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Collaborating around vertical and horizontal large interactive displays: which way is best?

Yvonne Rogers[a,*], Siân Lindley[b]

[a]School of Informatics, Indiana University, 901 East 10th Street, Bloomington, IN 47408, USA
[b]Department of Psychology, University of York, York, UK

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Abstract

Large interactive displays are increasingly being placed in work and public settings. An assumption is that the shared surface they provide can facilitate collaboration among co-located groups. An exploratory study was carried out to investigate this claim, and, in particular, to examine the effects of the physical orientation of a display on group working. Two conditions were compared: vertical versus horizontal. A number of differences were found. In the horizontal condition group members switched more between roles, explored more ideas and had a greater awareness of what each other was doing. In the vertical condition groups found it more difficult to collaborate around the display. A follow-up study explored how participants, who had previous experience of using both displays, determined how to work together when provided with both kinds of display. The groups exhibited a more efficient and coordinated way of working but less collaboration in terms of the sharing and discussion of ideas.

Keywords: Display technology; Collaborative co-located working; Large interactive surfaces

1. Introduction

Recently, there has been a growing interest in situating large interactive displays in a variety of work and public places. Motivations include enhancing co-located collaborative work (e.g., Mynatt et al., 1999), instilling a sense of community (e.g., Churchill et al.,

* Corresponding author. Tel.: +1-812-856-1095; fax: +1-812-856-4764.
E-mail address: yrogers@indiana.edu (Y. Rogers).

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2003), providing enhanced up-to-date awareness about a work practice (Greenberg and Rounding, 2001), and initiating informal communication among strangers (Brignull and Rogers, 2003; McCarthy, 2002). Many kinds of large displays are now available for supporting shared activities, including front and back projected wall displays, large flat PC-based screens, plasma displays, Mimio and SmartBoards.

An assumption of situating large displays in these kinds of settings is that they provide a large interactional space that can support more 'fluid' kinds of collaborative interactions (Johanson et al., 2002; Russell and Gossweiler, 2001). By fluid interaction is meant the easy transition between activities at the interface, such as writing, browsing and drawing; the smooth switching between individual and group work and the ability to move between display-based and external work (Scott et al., 2003). Compared with a co-located group trying to collaborate around a single PC, keyboard and mouse, large displays offer more scope for supporting these kinds of transitions. The interface can be designed to enable multiple users to switch between activities, through pointing, touching and interacting with different applications and information, using a variety of input devices (e.g., fingers, pens, pointers).

To exploit these new opportunities, however, requires understanding how the physical affordances of a technology affect the kinds of cognitive and social interactions that will result (cf. Gaver, 1996; Kreijns and Kirschner, 2001; Norman, 1993; Svensson et al., 2001). Examples of the physical affordances of a technology include its accessibility, visibility, 'shareability', and directness of interacting with and orienting towards. Little is known, however, about the nature of 'physical–social' effects of interactive displays on collaboration. Our research seeks to address this gap by investigating how the physical orientation of large interactive displays affects the way people work together. Our preliminary observations of the way large displays are used in meetings suggest that sitting or standing around a display can have differential effects on the nature of the social interactions and the way the collaboration proceeds. In particular, we noted how groups using wall-based whiteboards tend to have more asymmetrical collaborations than those working around a tabletop surface. To investigate this difference further we carried out a study that looked at the patterns of collaborative interaction that arise when groups are provided with a wall-based vertical surface to work *at* versus a table-based horizontal surface to work *on*. We also present a small follow-up study that looked at how groups, who had prior experience of using both displays, determine how to work together and appropriate the technology when provided with access to both kinds of displays. Our focus in both studies is on how information is created, shared and used by groups working together to solve problems.

2. Background

Early research on shared whiteboards (e.g., Elrord et al., 1992) focused mainly on local interaction issues, such as how to support electronically based handwriting and drawing, and the selecting and moving of digital objects around the display. Much of the research behind the PARCTAB system (Schilit et al., 1993) was concerned with how information could be communicated between palm-sized, A4-sized and whiteboard-sized displays

using shared software tools, such as Tivoli (Rønby-Pedersen et al., 1993). Since then, there has been growing interest in developing more direct styles of interaction with large displays, both wall-based and tabletop, involving freehand and gestures (e.g., Guimbretiere et al., 2001; Mynatt et al., 2003; Shen et al., 2004).

There has been less research on how the physical design and situating of displays affects the form of collaboration. One of the earliest efforts were the Electronic Meeting Rooms that were designed as purpose-built spaces (e.g., Nunamaker et al., 1997; Stefik et al., 1987). The physical layout of the rooms usually consisted of individual networked workstations embedded in tiered desks connected to a shared display at the front of the room. This design was to enable individuals to work on their own computer while also being able to contribute their work to a large communal display, using various group decision support tools. The set-up was intended to support highly structured forms of meetings. More recently, technology-enhanced rooms have been designed to support more intimate and informal meetings, including the iRoom (Johanson et al., 2002), iLand (Streitz et al., 2002) and Dynamo (Izadi et al., 2003). The iRoom was designed as a small meeting room with a large interactive table in the centre connected to a number of large interactive wall displays to enable small groups of practitioners (e.g., biochemists, engineers, architects) to view multiple related visualisations concurrently and to annotate and point to features of these. The iLand project was concerned with how the physical architectural space of a room affects the way technologies are used. An instantiation of the iLand vision was Roomware, which was designed explicitly with physical space in mind. Electronic walls, interactive tables and chairs were networked and positioned together so they could be used in unison in a way that augmented and complemented existing ways of informal collaborating. An underlying premise was that the 'natural' way that people work is to congregate around tables, huddle and chat besides walls and around tables. Dynamo (Izadi et al., 2003) was also designed to support informal and ad hoc meetings, providing various interlinked displays to enable people to use them as an extension of their physical setting, where documents, video, images, and other digital information could be accessed, shared, viewed, annotated or copied.

Observations of groups using interactive whiteboards to work together reveal that they often use a 'show and tell' mode of interaction, where group members bring up images on the display and point things out to each other by gesturing and pointing. However, the nature of this kind of collaboration can be asymmetrical. For example, Trimble et al. (2002) note that when a group of scientists used an interactive whiteboard during a meeting, one person interacted with the images being displayed while the others looked on. Jordan and Henderson (1995) first commented on this phenomenon, when observing pairs of researchers using a non-electronic whiteboard; the person nearest the board establishes him/herself as the scribe, making it more difficult for the other person to actively take the floor. Recently, Eden et al. (2002) have also noted that when people gather around a vertical whiteboard, they rarely work together. They suggest that people find it awkward standing next to each other, whereas those working around horizontal surfaces work in parallel more. Other studies of groups working around interactive tabletop displays, such as DiamondTouch (Dietz and Leigh, 2001), also support this latter finding, where the flat surface has been found to encourage the joint browsing, sharing and manipulation of images (Shen et al., 2002; Rogers et al., 2004).

These observations about the pros and cons of large interactive displays suggest that horizontal displays are better at supporting collaboration. However, to date, there has been no systematic comparison. The goal of the research reported here was to investigate how groups collaborate around a vertical versus a horizontal interactive large display, with a follow-up study exploring how group members experienced in both work together when provided with both forms of interactive display.

To investigate the various forms of collaborative interactions, qualitative analyses were carried out. In particular, the following were examined:

- the kinds of collaboration that take place in groups, in terms of the roles adopted and frequency of change, the suggestions generated and the discussion surrounding them
- the coordination of the problem-solving activity
- how control is established in the group
- how group attention and awareness is maintained

We also examined the group's use of everyday 'interactional resources' and 'informational resources' (e.g., Goodwin and Goodwin, 1996; Heath and Luff, 1992; Hutchins, 1995; Luff and Jirokta, 1998). By interactional resources is meant the coordinating mechanisms used in the organisation of talk (e.g., turn taking), visual conduct (e.g., the use of gestures, eye contact, body movement) and outlouds (where one person in a group deliberately shouts or speaks out to draw the others' attention to a part of the collaborative activity that needs their input, acceptance or approval, for progress to be made). By informational resources is meant the mediating role played by paper documents, computers and interactive information (e.g., Luff and Jirokta, 1998; Schmidt and Wagner, 2002) during collaborative activities, e.g., the way individuals in a group establish a common orientation to an artefact (such as a computer-based form) that needs focused attention at a given time in order for the task to progress. We also looked at the transitions between paper-based writing activities and display-based information seeking activities.

3. Study 1: the effects of horizontal versus vertical interactive displays on collaborative problem-solving

To examine the effects of display orientation on collaboration we decided to design a semi-experimental, semi-naturalistic study, trying to strike a balance between some of the control that is possible in laboratory studies and the ecological validity afforded in naturalistic studies. Groups of three participants were asked to come to a room, where a display and chairs were arranged. They were asked to carry out a problem-solving task together, involving searching for information and using this to decide upon a plan of action. The task was designed to be open-ended (planning an itinerary for different groups of tourists); there were no right or wrong answers. The groups were told that the aim of the study was to investigate the benefits of using different displays during group work. They were told they could use the various displays and informational resources how they wanted. After a familiarisation session, where they were introduced to the task

and the display system, they were given 20 minutes to complete the task. This was followed by a 10–15 minutes open-ended interview to discuss their experiences. They were asked to come back for a second session to carry out a similar problem-solving task using a different orientation of display. A control condition was also devised, where a different set of groups used a single user PC display.

The participant's actions and interactions were video recorded. Two video cameras were used; one recorded the display surface and the other a view of the group. Groups were also informally interviewed after completing the sessions to obtain their views on the different conditions. Questions asked were whether the group thought the horizontal or vertical display was better or worse for supporting group collaboration, what they thought about the input devices available to them, and the difference between using paper and the interactive display. Collaborative behaviour was assessed in terms of the kinds of actions (e.g., gestures) and interactions (e.g., requests, outlouds) that took place during the study and the participants' reflections afterwards.

3.1. Method

Three different conditions were compared:

(i) Horizontal table display (horizontal)
(ii) Vertical wall display (vertical)
(iii) A PC monitor (control)

The last condition was intended as a control to contrast how a small single user display was used in a group setting.

3.1.1. Participants

A mixed design was used to investigate the differences between the three conditions. Eight groups of three participants took part in *both* the vertical and horizontal conditions enabling their performance to be compared within groups and also for the groups, themselves, to reflect on their different experiences. To reduce training and practice effects, half the groups participated in the vertical condition first and the other four the horizontal condition first. The order of the specific task set for the two conditions was randomized. In addition, to minimize carry-over effects eight *different* groups of three participants took part in the control condition.

The participants were aged between 21 and 40. All were students taking various masters degrees in the same school and who knew each other. All groups were of mixed gender, either two males and one female or two females and one male. Participants were recruited via email and were paid £5 each for taking part per session.

3.1.2. The problem-solving task

A problem-solving task was devised involving decision-making and planning, where various informational resources had to be accessed for a solution to be reached. The task involved developing an itinerary for a day trip to London for a group of tourists with a specified budget. These were for a group of senior citizens and an American family.

To accomplish the task a series of decisions had to be made about:

- which activities to carry out in the morning, afternoon and evening
- the optimal order they should be visited relative to where the tourist group was at a given time
- which mode of transport to use between activities
- where to go for lunch and dinner
- how much each activity cost including the cost of transport
- whether the cost of their plan matched the budget allocation

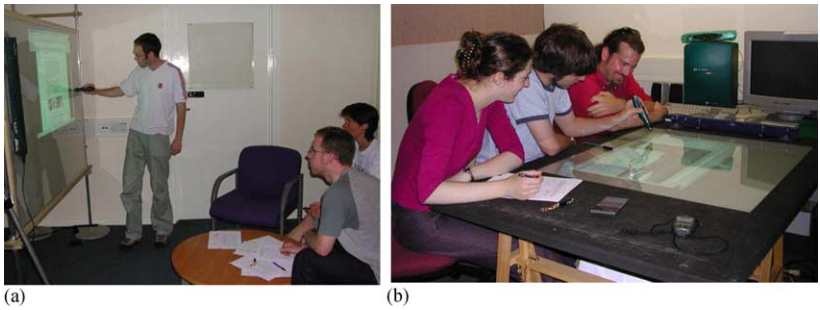
To solve the problem the groups had to write an itinerary. To access information they were provided with a set of websites.

3.1.3. Informational resources

A number of websites were bookmarked in a web browser that was accessible via the interactive displays. These included what to do in London, restaurant guides, and various transport sites and maps of London. The websites were deliberately chosen to enable the groups to (i) find appropriate activities for the tourists to do, (ii) plan the route to get to these, and (iii) calculate the cost of transport and the activities. A Mimio pen in the display conditions and a mouse in the control condition were provided to enable them to access the information. A form to fill in, notepaper, pencils and a calculator were also provided to enable them to work out and write down the itinerary.

3.1.4. Interactive displays

For the vertical condition an interactive display was built, using a 96 cm × 96 cm back projected piece of white plastic erected onto a chassis frame. This enabled information to be viewed and interacted with at standing height (see Fig. 1a). For the horizontal condition an interactive table was built, with an 80 cm by 80 glass surface embedded in a wooden frame, measuring 85 × 100 cm (see Fig. 1b). This enabled information to be viewed and interacted with when sitting in front of the display. For both conditions, the size of the screen projected onto the surface was 43 cm high and 59 cm across. Back projection was used in both conditions to prevent body shadows occluding the display. Interaction with



(a) (b)

Fig. 1. Photos showing (a) vertical and (b) horizontal condition.

both displays was supported through pointing; a Mimio system was attached to each surface, and a Mimio pen provided to select options from the displays. For the control condition a 17 in. monitor and mouse were provided on a table with three seats in front of it.

Three seats were also placed in front of the horizontal table, enabling the members of a group to sit side by side and to view and interact with the information on the display from the same perspective. The seating arrangement was chosen (as opposed to having the group sit around the table) to keep the orientation of the information fixed and the same for all members—as was the case for the other two conditions. While it is possible to flip the orientation of the displayed information using the data projector to different sides of the table, this can be clumsy, disruptive and require frequent recalibration, as found in an earlier pilot study.

In the vertical condition, the participants were required to stand in front of the display to interact with information on it. Our original idea was to provide only a vertical display. In another pilot study, however, the participants commented how standing up all the time in front of the display was very unnatural and socially awkward, making the task difficult to accomplish. In particular, they found it hard to talk with one another and be able to view all the information when in a line facing the display. They also found it hard to write notes while standing in front of the display, even when provided with clipboards. Switching between writing and interacting with the display was also found to be cumbersome, especially when trying to change between using an ink pen and the Mimio pen.

The purpose of our study was not to deliberately provide awkward and difficult conditions that could bias the outcome, but to design different physical arrangements that could enable us to understand more about how groups collaborate around interactive displays of different orientations. Thus, to allow the group in the vertical condition to talk, interact with the display and write notes comfortably we decided to provide a small coffee table and three chairs alongside the display. These were arranged so that participants could move readily between them and the display and read the information while seated. Similarly, to enable the group in the horizontal condition to write notes and to be able to read and interact with the displayed information, we designed the tabletop to have sufficient space for all to write on and for the group to have the same view by sitting along one side of it. Hence, in both conditions, participants could write on a surface comfortably and talk to one another while seated.

A laser pointer was also provided for each condition that could be used to point at information on the displays.

3.2. Findings

The video data collected for each session were reviewed, independently, by the two of us, and the talk, gestures, body movements and interactional use of resources transcribed. The analysis presented below focuses on the various collaborative interactions that took place and comments made in the interviews. The data is presented as a combination of means and standard deviations to show relative trends; snippets of conversation to indicate the nature of the discussions; observations of behaviours to highlight types of collaborative

Table 1
Mean number and standard deviations (in parentheses) of suggestions for the three conditions

Condition	No. of suggestions per group
Control	44.3 (9.10)
Horizontal	69.7 (10.05)
Vertical	58.7 (11.07)

behaviours, and quotes and comments from the interviews to report on the group's experiences. Statistical analyses are not presented here since the goal of the study was not intended to look at isolated controlled effects, but to be exploratory, examining and identifying different aspects of the physical–social effects of interactive displays on collaboration. To this end, the analysis is organized around the themes outlined in Section 2.

3.2.1. What kind of collaboration took place and how was the collaborative problem-solving activity coordinated?

As expected, one of the main findings from the study was that the kinds of collaboration varied across conditions, notably, in terms of roles adopted and frequency of change, ideas generated and discussion surrounding them. The groups tended to make most suggestions and subsequent discussions of what to do while interacting with the websites when in the horizontal and vertical conditions (the means and standard deviations are presented in Table 1). The groups made slightly more suggestions in the horizontal condition compared with when they were in the vertical condition. The least number of suggestions were made by the groups in the control condition, suggesting that this set-up was less conducive to group discussion and idea generation.

Examples of suggestions and surrounding talk while interacting with the displays and writing notes are provided in Table 2. As can be seen, the suggestions made by one

Table 2
Examples of suggestions and conversations surrounding use of displays when creating an itinerary

Group 1 in horizontal condition: two suggestions by different group members about where to go
All scan a list of tourist sites on London.com on display
P1 "Let's go to Madam Tussauds, they'd like that"
P3 "Yeah they'd like that. The place to go"
P2 "Or maybe the Victoria and Albert Museum?"
P1 "Yes they'll like that more. They'll remember that from their childhood"
P3 "How do you spell Victoria?" ⟨writes it down on the itinerary⟩.
Group 1 in vertical condition: one suggestion about travel followed by another about the interface
P3 "I think we should get a travel card"
P1 "Yeah"
P3 "umm, four pounds seventy each"
P2 "I think we should open some more browsers"
P1 "And get them all going".
P2 "Yeh Get them all going"
P1 "Get all those websites"
P3 "Ok Go to file and see if you can open new window"

Table 3
Means and standard deviations (in parentheses) of role changes as a function of person interacting with the display using the Mimio pen (the interactor) and person writing the itinerary

Condition	Role changes	
	Interactor	Itinerary writer
Control	1.4 (0.66)	0.4 (0.84)
Horizontal	4.8 (2.48)	0.1 (0.32)
Vertical	2.5 (2.12)	0

participant are acknowledged and supported by the others or 'challenged' with an alternative idea. The suggestions included reading options displayed on the websites and providing warrants for these in the context of the task, to ideas about how to improve their searching strategies.

The extent to which groups changed the role of itinerary writer was minimal in all three conditions. Once a group member elected to be the scribe it was implicitly understood that he/she remained in that position throughout the task. In contrast, there was more variability in the conditions of role changing for the interactor, i.e. the person in charge of interacting with the websites on the display (see Table 3). The most changes took place in the horizontal condition, where group members swapped possession of the Mimio pen on average four times during the session. The least number of role changes was found for the control condition, where it was rare for the mouse to change hands more than once during a session. In this condition, the person who took control of the mouse at the beginning of the task tended to drive the task and stay in that role throughout the session, while the others took the role of commentators. The group members commented on how difficult it was to take control of the mouse when in the possession of another person.

Groups found it easiest to switch role of being interactor in the horizontal condition. A reason why the person in the role of interactor changed more frequently in the horizontal condition was that whenever the current interactor placed the pen down on the table, in order to gesture or point to something on the display or to write something down, it had the effect of making the pen readily available to the others. When this happened there was rarely any explicit acknowledgement and only on one occasion did a member of a group use an outloud and say explicitly to the others "your go". Furthermore, when asked to comment on the use of the Mimio pen in both the horizontal and vertical conditions, the groups noted that the table offered more flexibility. For example, one participant stated that "the table encouraged the passing around of the pointer thing" and "everybody could write when you were at the table".

One of the effects of having a different person in the group take control of the Mimio pen in the horizontal condition was that different options were explored. As there was no ownership of the information currently displayed on the screen, the takeover was easy to accomplish, without any need for explicit negotiation. However, if the options that the new interactor accessed did not match up with the task constraints, the options from the previous interactor were revisited, and that member would talk through them again.

In the vertical condition, typically, one member took on the role of interactor at the beginning of the task and stood for most of the time in front of the display, while the other

two remained seated at the adjacent coffee table; one writing down notes and the itinerary and the other discussing the various options. A change took place only when it was perceived by a group member that the person at the display needed help (e.g., if he or she was struggling to find the necessary information). Also, one participant mentioned it was "too comfy" sitting in the chairs, making it hard for him to move.

Taken together, these observations provide further support that the simple acts of moving between being seated and standing and passing input devices between people are perceived to be socially difficult to accomplish in a group setting. For example, the person at the display, when asked whether they would have liked to have sat down and swapped roles, replied that it was difficult for them to know how to hand over the Mimio pen. It would require him/her having to explicitly offer the pen to the others, which was felt to be socially awkward, and, as one participant mentioned, "make out you were not up to it". Likewise, a similar problem was experienced with handing over control of the mouse. In contrast, when the shared input device could be placed down on the working surface and picked up by anyone, without any need for explicit acknowledgement (as was the case with the Mimio pen in the horizontal condition), role changing was facilitated. It appears, therefore, that the etiquette surrounding such seemingly trivial turn-taking mechanisms can substantially affect the nature of the collaboration that ensues in a group.

In addition, as was discovered in the pilot study, the groups mentioned how they thought it would have been uncomfortable to stand next to each other at the vertical display, trying to write notes and talk with each other. It happened only in three of the groups that all group members stood for a short period of time together in front of the display. When they did so, the group members commented on how difficult it was to view and refer to different parts of the display and see what the others were doing.

3.2.2. How was control established and how does this affect the collaborative activity?

A number of options were available to the members of the group when asking and telling each other what to do. Table 4 shows the methods used across conditions. The groups used verbal instructions most in the vertical condition, when giving directives. In the horizontal condition, the groups also used voice most but combined with gesture. Voice combined with laser was not used at all in either the control or horizontal conditions and rarely in the vertical condition. Unlike the more familiar and socially accepted way of gesturing to refer to something, the laser pen was commented on by several participants as a rude and "in your face" method.

It was also the case that the interactor in the vertical condition alternated between two modes of control: either he/she took control and became the 'driver' making the selections,

Table 4
Means and standard deviations (in parentheses) of directives used in the three conditions to take control of the interactions

Condition	Directives				
	Total	Voice	Gesture	Voice and gesture	Voice and laser
Control	7.5 (0.71)	2.0 (1.41)	0	5.5 (0.71)	0
Horizontal	14.6 (8.09)	3.8 (2.68)	1.0 (1.18)	9.8 (6.42)	0
Vertical	12.8 (8.03)	6.4 (4.36)	0.1 (0.3)	3.9 (4.59)	2.4 (3.83)

or he/she was 'driven' by the instructions of the others. When the interactor was in the driving position, he/she frequently turned around and spoke to the others, using the information displayed to legitimize his/her suggestions.

In contrast, when the interactor was being 'driven' by the others there was little discussion. The interactor remained facing the display with his/her back to the others, selecting the options and clicking on the links the others suggested (e.g., "go to the right, there", "click on that restaurant"). The seated members frequently gestured and pointed to where on the display they wanted the interactor to go to when giving their directions (e.g., "down a bit", "to the right"), even though the interactor could not see them—similar to the way people do when gesturing on the phone even though they know the other cannot see what they are doing.

3.2.3. How was attention and group awareness maintained?

Keeping aware of what each other is doing in a group is considered central to successful collaboration (Dourish and Bellotti, 1992). This requires group members to focus and coordinate their respective attentions on what each other is doing. In the control and horizontal conditions, the members of the group were physically close to each other, enabling them to all see and hear what each other was doing and saying. The group members focused their attention mainly on the interactions at the display, as indicated by their gaze towards the screen. The various activities of searching for information, discussing options and writing notes were done together. There was little evidence of parallel or separated working.

In contrast, in the vertical condition the focus of attention was more divided between the group members, frequently switching between what was happening at the display and at the table. Even though they remained close enough to see and hear each other, the group's attention inevitably became divided, with the interactor focusing on the display and the other two writing notes and/or the itinerary. To bring their foci of attention back together and keep aware of what each other was doing, explicit coordinating mechanisms were brought into play. One method was for the seated members to raise their voices and speak aloud about what they were planning and writing, to enable the interactor at the display to hear. Conversely, a tactic used to gain the attention of the seated members was for the interactor to turn to face them, move to the side of the display and point to the information on the display. The interactor also often returned to the coffee table and peered over the shoulders of the other two when not interacting with information at the display.

Outlouds, defined as spoken commentaries accompanying a participant's actions, were used in both the vertical and horizontal conditions to highlight the fact that text was being read or that decisions were being made. For example, the following quote from an interactor accompanied a number of decisions that were made while entering a search for a restaurant on the vertical display.

London West End… lunch… number of diners

In so doing, it made the other participants aware of the criteria that were needed, such as the number of diners, and of some of the decisions that were made, such as entering the location as London West End.

The participants commented on the different use of gestures in the two conditions. For example, one participant said, "(at the table) you can point at things, here (at the vertical display) you can sit back and you feel a bit removed from it".

The findings suggest that even though the vertical display and coffee table set-up required the group physically to break apart, the group members were adept at employing various explicit mechanisms to compensate for this and maintain awareness of each other's activities.

3.2.4. How fluid was it switching between paper and display-based interactions?

Writing notes was most frequent in the horizontal and control conditions. Much less writing took place in the vertical condition, where the participants found it harder to incorporate paper into the task. Group members also mentioned in the interviews that they found it easiest to switch between writing notes and picking up the Mimio pen to interact with the websites in the horizontal condition.

3.3. Discussion

The findings from this exploratory study suggest that the horizontal display condition facilitated the most collaborative and fluid interactions. The Mimio pen combined with the interactive tabletop encouraged group members to switch more roles, discuss ideas, keep attention focused and maintain awareness of what each other was doing. In this condition the Mimio pen was readily appropriated as a shared input device. It was easy for a group member to pick it up once another member had placed it down on the tabletop surface. In contrast, the same input device proved not to be as sharable in the vertical condition and the handing over of control and changing of roles rarely occurred. A reason for this was that there is no obvious place to put the pen down (cf. the flat surface of the horizontal table) when standing. It required a person to make a much greater and conscious effort to stand up and move towards the display or back to the coffee table to make the change over. As was found, this only occurred when the person at the display was having difficulty finding information.

The least amount of collaborative interaction took place in the control condition. Again, this can be attributed to the physical constraints of the type of input device that was used with the single user PC monitor. Switching control of the mouse between group members proved to be very difficult and awkward. The set-up afforded single use and not shared use. Even when a group member took their hand off the mouse, the others did not try to take it. Moreover, none of the participants used explicit speech acts to signal to the others they wanted to take over (e.g., "give me the mouse, it is my turn"). The only time a change occurred was when the current user explicitly handed over control of the mouse to someone else (e.g., "here you have a go"), which happened rarely.

Several of the participants commented that the interactive tabletop set-up seems well suited to creative and informal types of collaborative tasks, as mentioned for example by one participant, "I think the table would be quite good in a design environment… where you've got lots of pieces of paper and information you need to be looking at (alongside) the screen". However, they also associated the horizontal condition with being a more

free-for-all approach that, in turn, could lead to uncertainty in coordinating their work. For example, another participant stated that working at the table:

> was too messy. First I had the mimio pen, then you had the pen. There was too much chaos going on. I think a bit of structure would have been better to solve the task.

Another group member also noted, when comparing the two conditions:

> Your role was quite defined. When you were sitting here (vertical condition) we could concentrate on the itinerary whereas at the table we all made notes.

In sum, the findings from this initial study suggest that the physical affordances of input devices and displays can have a substantial effect on the nature of the collaborative interactions that ensue. In particular, displays and input devices that are physically located in proximity to each other and afford sharing and easy access are likely to facilitate more fluid collaborative interactions. More opportunities for idea generation, discussion and joint planning are likely when the physical set-up is designed such that all the group members find it easy to have a go at interacting with the informational resources and contribute to the ongoing activity. In so doing, each member can contribute, enabling potentially more solutions to be externalized and evaluated. However, it can be regarded by group members as inefficient, where it is not clear what each should be doing or whose turn it is. Having a display set-up configured to socially and physically constrain the way people collaborate—so they know who is doing what and where—can facilitate more coordinated and distributed ways of working, but on the other hand, can hinder other forms of collaboration such as shared idea generation.

In a follow-up study, we wanted to see how groups, who had experienced both conditions, would manage the problem-solving activity, if provided with both displays. Would they orient towards using the vertical or the horizontal display, based on their previous perception of what was the best set-up? Or would having available two large displays give rise to different work patterns altogether? Alternatively, would the group divide up the workload in terms of separate roles for each display; where different members interact *individually* with the displays to access information? Would they then *jointly* come together during the planning and development of the itinerary and, if so, how?

4. Study 2: the effects of providing both horizontal and vertical interactive surfaces on collaborative problem-solving

The goal of the follow-up study was again exploratory. The aim was to examine how groups, who are familiar with both display set-ups, determine how to collaborate on the same task when given the opportunity to view and access information using either or both displays.

4.1. Method

The problem-solving activity was designed to be similar to that used in the first study to enable comparisons to be made. Namely, the groups were required to come up with

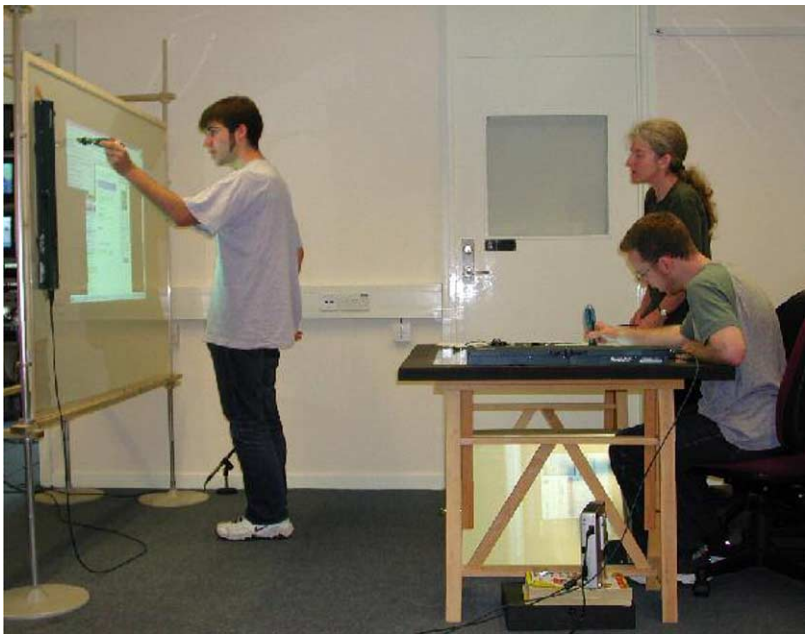


Fig. 2. Physical set-up of vertical and horizontal interactive displays.

an itinerary for a group visiting London for a day trip using various web-based resources. The task demands, however, were different in terms of the budget and group type they were provided with. In particular, they were asked to plan a day trip for a group of Japanese tourists. The same two displays were used but this time placed next to each other in the physical setting. Seats were provided around the horizontal table (see Fig. 2). Four groups of three participants took part; all had participated in the groups taking part in the horizontal and vertical conditions in the previous study. The groups were made up of different participants who had not worked together before. It was not possible to get all participants to return so only four groups took part.

At the beginning of each session, the groups were given the instructions. They were told they could take as much time as they wanted, move around freely and use either or both of the interactive displays as and when they wished.

4.2. Findings

4.2.1. What kind of collaboration and coordination took place?

A different pattern of group working emerged when the experienced participants were provided with both display options than in the first study. The groups decided to use both displays in a distributed way rather than orient towards all using one or the other. All realized that having two displays available to them enabled three distinct roles to be created: two interactors and one itinerary writer. This was not explicitly stated by any member of the groups, however, but emerged as a strategy early on in the session.

The pattern of distributed working that emerged within the groups was as follows: firstly, the groups sat down at the table and discussed the details of the task, the constraints of the budget and the nature of the tourist group. Following this, one member picked up a Mimio pen and began interacting with the websites on the horizontal table. The other two looked on and then another one picked up an ink pen and started making notes on a piece of paper, signaling that he/she had volunteered to take on the role of itinerary writer. The third member moved shortly afterwards to the vertical display to take on the role of second interactor.

These three roles remained fixed throughout the session. Only in one group did a role swap occur during a session, and that was when the itinerary writer went to assist the interactor at the vertical display, who was having difficulty finding a website. The type of information accessed was also for the most part fixed for each display; the horizontal display was used to find out about restaurants and places to visit while the travel arrangements were determined at the vertical display. This division of labour via display appears to have been determined by the participant who chose to start initially searching for information at the horizontal display, rather than from the display orientation being viewed as suited to a particular kind of searching activity. However, fortuitously, it was easier for all to see and refer to the large map of the London Underground on the vertical display than the other text-based websites providing information about where to go in London.

Much of the searching and decision-making was done individually in the groups. Compared with the previous study, there was little discussion of whether the choices selected were optimal and how they fitted the criteria set for their tourist group. The mean number of suggestions generated within the groups was considerably less (mean = 41.43, SD = 7.07) than in either the vertical or horizontal condition in the first study. Instead, there was a tendency for group members to use more outlouds; the two interactors typically reading out information they had accessed from the displays (one reading travel directions and the other activities to do) while the itinerary writer spoke aloud what he/she was writing and planning.

This trend towards a more 'streamlined' and efficient mode of working is, in part, to be expected due to the different group member's familiarity with the task. However, it could also be, partly, that the particular display set-up and roles the groups chose constrained how they subsequently collaborated, emphasizing the coordination of individual contributions rather than the sharing and discussing of ideas.

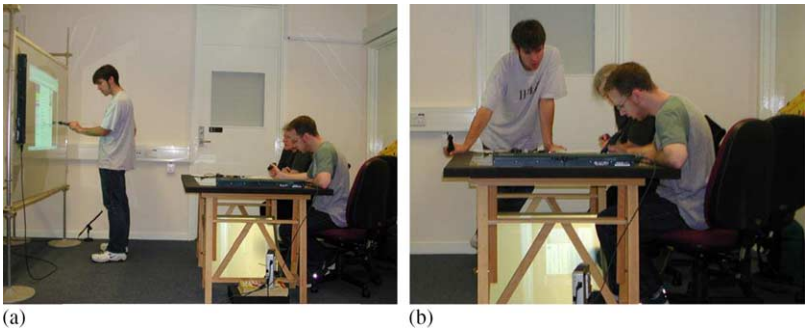
In group 1, for example, the roles were clearly demarcated throughout the task; the itinerary writer took a pivotal role, directing the other two to provide her with information she needed to work out the itinerary. In so doing, the two interactors' contribution to the task was largely marginalized to the role of information providers. While it is well known that individuals can dominate a group, it seems as if the technology set-up in this condition enabled the dominant group member to exploit the work space to her advantage, using the others as essentially proxies to get information and in so doing reducing their participation in the problem-solving part of the activity. In contrast, the person at the vertical display in group 2 frequently returned to the table to take part in the itinerary creation. Towards the end of the session, however, he remained seated at the table. In so doing, the group reverted to the working arrangement of the horizontal condition, choosing not to use the vertical display in favour of working with the others at the horizontal display.

While there was less discussion in the groups, it was observed how several of the computational tasks (e.g., working out the cost of the activities and how they fared with the allotted budget) were highly coordinated, where one participant completed part of the problem and the results were taken up by another to progress the task. In so doing, the computation was distributed across time, person and representation. For example, when providing information about suitable restaurants in group 4, the interactor at the horizontal display read out the prices for set menus. The itinerary writer wrote these down and then used the calculator to work out how much it would cost for a party of four to have the different priced set meals. The interactor waited for her to complete this part of the computation, and then mentioned the additional service charge, which she subsequently added to each of the partial totals.

These observations indicate how group coordination is facilitated with more experience at solving the same kinds of collaborative task. This finding in itself is unremarkable; it goes without saying that training and practice helps improve team coordination. For example, similar forms of emergent, distributed teamwork have been noted by Hutchins (1995) when observing the *implicit* learning that takes place between team members when establishing highly organized routines. Of interest here, was how access to multiple informational resources in the work place affects the *way* group working patterns evolve. Having access to two displays provided opportunities that the groups exploited by becoming more efficient in gathering information and carrying out the computational tasks.

4.2.2. How were group awareness and control maintained?

A downside of adopting a more distributed way of group working is that it makes it more difficult to maintain group awareness. Similar to the finding from the previous study, a main problem confronting the person who took on the role of interactor at the vertical display was, firstly, how to keep aware of what the others were doing and, secondly, how to relay his/her ideas back to the others sitting at the table. Whenever the interactor was using the vertical display, their back was turned to the others, effectively moving them out of the focus of attention (see Fig. 3a).



(a) (b)

Fig. 3. Photographs to show (a) an example of divided attention within the group. The two interactors are focusing on their own displays while the writer looks at the display and (b) the vertical interactor retuning to the table to focus on the other's interactions.

As with the first study, a number of strategies were employed to re-establish focus with the others, including turning around at the display to directly face the others, use of outlouds to get the attention of the others, and physically moving from the display back to the table to be in close proximity of the others (see Fig. 3b). In addition, the others in the group attracted the attention of the interactor at the vertical display by shouting out and giving directives to him/her as to what to do next. When being directed in this manner, the interactor did not turn his head around but listened to what the others were saying to him/her.

4.3. Discussion

The findings from this follow-up study showed that when experienced participants are provided with more displays—meaning they do not have to share or take turns in finding information to carry out their task—there is a tendency towards a more coordinated and distributed way of working. In this study, having two displays available invited two of the group members to use them to do separate tasks and the third to take on the role of itinerary writer. Once in these roles they remained fixed. A downside of adopting this more individually based working mode, however, is that the group members can find it more difficult to maintain awareness of each other. In this study, the group members used more outlouds and directives to maintain an awareness of and presence with the other members. One group also resorted, towards the end of the task, to working more closely together, using only one shared display to access information.

The groups in this follow-up study were familiar with the displays and the task, but had not worked with each other before. Hence, the findings are suggestive of how familiarity with the task and the display technology set-up affects the way groups collaborate. Further research is needed to investigate how groups, not familiar with working with the display technology and each other, collaborate for different kinds of tasks (e.g., design) when provided with multiple displays of different orientation and size.

5. Conclusions

The two studies reported here have shown how the physical affordances of an interactive display can promote different kinds of interactions and collaborative working styles. It was found that the degree of accessibility and shareability of displays and devices affects the way groups orient to a task and how they manage and coordinate their collaboration. A key finding was that tabletop displays encourage group members to work together in more cohesive ways. The main benefits include:

- enabling the group to refer to the same representations, making it easier for all members to contribute to the problem-solving at hand
- supporting more fluid interaction through close coupling between the creation of a plan, document, etc. and the digital information that needs to be accessed
- providing a physical surface that affords easy role swapping, and, in so doing, more alternatives to be put forward for discussion

Conversely, vertical displays were found to be difficult and awkward to collaborate around, especially when trying to switch between searching for information, drawing up a plan, using a calculator and writing notes. One possibility is to provide opportunities for the group members to write notes and perform calculations directly on the surface. Various annotation and computational tools are now available to support this. Providing increasing functionality as part of the same interactive surface, however, may cause the interface to become overly cluttered. Moreover, while providing closer coupling between the informational resources that are used and created, the display could end up becoming too much of a focal point, where the participants, figuratively speaking, begin to tread on each other's toes. In addition, some cognitive activities will always remain best carried out using paper and pencil, fingers or a physical calculator. More research is needed to explore these potential trade-offs.

One obvious advantage of vertical displays is that they can accommodate groups that are likely to change in size, and where information that needs to be shown and discussed is to an audience of people. Furthermore, the number of people that can sit alongside or round a table and have the same viewpoint is limited. Any more than a small group of three or four is likely to make it difficult for group members to talk to each other while also interacting with the display and writing notes. Developing innovative interactive tabletop surfaces that spin the software application, in the manner of a lazy Susan table, such as DiamondSpin (Shen et al., 2004), is one promising approach to enable more participants to collaborate around a table.

Our studies investigated how small groups of three collaborated when using displays of different orientation. Our current research is exploring how larger groups interact and collaborate over time when provided with different combinations of shared displays and devices (Brignull et al., 2004; Rodden et al., 2003; Rogers and Rodden, 2003). Other physical-socio factors that need to be considered include the use of different kinds of interaction style (e.g., multi-user gesturing and multiple input devices across displays) on collaboration and how increasing and varying the number of displays and devices in relation to group size affects the way groups coordinate and work together. Given our findings and those of others about the problems of providing seats when using vertical displays, a further challenge is to see whether vertical displays can be designed to support more fluid interactions for collaborative problem-solving and design activities that involve writing, pointing, computing, annotating, etc. that enable all group members to view the whole display and interact with it at the same time, without having to stand to the side, or feel uncomfortable switching between tasks or socially awkward.

In sum, our research suggests that where it is considered desirable for a group to participate in collaborative activities that involve using and creating an assortment of representations (e.g., joint idea generation and distributed planning), then horizontal interactive surfaces that closely couple the resources used and created during the various activities are most effective. On the other hand, vertical displays are better at providing a shared surface for communal and audience-based viewing and annotating of information that is to be talked about and referred to, e.g., the showing of visualisations, slideshows and the sharing of video and other media, as indicated by recent studies of community interactive boards (e.g., Izadi et al., 2003;

Churchill et al., 2003; Mynatt et al., 2003). Which way is best depends on what form of activity the display is to be used for.

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