The Effects of View Portals on Performance and Awareness in Co-Located Tabletop Groupware

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ABSTRACT
Tabletop work surfaces have natural advantages for co-located collaboration, but also have physical constraints that can make group work difficult. View portals have been proposed as a way to provide access to other parts of a table surface, and as a way to re-orient content for group members in different locations; however, there is little research on whether portals really do improve group performance, how much they help, and whether they change other aspects of collaboration. We report on two studies that evaluate the effects of portals on group performance and behavior. Our first study showed significant performance advantages for portals: people were able to complete tasks more quickly and with more equal division of labor. Our second study, with a realistic design task, showed that people used portals extensively and saw them as valuable, but that they affected people's ability to maintain awareness, coordinate access to objects, and understand the organization of the workspace. Our work demonstrates benefits and potential drawbacks of portals for tables, and suggests that designers should carefully consider both individual and group needs before implementing these and other tabletop view augmentations.

Author Keywords
Tabletop groupware; portals; performance; awareness

INTRODUCTION
Digital tabletops are now becoming common in research labs and organizational settings. One reason for the interest in these devices is that tables are a natural setting for collaboration, and provide many advantages for co-located group work. For example, tables traditionally allow for easy verbal and visual communication, simple and rich awareness of others' presence, location, and activity, and enough space to support both individual work and shared group areas.

However, there are also limitations presented by physical table settings. For example, the arrangement of the group around the table means that some people must look at work artifacts sideways or upside down (when they are being used by others), that people can interfere with one another when they are working in the same place, and that it can be difficult to see and reach other parts of the surface (either because of distance or occlusion from others' arms and bodies).

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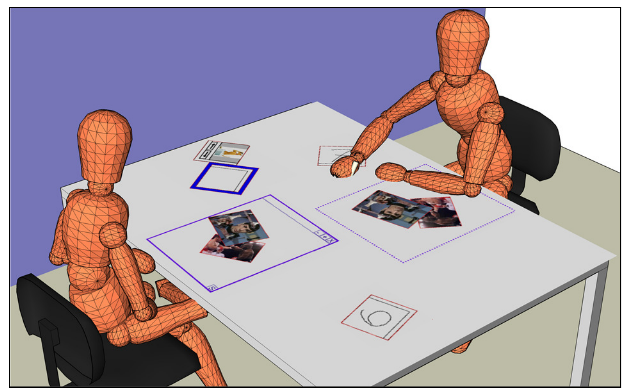

Figure 1. Tabletop portals – the left user has a portal that is showing the contents of the right person's work area.

Researchers have proposed augmentations to digital surfaces that are intended to address some of these limitations – for example, long-distance reaching techniques such as tractor beams, wormholes, or cursor extensions allow people to select and manipulate objects anywhere on the table (e.g., [1,20,23,38]); individual views provide additional or private space for people to work (e.g., [11,16,26,27]); and view portals allow people to temporarily duplicate regions of the table for easier access to objects or tools (e.g., [12,19,34,38]).

Augmenting tabletop collaboration with techniques like these poses a question for groupware designers: is it better to preserve the well-understood affordances and supports of a traditional tabletop setting (and live with the limitations), or is it better to add to the capabilities and affordances of a digital table to try and overcome the traditional limitations. The risk in augmenting digital tables is that the new techniques may compromise some of the characteristic benefits of tables (communication, awareness, and flexibility) that are so useful for collaboration.

Some research has shown that changes do occur – that group activity changes based on different factors in the tabletop setting. For example, the type of input device [9], the type of interaction (direct or indirect) [10], the type of embodiments used on the table [6,24], and the use of personal views [16] have led to a variety of effects on group performance, coordination, conflict, and territoriality at a digital table.

There is little previous research, however, about the effects of view portals on collaboration. Portals can substantially increase the power of a tabletop system – they can provide access to distant parts of the table, can allow reorientation of work objects to each user's perspective, and can allow people to work in the same area of the table without physical collisions – but these new capabilities could also take away from the existing strengths of tabletop settings. For example, the duplicate views that portals create can break the explicit connection between a user's embodiment and the artifacts being manipulated, possibly reducing awareness; similarly, portals create visual discontinuities in the table surface, potentially making it more difficult for users to understand the organization of the workspace and others' locations in it.

To provide initial knowledge about how view portals affect both group performance and group behavior, we carried out two studies. The first study looked at the potential performance benefits of portals in controlled conditions – that is, we examined whether, and by how much, portals can solve problems of reach and orientation on tables. The second study looked at how portals affected collaboration in a realistic and open-ended task, and collected subjective data about group awareness, coordination, and conflict, about people's ability to understand the overall organization of the workspace, and about overall performance and preferences.

The results of our first study show that in terms of performance, view portals do provide the intended benefits – they significantly reduce the time needed to reach distant objects, and they significantly reduce time and errors when working with objects that are oriented away from the user. In a two-person task, portals also led to more equality in the amount of work done by the two people – although participants reported being less aware of the other person's activities when portals were used.

In the second study, which used a realistic and open-ended task, participants all chose to use portals to organize their work activity, all stated that portals provided benefits in terms of reaching and orientation, and eight of twelve people said that portals improved the collaboration. However, participants again reported negative subjective effects of portals on their ability to keep track of what the other person was doing, and on their ability to understand the spatial organization of the workspace. Comments and interview responses from participants showed that portals introduced new barriers to awareness, understanding, and coordination – in particular, portals made it harder to see others' actions, which led to poor awareness and increased conflicts, and portals also led to people becoming overly focused on a single view rather than observing the entire tabletop.

These results indicate that view portals present groupware designers with a tradeoff between the needs of the individual and the needs of the group. Our studies are the first to demonstrate that portals can improve performance and reduce limitations of the table setting – but that there is a cost to issues important to the group. Our work shows that designers must carefully assess the need for awareness, coordination, and workspace understanding before deciding to make use of this (potentially high-performance) technique.

RELATED WORK

Tabletop workspaces and constraints

In tabletop work, people naturally divide the workspace into nearby personal areas and into more centrally located group work areas [29]. However, tabletop work often has a mixed focus in which people move back and forth between individual activities, subgroup interactions, and shared activities with the entire group [8,22]. This means that peoples' work locations can change over the course of an activity, and that they may need to access a variety of locations and artifacts on the tabletop. Three main problems can arise during mixed-focus collaborative work on a tabletop: that items are out of reach, that people can interfere with each other's access to different parts of the table, and that shared artifacts can only be oriented towards one person.

Reaching. When people switch between these work modes, they often change the artifacts and tools that they are working with, but the items they need are sometimes out of their reach [20,23]. People can adopt different strategies to retrieve the items that they need [36]: for example, they can lean across the table, stand up and walk around the table, or ask another person to pass the item. This problem has also been encountered with large wall displays (e.g., [12]).

Interference and access. When people have to work in a limited area (e.g., with a particular artifact or on a set of artifacts), they can have difficulties managing access due to space limitations. For example, several studies describe instances where people blocked another person's view or interfered with their ability to interact with the workspace [19,36]. Similarly, Doucette et al have shown that people avoid crossing over another person's arm on the table, meaning that people need to coordinate access when they need to use objects in different areas of the workspace [6].

Orientation. Orientation plays an important role in collaborative work on tables: collaborators use the orientation of shared resources to comprehend information, to communicate, and to coordinate work [15]. Orientation enables comprehension since repositioning an object enables individuals to read its contents more easily. As Kruger and colleagues found, people turn objects toward others during conversation, and use object orientation to help to partition the tabletop workspace into individual and group spaces [15]. In many tabletop situations, people must often try to interpret and make use of objects that are oriented away from them, and several sources indicate that it is difficult to comprehend information in this setting. Prior work in psychology (e.g. [13]), suggests that people are significantly slower when reading text that is oriented away from them. Wigdor and Balakrishnan [39] show similar results, but argue that the effects are less than the previous studies, since people can often accommodate some degree of rotation by changing the posture and position of their head and body.

Augmenting tables with new view techniques

Several solutions to the limitations of traditional tables have been proposed in prior work. These solutions often take the form of augmented view techniques for digital tables that provide people with new capabilities. Three of the main types of augmentations are techniques for reaching and reorientation, personalizable views, and digital portals.

Techniques to improve reaching and reorientation

Several techniques have been proposed for increasing a person's reach on large surfaces. These techniques use a variety of mechanisms, including pointing, distance reduction, miniatures, and wormholes.

Pointing-based reaching techniques allow people to point to distant objects on the table and drag them into proximity. For example, Tractor Beam [23] and "laser pointing" [20] use this method; simple indirect input with a mouse (e.g., [6]) uses similar principles.

Distance-reduction approaches magnify a person's reaching motions. There are two ways in which this can be done – by extending the user's locus of control (e.g., the Pantograph technique [20] or the I-Grabber tool [1]), or by bringing targets closer after an initial directional movement (e.g., using target proxies in the Drag-and-Pop technique [2]).

Wormholes provide regions on the display that will transport dropped objects to other places. This idea has been used for object transfer in multi-display environments (e.g., using different mouse buttons [6] or a list of displays [4]), and also on tables – the Dynamic Portals system [38] allows people to position the two sides of a wormhole anywhere on the table and move objects through the hole.

Workspace miniatures enhance reaching by creating a new representation where all objects are close (but much smaller). Miniatures give an overview of complex environments (e.g., [4]) but are also fast: for example, Nacenta et al. showed that reaching with a "radar view" miniature was faster than either a pantograph technique or laser pointing [20].

In addition, techniques have been developed to allow easier rotation of artifacts (e.g., RNT [14] or TNT [17]) or the entire table (e.g., DiamondSpin [31]). These simplify the process of reorienting content for a single person, but do not solve the problem of conflicting orientation for the entire group.

Personalized views for tabletop work

Researchers have considered several techniques that provide individuals with different views around a digital table – either to increase the available work area of the table, or to provide private information for each person.

For example, the tabletop workspace can be extended with people's personal devices such as smartphones or tablets (e.g., [29,34]). This approach is common in situations such as a shared card table, where each person's hand of cards is shown on a personal device. Other technologies have also been explored for extending the table – for example, the MisTable system presents 'fog screens' between each user and the table surface that can show individual views [27].

The space of the table itself can also be multiplexed to show different views to different people. A simple approach is to use transparency (e.g., for popup menus) so that people working in the same part of the table can still see their work artifacts [40]. Other technologies can provide completely different views. One approach uses LCD shutter glasses to divide the refresh rate of the table between multiple individualized views. This method, which can show both shared objects and private objects, was used in the early Single Display Privacyware technique [32], as well as the more recent Permulin table system [16]. Another approach uses physical display materials that provide different information depending on the user's position. For example, the Lumisight table [18] gave four users individual views of the workspace using Lumisty film, and the PiVOT system used multiple LCD displays, Lumisty, and an overhead projector to provide flexible and moveable personal views overlaid on top of a shared visual workspace [11].

Personalized view systems are dependent upon specialized hardware, which can limit the number of collaborators. In addition, the approach of providing a different view for each person moves away from one of the original advantages of tabletops – that everyone can see the same shared workspace. This can reduce consequential communication and feedthrough [8] and cause conflicts that do not occur in typical tabletop work (e.g., when people put their personal views into the same physical space on the table [16]). Portal-based systems, in contrast, maintain a single view for all participants, even though the table content is rearranged.

Digital Portals

Multiple views of a large workspace have been known since the first windowed user interfaces; however, the idea of views that are part of the workspace itself is more recent. One of the first common implementations was in the portals of the Pad++ system [3], which were rectangular regions that looked onto other parts of the workspace. Pad++ portals could be scaled arbitrarily, and provided long-distance visibility and long-distance action to other regions of the space. WinCuts is a similar idea [35] that allows users to create new windows that reference regions of existing windows on the desktop, letting them build customized interfaces for particular tasks. Tan and colleagues [35] also propose using WinCuts in co-present collaboration, where users create WinCuts of work areas on their laptops and share them on a large public display.

Several portal and view systems have been developed for large vertical displays. The Frisbee system [12] provides a portal to another region on a wall display, and users can pan and resize the portal area. Actions performed within the Frisbee portal are the equivalent of interacting with the referenced display area. Kahn et al. propose further modifications to the Frisbee system, such as support for multiple portals and the ability to rotate the content of the target area. Bezerianos and Balakrishnan [5] describe a related implementation, called canvas portals, that allows users to reach to distant areas on a large display. The system has several additional enhancements including variable shapes for portals, portal resizing, grouping of portals, and division bands within a portal.

Portals have also been implemented on tabletops – here we separate the specialized technologies that could be used to provide individualized views (discussed above) from the idea of displaying another region of the workspace in a portal (which is possible with any table system). Morris et al. [19] suggest that portals can play an important role in helping to coordinate group work in tabletop systems. Streitz et al. [34] describe the InteracTable, a tabletop system which allows users to create customizable views of other regions of the workspace. The views can be repositioned and reoriented so that they are tailored to each user's perspective. Tang et al. [36] describe a technique called ShadowBoxes that allows users to create views of other areas of the tabletop, with limited control over orientation and size of the view area.

Shen et al. [30] developed CoR2Ds, a portal based widget for providing access to tools that are far away; the widget can be rotated, moved, and resized (but only allows access to controls, not content). Finally, the Dynamic Portals technique (primarily used as an object-transfer technique, as described above) can also provide a view of the table at the other side of the wormhole; and manipulations of the portal can provide effects such as scaled views [38].

The effects of table augmentations on collaboration

Previous work has considered the ways that changes to group and table size, input technique, and embodiment type change the nature of collaborative activity on digital tables. Early work showed that although group size strongly affected collaboration in a shared construction task, table size had little effect [28]. Several projects have compared direct and indirect input in terms of their effects on performance [9], coordination and conflict [10,21,24], and spatial interference [36,37]. Some evidence suggests that indirect input changes natural collaborative behaviours such as territoriality [29], and leads to an increase in coordination problems [22].

Recent work has also looked at tabletop embodiments, which are necessary when a table system uses indirect input (such as mice) for interaction with the table. For example, Pinelle et al. [24] carried out a broad exploratory study that looked at ways that different arm embodiments affected behaviours in a tabletop game; they found differences between physical and digital arms, but that different types of digital embodiments had little effect (although people preferred more realistic representations). Doucette and colleagues have also looked at the effects of different arm embodiments on reaching and arm-crossing behaviour on tables [7]. This work also shows a dramatic difference between physical and digital embodiments, and very little difference between different types of digital representation. These researchers also showed that some of the effects of physical arms (e.g., reduced arm crossing) could be reintroduced by adding tactile feedback or motion changes to digital embodiments.

The effects of personalized views on collaborative coupling was tested in an evaluation of the Permulin system [16]. The study found that the individual views enabled greater parallelization of work, but that when work was loosely coupled, participants stayed almost entirely in their own individual views, reducing awareness of the other person.

These previous study show that augmenting the capabilities of a traditional tabletop can change collaboration in a variety of ways. The specific effects of portals on collaboration has not been considered, however – and portals differ substantially from techniques such as individualized views because portals, and the actions within them, are always visible to all participants around the table. In the following sections, we describe our implementation of a portal system for tabletops, and then report on two studies of how portals affected collaborative performance and behavior.

CUTOUTS: PORTALS FOR DIGITAL TABLES

We developed a representative portal-based interaction technique for tabletop groupware (called *cutouts*) that provides multiple flexible views of the artifacts on a shared tabletop [25]. Our implementation is based on three design goals that capture the main features seen in existing portal techniques (e.g., [12,18,34]): enable users to see and access any area of the table, regardless of distance or others' locations; enable users to work near another person without bumping into them; and enable users to orient digital artifacts to suit their current position at the table.

Cutouts provide portals to other regions of the workspace (Figures 1, 2, 3). Each portal is bound to a region on the table called its 'reference area,' and provides a duplicate virtual view all of the objects that are contained in the reference area. The portal can be moved anywhere on the table, and can be rotated to any angle (Figure 3). Users can interact with the objects shown in the portal, and all operations are applied to the original objects located in the reference area. A cutout is only a view, so destroying it does not affect the original.

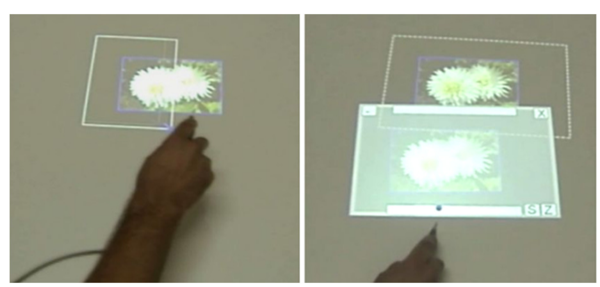

Figure 2. Left: creating a cutout. Right: the new cutout and dashed rectangle indicating reference area.

All instances of an artifact are 'live' and can be manipulated by users. If two users grab the same object, we use a "last-moved" strategy to determine where the object goes, allowing people to use social protocols to resolve the conflict. To aid in maintaining awareness of people's actions in a portal, cutouts display telepointers that show pen movements in both the reference area and the cutout.

Users can also change the coordinates of the reference area that is displayed in the portal using panning controls, and they can change the size of the reference area (which also changes the size of the portal). Finally, they can use zoom controls to shrink and enlarge the objects shown in the portal. These controls allow users to create a variety of customized views that show areas of the table at any size and orientation.

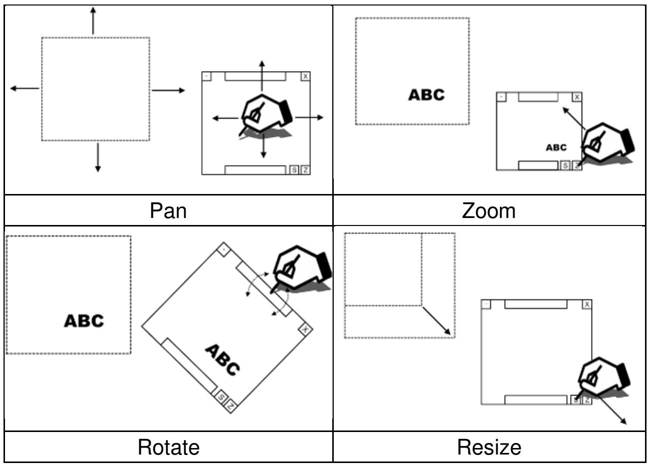

Figure 3. Pan, zoom, rotate, and resize operations on cutout (dashed rectangle indicates change to reference region).

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Users create cutouts by dragging their pen to define the reference area (see Figure 3). Initially, the portal has the same size as the reference area, and has toolbar regions at the top and bottom that provide several controls. A dashed line is drawn around the reference area using a random color, and the same color is used on the cutout border. Users can destroy a cutout by clicking on the "X" button in the portal's toolbar.

We conducted two studies to evaluate the usefulness of portals as a way of managing shared work in tabletop systems. Our overall goal was to assess the quantitative and qualitative effects that cutouts have on the group process. The first study was a controlled experiment where we assessed the effects that cutouts have on group performance and participation. The second was a qualitative study where we evaluated cutouts during a more realistic task, where pairs of people designed a series of webpages.

STUDY 1: PERFORMANCE BENEFITS OF PORTALS

We carried out a controlled study to examine the potential benefits of portals in situations where people need to reach other areas of the table, and where they need to work with artifacts that are oriented away from them. This study established baselines using simple atomic actions that are building blocks in more realistic tasks, and also combined these actions in a simple two-person puzzle game. Our goals were to determine whether portals had a beneficial effect on performance, and what the size of that benefit was.

Methods

We recruited 20 participants (10 men, 10 women, mean age 25.6 years), from a local university. Participants were recruited in same-sex pairs. All were regular computer users (more than 8 hours/week), and 9 had previous experience with using tabletop display systems.

The experiment was conducted on a top-projected table (125x160cm) with 1024x768 resolution. A custom study system was built in Java; all participant input was handled using a Polhemus Liberty tracking system with two pens. Interaction with the table in all conditions involved touching the table with the pen to manipulate objects. There were two within-participants study conditions: the *standard table*, which provided no augmentations, or *portals*, which provided an additional view portal to address distance or orientation limitations for the task, as described below.

Tasks

Baseline tasks: reaching and orientation

The first tasks involved simple reaching and matching activities to determine baseline effects on performance. In the reaching task, participants repeatedly reached for objects and dragged them to a central location (Figure 4, left). For the standard table, objects were positioned 100cm from the central location, and participants had to lean forward to touch the objects with the pen. In the portals condition, a portal of the objects and the central location was created before the trial, scaled to 25%, and positioned in front of the participant. The Fitts's Law index of difficulty for the two tasks are the same (since although the targets are closer, they are also smaller); however, the standard view requires much larger movements of the whole arm.

In the orientation task, participants had to match a given shape to one of four shapes on the table. In the standard setup, we tested two cases: the cue shape was right-side up for the participants, but the reference shapes could be either upside-down or right-side-up; in the portals condition, a portal was used to create a copy of the reference shapes that was oriented towards the participant (Figure 5).

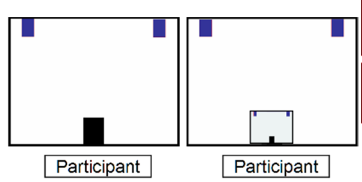

Figure 4. Reaching task (standard left, portal right)

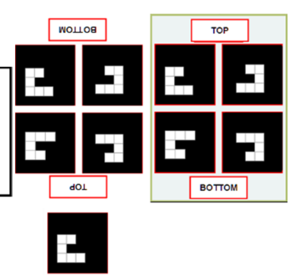

Figure 5. Orientation task (standard left, portal right)

Group task: puzzle game
Participants sat on opposite sides of the table from each other. During each game, eight targets were displayed on the table (see Figure 6). Each target displayed two white cursive letters on a black background. All targets and all letters faced the same direction (right-side-up for participant A).

Match cards were shown at the corners of the table. When a user tapped on a card, it turned over and rotated to face them. Participants were instructed to select the target card that matched these cards; when a correct match was made, a new match card would appear. Sound feedback indicated correct and incorrect matches. Each game included 16 cards, two for each target. Cards were presented in random order. The game ended when all cards were matched with their targets.

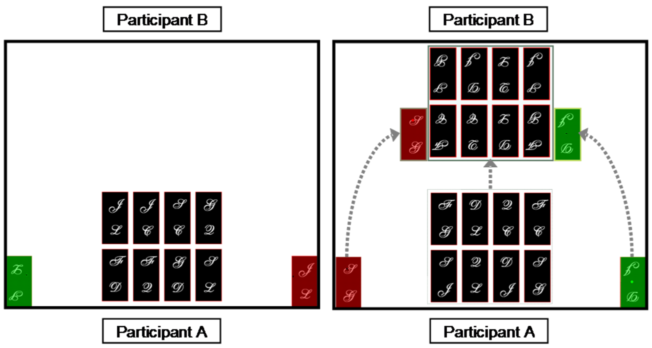

Figure 6. Puzzle game. Standard table shown at left, portals at right. Arrows connect cutouts and their reference areas.

Groups completed two games, one with the standard table (where participant B had to view the targets upside-down, and reach to the other side of the table for the cards), and one with portals, such that participant B saw a rotated view of the targets, and closer versions of the match cards.

Procedure
Participants were given basic training with the table and the input devices, and the experimenter demonstrated the tasks in each condition. Participants carried out the baseline tasks individually, and then completed the puzzle task as a group.

For the reaching baseline task, participants completed one training block and one test block of 24 trials each. For the orientation task, participants completed one training block of four trials and then three test blocks of four trials each. A different set of targets were used in each block.

In the puzzle task, groups carried out short training tasks in each condition, and then eight experimental tasks (four in each of the standard-table and portals conditions). In all cases, participants were instructed to work together and to complete the task as quickly as possible; they were not given any instructions on what strategy to use. A different set of targets were used for each game.

Experiment Design
We analysed performance for each task separately. For the reaching task, we used a single factor design (*table configuration*) with two levels (standard and portals). For the orientation task, we had three levels (standard right-side up, standard upside-down, and portals). For the puzzle game, we used two levels (standard and portals). Condition order was balanced using a Latin square. The study system recorded all dependent measures (e.g., completion times, errors, and the number of cards completed by each user in the puzzle game). Subjective data was collected using a questionnaire. Analyses used ANOVA and Repeated-Measures ANOVA tests, and Tukey Honestly Significant Difference tests for follow-up comparisons.

Results – Baseline tasks

Reaching
Participants took considerably more time (almost one second per trial) to carry out the task on the standard table than in the portal view (Figure 7). A one-way ANOVA showed that the difference was significant ($F_{1,9}$=30.1, p<0.001, η^2_p=0.62).

Orientation (Matching task)
RM-ANOVA showed a significant main effect of table configuration on completion time ($F_{2,38}$=36.35, p<0.001, η^2_p=0.66). A Tukey HSD test showed that the upside-down condition was significantly slower (by about 3 sec per trial) than the right-side-up and portal conditions (p<0.05), but that there was no difference between the latter two (Figure 7).

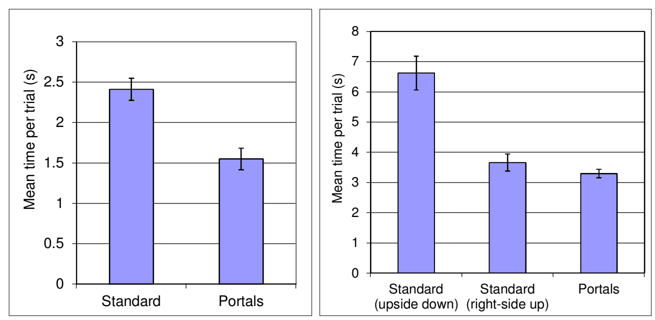

Fig. 7. Performance in reaching (left) and orientation (right).

Results – Group puzzle game

Completion time
Mean completion times are shown in Figure 8. RM-ANOVA showed a significant main effect of configuration ($F_{1,9}$=30.67, p<0.001, η^2_p=0.77). With cutouts (mean 42 sec), the group was faster than with direct touch (52 sec).

Group participation levels
We compared the number of cards that were correctly matched by each player. RM-ANOVA showed a significant main effect of configuration ($F_{3,57}$=54.73, p<0.001, η^2_p=0.74). Figure 8 shows the mean number of cards correctly matched in each condition (each game consisted of 16 cards). On the standard table, the player who saw the targets upside down averaged only 6 of 16 cards; with portals, the portal user averaged 8.4 of 16. A Tukey HSD test showed that this difference was significant (p<0.01).

We also examined error rates for the group puzzle task, but RM-ANOVA showed no significant difference between the configurations ($F_{3,57}$=1.30, p=.284).

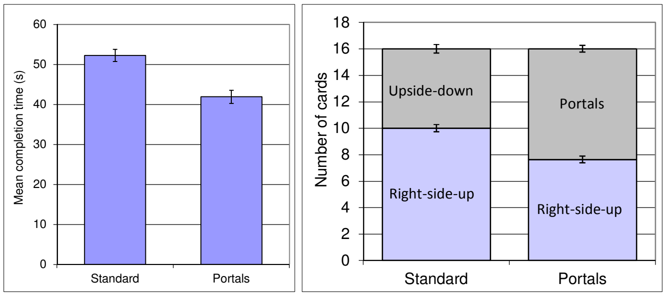

Figure 8. Completion time (left), participation level (right).

Questionnaire responses

Participants answered a series of open ended questions in a questionnaire administered at the end of the study. We summarize the results below.

Working together as a group. Participants were asked which technique allowed them to work together as a group more effectively. Most selected portals (19/20). When asked why, most participants (12/20) indicated that portals allowed them to work together without interfering with each other. Several people indicated that portals minimized physical collisions, for example: "when we had a cutout, we did not have to cross arms." Others indicated that cutouts helped them to avoid occlusion problems: "With no cutouts, either I blocked the other person's view or I was blocked."

Benefits and drawbacks of using portals. People stated that portals provided several benefits: they reduced physical effort, made rotated objects easier to understand, and were faster because they brought items nearer. A few participants also stated some drawbacks. Four people felt that there was less interaction with their partner when using portals. One person stated that that he "didn't really feel like we were collaborating." Another person wrote that she "was unaware of my partner's actions until the cards ran out."

Summary of Study 1

Our results demonstrate that portals can significantly improve performance in situations where the limitations of a physical table setting are apparent – i.e., reaching and re-orientation. Portals allowed people to complete the tasks faster when they were in a disadvantaged setting (far away, or across the table); and in the puzzle game, this led to a more equal distribution of work between the two people.

It is important to note, however, that portals were not essential for success – people were still able to reach to the other side of the table, and were able to interpret upside-down artifacts – it just took them longer to do so. In addition, the performance improvement with portals, although significant, was not enormous – e.g., improvement of a second in a reaching tasks, or three seconds in a matching task, or two extra cards in a 16-card puzzle. This indicates that the limitations of traditional table settings do not (usually) prevent collaborative success, but rather act as a hindrance. This means that the need for portals depends on the performance requirements of the task – and portals will become more important as performance becomes more of an issue. They are likely to become more valuable as the number of reaching actions or the number of reorientation tasks grows, or as tables become larger (thus increasing the performance advantage over standard reaching).

In addition, the study showed early indications that portals can change the way in which collaboration occurs. Although only a few participants commented on these changes, those that did felt that qualities such as group awareness and a shared group focus were reduced by the portals.

STUDY 2: EFFECTS OF PORTALS ON COLLABORATION

Our second study focused on the subjective effects of view portals on group collaboration behaviors – maintaining awareness, coordinating access to shared objects, avoiding conflicts, and working together smoothly. In this study, we used a realistic open-ended task (designing webpages), and we gathered observations, questionnaire results, and interview data, rather than performance measures as seen above, in order to explore the qualitative effects that portals have on collaboration processes.

Methods

We recruited 12 participants from a local university (mean age of 24.6 years; 1 female). All were Computer Science students, and all were frequent computer users (more than 20 hours a week). Ten participants had past experience with using tabletop display systems, but none had used portals.

The experiment setup was similar to that described above, but with a larger table (1536x1024 pixels, display area of 178x118cm). A custom study system was built in Java; participant input was again handled using a Polhemus Liberty tracking system with two pens.

Task

Pairs completed two website design tasks (see Figure 10) that involved manipulation and arrangement of several web-page elements on the table surface (e.g., pictures, headings, text boxes, and icons). The elements existed as separate objects on the table, and could be dragged and rotated using the stylus. This task incorporates basic actions that are part of many real-world activities carried out on tables – such as moving and rotating individual items, accessing tools and resources that are common to all participants, and organizing objects using the space of the table.

Participants were given a design scenario and were asked to create a mockup that shows the visual layout for two web pages from the site, maintaining a consistent overall look. Each group completed two design scenarios (one for an online florist, and one for a travel website), and they were given 15 minutes for each. Participants were told to create the home page and a detail page in both tasks, but they had freedom to choose content and layout, to move around the table, and to use any strategy for carrying out the task.

The application provided tools and catalogs of pictures that could be used to create the pages. The catalogs contained both generic interface items (e.g., buttons and icons) and scenario-specific content (e.g., pictures of flowers and holiday destinations). Participants could create handwritten labels for the text on the page. At the end of the table, two rectangular "paste-up" areas were provided to produce the webpage designs. Portals were implemented as described above, and users had access to all of the controls (move, rotate, zoom, resize, pan).

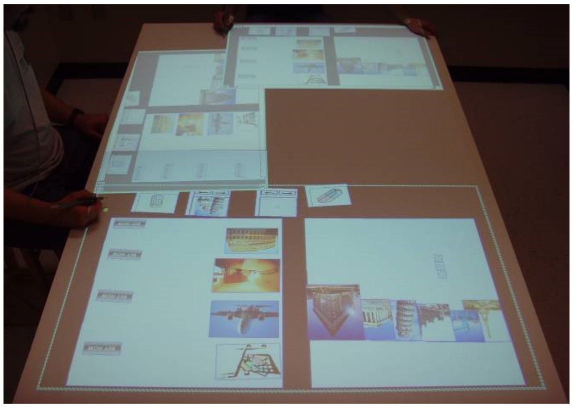

Figure 10. Web design task. Web pages are at the bottom and both users (top and left) have a cutout of that area.

Procedure

Participants were given basic training with the table and the input devices. The experimenter explained the application, demonstrated each of the web design tools, and explained and demonstrated the portals. Participants then completed a 15 minute training trial, where they were asked to create portals and to experiment with the controls. After the training session, they completed two 15-minute sessions, where they designed pages for two different websites. Participants were asked to switch locations at the end of the first session. At the end of the session, participants completed a questionnaire about the collaboration (Figure 9) and provided additional comments that were discussed in a short follow-up interview.

How did portals affect:
1 … your ability to work together as a group? 2 … your ability to track others' actions during the task? 3 … your ability to understand where objects are located? 4 … your ability to work with objects that are not near you? 5 … your ability to work with objects that are not oriented to you? 6 … the amount of physical effort needed to interact with objects? 7 … the amount of mental effort needed to interact with objects?

Figure 9. Experience questions given at the end of the session (7-point scales, and space for open-ended comments).

Results

Use of portals during the task

All of the participants stated that they felt comfortable using portals by the end of the training session, and all twelve people used portals during both of the tasks. The portals took some time to set up, but there were no noticeable problems using the controls while carrying out the tasks. Most groups adopted a similar strategy in using portals. Their personal territories were perpendicular to the paste-up regions at the end of the table, so they both created portals that could be scaled and rotated to fit into their own workspaces at the sides of the table (see Figure 10). In addition, most of the groups moved the tools and image catalogs near to the paste-up regions, so that they would also be available in the individual portal views. People had to move around the table initially in order to create the cutouts, but after this was complete, people spent most of their time sitting down and working from the area in front of them. Some participants occasionally got up to look at the paste-up areas, but this only occurred a few times during the session.

People used their individual portals extensively during the trial, and most of their interactions with the table were carried out through a portal. Pan and resize controls were often used when setting up a portal, when the person was trying to get the cutout positioned so that they could view the regions of the table where they were going to design the website. Zoom controls were used when people were trying to fit the cutout into their personal territory.

Four of the groups interacted regularly throughout the task, and jointly worked on the webpages, but not necessarily at the same time. People had ongoing discussions about the designs that they were developing and about the elements that they were adding to the pages. However, two other groups used a divide and conquer approach, where the participants each worked on a separate page, and little direct interaction took place between them.

Questionnaire responses

The questionnaire asked people about how portals affected their collaboration, in terms of awareness, understanding of the table space, managing orientation differences, reaching, and mental and physical effort (see Figure 9). The seven-point scale used semantic anchors ("made it much easier" at one end, "no difference" in the middle, and "made it much more difficult" at the other end).

The results are summarized in Figure 11. Portals were ranked favorably in several areas: working together as a group, working with distant objects, managing orientation differences, and physical effort. People had a more negative opinion of cutouts in three other areas, although most of the responses in these areas are close to the "no difference" value on the scale. These areas are tracking others' actions, understanding object location, and mental effort.

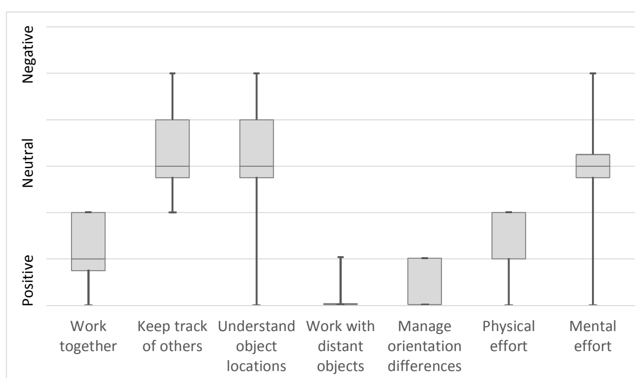

Figure 11. Questionnaire responses (box shows Q1-Q3 and median; whiskers show maximum and minimum)

Participant comments and discussion

Additional information about the topics in the questionnaire were gathered through open-ended areas on the survey form, and through follow-up questions in a short interview. In the following paragraphs we summarize participants' views on each of the topics considered in the questionnaire.

Working with objects and areas that are far away

Participants were uniformly positive about the value of portals both for seeing and reaching different areas of the table. One person stated "I could reach far places and I could see far places easier" (P3); others said "I never had to reach" (P1), "no more reaching!" (P9), and "very awesomely easy" (P8). Two participants mentioned that the portals meant that they did not have to get up as often to move around the table ("I didn't have to get up" (P4), "I didn't have to reposition the chair" (P11)). One participant also mentioned that the zoom function can bring items closer even within the portal (P12), which echoes the results of the reaching task in Study 1. The only negative comments about reaching had to do with the time it took to set up the portals and get them sized and rotated appropriately for the task (P6, P7, P8).

Working with objects that are oriented away from the user

Participants were also very positive about the portals' ability to reorient work artifacts to suit their own position at the table. This was seen as easy to do with the cutouts tools (e.g., "easy to reorient objects to my desired perspective" (P1), "when I needed to I could just re-orient the cutout" (P9)), and it was clear to the participants that this reorientation worked for all of the group members (e.g., "everyone can have the cutout oriented towards them" (P2)). In addition, two participants stated that having the correct orientation was particularly important for a design task – one stated that "alignment and orientation are very important for artistic design" (P3). Finally, one participant said that portals let him make better use of the space of the table ("with cutouts, it was easy to use the other side of the table" (P7)).

Effects on physical effort

Overall, participants felt that the portals reduced the amount of physical effort they had to expend during the task. As discussed above in terms of reaching, the reduced effort was due to a reduction in the distance that people had to reach, and a reduction in the number of times that people had to stand up and move around the table. Participants stated that with portals, there is "no reaching or standing up or moving around the table" (P1) and that "I can do the whole thing just sitting" (P2). This was clearly seen as a benefit, as stated by one participant: "Yay – [it] helped a lot by minimizing reaching and movement distance" (P6).

As we discuss further below, however, reduced movement can also have implications for the group as a whole. Movement around the table is something that is costly to the individual, but that is valuable to the group – in that people standing up and walking to different locations is an obvious signal of their activities and focus.

Effects on mental effort

The questionnaire responses about mental effort were much more divided than those about physical effort (see Figure 11), and people's comments also showed a much wider variance. Participants discussed both positive and negative aspects of portals, relating to three different kinds of mental effort in the task. First, people discussed the reduced mental effort that came from having task objects oriented right side up (e.g., "objects aligned to me are easy to understand" (P3). Second, several participants mentioned that having multiple parts of the table that were copied and reoriented could be confusing, at least at first. For example, one person said "keeping track of what is in where was a bit more difficult" (P9); another stated that "it was confusing […] between cutouts, table, and other cutouts" (P2). Third, participants mentioned the additional effort needed to learn and manage the portal tools themselves – one person said "there is definitely a learning curve" (P1); another said "[there was] a little effort getting the cutouts set up and positioned" (P2).

Ability to track others' actions during the task

This question on maintaining awareness led to the least positive results in the questionnaire (although still more neutral than negative), and to several comments from participants. The main result from the discussions was that portals appeared to allow people to focus more on their own work, at the expense of maintaining awareness of the other person. There were numerous comments in this area: for example, "I was too busy looking at my own work" (P1), "I did not really notice them at all" (P2), and "I didn't really follow his actions" (P3). It is possible that this reduction in awareness would occur on a standard table as well (e.g., if people became immersed in their local work), but it does seem clear that portals increased the effect. As described above, people moved around the table much less often, and made fewer large reaching gestures – both of which provide obvious awareness cues. Similarly, the ability to have all the necessary artifacts within one's personal work area may have reduced the need for people to look over at the other person's area – as one person stated, "I could look over whenever I wanted to see the other person's work, but when I focused on my task I wasn't very aware of him" (P8).

The second awareness issue that came up in discussions was that of the telepointers that were used to show others' actions in portals (or in reference areas). Several people mentioned that they were not able to see the telepointer adequately – for example, one person stated "embodiment was a problem, as I found it difficult to know from the cutout if he was flipping through pictures or not" (P5); another said "I could not tell clearly what the other user was doing" (P6). These comments suggest that awareness representations in a tabletop's large and visually busy space may need to be made more obvious than what would be needed for other kinds of groupware.

The lack of awareness did on occasion lead to conflicts in the system, in which both people would simultaneously attempt to grab a picture or page through the image catalog. Three participants mentioned these coordination difficulties – for example, one said “sometimes, if I wasn’t paying attention, we got in each other’s way” (P4).

Ability to understand the organization of the table

This question received neutral rather than positive scores, and there was a mixture of positive and negative comments from participants. Some people felt that they had no difficulties understanding the table surface (e.g., “the cutout didn’t change my ability to understand where objects are located” (P5), or “spatial location understanding was not really affected” (P6)). Several others, however, made comments that suggest that there were some problems. For example, one person said “I would get confused between the cutout and the original and try to move one or the other where it could not go” (P1); another said “the different frame of reference between the cutout and the page view made it a little counter intuitive to drag between them” (P2). Part of the problem is caused by the duplicate views, each with different locations and orientations, but the reduced awareness may have also contributed to spatial confusions – as one person stated, “things moved without my seeing someone move them, so it was a bit harder” (P9).

One result of the added complexity of the table surface (with portals) was that some participants focused more on their own areas and portals – which may have reinforced the lack of awareness discussed above. For example, one person stated “I just took my own view and went ahead with it” (P11); another stated that, “I may think of where [an object] is in my setup rather than where it is on the table” (P8).

Overall effect on ability to work together as a group

Participants were overall very positive about the effects of portals on the collaboration – both in their questionnaire responses and their comments. The improved access to the different areas of the table, and the ability to both work with right-side-up artifacts were mentioned by several participants as main benefits – to the group, and not just to the individual. This suggests that group members see the overall efficacy of the group as a critical aspect of the overall task of “working together,” and that allowing everyone to contribute equally may outweigh the reduced awareness of others’ activity or of the workspace’s organization.

Our task was not highly interdependent (people needed to maintain consistency and ensure that their pages were similar, but could still divide the task fairly completely), and it may be that portals made it possible for people to parallelize their activity more than a standard table would allow. This is reflected in participant comments: one person said “[portals] were good for divide and conquer style – we mostly worked individually, but towards a common goal and working off of one another” (P8); another stated that a main benefit of portals was that they allowed “more freedom” in the task (P12). A third participant summed up this effect of portals on the overall collaboration by saying “it was easier to do cooperative work, with each working on their own, but difficult to coordinate on the same page” (P10).

At the end of the interview, we asked people whether they would choose to use portals if they were available in the future. Nine of the twelve participants said that they would use portals, and three did not state a preference.

DISCUSSION

Our studies show that view portals can have substantial effects on group work at digital tables. Both study 1 and study 2 show that portals can overcome some of the limitations presented by the table environment – allowing people to reach distant areas of the table, allowing them to reorient artifacts to their own perspective, and allowing people to work in the same area without physical conflicts. However, there are also effects on collaborative behavior – most notably on group awareness, coordination, and understanding of the organization of the table surface. These effects are to some degree a result of the way that groups organized their portals (i.e., with each person having a view of the page layout space), but represent a common organization of portal views, and therefore a common set of drawbacks that can occur.

View portals therefore present a tradeoff for groupware designers – in which the system can support the needs of either the individual or the group, but not both simultaneously. This general issue has been noted in previous CSCW research [8], but for distributed groupware rather than co-located collaboration at tables. This is an interesting comparison, because in some ways view portals take the co-located setting of a table and make it more like distributed groupware – that is, if each group member creates a portal and focuses only on that window, things become very similar to the distributed setting where each person looks at their own display’s view of the workspace [33]. Given that the natural collaborative affordances of tables are one of the main reasons why people gather around them in the first place, it seems to be an odd choice to disable those affordances through the use of portals (or personalized views, which go even further in this direction).

Tabletops provide a strong group focus by enforcing a working style that can disadvantage some people and some types of work organization. Designers can attempt to get some of the best of both worlds, by providing the power of portals but attempting to repair some of the awareness or coordination problems that can result from their use. In our implementation of portals, we attempted to address the need for additional awareness information by using a telepointer. However, our studies suggest that some people did not see the pointer because it was not large enough to stand out from all of the other visual information present in the workspace (including work objects and multiple portals and reference-area markers). It is possible that larger and more obvious telepointers will increase the noticeability of others’ actions within a portal – and that other techniques from distributed groupware (such as enlarged actions, or persistent traces [8]) can improve people’s ability to maintain awareness.

As mentioned above, however, moving too far down this path could lead to a situation where the natural value of co-located tabletops is lost; more work is needed to determine an appropriate balance between the needs of individuals and groups in tabletop groupware settings. It is clear from our realistic-task study that users see the value of portals, and choose to use them when they have the chance. Participant comments in this study also showed that users see the success of the overall collaboration, to some degree at least, as the sum of the individual contributions from the group members rather than the level of shared group focus that exists during the task. This echoes earlier discussions in CSCW of "mixed-focus" collaboration [8,16,22], in which most of the work is individual, but carried out in a context of others' activity. If mixed-focus collaboration is in fact the norm, then it may be that designers should be focusing as much on features that enhance individual work as they are on features that support the group as a whole.

Generalization to other technologies and settings

Three factors in tabletop collaboration are important in considering the generalization of our results to other settings – group size, input technology, and other types of tabletop augmentations. First, it is likely that increasing group size – and therefore increasing the number of portals on the table – will accentuate both the positive and negative results seen in our studies. For example, more people around the table may lead to increased difficulty in accessing different work areas, which could increase the usefulness of portals in allowing different people to reach distant areas and work in the same region. However, the increased visual clutter from multiple portals is also likely to further reduce understanding of the workspace and group awareness, potentially leading to local conflicts (e.g., trying to manipulate the same object) or problems with higher-level coordination.

Second, our results can also generalize to other types of input technology and other types of display. Changing the type of input (e.g., to multi-touch finger input instead of pens) is not likely to change the way that portals are used – but it does mean that awareness techniques such as telepointers may have to be altered (e.g., to show "video arms" rather than individual pointers). Changes to the table environment may also affect our results – for example, larger tables make reaching more difficult, which can in turn make portals and other reaching techniques more valuable. We also expect our results to apply to vertical displays as well as horizontal tables – although orientation is not an issue in these settings, both the reaching benefits and the potential awareness drawbacks could occur when using portals on wall displays.

Third, we expect that some of our results will also generalize to other types of table augmentations. Reaching techniques such as the pantograph [20] or the I-Grabber [1] may also have negative effects on awareness, since they allow people to manipulate artifacts without the obvious awareness cue of a physical body [7]. However, these techniques do not break the continuity of the table's work surface (the way that a portal does), which may reduce problems of understanding; similarly, reaching techniques are temporary and add less visual clutter to the workspace. Finally, the negative effects of portals on awareness are likely to be exaggerated in situations where the table provides people with separate individualized views. When others cannot see a person's view at all, it becomes very difficult to maintain awareness of their work [16]; the consistent visibility of everyone's views may be a collaborative advantage of portals, despite the increased visual clutter.

CONCLUSION

Portals have been proposed as a way to overcome some of the limitations of co-located tabletops – they can provide access to other parts of a table surface, and can allow re-orientation of content for group members in different locations. We carried out two studies to examine the effects of view portals on collaborative performance and collaborative behavior. Our first study showed significant performance advantages for portals: people were able to complete tasks more quickly and with more equal division of labor. Our second study, with a realistic design task, showed that people used portals extensively and saw them as valuable, but that they affected people's ability to maintain awareness, coordinate access to objects, and understand the overall organization of the workspace. Our work demonstrates both benefits and potential drawbacks of portals, and suggests that designers will need to carefully consider both individual and group needs before implementing portals in tabletop groupware.

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