Impacts of Enhanced UI Feedback on

Shoulder to Shoulder Computing

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ABSTRACT

To examine the impacts of enhanced UI feedback on shoulder-to-shoulder computing, we conducted a study using a simple picture puzzle on a computer with one display, two mice, and one keyboard. After adding sound, color differentiation, status indicators, and a graphical history, the accuracy with which subjects reported the actions of the person sitting next to them increased significantly. Participants also took more time to complete the puzzle. Subjects shared the keyboard more when using the enhanced UI. We also found participants sitting to the left of the screen to be considerably more productive across both UIs.

Keywords

CSCW, groupware, shoulder to shoulder, single display groupware, co-located collaboration, multi-person interfaces, multi-user interfaces, multiple input devices, mice, awareness, turn taking, shared understanding, seat position, left and right

INTRODUCTION

Families and friends watch television together, but we design most PC applications for a lone user. Recently, interest has grown in PC applications targeting several co-present users.

We define "shoulder-to-shoulder computing" as two or more people gathered around a single display to perform an activity together. Note that they can have additional subsidiary displays (e.g. Myers et al.'s Pebbles [17] and not Danesh et al.'s Geney [7], since they have no central display).

Most people use applications in a shoulder-to-shoulder setting already – a simple survey within our team revealed the following list of applications that people use together: Word, PowerPoint (creation and presentations), Visual Studio, games (helping, doing, or watching), web browsing, and technical support.

Shoulder-to-shoulder computing is in everyday use but the lack of application or device support renders aspects of this use frustrating: people fight over mouse control, loose concentration, and retain less knowledge [12].

Our study is a step towards addressing these frustrations through the issues discussed in the following subsections.

Control

Games often allow multiple game controllers – one for each participant (e.g. Project Gotham Racing [18]). But for most applications, users must find a way to share the scarce resource of the mouse, the keyboard, or the remote control. This is typically achieved by giving one person physical control of the application.

Turn Taking and Roles

Other ways of distributing control include turn taking and roles. The Extreme Programming practice of paired programming [1] leads to turn taking. Programmers work in pairs on the same piece of code. One person types and gets review and discussions from their partner. The typist changes as the code touches different areas of expertise of the programmers.

Roles can also be useful; for example, one person taking a leadership role using the mouse to select parts of text for the other person to work on.

Collaboration and Competition

One can divide many tasks into a number of different roles. Hence, we can foster or discourage collaboration. For example, newspaper crosswords allow several people to work on different parts of the solution space independently. Competition between partners working on an application is the whole point of many shoulder-to-shoulder games [18].

Shared Understanding and Awareness

Imagine two people editing a Word document together. One of them selects a sentence to edit, and the other one switches from 'Print Preview' to 'Outline' view. The substantial screen change would be totally unexpected by the first person – breaking their sense of shared understanding.

The study described in this paper looks at awareness and shared understanding as well as enjoyment, collaboration, turn taking, and roles, in a shoulder-to-shoulder application. We find that UI feedback has several effects including a significant increase in awareness accuracy. We also find that the subject sitting to the left of the screen is startlingly more productive.

RELATED WORK

Early research into shoulder-to-shoulder computing goes back to the mid-eighties with the work on experimental meeting rooms at Xerox PARC (for example Stefik et al.'s [20]). Since the mid-nineties, there have been four strands of overlapping work on shoulder-to-shoulder computing:

1. Pair Programming (See for example Beck's [1])
2. Meeting rooms, whiteboards, and brainstorming (See for example Moran et al.'s [16] and Myers et al.'s [17])
3. Children's education, storytelling, and drawing (See for example Druin et al.'s [8] and Inkpen et al.'s [12])
4. Mixed and augmented reality spaces (See for example Ishii et al.'s [14], Billinghurst et al.'s [6], and Benford et al.'s [5])

The work on mixed reality, augmented reality, and ambient displays often applies to larger spaces where several people can gather. But the applications can also be used without two co-present users, and so isn't strictly shoulder-to-shoulder computing.

Overviews of shoulder-to-shoulder computing are contained in Stewart et al.'s [21] and Inkpen et al.'s CSCW Workshop [11].

Work on single user UI and on remote collaboration may also be applied or extended to shoulder-to-shoulder computing problems – for example Greenberg's work in Gutwin et al.'s [10] and Zanella et al.'s [23].

Our work adds new information to the following areas of shoulder-to-shoulder computing:

Enjoyment

Whether shoulder-to-shoulder computing is more fun or more effective has been addressed by Stewart et al.'s [21] and Inkpen et al.'s [13]. They report an increase in educational value and a decrease in frustration when paired subjects each have a mouse. Their subjects were all children, however, and our work extends this with some minimal questionnaire data among adult, computer literate subjects.

Awareness

There is some debate about the style of UI feedback to use in shoulder-to-shoulder computing with Bederson et al. [3] favoring local tool boxes while Myers et al. [17] favor tools associated with the users away from their curser. Zanella et al. [23] overcome some criticisms of the local tool approach through their study of transparency to avoid interference. Both Stewart et al. [21] and Meyers et al. [17] report that color differences between users are not useful. We found feedback mechanisms caused a significant increase in awareness. Color changes were a key part of our UI feedback mechanisms.

Time Taken and Productivity

Stewart et al. [21] discuss potential downsides of shoulder-to-shoulder computing. Increased length of time taken is one, perhaps due to the reduced influence of a single strong willed individual. In Farnham et al. [9] the shared browsing UI which subject's reported as most fun was not the UI they were most productive with.

Our study supports Stewart et al.'s [21] intuition and provides additional data on reduced rate of work.

Collaboration

There are some empirical studies of collaboration in the shoulder-to-shoulder literature (e.g. Stewart et al.'s [22] and Inkpen et al.'s [12]) and some work on fostering collaboration in shoulder-to-shoulder computing through application features (e.g. Benford et al.'s [4]). Again the subjects of these studies are children. Our analysis includes video data showing collaboration changes and data on collaboration changes due to differing roles adopted by our subjects.

Turn Taking

Inkpen et al. [13] studied the effects of turn taking protocols on children's effectiveness and learning. Our preliminary study examined the turn taking behavior between adults and showed a surprising relationship between UI changes and turn taking behavior.

Side Differences and Roles

Our preliminary study examined differences in behavior of adult subjects that depend on whether they choose to sit on the left or right of the screen. We know of no other work on these effects in shoulder-to-shoulder computing.

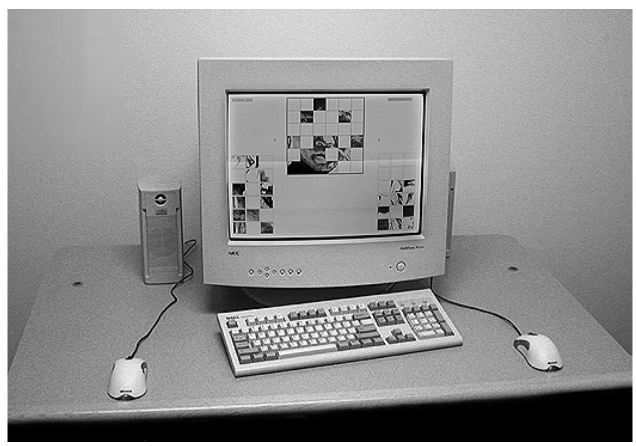

Figure 1 Experimental Setup

USER STUDY

Experiment

We developed an experiment based around a simple picture puzzle based on drawings by Risdon [19] (see the color plate) which subjects solved in pairs. Each user had a mouse and there was one keyboard placed between them (see Figure 1 for setup). We placed 18 picture tiles to the left of the screen and only the user sitting on the left could initially move them. We placed the other 18 pieces on the right and their use was initially restricted to the other user. The tiles had to be placed onto a 6x6 grid.

We gave our pairs of subjects two mice, one keyboard, and one screen.

At the start of the task the subjects studied a large thumbnail of the finished picture. Then one of them clicked a `Mix' button that made the thumbnail disappear and mixed up the pieces. We mixed the tiles using the same randomly generated sequence of swaps each time. Also, when a subject clicks the `Mix' button a text box opens with text that asks subjects to type in a name for the puzzle.

We manipulated the UI feedback between two conditions as follows:

Condition 1: Both subjects had a yellow pointer and yellow borders around the pieces they selected. There were no sounds at all during this condition. When a subject placed a piece into the correct spot, it took on a yellow tint.

Condition 2: We provided four UI enhancements:

1. Different colors: yellow (RGB hex value #FFFF00) for the subject on the left and lime green (RGB hex value #00FF00) for the subject on the right. We used these colors for the pointer and the shading on correct pieces.

2. Arrows: We temporarily displayed an arrow after a subject had moved a piece to indicate the move. The arrow was either yellow or green, depending on the user.

3. Graphical history: Each time a subject moved a picture tile we added a small square to a running total along the top of that subject's side of the screen. If the subject placed the piece into the correct spot, the small square contained a checkmark.

4. Sound: We added sounds to indicate moves. The sounds were the same for both users. We also added a sound when a subject placed a piece correctly and this sound was different for each subject.

Subjects could place their own picture tiles onto blank squares in the grid. They could pick up un-tinted picture tiles from the grid and move them. Tinted picture tiles were in the right place and could not be moved.

The color plate shows most of these UI features.

Subjects worked together on the puzzle for three minutes, and then we interrupted the subjects with a white screen which hid the puzzle and handed them a questionnaire to complete in silence. The questionnaire contained questions about enjoyment, collaboration, and testing the awareness of their own and their partner's moves. Having completed the questionnaire, subjects resumed working on the puzzle until it was completed.

Subjects were prompted to enter text three times within each puzzle session:

1. They were asked to title the puzzle after pressing the `Mix' button
2. They were asked for their name after the interim questionnaire
3. They were asked for a brief description of the puzzle upon completion.

We used 24 subjects in 12 pairs. Subjects were mostly recruited from within our organization, and we controlled for gender, computer experience, and existing acquaintance with each other. Of the 12 pairs 4 were male and 8 were female. There were four sessions in each experiment, a practice session and an experimental session for each of the two UI conditions.

Our implementation used a toolkit we had previously developed that enables web developers to quickly build collaborative applications. Our puzzle used DHTML, VML, and our toolkit. The subjects' mice were actually connected to two additional PCs that used the mouse position to replicate a cursor position on the central PC where the puzzle was solved. Other technologies that support multiple mouse input include Direct Input under Windows 98 [15] and Bederson's MID [2].

We recorded log files containing cursor positions, text input, and picture tile moves. We also used the questionnaires and video of the subjects as data sources.

Results and Discussion

Though we designed our experiment to examine awareness and shared understanding in shoulder-to-shoulder computing under varying UI feedback conditions, a number of related results were also obtained and are discussed below.

All statistical tests are within-subjects and two-tailed unless stated otherwise. Most questionnaire items used a five-point response scale that ranged from 1 (*Not At All*) to 5 (*Very Much So*).

Enjoyment

Our hypothesis was that solving a puzzle with a friend would be enjoyable, and we were not expecting any changes between the sparse UI and the enhanced UI conditions.

In the questionnaire, we asked subjects

- Did you enjoy working on the puzzle?
- Did you have fun working on the puzzle with your partner?

Table 1 shows that respondents gave high ratings for both questions (the average answers are 4.4 to both questions). There was a marginal drop in reported enjoyment ($p=0.08$). Our speculation, based on subjects comments made to each other during the experiment, is that subjects disliked the aesthetic effect the different colored tinting had on the picture as it was solved (see color plate).

This high marking supports the finding on two mice shoulder-to-shoulder computing reported in the research by Stewart et al. [22] and Inkpen et al. [13] (both for child participants).

We have not yet conducted any further analyses of enjoyment factors (for example, a linguistic analysis of the audio track), nor did we control for the puzzles' inherent fun.

Awareness

We hypothesized that the enhanced UI would impart on users a greater awareness of their partner's actions with no reduction in awareness of their own actions.

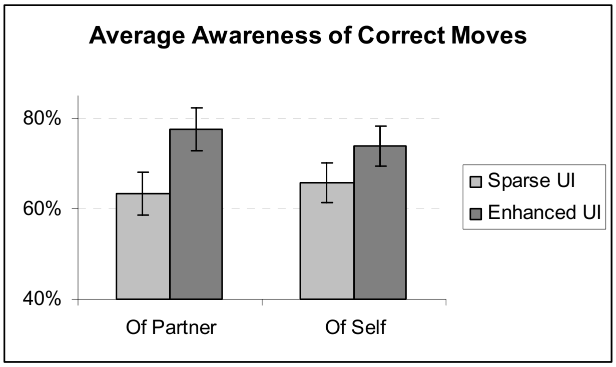

Chart 1

To test this hypothesis we asked subjects "How many tiles did your partner place correctly?" and "How many tiles did you place correctly?" Using the log files we were able to measure subjects' accuracy. Consistent with our hypothesis we found that subjects were significantly more accurate in their guesses as to the number of correct moves their partner had made when they used the enhanced UI. Chart 1 and Table 1 show this significant change in average accuracy from 66% to 78%. When participants used the enhanced UI, they were also more accurate in their guesses about how many correct moves they had made themselves – although the difference was not significant. Chart 1 and Table 1 show how the average accuracy of responses to this question changed across the two conditions from 66% to 74%.

Therefore we found that UI feedback can increase the awareness of one's partner's actions during shoulder-to-shoulder computing. As discussed this is important to achieve a shared understanding of the task. In this experiment shared understanding was achieved without an associated reduction in awareness of one's own actions—in fact, there was a trend toward increasing awareness of one's own moves, though it was not statistically significant.

Replies to the question "To what extent were you aware of what your partner was doing?" went from an average of 3.4 using the sparse UI to 3.7 using the enhanced UI. Though this is a non-significant increase (see Table 1), it suggests that the increased awareness is not conscious.

Interestingly, the difference in awareness of one's partner's actions and one's own actions is less pronounced in the puzzle than we expected. We expected subjects to be more aware of their own moves than their partner's moves. Comparing the mean accuracy about subjects' partner's correct moves and subjects' own correct moves using just the sparse UI (see Chart 1 and Table 1) shows means of 66% accuracy about oneself and 63% accuracy about one's partner under the sparse UI condition. This change is only marginally significant ($t=-1.74$ $p=0.06$). Perhaps a different choice of application to base our experiment on – one where awareness was more crucial to progress - would have drawn out the distinction.

Time Taken and Productivity

Stewart et al. [21] report an increase increased length of time taken as a potential downside of shoulder-to-shoulder computing. We explored the question of productivity to find out if there was a significant difference between the two UIs.

We asked subjects "Was solving the puzzle hard?" and also measured the time it took to complete the puzzle. The average response to the self-reported difficulty was 3.1 and there were no significant differences between the two conditions. See for detailed results. Though we found no difference in reported difficulty, we did find a significant increase in the time subjects took to solve the puzzle. Users took an average of 322 seconds to complete the puzzle when using the sparse UI and an average of 400 seconds when using the enhanced UI. The change is significant (see Table 1).

However, taking more time is not necessarily a bad thing. Most of us would dislike an application that enabled us to watch a feature film in ten minutes as it would reduce the time we spent with friends and family.

By choosing an application for our experiment that more clearly linked productivity to awareness of one's partner's actions and shared understanding we might not have seen this result. Indeed, the UI variation without the initial thumbnail discussed earlier forced far greater collaboration. But this is an important result: when designing a UI for shoulder-to-shoulder application there may be tradeoffs between shared understanding and productivity.

Subject pairs responded very differently to the puzzle task in terms of time and performance pressures. Those who felt it to be a competitive task made comments like "We're wasting a lot of moves here" while others explicitly pointed out that "It's not a competition".

Collaboration

We wanted to explore the effects our variations in UI conditions would have on collaboration between participants. Because pairs sat next to each other, we did not expect the computer to be the medium through which much of the collaboration and interactions took place.

Our measurements of collaboration came from questionnaire questions and analysis of the video footage.

We asked subjects: "To what extent did you feel you and your partner were working together?" (average answer 4.0) and "Did you feel you and your partner had any conflict in making your decisions?" (average answer 1.7)

Subjects reported a clear sense of collaboration – the partners did not feel they were working independently. Table 1 contains the detailed results.

In our video analysis, we counted the number of times participants pointed at the screen and the time the spent talking to each other, both of which are signs of collaboration between them. We found that partners pointed significantly more when they used the enhanced UI, compared to when they used the sparse UI. Chart 2 and Table 1 shows a significant increase in gestures towards the screen – up from an average of 0.4 gestures per session using the sparse UI to an average of 1.5 using the enhanced UI. This is a significant change.

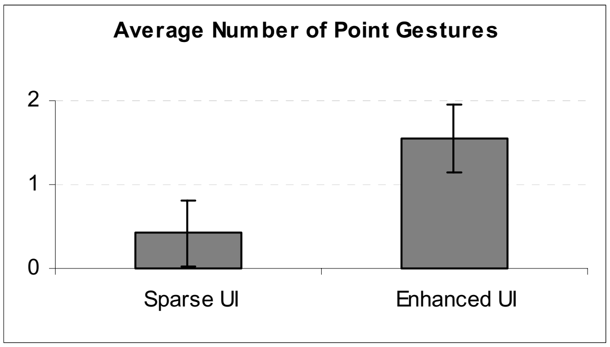

Chart 2

Though participants tended to talk to each other less when using the enhanced UI, the difference was only marginally significant. Chart 3 and Table 1 show that time talking goes down from an average of 37.4 seconds to 31.5 seconds.

We speculate that the increased awareness of each other's moves when using the enhanced UI has reduced the need to establish a shared understanding of each other's intentions through the spoken word. We also suggest that using the enhanced UI also increased one's interest in pointing out where the tile one's partner is working on should go.

Anecdotally, we found that pointing at the screen with one's finger is far more effective (i.e. requires less clarification and repeats) than pointing with one's cursor. Further work is required to establish if UI conditions affect the frequency of finger and cursor pointing.

Turn Taking

We did not contrast two mice and one mouse shoulder-to-shoulder computing (this has been done before – by Inkpen et al. [13]). However, we did provide several occasions when only one of the subjects would be able to use a scarce resource: clicking the `Mix' button and the three occasions subjects were asked to enter text.

Because the subjects were in the same room we were not expecting the UI to have any effect on turn-taking behavior. Interpersonal cues about who would perform which actions were strong. Indeed, there was no appreciable difference between the two UI conditions for who clicked the `Mix' button (see Table 1 for details).

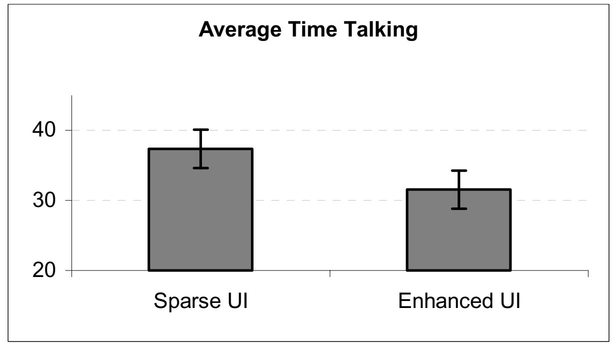

Chart 3

However, we found a trend emerging as to whether or not subjects swapped the keyboard to input text during the session. Table 1 shows this increase in turn-taking across the two UI conditions. Of the three occasions keyboard input was required, 4 of 12 pairs swapped at least once under the sparse UI condition while 9 in 12 pairs swapped at least once under the enhanced UI condition. This difference was not statistically significant (Table 1; McNemar test for correlated proportions). However, this trend suggests that the increased awareness of subjects' partner's moves discussed earlier may be part of an increased general awareness of their partner.

	Sparse UI		Enhanced UI		Difference	
	m	SD	m	SD	t	p
Measurements						
Time Taken (sec.)	322.0	138.6	400.0	179.0	-4.0	0.00
Awareness of Partner	0.6	0.2	0.8	0.1	-3.0	0.01
Awareness of Self	0.7	0.1	0.7	0.1	-1.9	0.09
Time Talking (sec.)	37.4	14.6	31.5	14.7	2.1	0.06
Pointing instances	0.4	0.6	1.5	1.6	-2.8	0.01
`Mix' button right	0.9	0.3	0.8	0.4	1.0	0.34
Keyboard Swaps	33%	N/A	67%	N/A	N/A	0.13
Questionnaire						
Enjoy?	4.6	0.5	4.3	0.6	1.9	0.08
Hard?	3.2	0.6	3.0	0.7	0.9	0.40
Fun with partner?	4.4	0.4	4.4	0.5	0.6	0.58
Working together?	3.9	0.9	4.0	1.0	-0.2	0.81
Conflict?	1.7	0.7	1.6	0.5	0.4	0.72
Aware partner doing?	3.4	0.9	3.7	0.8	-1.7	0.11

Table 1 Detail of UI Results

Side Differences and Roles

The results of the previous section led us to question where the keyboard inputs were coming from: the left or the right? The result was clearly biased towards the right, and so we started to explore whether other participant behavior showed a left or right bias – regardless of the UI conditions. Unfortunately, we were not expecting any such differences when we designed our preliminary study, so we did not control where subjects sat nor did we ask them why they choose the side they sat on.

We found a series of significant differences between the behavior of those who sat on the right and those who sat on the left. Though the subjects on the right were more likely to click the `Mix' button and to input text at the keyboard, they made significantly fewer correct moves in the first three minutes of the puzzle, used significantly fewer of their partner's tiles, and talked significantly less.

Table 2, Chart 4, and Chart 5 highlight two of these results: the significant difference in presses of the `Mix' button from 0.25 on the left to 0.62 on the right and the significant difference in average right moves in the first three minutes from 22.58 by the left subject to 16.58 by the right. There is a significant difference in time talking (averages of 81 seconds from the left and 56 from the right). Pointing at the screen also differs significantly (averages of 2.46 from the left and 1.46 from the right). Collaboration, measured through the number of tiles moved that were already moved by the subject's partner, significantly differs (averages of 6.33 from the left and 3.00 from the right).

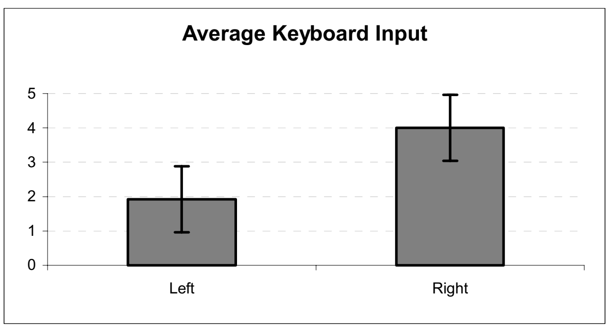

Chart 4

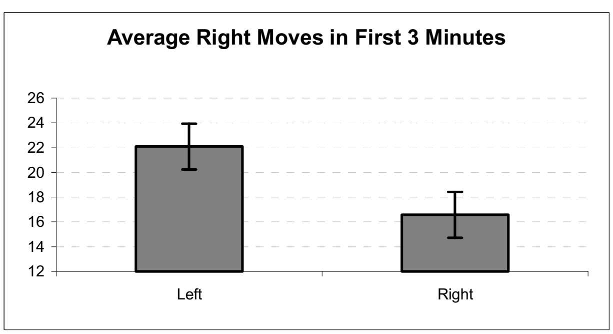

Chart 5

We would like to propose two explanations for the bias to the right of keyboard input. First, because only one of our subjects was left handed (and she normally uses the mouse to the right of her keyboard), each subject sitting on the right preserved his or her familiar layout of keyboard on the left and mouse on the right.

A second possibility is that clicking the `Mix' button established the subject on the right as the one to lead on input especially since the first input box appears as a result of the `Mix' button click. We placed the `Mix' button slightly to the right of the screen (approximately 2" from the center line) and we did not vary its position throughout the experiment.

Having established the role of the right hand subject, the left hand subject may assume a complimentary role, e.g. a coordinator and an implementer.

So, placement of UI features on the screen or devices around the screen may have an influence on behavior in shoulder-to-shoulder computing – especially in the two-person case where there is a person on the left and a person on the right.

One might also account for all the biases by different personalities opting for the different seats at the start of the experiment. Further experiments are required to understand this better.

	Left		Right		Difference	
	m	SD	m	SD	t	p
Keyboard Input	1.92	1.68	4.00	1.65	-2.18	0.05
`Mix' Button	0.25	0.62	1.75	0.62	-4.18	0.00
Right Moves	22.08	6.27	16.58	8.23	2.97	0.01
Using Partner's Tiles	6.33	5.66	3.00	3.36	3.30	0.00
Time Talking	81.33	35.94	56.50	27.83	2.64	0.02
Pointing At Screen	2.46	3.03	1.46	2.25	0.93	0.37

Table 2 Detail of Side Difference Results

CONCLUSIONS

This paper presents the results from an initial study into the impacts of increased UI feedback on shoulder-to-shoulder computing. We added color and sound differentiation and graphic history and status indicators to a picture puzzle task which paired subjects had to solve using a mouse each and a shared keyboard. A summary of our key results follows:

Enjoyment – it is fun! Adult subjects enjoyed tackling the task in a two mice shoulder-to-shoulder setting.

Awareness and Shared Understanding – our increased UI feedback did improve subjects' awareness of their partner's actions.

Time Taken and Productivity – the cost was increased time taken to complete the puzzle. There are situations where this would be a benefit (many leisure applications are supposed to take time) and situations where it could be ameliorated (tasks where increased awareness is required for productivity).

Collaboration – our increased UI feedback had an effect on face to face collaboration: subjects pointed more and talked less. We believe this is due to the increased awareness.

Turn Taking – surprisingly, enhanced UI feedback may lead to increased turn taking at the keyboard. This could also be attributed to increased awareness though it is difficult to believe that a computer UI can make one more aware of a person one is sat next to physically!

Side Differences and Roles – we saw a marked preference for the subject on the right to enter text at the keyboard. Most other measures we took favored the subject on the left. This may be due to adopted roles affecting the choice of seating or it may be that the set up and UI influence adopted roles.

These findings, based on one task and 12 pairs of subjects, should be considered tentative until confirmed by additional studies.

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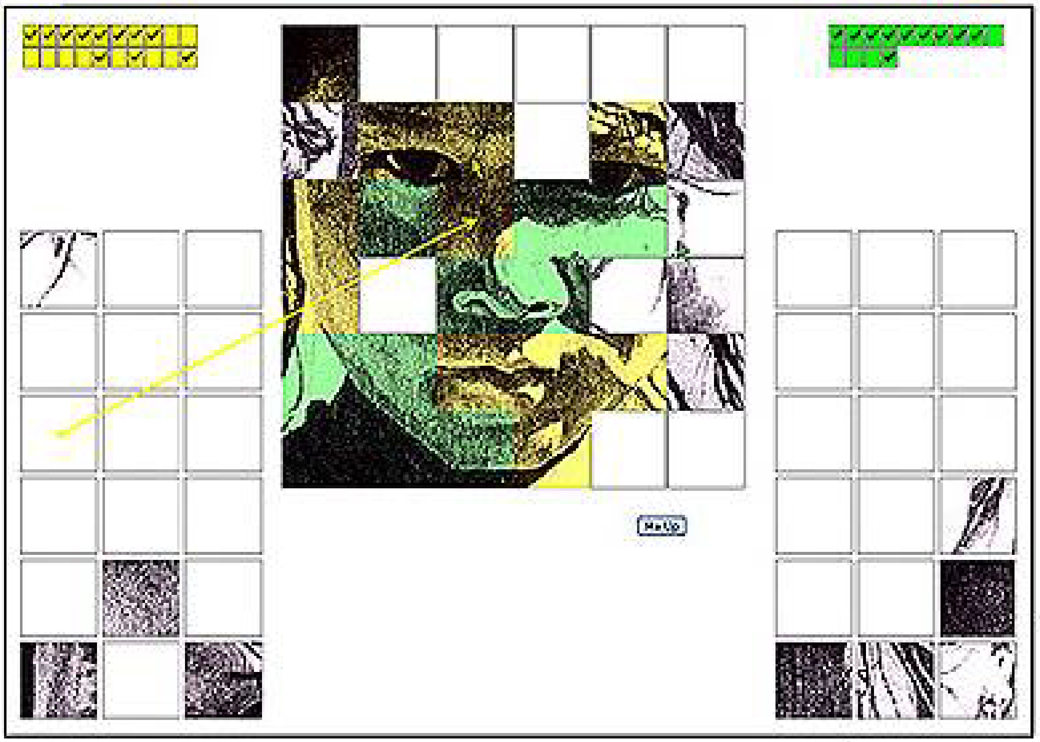
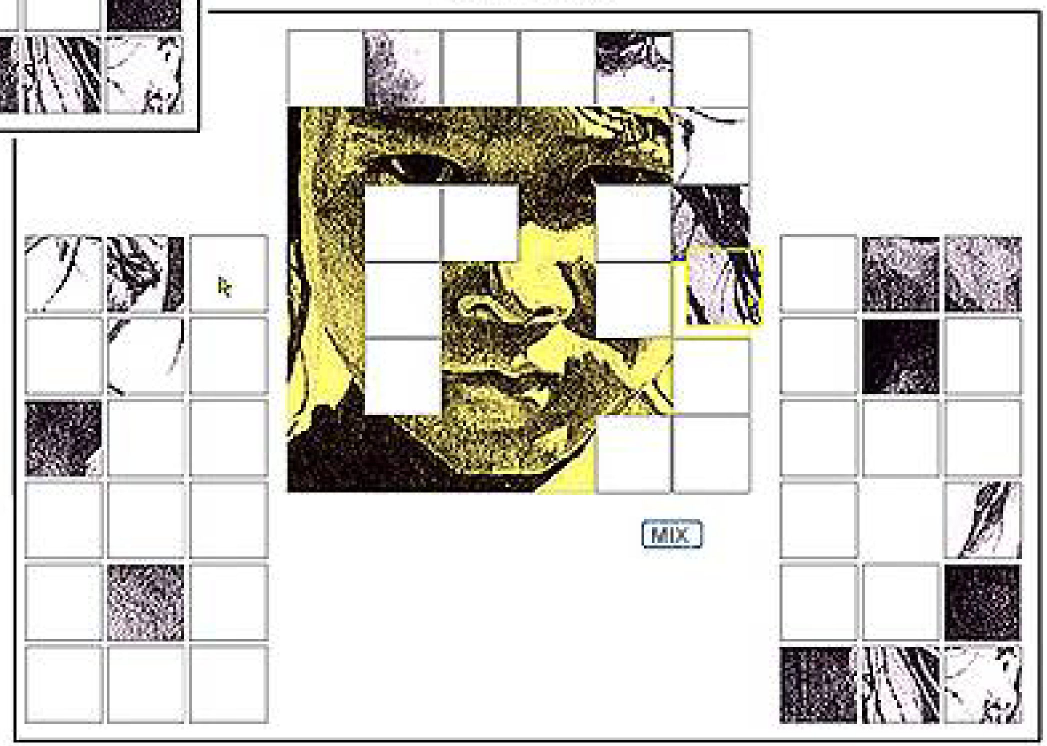
Enhanced UI



First Keyboard Input

Sparse UI



Interruption After 3 Minutes