraints of touch interfaces may regulate such potential conflicts. However, touch input may cause other conflicts as users may physically block access, like what Marshall et al. observed for children around a tabletop [19].

Touch avoidance. Previous work has found people to avoid reaching close to others, with very few instances of crossing arms [6]. In contrast, we saw participants frequently reach in front of others; many participants commented on this, however. We speculate if these differences are caused by the different form factors of vertical and horizontal displays or by other factors; empirical comparisons are needed.

Equal participation. Earlier work [20] has found higher inequality (I = .45) with multiple-mice than multi-touch (I = .25) on a tabletop display, and less perceived chance of one participant dominating the task. In contrast, the wall-display we used afforded quite equal participation regardless of input method (I = .21), perhaps because it offers more space and opportunity for interacting. However, Marshall et al. also used a more realistic design task, which might have given rise to different group dynamics [20].

Implications

We see several implications for collaborative work on wall-displays. First, our results suggest that wall-displays can afford equal participation regardless of input, making them suitable in situations where this is desirable. As expected, the negotiation task resulted in an index of inequality than was higher than in the puzzle task, but that was still low. Techniques dedicated to promoting equal participation [e.g., 5] may not be necessary, at least for some tasks.

Second, our results show different issues in maintaining awareness of others' actions on wall-displays with mouse and touch input than research has found for tabletop collaboration, suggesting a need for other design guidelines.

Third, while touch seems suitable for collaboration, there is an associated cost to reaching distant content and problems with physical interference that need addressing. Indirect input methods do not have these problems. Research has explored combining touch and mid-air gestures [15,30], and recent work suggests a place for mid-air gestures for interacting with wall-displays when there is a cost to using touch [15]. The present study demonstrates situations where such costs of touch materialize for collaborative work—when space in front of the display is scarce or when users need access to distant objects and other users stand in their path—that call for new interaction techniques.

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REFERENCES

1. Alec Azad, Jaime Ruiz, Daniel Vogel, Mark Hancock, and Edward Lank. 2012. Territoriality and behaviour on and around large vertical publicly-shared displays. *Proceedings of the Designing Interactive Systems Conference*, ACM, 468–477. http://doi.org/10.1145/2317956.2318025
2. Anastasia Bezerianos and Ravin Balakrishnan. 2005. The vacuum: facilitating the manipulation of distant objects. *CHI '05: Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM Press, 361–370. http://doi.org/http://doi.acm.org/10.1145/1054972.1055023
3. Jeremy P Birnholtz, Tovi Grossman, Clarissa Mak, and Ravin Balakrishnan. 2007. An exploratory study of input configuration and group process in a negotiation task using a large display. *Proceedings of the SIGCHI conference on Human factors in computing systems*: 91–100. http://doi.org/10.1145/1240624.1240638
4. Andrew Bragdon, Rob DeLine, Ken Hinckley, and Meredith Ringel Morris. 2011. Code space: touch + air gesture hybrid interactions for supporting developer meetings. *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, ACM, 212–221. http://doi.org/10.1145/2076354.2076393
5. Joan Morris DiMicco, Anna Pandolfo, and Walter Bender. 2004. Influencing Group Participation with a Shared Display. *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, ACM, 614–623. http://doi.org/10.1145/1031607.1031713
6. Andre Doucette, Carl Gutwin, Regan L. Mandryk, Miguel Nacenta, and Sunny Sharma. 2013. Sometimes when We Touch: How Arm Embodiments Change Reaching and Collaboration on Digital Tables. *Proceedings of the 2013 Conference on Computer Supported Cooperative Work*, ACM, 193–202. http://doi.org/10.1145/2441776.2441799
7. Clifton Forlines, Daniel Wigdor, Chia Shen, and Ravin Balakrishnan. 2007. Direct-touch vs. Mouse Input for Tabletop Displays. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 647–656. http://doi.org/10.1145/1240624.1240726
8. Carl Gutwin and Saul Greenberg. 2002. A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Comput. Supported Coop. Work* 11, 3: 411–446. http://doi.org/http://dx.doi.org/10.1023/A:1021271517844
9. Chad Harms and Frank Biocca. 2004. Internal Consistency and Reliability of the Networked Minds Measure of Social Presence. Retrieved September 29, 2015 from http://cogprints.org/7026/
10. Vicki Ha, Kori M. Inkpen, Tara Whalen, and Regan L. Mandryk. 2006. Direct Intentions: The Effects of Input Devices on Collaboration Around a Tabletop Display. *Proceedings of the First IEEE International Workshop on Horizontal Interactive Human-Computer Systems*, IEEE Computer Society, 177–184. http://doi.org/10.1109/TABLETOP.2006.10
11. Kirstie Hawkey, Melanie Kellar, Derek Reilly, Tara Whalen, and Kori M. Inkpen. 2005. The proximity factor: impact of distance on co-located collaboration. *Proceedings of the 2005 international ACM SIGGROUP conference on Supporting group work*, ACM, 31–40. http://doi.org/http://doi.acm.org/10.1145/1099203.1099209
12. Eva Hornecker, Paul Marshall, Nick Sheep Dalton, and Yvonne Rogers. 2008. Collaboration and interference: awareness with mice or touch input. *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, ACM, 167–176. http://doi.org/http://doi.acm.org/10.1145/1460563.1460589
13. Petra Isenberg, Anastasia Bezerianos, Nathalie Henry, Sheelagh Carpendale, and Jean-Daniel Fekete. 2009. CoCoNutTrix: Collaborative Retrofitting for Information Visualization. *Computer Graphics and Applications: Special Issue on Collaborative Visualization* 29, 5: 44–57.
14. Mikkel R. Jakobsen and Kasper Hornbæk. 2014. Up Close and Personal: Collaborative Work on a High-resolution Multitouch Wall Display. *ACM Trans. Comput.-Hum. Interact.* 21, 2: 11:1–11:34. http://doi.org/10.1145/2576099
15. Mikkel R. Jakobsen, Yvonne Jansen, Sebastian Boring, and Kasper Hornbæk. 2015. Should I Stay or Should I Go? Selecting Between Touch and Mid-air Gestures For Large-Display Interaction. *Proc. INTERACT 2015, LNCS 9298*, Springer, 455–473. http://doi.org/10.1007/978-3-319-22698-9_31
16. Tejinder K. Judge, Pardha S. Pyla, D. Scott McCrickard, Steve Harrison, and H. Rex Hartson. 2008. Studying Group Decision Making in Affinity Diagramming. Retrieved March 15, 2013 from http://eprints.cs.vt.edu/archive/00001043/
17. Azam Khan, George Fitzmaurice, Don Almeida, Nicolas Burtnyk, and Gordon Kurtenbach. 2004. A remote control interface for large displays. *Proceedings of the 17th annual ACM symposium on User interface software and technology*, ACM, 127–136. http://doi.org/10.1145/1029632.1029655
18. Can Liu, Olivier Chapuis, Michel Beaudouin-Lafon, Eric Lecolinet, and Wendy E. Mackay. 2014. Effects of Display Size and Navigation Type on a Classification Task. *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, ACM, 4147–4156. http://doi.org/10.1145/2556288.2557020
19. Paul Marshall, Rowanne Fleck, Amanda Harris, et al. 2009. Fighting for Control: Children's Embodied

Interactions when Using Physical and Digital Representations. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 2149–2152. http://doi.org/10.1145/1518701.1519027

20. P. Marshall, E. Hornecker, R. Morris, S. Dalton, and Y. Rogers. 2008. When the fingers do the talking: A study of group participation for different kinds of shareable surfaces. *Proceedings of TABLETOP '08*, IEEE Computer Society, 37–44.
21. Joseph E. McGrath. 1984. *Groups: Interaction and Performance*. Prentice-Hall, Inc., New Jersey, USA.
22. Christian Müller-Tomfelde, Claudia Schremmer, and Anja Wessels. 2007. Exploratory study on concurrent interaction in co-located collaboration. *Proceedings of the 19th Australasian conference on Computer-Human Interaction: Entertaining User Interfaces*, 175–178. http://doi.org/10.1145/1324892.1324925
23. Brad A. Myers, Rishi Bhatnagar, Jeffrey Nichols, et al. 2002. Interacting at a Distance: Measuring the Performance of Laser Pointers and Other Devices. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 33–40. http://doi.org/10.1145/503376.503383
24. Miguel A. Nacenta, David Pinelle, Dane Stuckel, and Carl Gutwin. 2007. The effects of interaction technique on coordination in tabletop groupware. *Proceedings of Graphics Interface 2007*, ACM, 191–198. http://doi.org/http://doi.acm.org/10.1145/1268517.1268550
25. Peter Peltonen, Esko Kurvinen, Antti Salovaara, et al. 2008. It's Mine, Don't Touch!: interactions at a large multi-touch display in a city centre. *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, ACM, 1285–1294. http://doi.org/http://doi.acm.org/10.1145/1357054.1357255
26. Brianna Potvin, Colin Swindells, Melanie Tory, and Margaret-Anne Storey. 2012. Comparing Horizontal and Vertical Surfaces for a Collaborative Design Task. *Adv. in Hum.-Comp. Int.* 2012: 6:6–6:6. http://doi.org/10.1155/2012/137686
27. Y. Rogers and S. Lindley. 2004. Collaborating around vertical and horizontal large interactive displays: which way is best? *Interacting with Computers* 16, 6: 1133–1152. http://doi.org/10.1016/j.intcom.2004.07.008
28. Yvonne Rogers, Youn-kyung Lim, William R. Hazlewood, and Paul Marshall. 2009. Equal Opportunities: Do Shareable Interfaces Promote More Group Participation Than Single User Displays? *Human–Computer Interaction* 24, 1: 79 – 116.
29. Farzan Sasangohar, I. Scott MacKenzie, and Stacey D. Scott. 2009. Evaluation of Mouse and Touch Input for a Tabletop Display Using Fitts' Reciprocal Tapping Task. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 53, 12: 839–843. http://doi.org/10.1177/154193120905301216
30. Alexander Schick, Florian van de Camp, Joris Ijsselmuiden, and Rainer Stiefelhagen. 2009. Extending Touch: Towards Interaction with Large-scale Surfaces. *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, ACM, 117–124. http://doi.org/10.1145/1731903.1731927
31. Stacey D. Scott, M. Sheelagh, T. Carpendale, and Kori M. Inkpen. 2004. Territoriality in collaborative tabletop workspaces. *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, ACM, 294–303. http://doi.org/http://doi.acm.org/10.1145/1031607.1031655
32. Daniel Vogel and Ravin Balakrishnan. 2005. Distant Freehand Pointing and Clicking on Very Large, High Resolution Displays. *Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology*, ACM, 33–42. http://doi.org/10.1145/1095034.1095041
33. Diane Watson, Mark Hancock, Regan L. Mandryk, and Max Birk. 2013. Deconstructing the Touch Experience. *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces*, ACM, 199–208. http://doi.org/10.1145/2512349.2512819
34. Nicola Yuill and Yvonne Rogers. 2012. Mechanisms for collaboration: A design and evaluation framework for multi-user interfaces. *ACM Trans. Comput.-Hum. Interact.* 19, 1: 1:1–1:25. http://doi.org/10.1145/2147783.2147784