Effect of Screen Configuration and Interaction Devices in Shared Display Groupware

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ABSTRACT
Interactive tabletop and wall surfaces support collaboration and interactivity in novel ways. Apart from the traditional keyboards and mice, such systems can also incorporate other input devices, namely laser pointers, marker pens with screen location sensors, or touch-sensitive surfaces. Similarly, instead of a vertically positioned desktop monitor, collaborative setups typically use much larger displays, which are oriented either vertically (wall) or horizontally (tabletop), or combine both kinds of surfaces.

In this paper we describe an empirical study that investigates how system constraints can affect group performance in high pace collaborative tasks. For this, we compare various input and output alternatives in a system that consists of interactive tabletop and wall surface(s). We observed that the performance of a group of people scaled almost linearly with the number of participants on an (almost perfectly) parallel task. We also found that mice were significantly faster than laser pointers, but only by 21%. Also, interaction on walls was significantly faster than on the tabletop, by 51%.

Categories and Subject Descriptors
H.5.2.h [**User Interfaces**]: Input devices and strategies; H.5.3.c [**User Interfaces**]: Group and Organization Interfaces – Computer-supported cooperative work.

Keywords
Laser pointers, tabletop, interactive walls, CSCW.

1. INTRODUCTION
Based on the increasing affordability of large-scale display and input technologies, interactive tabletop and wall surfaces have recently been investigated in the research community. Furthermore, a growing number of people acknowledge the utility of computer-aided collaboration systems in problems that necessitate collaboration among individuals with different skills and backgrounds [3]. Shared display groupware (SDG) systems allow multiple people at a single location to work together on digital artifacts. Furthermore, SDG systems can easily keep track of all interaction events for immediate undo, as well as later study, analysis, and record keeping. Data exchange is also facilitated. Co-located interactive systems also have the advantage that they maintain the advantageous features of face-to-face communication and do not suffer from the known overhead of communication through a different channel, such as an audio/video link.

Fully interactive tabletops and interactive walls are one of the few technologies that seamlessly aid co-located collaborative activities. One contributing factor is that user interfaces for SDG systems are typically designed to require less-than-average computer skills. The corresponding software typically offers only options that are pertinent to the current task, thus reducing the complexity of the user interface. Similarly, the input modalities are kept as simple as possible, without offering too many alternatives. All these strategies directly and indirectly increase the number of people who can actively participate in a collaborative effort.

1.1. Effect of Number of Participants on Collaboration
In collaboration, multiple people work together towards a common goal. Generally, collaboration happens because a task can be accomplished either faster, with better quality, or because goals with larger scope can be attacked. However, collaboration involves communication overhead, and hence some efficiency is typically lost in the process. For example, conflict resolution on simultaneous interaction consumes time. This overhead usually results in e.g. three people performing a task only 2.5 times as fast. However, the amount of the overhead depends strongly on the nature of the task. In closely coupled tasks this overhead can be much smaller. In some instances it is even possible that some tasks can be completed more *efficiently* by more people, that is, more work will be accomplished by *each* person on average (carrying a very heavy object up the stairs is an example – one person will find this kind of task very hard and will require much more time).

Ryall et al. [19] looked into the effects of table size, group size, and the work strategies around the table in a poem composition task. As was expected, larger groups performed faster than smaller ones. Performance did not scale linearly in the number of participants; a group of 4 people was only about 50 % more productive than a group of 2 (there was no group of size 1). However, in that experiment, the task was cognitively relatively demanding as it required all people to read printouts and recreate the contents with word tiles on the table. Given that participants were novices, part of the overhead is clearly due to the fact that communication patterns and conflict resolution strategies were not "optimal". Consider e.g. the same task performed by three experts. They would briefly discuss the overall strategy, then work in parallel at peak performance, and only merge results and/or share observations from time to time. As experts rarely make errors, the communication/cognitive overhead would be very small. Given a group of people with such a level of expertise, any overhead introduced by the technical system (i.e. the *system-dependent overhead*) will have relatively much more negative effects than in novice collaboration.

The study presented in this paper attempts to deduce a lower bound of *system-dependent overhead* by investigating the average individual performance in groups of various sizes. From a technical standpoint, it is desirable that individual performance during collaboration drops as little as possible, compared with solo activities. Consequently, our experimental design attempts to ignore (most of the) interpersonal communication overheads and focuses more on technical factors, such as whether there is a need to improve the *technical* capabilities of the infrastructure.

1.2. Laser Pointers

Most existing large collaborative systems employ touch sensitive screens, pen-based systems, or mice as the primary means for user interaction. These devices require (almost) no training. Sometimes touch sensitive systems use gesture recognition [5] to enhance the interface via gesture commands. But this kind of interaction technology is known to suffer from the discoverability problem, i.e. without training it is hard to discover the gestures. Pen-based systems share most of the properties of touch sensitive systems. Both touch screens and pens require direct touch, i.e. do not work at a distance. Mice, on the other hand, are a well-known input technology from desktop systems, which provide only indirect pointing. One of the limitations of mice in collaborative setups is the lack of awareness of where one's partner is pointing, exacerbated by the usually very small distance that the mouse typically travels on supporting surface.

Laser pointers as input devices have been investigated in several large screen setups (e.g. [1], [14], [15], [21], [23]). One of the biggest advantages of laser pointers is that they can provide both close-range manipulation (by touching the surface with the laser pen for precise manipulation) as well as the ability to work at a distance. Additionally, laser pointers are straightforward to use. Moreover, and most importantly, in multi-user laser pointer systems [14] the saliency of laser dots on a screen not only gives each user instant feedback as to their own pointer's location, but also helps to enhance the awareness of other people's actions. Finally, using a laser pointer from a distance reduces obscuration of the screen by hands/fingers/pens and reduces dirt accumulation on the screen.

Laser pointers have been already compared with mice in a standardized evaluation [14]. In that study the laser pointer was found to be slower than the mouse by about 10%. However, in that experiment, an NTSC video camera was used, which has a relatively slow refresh rate of 30 Hz (or 60 *fields* in interlaced mode) and the laser pointer casing was relatively bulky. A similar performance disadvantage of laser pointers with respect to mice was noted in other work as well [13]. In informal experiments with a similar setup we observed that the camera's sampling rate may have a noticeable effect of the performance of laser pointers as input devices. Hence, we employ a set of high-speed non-interlaced cameras in the current study, with a refresh rate of 120 Hz. This compares favourably with the performance of a typical desktop mouse[1]. As an NTSC camera yields only half the pixel resolution of a typical computer projection screen, we use multiple cameras in a tiled arrangement, as well as sub-pixel accurate dot-location algorithms to ensure that the effective resolution of the input device is at least three times the pixel resolution of the screen in each dimension in the worst case (with an average of five times the resolution). We believe that this design decision addresses a technical performance bottleneck that may disadvantage laser pointers a priori.

[1] The sampling rate of USB mice is typically 125 Hz.

1.2.1. Laser Pointers vs. Mice

A computer mouse has the advantage of familiarity for most computer users in many scenarios. The mouse's inherent stimulus-response (SR) compatibility[2] problem is well documented in the literature, and easily observed by watching children learn to use the mouse. However, practically all computer users have fully adapted to this issue and their performance is not affected anymore. Nevertheless, when attempting to use a mouse under different conditions, such as using a mouse with large interactive surfaces, various problems may reappear. First, the relative orientation of users to the work surface matters. E.g. users will approach a whiteboard from either side or from the middle, but can work from any accessible side of a tabletop. Especially on tabletops, this means that moving the mouse may move the cursor 90 degrees relative to the real motion, which confuses users. Second, a mouse is a *relative* pointing device, which leads to the phenomenon that on large screens users are more likely to loose the location of the mouse cursor. In such cases, users typically have to laboriously scan the display to locate the (relatively small) cursor again. In line with this argument, a study by Ha *et al.* [9] indicated that styli used on a touch screen were more natural to use and allowed better support for gesturing compared to mice. On the other hand, no investigation was performed in that work as to how good these devices are for *pointing* performance.

Our present study attempts to quantify the abovementioned factors and determine if the fact that mice suffer from SR compatibility and are *relative* pointing devices has measurable impact on performance when compared side-by-side with lasers in a co-located collaborative environment The intent of this comparison is to reveal information that will allow designers of future collaborative systems to make better design choices.

1.3. Shared displays

Shared displays in a co-located setting provide a unique set of benefits. Practically all successful large screen technologies directly support a larger angular field of view. This improves interaction comfort through better readability of the presented information and/or the fact that more information can be displayed at the same time. It also greatly increases visibility of data even if the participants change their physical positions within the working area (e.g. by moving closer to a wall). Additionally, having multiple distinct screens allows people to better manage their collaboration, e.g. by assigning screens to specific activities or specific kinds of data. Overall, collaboration with shared displays provides the richness present in face-to-face interactions combined with the advantages of the use of computers. The computer aspect adds here many useful facilities, such as digital operations, save, load, undo, automatic logging, etc.

Tabletop displays, as described by Scott *et al.* [20], "are digital tabletops that support small-group collaborative activities, such as group design, story sharing, and planning". Table surfaces also have the additional benefit of familiarity, as tables are a ubiquitous technology used in everyday interactions. Since tables are usually significantly larger than standard displays they also afford each individual a personal space.

Orientation, however, causes problems with tabletop displays, as there is no unambiguous "top" to a table. Because the orientation

[2] This relates to the fact that a horizontal *forward-backward* mouse motion corresponds to an *up-down* motion of the cursor on the vertical display.

of users around the table can be drastically different, actions like reading documents can become more difficult than usual. Despite that, one study by Rogers and Lindley [18], in which direct contact pointing was used, has found horizontal displays to be more enabling for parallel work than vertical displays. Another group also supports this argument [5], mentioning that flat surface encourage joint browsing, sharing and manipulation of images. Vertical surfaces were considered "awkward" as people are expected to stand beside one another, which is less appropriate for collaboration. As our system merges horizontal and vertical surfaces into a single system, we consider our set-up to be sufficiently different from the ones in [5] and [18]. Hence, we believe that any findings from our research will complement the results uncovered in the work of those authors.

1.4. Motivation

Overall, our present study attempts to quantify the above-mentioned compromises of familiarity vs. inherent suitability for different pointing tasks between lasers and mice as input devices. Furthermore, we investigate the differences between tabletops and walls as interactive surfaces in co-located collaborative environments. This will give guidance for more informed choices for system and user interface design. Furthermore, it will yield directions for designers for choosing what sort of information to place on what kind of surface and, even more importantly, which kind of interaction to support on which screen. Finally, we will investigate how overall performance scales with adding more users.

2. EXPERIMENTAL SETUP

2.1. Apparatus

The experiment was performed on the Multi-User Laser Table Interface (MULTI) platform [22]. Although MULTI (Figure 1) includes *three* wall displays and a tabletop display, in our study we employed only the table and the middle wall. While these screens are oriented differently, they have almost the same size, i.e. 1.1 m by 1.5 m (3¾′ by 5′) each. To facilitate software creation and simplify the system design, a single computer drives all five projectors (3 walls and 2 for the table). All five displays feature fully accelerated 3D graphics hardware. To eliminate potential problems with shadows, back projection is used for all display surfaces. Additionally, the tabletop display uses two seamlessly tiled projectors to provide increased resolution, compared to the wall screens. Whenever desired, the two tiled screens can be combined into a single display through graphics driver functionality, creating a 1536 x1024 pixels continuous horizontal working area. This mode was used in this experiment for the table display.

The dimensions of the table itself (1.3 x 1.7 m, approx. 4' x 5'8") permit five people to sit comfortably around it, with two people each on the left and right sides, and a single person at the end. In our study we chose to seat only three people around the table, one on each accessible side, thus providing a larger amount of space between participants.

The MULTI system supports multiple laser pointers and mice (Figure 2) concurrently and independently. This is achieved by multiplexing the laser diodes in the laser pointers, synchronized with the camera frame rate [14], [17]. Application software running on MULTI can either receive all pointing events by user identifier or enable a mode, in which any laser event is mapped to a single (shared) mouse cursor. During the experiments we used the first mode, i.e., our application interpreted the events and generated the cursors without relying on a system cursor. Multiple optical mice are supported via the CPN-mouse package [4], which allows applications to obtain separate pointing events for all mice connected to a computer.

Figure 1. MULTI – A collaborative system with an interactive tabletop and three interactive walls (left and right screens were not utilized)

In this study, we paid close attention to the following issues to ascertain that possible confounding factors were accounted for:

- While the table and the wall had differing orientation, we chose a square portion of each surface, the middle part of the wall, and the bottom portion of the table. Hence, each interactive area was 1.1-by-1.1 m.
- The tabletop has higher resolution. Hence, the targets were sized so that the physical sizes matched (i.e. the tabletop targets were proportionally large in terms of pixels, but targets were physically the same size on both screens).
- Although the table has a barely visible seam due to the use of two projectors, we positioned the experimental targets so that the seam did not intersect any of the targets.
- Since mice work in screen coordinates, we scaled their sensitivity so that the sensitivities are equal in the physical coordinates. In other words, an identical physical movement resulted in the same amount of cursor motion on the different screens.
- As explained above, laser pointers are tracked at 120 Hz, which is almost identical to the 125 Hz sampling rate used by the USB mice. Moreover, while both mouse positions as well as laser pointer locations are measured with higher accuracy than screen location, both are reported only at integral pixel locations.

2.2. Task

Our experiment consisted of having groups of three people play a computer controlled targeting game. The game is based on the ISO 9241-9 pattern [12], which has been used previously to evaluate pointing devices [1], [6]. Thirteen circular dots (with diameter 4.0 cm) were arranged along the edge of a larger circle with 0.30 m diameter (Figure 4). For each circle, one of the dots was initially highlighted with green colour and the players were supposed to acquire that target first. After clicking on this target, another dot roughly diametrically opposite from the preceding one becomes highlighted. This is repeated until all targets in the circle have been hit. The index of difficulty of such task is approximately 2.9 bits, computed as $\log_2$ (*distance*/*width*+1).

Figure 2. Mouse and laser pointer used in the study.

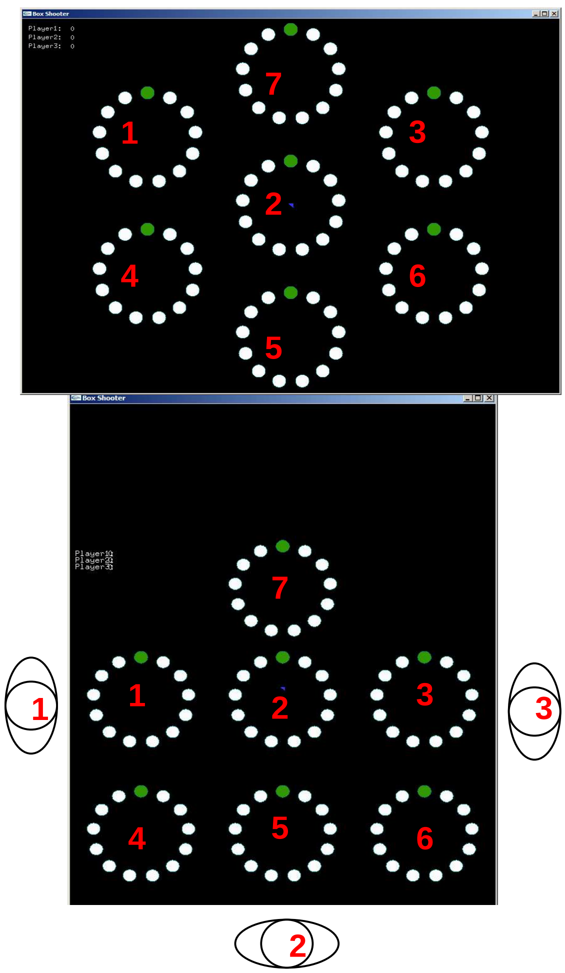

Figure 3. Simultaneous overview of all targets on the wall and table surface. The positions of the players are marked. Only one surface was active at any given time.

Seven instances of these large circles were arranged in a square sub-area of the wall and a table surface (Figure 1). Depending on the condition, either the wall targets or the table targets were displayed, but not simultaneously. The placement of the circles creates a situation, where some targets are much more easily accessible to certain players compared to other targets.

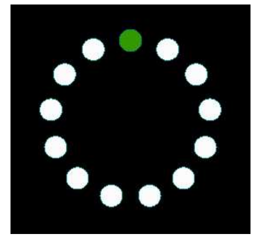

Figure 4. One of the patterns used in the study.

To test the influence of the number of participants on collaboration, different subsets of the target patterns were enabled in different conditions. To ensure that only the correct subset of participants could collaborate, the computer disabled inactive input devices. The middle circle (#2) was always visible, circles #1, #3, and #5 were visible only if the user closest to it was participating, and, #4, #6, and #7 were visible only when both adjacent users were active. As an example, when users 1 and 3 participated, only circles #1, #2, #3, #7 were active. If user 2 was working alone, only circles #2 and #5 were active. All circles were active when all players were participating. For each correctly clicked green target one point was awarded in the game. Points were deducted for clicks on non-highlighted circles. For clicks on the background (i.e. a missed target), the score was not affected, but the data for such an action was still logged for later analysis. The scores for all users were visible in a corner of the currently active display.

We chose this game task for its simplicity. While it is a typical motor performance task adapted for multiple people, it allows both for parallel work as well as easy collaboration. The cognitive load in this task is minimal, i.e. we can use this task to investigate maximum collaborative performance. In general, users could collaborate in two possible ways. One is “plain” parallel work, as there are at least twice as many targets as users and users were free to select any target and to work independently on each circle. The second possibility was a synchronized collaboration for a circle, where two people alternatively click on targets located on opposite sides of the same circle. This last alternative has clearly the largest potential for speedup as it minimized moving distances for each participant – thus providing potentially even higher performance.

2.3. Participants

We ran four groups of three people for a total of 12 participants with ages ranging from 20 to 29 years, average 23.7. They were recruited from a local university campus and were compensated for their participation.

2.4. Experimental Design and Procedure

Each of the four combinations of (display) $\times$ (input device) was tested with each group size, ranging from one to three persons. Additionally, each of the seven possible groupings of three users (3 singles, 3 doubles, 1 triple) was explored for each display and input device condition. We counterbalanced the order of the conditions via Latin Square, to compensate for potential learning transfer effects. Hence, there were a total of 28 trials for each of the four groups, each lasting 100 seconds.

The total participation time was slightly less than 1 hour, taking into account the introduction and final questionnaire. Participants were first informed about the nature of the experiments. They were instructed to hit the green targets as quickly as possible, while avoiding clicks on non-green targets. Although they could see individual scores on the screens, we informed them that it was the overall score of their team that should be maximized. Participants were free to either sit or stand. With the exception of the table condition with laser pointer interaction, the participants sat on height-adjustable chairs around the table in the positions as marked on Figure 1. The positions, in which the users sat, did not change throughout the experiment (i.e. each position was assigned to 4 out of 12 participants). During the table conditions with a laser pointer, users usually stood up to be more comfortable with the aim. During the wall conditions, although the positions always remained the same, the participants typically rotated on their chairs toward the display.

3. RESULTS

For all conditions, the following data was collected: time stamp, coordinates of pointing device click, user id, coordinates of the target and if it was hit correctly, current target colour, and the current user's score.

All data was manually scanned for errors and processed to extract the following information:

- Number of green targets clicked
- Number of non-green targets clicked
- Number of clicks outside of the targets
- Offset between a click and the corresponding target

Subsequently, the final game scores for each of the 48 trials were subjected to ANOVA. We chose not to analyse the pointing actions as classic 2D Fitts' tasks (e.g. see [13]), as our procedure can directly measure pointing device throughput via the scores, and which automatically takes errors into account. To compute the actual throughput for each of the conditions, one would have to multiply the score by the *ID* of the task (2.9 bits) and then divide it by the length of the trial (100 s). We did not do this for the graphs, as the device throughput metric is not commonly applicable for analysing target misses, or for computing group performance.

3.1. Effect of Number of Users

Not surprisingly, groups with more users achieved higher cumulative scores, with the total scores almost monotonically increasing with the number of participants (see Figure 5).

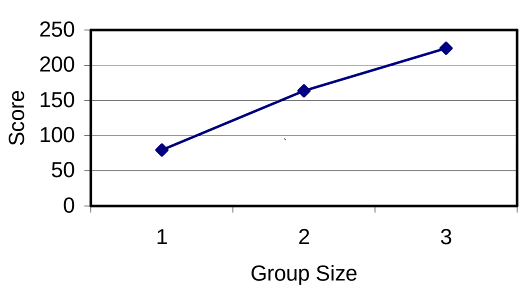

Figure 5. Increase of performance with larger group sizes.

There was an effect of the group size on *individual* performances, with participants of groups of two performing best, and groups of three performing slowest, $F_{2,143} = 5.00$, $p < 0.05$. Pairwise, only participants of groups of size two and three were found to be statistically different. The following figure[3] visualizes this:

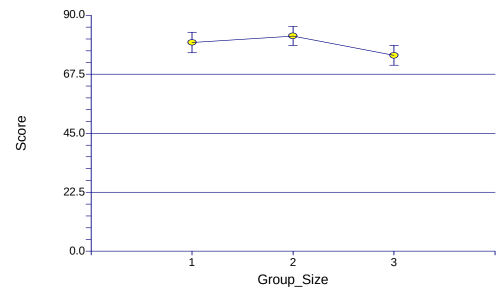

Figure 6. Individual performance by group size. Bars show standard error.

3.2. Table vs. Wall

We found a main effect of the surface type on the scores. $F_{1,143} = 63.85$, $p < 0.001$. While working on the wall surface, participants achieved 51.2% higher scores, 94.8 vs. 62.7 per 100s test time interval. See Figure 7 for details.

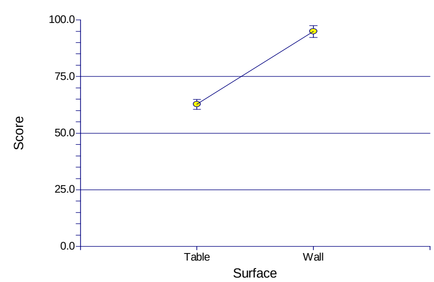

Figure 7. Main effect of surface condition.

Another effect was observed on the number of times players missed their targets. While they missed 24.4% more often in the wall condition, the difference was not statistically significant: $F_{1,143} = 3.09$, $p = 0.11$. Figure 8 illustrates this relationship.

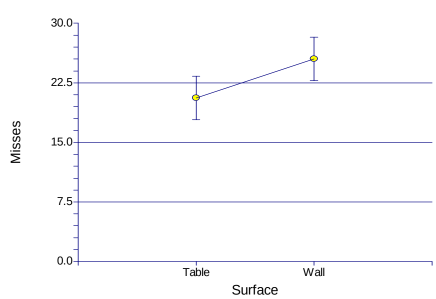

Figure 8. Number of targets missed.

[3] In this and the following figures, the error bars visualize standard error.

3.3. Lasers vs. Mice

There was a main effect of interaction device on the scores, $F_{1,143} = 30.60$, $p < 0.001$. While working with mice, subjects achieved scores that were 20.8 % higher, 86.19 vs. 71.35 per 100 s test time interval. See Figure 9.

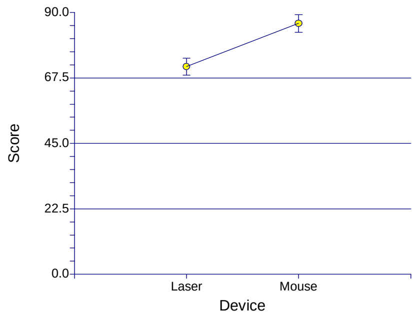

Figure 9. Main effect of input device on score.

The number of misses, i.e. clicks outside of the circles, was also significantly higher for the laser pointers. $F_{1,143} = 9.32$ $p < 0.05$. While working with mice, subjects missed only 47% as often, compared to laser pointers (Figure 10).

3.4. Secondary Interactions

3.4.1. Score

The scores depend on the combination of (*pointing device*) × (*working surface*), $F_{1,143} = 6.09$, $p < 0.05$. A Tukey-Kramer Multiple-Comparison Test indicates, that all pairs are different from all the other pairs (*DF* = 9, *MSE* = 106.83, *Critical Value* = 4.41). Figure 11 illustrates the associations.

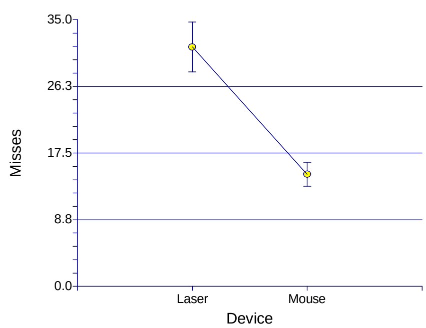

Figure 10. Main effect of input device on number of targets missed.

3.4.2. Misses

There was a main effect of (*pointing device*) × (*working surface*) on number of misses as well, $F_{1,143} = 12.59$ $p < 0.01$. Statistical significance was only found in the pair wise comparisons (mouse, table) vs. [anything], and (mouse, wall) vs. (laser, table). Figure 12 illustrates these relationships.

4. DISCUSSION

Each participant in a group of two achieved individually *more* compared to their individual performance. However, three people together achieved on average less than alone. One potential explanation is the nature of the task (clicking alternately on the opposite sides of a circle), which favours a group of two people more than a group of three. Another potential explanation is that the cost of synchronizing physical movements (i.e. communication through the system) outweighs potential benefits of optimising the task flow for performance. However, we do not have any further data on this at this point. Our result is different from a result obtained in [19], where doubling the group size increased the group performance only by about 50%. The difference to our results is likely due to the different tasks involved. Ryall *et al.* used a common high-level task, which required extensive communication between participants, whereas our task was simpler, highly parallelizable, and allowed for great flexibility in forming subgroups for collaboration. Our result is also different in nature from findings in [18]. There, a horizontal condition showed somewhat better performance, measured in the *frequency of communication* between participants. We cannot tell at the moment, how the frequency of communication correlates with an overall success of the activity. Rogers, and Lindley included no metrics describing the speed, or accuracy, of pointing tasks, thus we cannot make a direct comparison.

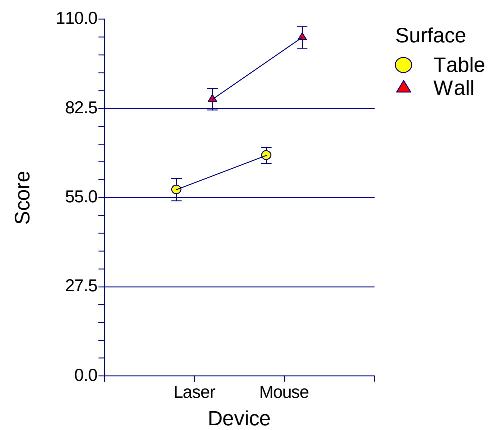

Figure 11. (Pointing device) × (working surface) interaction for total score.

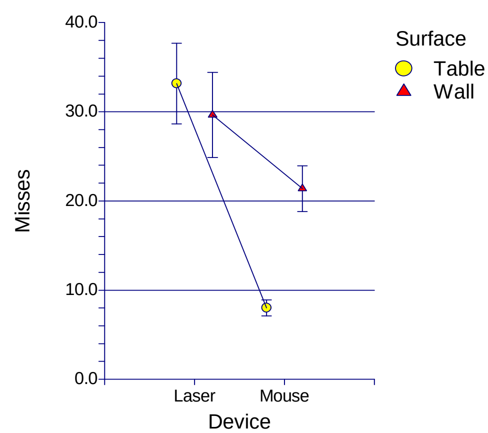

Figure 12. (Pointing device) × (working surface) interaction for misses.

The finding that vertical wall surfaces were faster and apparently easier to manipulate on was not expected. The table surface is much closer to the users and hence should afford a noticeably higher pointing precision and hence also larger overall performance. However, the analysis of the experiment shows the opposite. One potential explanation for this is that the relatively large size of the circles was better suited for a larger viewing distance, i.e. people could more easily focus on a circle as a whole on the wall. However, the size of the targets was moderate enough, so that even at the shorter distance on the table most of the circles would fit into a 40–60 degree field of view. Another, more viable, explanation is that effect of relative orientation of participants to the wall display. As we did not automatically collect data on participant orientation relative to the table, we are do not have data on this. However, from our observations during the experiment, we can say that whenever there were targets on the wall, *all* participants sitting at the sides of the table oriented themselves *towards* the wall regardless of input device. Much more important, however, is the fact that, if we analyze only the data for the "central" person, i.e. the person who is already oriented correctly towards the wall, the effect *still* persisted – i.e. the main effect of the devices and the surface orientations was statistically significant for this person alone, too. This eliminates orientation as a strong potential explanation. Hence, we can only hypothesize that it is the relative tilt of the working surface that matters: when the surface is not orthogonal relative to the view direction of a person, the perspective distortion affects performance. On the other hand, all users in our study can see wall screens at an angle close to 90 degrees with the surface (i.e. an undistorted view). Parker *et al*. [16] speculated that effect of perspective changes may affect the precision of the pointing tasks. Guiard *et al.* [8] investigated the effects of pointing in a prospectively distorted space and observed a non-linear increase of movement time for object selection in such spaces. We did not observe such effects; however, the view distortions and the *ID*-s in our study were not as extreme as in Guiard's study. Wigdor *et al.* [24] investigated which relative orientations of the horizontal control space and the vertical display perform best. Generally, the speed drops whenever the display and the input device are not in front of the user or at some small angle with respect to him or her. However, our results cannot be compared to those, as we used *direct* pointing, utilized *horizontal* displays and for the vertical display conditions the angles toward the display were moderate. Moreover, this cannot be fully explained by differences in perception of the targets themselves (e.g. see [25]), as circular targets are among the most robust to differences in orientation.

Our study also investigates the difference between laser pointers and mice. Earlier studies have already shown the lasers to be slightly slower than mice (e.g. [14]). Although the hardware employed in this study is superior to the hardware used by others, namely, we track laser pointers at 120 Hz, compared to 30 Hz, we have not been able to demonstrate any improvement of performance. The difference between the laser and mouse is more pronounced on the wall display, and we attribute the difference to the greater distance relative to the display, i.e. the fact that interaction with the wall required remote pointing with the laser pointers. Clearly, hand jitter is the most likely explanation for the worse performance of the remote condition. The table condition was less affected as pointing was relatively short-distance, sometimes close to touching. The stimulus-response incompatibility did not manifest itself; mice were consistently faster than laser pointers and had fewer target misses. Another interesting observation is that the difference between pointers and mice in terms of target misses is much less pronounced on the wall than on the table: mice exhibited fewer misses on the table than on the wall, while for the lasers the difference in errors was not apparent.

Touching a surface with a laser is very similar to touching it with a pen. Thus, we believe that our results generalize at least partially to pen-based systems. However, one difference between lasers and pens is that our laser pointers are not pressure sensitive and that left mouse clicks, corresponding to stylus taps, have to be produced via clicking a button on a side of the laser pointer. A second difference is due to laser pointers' having much longer pointing range, which means that users did not always have to touch the surface. In fact, most of the time they didn't, according to our observations during the study. However, while working on the table, users typically held their laser pointers very close to the table surface. Although this may technically mean that we cannot generalize directly, we do not consider these differences fundamental. The study by Parker *et al*. [16] used a tracker-augmented stylus. However, the conclusions of that paper can be extended to cover use of laser pointers relative to styli: lasers will be preferable for *both* close and far pointing, as they seamlessly combine the support for both pointing scenarios. Also, it could be inferred that, if working with *equally* distant targets, close and far pointing differ only in a single scaling coefficient both in speed and in accuracy.

Finally, it has been shown in the past that tabletops better facilitate collaboration [10][11], and that direct pointing works best on such horizontal surfaces. Based on this, our results suggest that it is best to utilize tabletops, coupled with a pointing device like a laser pointer, in situations, were quality of interactions between users is especially important for task completion (e.g. brainstorming session). On the other hand, for tasks, in which a significant amount of interactivity with the system is expected (e.g. architectural layout), it will be more appropriate to utilize wall displays. The choice of input device for an interactive wall depends, as before, on the nature of interactivity and need for close collaboration. For loosely coupled tasks, mice might be preferred as it is ultimately the fastest device. Direct pointing devices in this situation will however have the benefit of providing better awareness of others' actions.

4.1. Comparison with Touch Input

Forlines et al. [7] compared direct-touch input on a tabletop with mouse input. Among the advantages of the touch-based interaction is the possibility of natural bimanual input, it was found to be slower and more error prone than mouse input, especially for smaller targets. The authors also conclude that mouse input may be more appropriate for a single user working on tabletop tasks requiring only a single point interaction.

One of the fundamental limitations of the direct touch input is, as mentioned above, the need to be able to reach any and all points of the interaction space. That becomes difficult or impossible, as the involved display screens grow larger.

5. CONCLUSION

In this study we have confirmed that mice still have an advantage over laser pointer in a co-located collaborative system. We have also observed that vertical wall surfaces yield higher pointing performance compared to tabletops. This does not mean that tabletops using laser pointers are prone to disappear – without doubt, there can be situations, yet to be systematized, which will suggest that particular combination of interactive surface + input device.

While the tabletops might have an advantage in situations where people have to visualize appropriate data at close range, the study indicates that *walls* are preferable when more efficient interactivity is desired and that in this context direct pointing devices are preferable if better activity awareness is expected. This result is especially worth highlighting, given the recent surge in popularity of tabletop interfaces.

6. FUTURE WORK

In our experiments we discovered a remarkable difference of 51% in speed between table and wall surfaces (see Figure 7 and Figure 11). While it is possible to determine all, or most of the factors that could have played a role in generating such a difference, such as variations in perspective, in the field of view, in posture etc., influence of none of such factors alone can explain this dramatic difference, when taking into account presently known facts (e.g. from [9][10][16][24]). Clearly, *several* factors are likely to play a role here. Determining the relative contributions of these factors is a subject of our ongoing research.

In contrast, the superiority of mice over laser pointers can satisfactorily be explained by the ubiquity of mice as input devices.

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