Comparing Multi-Touch Tabletops and Multi-Mouse Single-Display Groupware Setups

Thomas E. Hansen and Juan Pablo Hourcade
Department of Computer Science
University of Iowa
14 MacLean Hall, Iowa City, IA 52242 USA
{tehansen, hourcade}@cs.uiowa.edu

ABSTRACT

In spite of all the attention paid to multi-touch tabletop displays, little is known about the collaborative tasks they are best suited for in comparison to alternatives such as multi-mouse Single-Display Groupware setups. In this paper, we share the results of a study we conducted comparing a multi-mouse Single-Display Groupware (SDG) setup (two mice, 15” vertical display) to a multi-touch tabletop display (81cm by 61cm) for visual tasks that require coordination and collaboration. In the study, participants were more efficient when using the multi-mouse SDG setup, but preferred the multi-touch tabletop. We use the study as a platform for discussing how to interpret results from studies that compare an exciting technology to one that is not.

Categories and Subject Descriptors

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors.

Keywords

Excitement, familiarity, evaluation, single display groupware, multi-touch display, collaboration, coordination.

1. INTRODUCTION

Multi-touch displays have recently attracted a lot of attention within the human-computer interaction community as seen in the increasing number of sessions in the past couple of CHI conferences. In spite of their increasing availability, tabletop multi-touch displays are still quite novel for most users. In addition, within the research community, we propose that they still have an aura of freshness and excitement that does not apply to anything involving a computer mouse. Given this situation, comparing multi-touch tabletops to less exciting technologies such as multi-mouse Single Display Groupware (SDG) (multiple mice, vertical displays) can run into serious bias problems from both users and researchers.

We believe it is important, as novel and exciting technologies arrive, to compare them to existing alternatives and learn which is better suited for different types of tasks. It is very tempting to assume that novel and exciting technologies will be better than older and dull ones. As Stephen Jay Gould cautioned: “We naturally favor, and tend to overextend, exciting novelties in vain hope that they may supply general solutions or panaceas when such contributions really constitute more modest albeit vital pieces of a much more complex puzzle” [2]. For this reason, we believe it is crucial to learn, through controlled studies, what the actual benefits and drawbacks of new technologies are.

We, like many others in the human-computer interaction field, have made investments in large multi-touch displays, given the potential we see in them for supporting collaboration and providing a new kind of canvas for creative endeavors. For that reason we are interested in learning about what tasks are best suited to them, justifying the extra expense involved in acquiring this hardware and the extra space required by it when compared to connecting an extra mouse to a laptop or desktop computer.

In this paper, we share the results of a study we conducted comparing a multi-mouse SDG setup to a multi-touch tabletop display for visual tasks that require coordination and collaboration. The study is the first of a series of studies meant to identify the tasks that are best suited for each. In the study participants completed tasks more quickly with the multi-mouse SDG setup, but preferred the multi-touch tabletop displays. Besides sharing the results of the study, we contribute a continuation of the discussion in our research community on how to interpret results of studies comparing technologies that are largely perceived as fresh and exciting to others that do not have that characteristic.

2. RELATED WORK

2.1 Collaboration in Multi-Touch Setups

Many studies have been presented in the past few years regarding collaboration with multi-touch setups Ryall et al. [21] discuss their experience in the use of multi-touch surfaces and present issues such as accidental input, interactive elements needing to be larger for finger-based interactions, and how users can interfere with each other’s actions both intentionally and unintentionally.

Tse et al. [27] studied collaboration by pairs of users on a tabletop display and found that speech and gestures served both as a way to interact with the display and to communicate with others.

Looking at size and territoriality of use, Ryall et al. [20] found that a small change in tabletop size did not have an effect on the efficiency of groups completing collaborative tasks. Scott and Carpendale [22] have studied territoriality in tabletop displays, finding they enable the establishment of personal, group and storage territories.

MexIHC 2010, November 8, 9 & 10, 2010.

Published by Universidad Politécnica de San Luis Potosí

Figure 1. On the left, participants completing a task with a multi-mouse SDG setup. On the right, participants completing a task on our multi-touch setup

Gross et al. [4] designed cueTable to investigate collaborative games in multi-touch tabletops. In this game, they found instances of teaching and assistance, but not of players asking for help. Similarly, Khaled et al. [12] explored collaborative gameplay in multi-touch surfaces by observing players play two games. They found collaboration tended to occur when players performed parallel tasks toward a single aim. Most of the enjoyement also appeared to come from the novelty of the interface as opposed to the ludic qualities of the games.

Nacenta et al. [17] discuss how different types of interaction techniques can affect the way people collaborate on a multi-touch tabletop surface. In particular, they found drag-and-drop to work better than other techniques.

Piper and Hollan [19] found advantages in the use of multi-touch surfaces over the use of paper for small study groups reviewing study materials. In particular, the students were more likely to solve problems on their own instead of using answer keys when using the multi-touch surface.

Harris et al. [7] studied the impact of multi versus single-touch surfaces on children's collaborative tasks. They found that when using multi-touch surfaces children talked more about the task they were completing, whereas they spent more time talking about turn taking when using a single-touch surface.

The literature has thus far then demonstrated some possible advantages for the use of multi-touch surfaces and displays for collaborative tasks, although the examples above do not provide any comparisons with less expensive and more accessible collaborative setups.

2.2 Multi-Mouse Single Display Groupware Setups

There were many studies on multi-mouse SDG setups about 10 years ago, with a few more recent efforts mostly concerned with supporting education in developing regions (e.g., [14], [9]).

Inkpen [10] [11] conducted much of the early research on multi-mouse SDG setups, looking for ways to support synchronous collaboration as well as give-and-take protocols.

Hourcade et al. [9] developed KidPad, a collaborative storytelling tool in which children could create stories together using a multi-mouse SDG setup. Stanton and Neale [23] studied the use of KidPad and found advantages in the distribution of interaction and dialogue when children each got their own mouse instead of having to share one.

A more recent example of multi-mouse SDG is Mischief [14][15]. It takes multi-mouse SDG to greater scales by having dozens of mice connected to one computer. It has been used for educational applications in developing regions. Pawar et al.'s [18] work is another example of multi-mouse SDG being used for educational purposes in developing regions.

2.3 Comparisons between Touch and Mouse Input

Forlines et al. [1] compared direct-touch and mouse input for tabletop displays for single users. They found that bimanual tasks benefited from multi-touch input, while single-point interactions were more appropriately handled with the mouse. No evaluation was conducted of collaborative tasks.

Hornecker et al. [8] compared multi-mouse and multi-touch interactions on large tabletop displays for collaborative tasks. The study was unusual in its use of a multi-mouse setup with a horizontal tabletop display, a setup rarely if ever used in research projects and even less common in real-world use. They found more interference in the multi-touch condition. However, participants were more likely to assist each other without request, and were more likely to hand objects to another participant in the multi-touch than in the multi-mouse condition.

Muller-Thomfelde and Schremmer [16] studied collaborative puzzle solving tasks where participants could use a mouse or touch a horizontal tabletop display. They found similar collaboration patterns regardless of the form of interaction, with little evidence to argue for a particular device. They also found that participants were more likely to hinder each other's actions if they both used touch interactions.

3. RESEARCH GOAL

In spite of all the research that has been conducted, it is not clear what collaborative tasks are best suited for multi-touch displays instead of multi-mouse SDG setups.

The goal of this study was to learn about the differences in behavior of pairs of users using a multi-mouse SDG setup (two mice, a 15" vertical display) or a multi-touch tabletop display when performing visual tasks that require collaboration and coordination.

We chose what we thought were the best two setups for multi-touch and multi-mouse SDG to support collaboration. Manipulating only one variable (i.e., multi-mouse versus multi-touch) would have resulted in an unfair comparison of the two setups. We tried multi-touch on tablets for the same task and it resulted in hands occluding most of the screen and fingers running into each other. With a vertical large screen multi-touch setup we ran into occlusion by the body of the other person. Multi-mouse setups with large screens lost the advantage of easily seeing all of the display. In this study, we compare the best of both setups to learn about how they compare in supporting a particular collaborative task.

We realize that eventually it would be ideal to test different kinds of tasks and learn about what factors are behind the differences between the two setups. This is a first step that can be used to justify further research on the difference between the two setups. To fully account for all possible variable interactions plus a few different tasks, we would have needed an enormous full-factorial design (e.g., 2 input modalities x 2 display orientations x 2 display sizes x 4 different tasks). We suggest it is unwise to pursue such studies without evidence that major differences exist in the first place.

4. METHOD

4.1 Participants

Twenty volunteers (7 female, 13 male) between the ages of 18 and 41 (mean 26.5) participated in the study as pairs in ten groups. Their educational background ranged from high school graduates to PhDs. We recruited volunteers using posters and class announcements. They were not compensated for their participation. Their mean computer experience was 16 years and their mean computer use per day was 6.1 hours. None of the participants had previously used a multi-mouse SDG setup or a multi-touch display. Some of the pairs knew each other, others did not.

4.2 Materials

Our multi-mouse SDG setup uses two USB mice connected to an Apple MacBook Pro running Windows XP. We use Windows XP's rawinput API through Python to get access to the input data from both the mice and pipe it to the PyMT research toolkit [6]. Participants used this setup sitting down. See Figure 1 for a picture of a session using this setup.

We used a frustrated total internal reflection (FTIR) rear projected multi-touch display constructed using the technique described in [5]. It uses a Point Grey Research Firefly MV camera capturing 640 by 480 pixel images at 60 Hz connected to a Dell XPS desktop computer. For touch detection we used touchlib [26], which generates events that are received by the PyMT research toolkit [6]. Our tabletop multi-touch display is 122cm high. The touch sensitive display is 81cm by 61cm (32” by 24”). One side of the display (81cm side towards the back) is not accessible. Participants were free to move around the three accessible sides and used the display standing up (see Figure 1).

4.3 Task

Inspired by the game Planarity [25], we presented users with an abstract task that required their visual coordination and collaboration. We chose this task instead of a more concrete task to increase the generalizability of the results at the cost of reducing environmental validity. The task consisted of untangling a ring graph with randomly placed vertices by dragging its vertices until none of the edges overlapped (see Figure 1). We used four different graph sizes (10, 15, 20, and 25 vertices).

We chose this specific abstract task for these additional reasons:

- With the exception of being able to perform more than two concurrent drag operations on the multi-touch screen, the task is exactly the same and can be mapped to both setups without modifications.
- As a user moves vertices trying to solve the problem, she/he is also changing the overall problem, requiring at least some degree of coordination between users.
- The task is performed using only basic drag operations, making it easy for participants to understand, and applicable to many mouse and touch user interfaces.
- It is clear when participants complete the task successfully, which makes the task ideal for a research study, enabling the evaluation of efficiency.

We should note that we were not sure which setup would be best suited for the task. The greater awareness of what partners are doing provided by multi-touch tabletops would be useful given the required coordination. The ability for a single user to drag multiple nodes simultaneously could also benefit the multi-touch tabletops. Quicker pointing and dragging with the mouse could benefit the multi-mouse SDG setup. So could the familiarity of participants with using mice, and the ability to easily see the entire display.

4.4 Procedure

The experiments were conducted in a research lab. Participants were paired with other volunteers. They were given a chance to familiarize themselves with the multi-touch setup for up to fifteen minutes using various small demo applications we have written (painting, photos, maps, and so forth.). Just before starting the experiments the participants were shown one instance of the task being completed by a researcher explaining the goal and how many blocks/tasks they would be completing. Participants were instructed to “try to solve the puzzle as efficiently as possible together.”

Each pair of participants completed four blocks consisting of eight tasks each. For each block participants completed four tasks with one setup, then moved to the other setup and completed the second set of four tasks, completing a total of 16 tasks with each setup, 32 tasks total. The four tasks completed with each setup for each block varied in difficulty by using four graph sizes (10, 15, 20, and 25 vertices). We used a partially balanced Latin Square to determine the order in which the participants saw the four levels of difficulty within a block. Half of the pairs started their blocks on the multi-touch display, the other half on the multi-mouse SDG setup.

4.5 Design

The independent variables were: input modality (multi-touch display or multi-mouse SDG), number of vertices, and block number (all within-subjects). The dependent variables were: task completion time, number of drag moves per task, total length of drag moves per task, number of words spoken per task, and number of words spoken per minute.

We collected data by logging all input events, video recording sessions, as well as using demographics and post-study questionnaires. Due to bugs in the logging software, we lost data on three tasks for one pair, and one task for another pair, all with the multi-mouse SDG setup. We excluded these tasks from our statistical analysis. Using the video recording we counted the

	Input Device	*Number of Vertices*	*Block #*
Completion Time	F(1, 7)=13.519, p<.01	F(1.4, 9.6)=57.3, p<.001	not significant
Number of Drags	F(1, 7)=24.628, p< .01	F(3, 21)=111.5, p<.001	not significant
Length of Drags	not significant	F(1.2, 8.5)=69.8, p<.001	not significant
Number of Words	F(1, 8)=16.493, p<.01	F(3, 24)=22.7, p<.001	F(3, 24)=5.584, p<.01
Words/ minute	F(1,6)=14.447, p<.01	not significant	not significant

Table 1. Result of repeated measures ANOVAs. Significance of input device, number of vertices, and block number on completion time, number of drags, length of drags, number of words spoken and words per minute

number of words spoken by each pair for each task. We also used the logged event information for visualization purposes (e.g. trajectories, screen activity maps, animating/replaying the experiments) in hopes of finding useful information or relationships. For drag events, we corrected for accidental drops that sometimes occur in multi-touch displays by ignoring these drops if they were less than 500 milliseconds long.

5. RESULTS

5.1 Quantitative Measures

We conducted tests of within-subjects effects using repeated measures ANOVAs on SPSS 17.0. The results of our analysis are displayed on Table 1. When sphericity could not be assumed, we used the Greenfield-Geisser adjustment. We present the results in more detail below, organized by dependent variable.

5.1.1 Completion Time

The input modality (multi-mouse SDG vs. multi-touch) had a statistically significant effect on task completion time. Participants completed tasks faster with the multi-mouse SDG setup than with the multi-touch setup (p<.01, power=.882). Figure 2 shows box plots of the completion times, which also illustrate the greater variability in performance in the multi-touch setup.

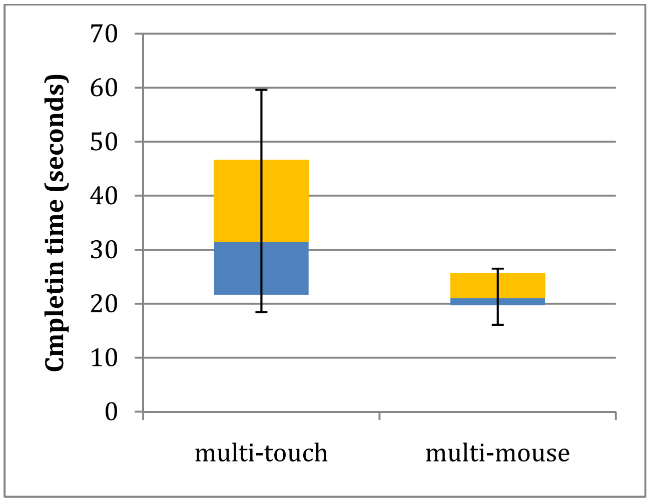

Figure 2. Box plots showing mean completion time for each of the pairs of participants by input modality.

Not surprisingly, the number of vertices also had a statistically significant effect on task completion time, with tasks involving more vertices leading to longer times (p<.001, power=1.0).

We also looked for interactions between independent variables and found that there was a statistically significant interaction for input modality and number of vertices in a task (p<.01, power=.981). In studying this interaction, we can see that even though participants on average were faster with the multi-mouse SDG setup no matter the number of vertices, the differences became greater with tasks involving more vertices. See Figure 3.

Block number did not have a statistically significant effect on completion time. We also tested for other statistically significant interactions between independent variables and found none.

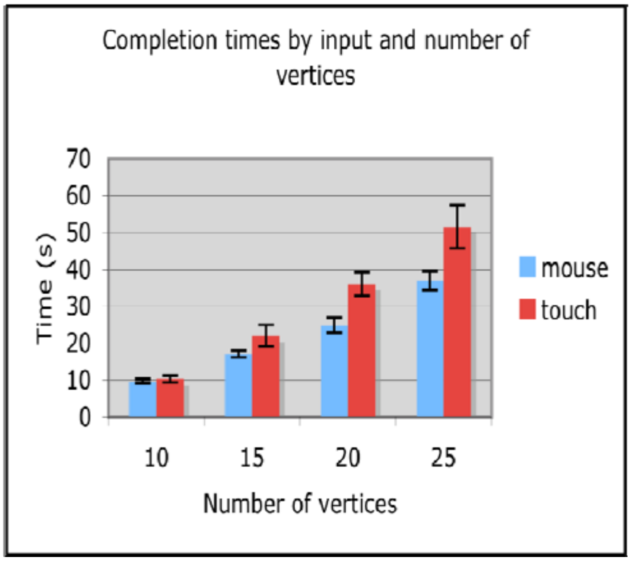

Figure 3. Mean completion time in seconds by number of vertices and input modality. Error bars are two standard errors long.

5.1.2 Number of Drags

The input modality had a statistically significant effect on the number of drags per task (p<.01, power=.988). Participants used less drags with the multi-mouse setup than with the multi-touch setup. Figure 4 shows box plots that again highlight the greater variability in performance under the multi-touch condition.

As may be expected, the number of vertices in a task also had a statistically significant effect on the number of drags, with more vertices leading to more drags (p<.001, power=1.0).

There was a statistically significant interaction between input modality and the number of vertices in a task (p<.001, power=1.0). The differences between the two input modalities were more pronounced for tasks with more vertices. See Figure 5.

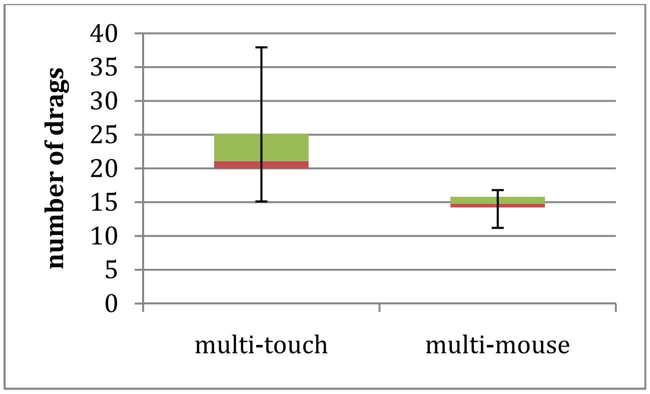

Figure 4. Box plots showing mean number of drags for each of the pairs of participants by input modality.

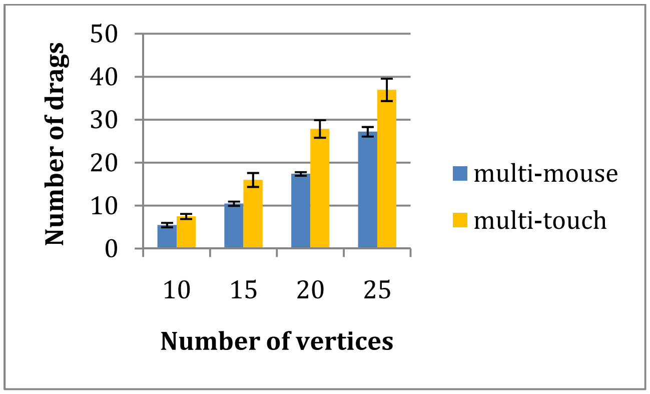

Figure 5. Mean number of drags by number of vertices and input modality. Error bars are two standard errors long.

Block number did not have a statistically significant effect on the number drags. There were also no statistically significant interactions between the other combinations of independent variables.

5.1.3 Length of Drags

Only the number of vertices had a statistically significant effect on the length of drags, with more vertices leading to greater lengths (p<.001, power=1.0). Input modality and block number did not have a statistically significant effect. The combinations of independent variables did not have a statistically significant interaction.

5.1.4 Words Spoken per Task

Input modality had a statistically significant effect on the number of words spoken during tasks (p<.01, power=.943). Participants spoke more words per task when using the multi-touch setup than when using the multi-mouse SDG setup. The box plots in Figure 6 again highlight the differences between the two input modalities and the greater variability under the multi-touch condition.

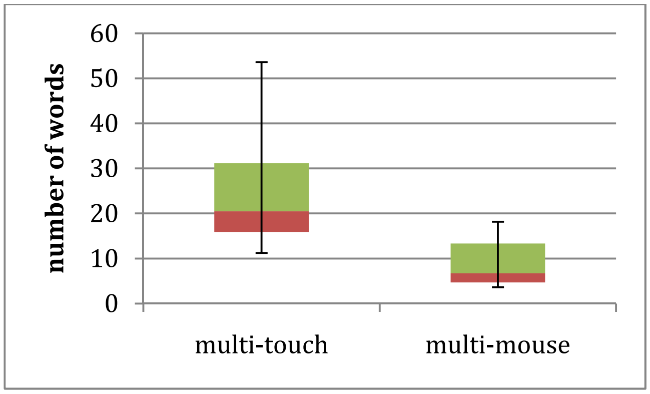

Figure 6. Box plots showing mean number of words spoken per task for pairs of participants by input modality.

As with the other dependent variables, the number of vertices in a task also had a statistically significant effect on the number of words spoken per task, with more vertices leading to more words spoken per task (p<.001, power=1.0).

In this case, the block number also had a statistically significant effect on the number of words spoken per task, with less words spoken in later blocks (p<.01, power=.901).

There was also a statistically significant interaction between input modality and the number of vertices in a task (p<.01, power=.966). Again, tasks involving more vertices led to greater differences between the two input modalities.

In addition, there was a statistically significant interaction between input modality and block number (p<.05, power=.637). In this case, the differences between input modalities decreased as the experiment progressed. Figure 7, showing words spoken per task by block number and input modality, suggests the decline in the number of words used as the experiment progressed is largely due to the multi-touch modality.

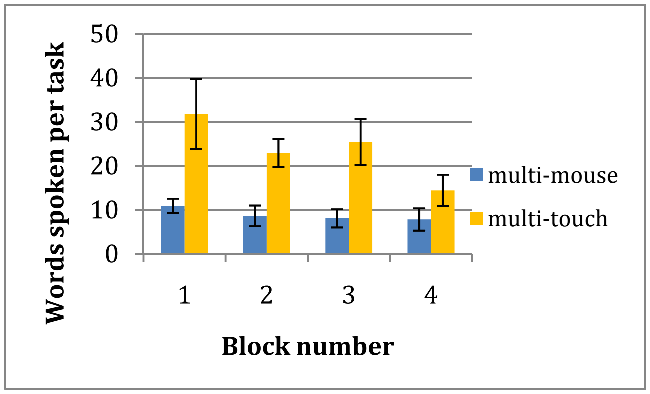

Figure 7. Mean number of words spoken per task by block number and input modality. Error bars are two standard errors long.

5.1.5 Words Spoken per Minute

Input modality had a statistically significant effect on the number words spoken per minute (p<.01, power=.883). Participants spoke roughly twice as many words per minute under the multi-touch condition than under the multi-mouse condition. Figure 8 shows box plots comparing the two input modalities.

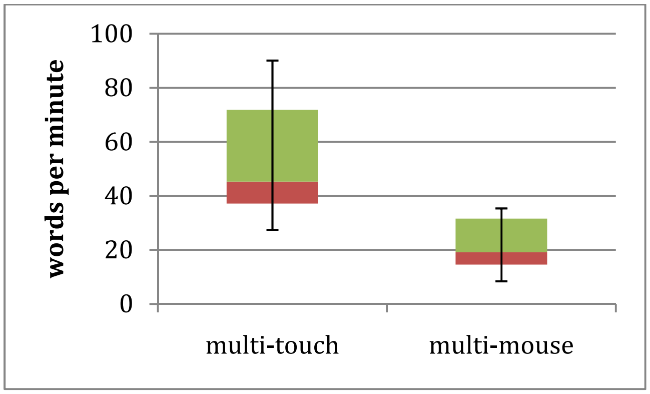

Figure 8. Box plots showing mean number of words spoken per minute for pairs of participants by input modality.

The number of vertices did not have a statistically significant effect on the number of words spoken per minute. Neither did block number.

There was a statistically significant interaction between input modality and number of vertices ($p<.05$, power=.654). The differences between input modalities were greatest for tasks involving 10 vertices. See Figure 9 for a bar chart showing the mean number of words per minute by number of vertices and input modality. There were no other statistically significant interactions between the independent variables.

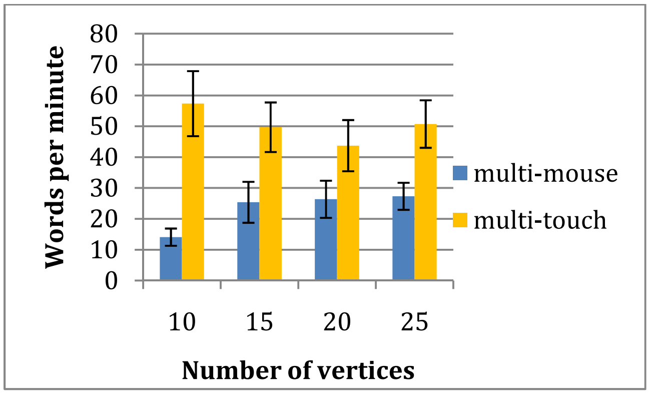

Figure 9. Mean number of words per minute by number of vertices and input modality. Error bars are two standard errors long.

5.1.6 Participant Preferences

According to a post-study questionnaire, 16 out of 20 participants preferred the multi-touch setup over the multi-mouse SDG setup (Chi-Square, $p<.01$), and 13 out of 20 thought it was easier to complete tasks on the multi-touch setup (not significant). On the other hand, 15 out of 20 selected the multi-mouse SDG setup as the faster of the two (Chi-Square, $p<.05$).

5.2 Qualitative Observations

Participants commented that it was easier to know what the other person was doing when using the multi-touch setup. Lack of similar awareness caused them to sometimes try to pick the same vertex when using the multi-mouse SDG setup.

When going through video to count the number of words spoken, we also noticed that participants spoke in more complete sentences when using the multi-touch setup, conversing with each other. When using the multi-mouse SDG setup, they were more likely to do the equivalent of "thinking aloud", giving a commentary of what they were doing to keep their partner informed.

6. DISCUSSION

6.1 Possible Reasons for Quantitative Results

All the quantitative results clearly point at the multi-mouse SDG setup as being more efficient than the multi-touch setup. This was consistent whether looking at completion times and number of drags.

The only quantitative result that could be presented as a positive for the multi-touch setup is that participants spoke more to each other when using the multi-touch setup. Coupled with our qualitative observations that participants tended to use more complete sentences when using the multi-touch setup, this suggests that participants may have engaged in better oral communication under the multi-touch condition.

There are many possible reasons behind the results that favored the multi-mouse SDG setup in terms of efficiency. First, participants were familiar with using mice. Mice also require shorter body motions, making it quicker to move the same vertex. In addition, mice enabled participants to quickly and easily reach any part of the screen, something they could not always do with the multi-touch display.

The smaller screen used in the multi-mouse SDG setup also enabled participants to see the whole puzzle at a glance. On the other hand, the multi-touch display was larger, which may have impeded a full view of the puzzle. This would have been hampered further by the occasional occlusion caused by the other participant's arms and hands.

The lack of familiarity with the multi-touch setup could also mean that participants could improve over time, except this was not reflected in our study as participants did not improve their performance with each subsequent block.

While the tasks required coordination between participants, it was clear what a correct outcome was, which would not be the case for open-ended tasks. While there could have been some advantage in using more than one finger at a time on the multi-touch display in our tasks (and many participants took advantage of this), there could be other tasks where multi-finger input could provide greater advantages.

6.2 Exciting versus Dull Technologies

Greenberg and Buxton [3], as part of a discussion on how evaluations can stifle innovation, also mention the issue of existence proofs and risky hypothesis testing. They argue that novel techniques are often evaluated by setting up a favorable scenario, providing "existence proof" of at least one case in which the novel technique works better than an existing technique. They propose this is weak science. Instead, they encourage risky hypothesis testing, where the limits of a novel technique are tested.

We believe this also applies to comparisons of technologies that are perceived as fresh or exciting in the community to technologies that do not have those attributes. Just like there is a danger in stifling innovation with evaluations, there is also a danger of over-hyping and exaggerating the positive attributes of technologies that appear exciting and fresh.

Consider the results of this study, and think about what would be the reaction if the results were the opposite. In that case, a typical interpretation might have been that the fresh and exciting technology provided greater efficiency, and that user preference was biased because participants still feel more comfortable using a more familiar technology. It would be seen as another win for the fresh and exciting technology.

What we have is the opposite though. And the reaction is unlikely to be the same. The less exciting technology was more efficient, but participants preferred the fresh and exciting technology. This will typically not be seen as a win for multi-mouse SDG, but as a poor choice of task for favoring multi-touch tabletops. In other words, the task was not proper for providing "existence proof" (note that there has yet to be any "existence proof" for multi-touch over multi-mouse SDG for collaborative tasks), and it did not generate the desired results for "risky hypothesis testing".

At the same time, the results should not mean that multi-touch tabletops should be dismissed. Studies like this help the research community understand the limits of a particular technology and the tradeoffs involved when compared to other technologies. In this case, we learned that multi-touch tabletops may not provide efficiency advantages over multi-mouse SDG for tasks similar to those tested.

We believe the human-computer interaction community should encourage more studies such as this that aim to test the limits of technologies. This is particularly important for technologies that generate a lot of excitement in the research community. At the same time, we caution about the need to avoid biases based on the excitement behind a particular technology.

6.3 Limitations

The main limitation of this study is that it does not provide information on the reason for the differences between the two setups. Because the setups differed in display size, orientation, and input modality, it is unclear which of these factors made a difference. We propose that the difference is likely a result of interactions between all three of those variables. This study justifies a larger full-factorial experiment to further study the interactions between these variables.

7. CONCLUSION

We presented the results of a study comparing a multi-mouse SDG setup to a multi-touch tabletop display for visual tasks that require coordination and collaboration. The results of our study suggest that there are visual collaborative tasks for which pairs of people will be more efficient using multi-mouse SDG setups than multi-touch tabletop displays. In spite of these efficiency advantages, participants preferred the multi-touch displays. We believe studies like this that identify limits in technologies that generate a lot of enthusiasm are valuable contributions to HCI research.

8. ACKNOWLEDGEMENTS

We would like to thank the participants for their help in conducting the study. The University of Iowa's Mathematical and Physical Sciences Funding Program supported this research.

9. REFERENCES

[1] Forlines, C., Wigdor, D., Shen, C., and Balakrishnan, R. 2007. Direct-touch vs. mouse input for tabletop displays. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. CHI '07. ACM, New York, NY, 647-656.

[2] Gould, S.J. (1996). *The Mismeasure of Man*. New York: Norton.

[3] Greenberg, S. and Buxton, B. (2008). Usability evaluation considered harmful (some of the time). In *Proceedings of CHI 2008*. ACM Press: pp. 111-120.

[4] Gross, T., Fetter, M., and Liebsch, S. 2008. The cuetable: cooperative and competitive multi-touch interaction on a tabletop. In *CHI '08 Extended Abstracts.* ACM Press: pp.

[5] Han, J. Low-cost multi-touch sensing through frustrated total internal reflection. Proc. UIST, 2005.

[6] Hansen, T.E., Hourcade, J.P., Virbel, M., Patali, S. and Serra, T. (2009). PyMT: A Post-WIMP Multi-Touch User Interface Toolkit. *Proceedings of Tabletop 2009*. ACM Press: pp. 17-24.

[7] Harris, A., Rick, J., Bonnett, V., Yuill, N., Fleck, R., Marshall, P., and Rogers, Y. 2009. Around the table: are multiple-touch surfaces better than single-touch for children's collaborative interactions? In Proceedings of the 9th international Conference on Computer Supported Collaborative Learning - Volume 1, 335-344.

[8] Hornecker, E., Marshall, P., Dalton, N. S., and Rogers, Y. 2008. Collaboration and interference: awareness with mice or touch input. In Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work. CSCW '08. ACM, New York, NY, 167-176.

[9] Hourcade, J., Bederson, B. and Druin, A. Building KidPad: an application for children's collaborative storytelling. Software Practice and Experience, 2004, 34, 895-914.

[10] Inkpen, K., Booth, K. S., Gribble, S. D., and Klawe, M. 1995. Give and take: children collaborating on one computer. In Conference Companion on Human Factors in Computing Systems. CHI '95. ACM, New York, NY, 258-259.

[11] Inkpen, K. M., Ho-Ching, W., Kuederle, O., Scott, S. D., and Shoemaker, G. B. 1999. This is fun! we're all best friends and we're all playing: supporting children's synchronous collaboration. In Proceedings of the 1999 Conference on Computer Support For Collaborative Learning. Computer Support for Collaborative Learning. International Society of the Learning Sciences, 31.

[12] Khaled, R., Barr, P., Johnston, H., and Biddle, R. 2009. Let's clean up this mess: exploring multi-touch collaborative play. In *Proceedings of the 27th international Conference Extended Abstracts on Human Factors in Computing Systems*

[13] Microsoft Surface. http://www.microsoft.com/surface/

[14] Moraveji, N., Kim, T., Ge, J., Pawar, U. S., Mulcahy, K., and Inkpen, K. Mischief: supporting remote teaching in developing regions. In Proceeding of the Twenty-Sixth Annual SIGCHI Conference on Human Factors in Computing Systems (2008), 353-362.

[15] Moraveji, N., Inkpen, K., Cutrell, E., and Balakrishnan, R. 2009. A mischief of mice: examining children's performance in single display groupware systems with 1 to 32 mice. In Proceedings of the 27th international Conference on Human Factors in Computing Systems. CHI '09. ACM, New York, NY, 2157-2166.

[16] Müller-Tomfelde, C. and Schremmer, C. 2008. Touchers and mousers: commonalities and differences in co-located collaboration with multiple input devices. In Proceeding of the Twenty-Sixth Annual SIGCHI Conference on Human Factors in Computing Systems. CHI '08. ACM, New York, NY, 1149-1152.

[17] Nacenta, M. A., Pinelle, D., Stuckel, D., and Gutwin, C. 2007. The effects of interaction technique on coordination in tabletop groupware. In Proceedings of Graphics interface 2007. ACM, New York, NY, 191-198.

[18] Pawar, U. S., Pal, J., Gupta, R., and Toyama, K. 2007. Multiple mice for retention tasks in disadvantaged schools. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. CHI '07. ACM, New York, NY, 1581-1590.

[19] Piper, A. and Hollan, J. D. 2009. Tabletop displays for small group study: affordances of paper and digital materials. In Proceedings of the 27th international Conference on Human Factors in Computing Systems. CHI '09. ACM, New York, NY, 1227-1236.

[20] Ryall, K., Forlines, C., Shen, C., and Morris, M. R. 2004. Exploring the effects of group size and table size on interactions with tabletop shared-display groupware. In Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work. CSCW '04. ACM, New York, NY, 284-293

[21] Ryall, K., Morris, M., Everitt, K., Forlines, C. and Shen, C. Experiences with and observations of direct-touch tabletops. *In Proc. IEEE TableTop*, 2006.

[22] Scott, S.D., Carpendale, S. (2006). Investigating Tabletop Territoriality in Digital Tabletop Workspaces. Technical Report 2006- 836-29, Department of Computer Science, University of Calgary., Calgary, AB, Canada.

[23] Stanton, D. and Neale H.R. 2003. The effects of multiple mice on children's talk and interaction. Journal of Computer Assisted Learning, 19(2). p. 220--228.

[24] Stewart, J., Bederson, B. B., and Druin, A. 1999. Single display groupware: a model for co-present collaboration. *Proceedings of CHI 99*, 286-293.

[25] Tantalo, John. Planarity. http://www.planarity.net/

[26] Touchlib. http://nuigroup.com/touchlib/

[27] Tse, E., Shen, C., Greenberg, S., and Forlines, C. 2007. How pairs interact over a multimodal digital table. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. CHI '07. ACM, New York, NY, 215-218.