

A Pre-experiment on Effects of Horizontal and Vertical Touch Displays on Group Work in Card Classification Tasks

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Abstract— In order to verify the strengths and weaknesses of horizontal and vertical interactive displays, we designed a card classification task in which the directional properties of information are considered. We especially focused on investigating the impact of the directional properties of information on user performance and exploring the optimum group size for horizontal and vertical touch displays of the same size. We developed and evaluated some objective and simple methods to measure and analyze user performance including eye contact, time of utterance, and user arrangement. A pre-experiment was conducted in which groups ranging from two to six people performed the task on both a horizontal and a vertical display. Results show that, during the card classification task, more eye contact around the horizontal display but no difference in verbal participation between the two environments. Some evidence indicates the user performance was affected by the directional properties of information. We found the difference in user arrangement of different group size between the two environments in our tasks. We expect to conduct a large-scale experiment to collect more evidence to test our hypotheses.

Keywords—horizontal display; vertical display; directional properties of information; group work; card classification

I. INTRODUCTION

Large interaction displays are frequently used in public spaces and workplaces as they are considered to be able to facilitate collaboration. When focusing on the angle of the display, which is one of the four display factors defined by Mandryk[1], it is worth exploring the vertical and the horizontal ones since they are most widely used in nowadays. Former studies on horizontal and vertical displays analyzed the impact of these displays on collaboration by comparing the participants' performance under the combination of display factor, task, and interaction method[2][3][4][5][6][7]. However, there are two main problems in these studies. First, they didn't consider and compare the impact of the direction of the information presented on the display. Second, they didn't compare the optimum group size for the two types of touch display of the same size.

To solve these problems, we designed card classification task with broad applicability in which the directional properties of information are considered and developed some objective and simple methods to measure and analyze the user performances for horizontal and vertical displays. We conducted a pre-experiment in group work with groups ranging from two to six people to test five hypotheses. We

expected to investigate the impact of the directional properties of the information on user performance and to explore the optimum group size for horizontal and vertical touch displays of the same size so as to provide advice to aid in future interface designing of horizontal and vertical displays. We also believe that these findings could help to make a better use of a touch display of a certain size, such as inducing user behaviors around the display.

In this paper, we will discuss related studies, explain our experimental design and the five hypotheses we tested, present the results we obtained, and discuss our conclusions and future work to be done.

II. RELATED WORK

Many comparative studies of horizontal and vertical displays have been carried out to provide a better understanding of the effects of display factors on users (see Table 1). It is considered that horizontal displays can facilitate equality of physical and verbal participation while vertical displays are effective for exhibiting information. However, there are two main problems in these studies.

First, no studies have considered and compared the impact of the directional properties of the information handled within the tasks that were performed. Suzuki[8] investigated and ascertained the effect of angle of view on recognition of facial expressions. Their findings revealed that the direction of information will affect people's cognition and performance during the execution of the task. Previous studies didn't consider the bias caused by the directional properties of information. For example, Potvin[3] tried to compare the eye

TABLE I. COMPARATIVE STUDIES OF HORIZONTAL AND VERTICAL DISPLAY (H: HORIZONTAL V: VERTICAL)

Author	Task	Information with/without Directional properties	Interaction method	Group size	Sit or Stand
Inkpen[2]	Route planning	with	Pens	2	H:sit V:stand
Potvin[3]	Software designing	with	Pens	2	stand
Rogers[4]	Itinerary planning	with	Mimio pen	3	sit (except interactor)
Forlines[5]	Visual search	with	keypad	1,2,4	sit
Pantidi[6]	Concept map	with	H:multi-touch V:pen	9-10	Free form
Pavlovych[7]	Target acquisition	without	Laser pens, multiple mice	1,2,3	Free (Position is fixed)

contact occurring around the horizontal and vertical surfaces and made the users perform the task in a standing position so as to prevent the results from being affected by the user arrangement. However, the direction of the UML class diagram actually affected the user arrangement and thus biased the results. In addition, group work around a touch display could be seen as a combination of Intra-cognitive and Inter-cognitive communication[9]. The understanding about the effect of directional properties of information on human cognitive characteristics could facilitate the interaction. Second, no studies have compared the optimum group size for horizontal and vertical displays of the same size. All the related studies that focused on group size gave the result that larger group size would lead to shorter completion time or better performances[5][7][10]. However, there is a possibility that the completion time would start to increase or the performance would start to get worse when the size of the group crosses a certain threshold.

III. HYPOTHESES

On the basis of former studies, we formulated five hypotheses that were tested in the experiment.

- H1) Within the same group size, for the classification of cards without directionality, the completion time on the horizontal display is shorter than on the vertical display. For the classification of cards with directionality, the completion time on the vertical display is shorter than on the horizontal display (Participants have the same angle of view around the wall display so that it might be easier to recognize the information with directionality).
- H2) The completion time would initially decrease as the group size increased[5][7][10] and start to increase when the group size crossed a certain threshold.
- H3) More eye contact would occur around the horizontal display than the vertical display[2].
- H4) Equality of verbal participation will not differ between the horizontal display and the vertical display[3].
- H5) The distance the users moved would be longer around the vertical display than around the horizontal display (a high degree of full body movement around the vertical display was observed in Inkpen's experiments[2], but no quantitative measurement).

IV. EXPERIMENT DESIGN

We used a $2 \times 3 \times 5$ factorial design with 3 factors: display orientation, task and group size (see Table 2). We also tried to design some efficient and simple measurement method with acceptable accuracy to record and analyze the user performance around the displays.

A. Task

We will examine the influence of the directional properties of information by presenting two types of information, information with and without directionality, in our tasks. Information without directionality such as symmetric patterns could be recognized without any trouble from any angle of view. In contrast, changes in the angle of view would cause some problems in recognizing the information with directionality. All the information can be classified into two types, as shown in Fig. 1, and both of them have directional properties. Single words and characters are always recognized

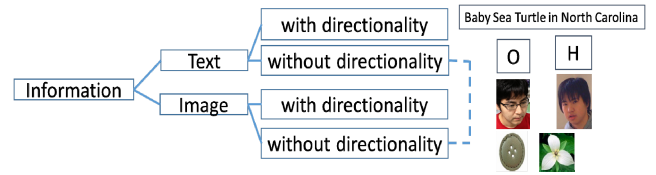


Fig. 1 Types of information with examples.

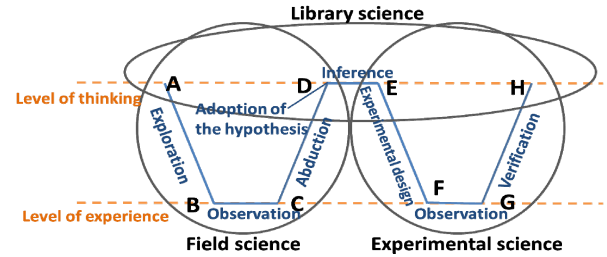


Fig. 2 W-shaped problem solving model.

as patterns so that they have the same directional properties as pictures without directionality. Thus, we designed three types of subtasks for pictures with directionality, pictures without directionality, and character strings in Japanese.

Former studies focused on some particular task to verify the difference between a horizontal and a vertical display in the particular fields such as software designing or itinerary planning. We focused on common tasks in collaboration as opposed to focusing on designing a particular task so that the results would have broader applicability. Kawakita[11] proposed a W-shaped model (see Fig.2) by organizing and modeling the process of problem solving. He also indicated that this model could be applied to all the problems. He focused on the process of C-D and proposed KJ method which has been used in numerous fields to help solve a wide range of problems. A narrow sense KJ method involves card making, grouping, naming and chart making. The broad sense KJ method, also called cumulative KJ method, can be used in each process of the W-shaped problem solving model by performing several rounds of the narrow sense KJ method. The KJ method is now widely used in various applications such as corporate training, school education, and numerous kinds of workshops.

The foundation of the KJ method, card grouping process, is an act of classification of information. Classification is proved to be a technique that is useful in a wide range of applications such as human cognition, decision-making and creative activity. According to Kelly's Personal Construct Theory[12], people categorize information to help them understand the world and describe their own categorization of the world with reasonable validity and reliability. Roy[13] found that when providing support to decision makers, one useful analysis method is to classify multiple choices into predefined groups. Furthermore, card operation is commonly used for multi-touch displays. For the above reasons, we

TABLE II. EXPERIMENTAL DESIGN

Factors	Levels	Method
Display	2 (Horizontal /Vertical)	Within subjects
Task	3 (pictures with/without directionality, character strings)	
Group size	5 (from 2 to 6)	Between subjects

decided to design a card classification task. The contents of the card classification task are shown in Table 3.

B. Apparatus

We used the apparatuses shown in Table 4 to record user performance and raw application logs. The experiment environment is shown in Fig. 3. One of the Kinects was set up on the ceiling. Four Kinects were set up around the horizontal environment and three around the vertical environment. We used a 55" multi-touch display that can detect 32 touch points simultaneously and designed a card classification application to run on it. The participants were asked to classify 60 digital cards equally into three groups by putting them into the three frames presented on the display. The cards could be enlarged, moved, and rotated freely. The application (see Fig.4) would start to record the coordinate and rotation angle of each card when the start button was touched. When the stop button was touched, the answer would automatically be judged as correct or incorrect. The task would continue until they had classified all the cards correctly.

The display was placed horizontally or vertically in accordance with the experiment requirements. Both environments were designed to be used in a standing position. Since the average height of a Japanese adult is 165 cm (male 172 cm, female 158 cm), we used the bodily proportions and the mean stature for Japanese[14] and the Ergonomics of Touch Screens[15][16] to determine the ideal placements of the display as follows:

1. The top of the horizontal surface was placed at the height of 106.6 cm (5 cm above elbow height, the ideal height for precision work).
2. The bottom edge of the vertical surface was placed at the average height of the elbow (101.6 cm) and could thus be touched with the elbow joint at a 90 degree angle.

TABLE III. CONTENTS OF THE TASK

No.	Content	Type of information	Number of cards
1	Portrait	Information with directionality	60
2	Symmetric image	Information without directionality	60
3	News title	Information with directionality	60

TABLE IV. EQUIPMENT AND MEASUREMENT ITEMS

Apparatus	Number	Measurement item
multi-touch display	1	Completion time, coordinate and rotation angle of cards
Kinect	5	User arrangements
360 degree video camera	1	Facial expression
directional microphone	6	Time of utterance
throat microphone	6	
IC recorder	6	
AR Marker	6	Head position and angle

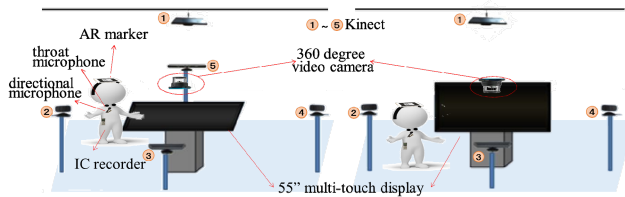


Fig. 3 General view of the experiment environment.

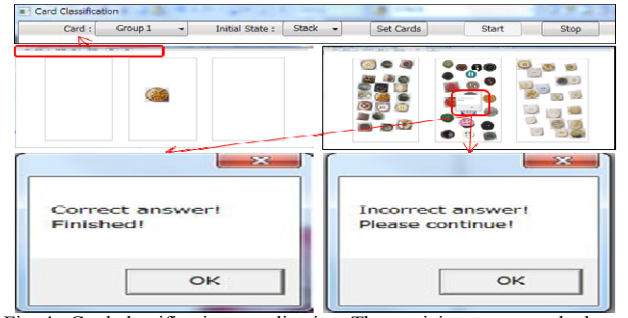


Fig. 4 Card classification application. The participants were asked to classify 60 digital cards equally into three groups by putting them into the three frames presented on the display.

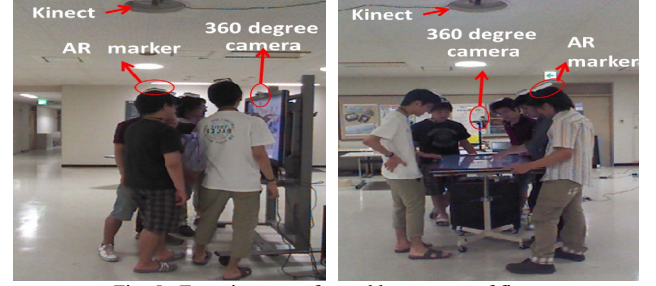


Fig. 5 Experiment performed by a group of five (left: vertical; right: horizontal).

C. Measurement Methods

We developed several efficient, simple methods to measure and analyze the user performances.

The Kinects around the display were used to track the skeletons of the participants. The Kinect set up on the ceiling recorded both the RGB images and the depth images.

We asked each participant to wear an AR marker on the top of the head and used ARToolKit to record the positions and angles of their heads. Eye contact would be counted as having been made if two participants' AR markers simultaneously entered each other's effective visual field, which is approximated to an elliptical cone. We conducted an experiment during which six participants looked at each other in a sequential order to verify the measurement method's accuracy. The overall performances proved to be reasonably good, with the precision 82.5% and recall 66.0% around the horizontal display and the precision 82.1% and recall 69.7% around the vertical display.

We used a combination of a throat microphone and a directional microphone to record each participant's speech simultaneously into left and right channels and calculated each participant's utterance time according to the correlation coefficients in the frequency domain of the two channels. Four parameters were tuned for each participant to achieve a balanced accuracy.

D. Participants

Twenty graduate students (eighteen males, two females) participated in the experiment. They were randomly divided into groups of two to six. Their heights ranged from 153 to 190 cm (M=170 cm). All of them had previous experience using touch devices (tablets or smartphones).

E. Procedure

First, the participants were given an introduction to the experiment and some time to familiarize themselves with the card classification application. They first completed the three tasks on the horizontal display. After five minutes rest, they went on to complete the same three tasks on the vertical display. They were asked to classify the 60 cards evenly into three groups and could move freely around the display while doing so. After the experiment, each participant answered a NASA-TLX[18] questionnaire about the mental and physical effort required in the task. They answered the questions using a 10-point rating scale and explained the differences they had identified between the horizontal and vertical displays.

V. RESULTS

A. Evaluation of Measurement Methods

We collected the position and the angle of each participant's head with ARtoolkit and estimated the possible eye contacts in both environments. We checked these results against a recorded video and found there were more false positives around the horizontal display than the vertical display due to the unpredictable behavior habits of some participants. We decided to use recorded videos to count the eye contact instances manually to gain more accurate eye contact data in the large-scale experiments. With respect to the recording of speech, 18 out of 30 trials were recorded successfully. In the other 12 the equality of verbal participation could not be calculated because the positions of two participants' throat microphones were changed during the task, resulting in incomplete records. We would use a headset with a noise-canceling microphone in the future experiments.

The Kinect set up on the ceiling successfully recorded the depth data. We created a zero matrix of the same size as the raw depth images. For each frame, if the depth value of a pixel was in the preset range (approximately just above the participants' shoulders), the corresponding element of the matrix would be increased by 1. After all the frames were processed, we got a heat map of the participants' position by visualizing the cumulative depth data properly. Participants' skeletons could not always be tracked by the Kinects around the display because there was insufficient distance between the participants. Thus, we would continue to use the Kinect on the ceiling to get the heat maps according to the depth data.

B. Evaluation of the Hypotheses

We organized and evaluated the obtained results according to the 5 hypotheses. Both H1 and H2 are related to the completion time, the directional properties of information, and the group size. Our small sample of data did not allow us to perform additional statistical analysis about H1 and H2.

1) H1: directional properties

As shown in Fig.6, for the task of pictures without directionality (symmetric images), three out of five results indicated the completion time was shorter on the vertical display. For the task of pictures with directionality (portraits), four out of five results indicated the same thing. For character strings (news titles), the completion time was much longer on the vertical display because of the controversial classification

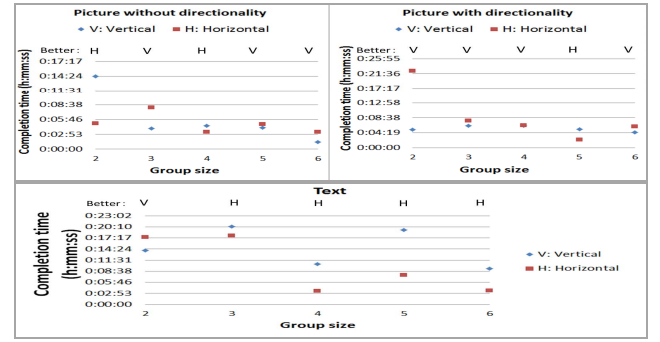


Fig. 6 Completion time.

criteria (according to the participants' feedback from the questionnaire). Thus, we excluded the comparison of completion time needed for text from consideration and will need to conduct new experiment trials. Although we believe more trials are needed, we tend to especially believe in the validity of the results showing a shorter completion time for picture cards with directionality on the vertical display.

2) H2: group size

In Fig. 6 we can see the tendency for completion time to steadily decrease with group size but no sign of it rising again. Thus, to further test H2 it will be necessary to run the task with a group of seven or more members.

3) H3: eye contact

The detected eye contact results shown in Table 5 are based on the use of ARToolKit to estimate eye contact instances. Data of the horizontal display were revised according to the video record. Paired t-tests showed that the horizontal display was significantly different from the vertical display ($t(14)=5.36, p=0.0001$).

4) H4: verbal participation

We used an index of inequality, I , previously used by Marshall[17] to measure the equality of participation in discussions. This was calculated for each group using equation (1) below, where N is the group size, E_i is the expected cumulative proportion of events if each participant contributes equally, and O_i is the observed cumulative proportion of events starting with the participant who contributed least.

$$I = \frac{(1/N) \sum_{i=1}^N (E_i - O_i)}{(1/2)(1 - 1/N)} \quad (1)$$

We calculated I using each participant's time of utterance for each task. The results no significant differences between the seven pairs of data (see Table 6 and Fig. 7).

TABLE V. DETECTED EYE CONTACT INSTANCES

Group size	2			3			4			5			6		
Horizontal	0	0	0	2	3	0	2	1	2	3	2	2	2	1	2
Vertical	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE VI. INDEX OF INEQUALITY

Group	Horizontal	Vertical
2	0.26	0.02
4	0.06	0.26
	0.15	0.22
	0.09	0.13
5	0.34	0.3
	0.42	0.17
	0.44	0.19
6	0.13	0.27

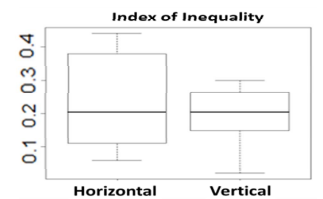


Fig. 7 Distribution of index of inequality

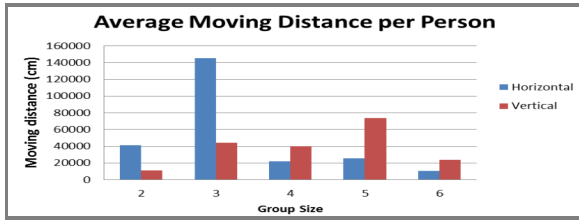


Fig. 8 Average moving distance calculated from the coordinates.

5) H5: moving distance

Fig. 8 shows the average moving distance of each member in each group. Our small sample of data did not allow us to perform statistical analysis. For groups of two or three, the members moved a longer distance around the horizontal display. For groups of four or more, however, they moved a longer distance around the vertical display.

C. Subjective Evaluation

The questionnaire results based on NASA-TLX are shown in Table 7. The vertical display was perceived as more mentally and physically demanding to operate than the horizontal display.

With respect to subjective preferences, 70% of the participants preferred the horizontal display for pictures without directionality, 75% preferred the vertical display for text, 72% felt it was easier to look at each other around the horizontal display, 85% didn't feel any difference between the two environments in terms of talking time, and 75% felt it was easier to move around the horizontal display.

VI. DISCUSSION

A. Effects of the Directional Properties of Information

We found some evidence that indicated the directional properties of information affected user performances.

Table 8 shows the average rotation angle of each card during each task. The results show that participants rotated the text cards much less than the picture cards but the difference was not significant. We recorded the yaw angle of their heads in the camera coordinate system shown in Fig. 9, and calculated the average of the absolute value so as to judge the direction they faced. Table 9 shows the average yaw angle of the participants' heads in each task. One-way repeated measures ANOVA showed a significant effect of the information types ($F(2,8)=13.07$, $p=0.003$) around the horizontal display. Post-hoc pairwise Bonferroni corrected comparisons showed significant differences between the picture cards and text cards (pictures without directionality vs. text: $p=0.003$; pictures with directionality vs. text: $p=0.02$), which revealed that participants intended to turn their head towards the same direction for a same angle of view around the horizontal display.

The heat maps generated by the Kinect depth data of each task showed that, around the vertical display, starting with group of four, the participants tended to stand in two or more layers. They stood a certain distance from the screen to get an overview. Fig. 10 shows the heat maps of the groups of five

TABLE VII. RESULTS OF THE QUESTIONNAIRE. SIGNIFICANT DIFFERENCES ARE MARKED WITH *

Item	Horizontal	Vertical	Sig.
Mental Demand	5.2	5.6	
Physical Demand	4.2	6.1	*
Temporal Demand	3.7	4.8	
Performance	4.3	5.9	*
Effort	4.6	5.7	
Frustration	4.4	6.2	*
Total Demand	4.3	6.1	*

TABLE VIII. AVERAGE ROTATION ANGLE (DEGREE) OF EACH CARD

Group size	Pictures without directionality		Pictures with directionality		Character string	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
2	0.57	49.13	80.26	2.55	9.31	3.55
3	28.96	12.98	19.79	10.60	14.43	14.69
4	13.73	15.52	15.14	14.63	1.94	0.02
5	28.69	14.60	20.12	13.89	7.32	11.06
6	18.09	16.92	9.68	12.49	2.66	3.51
Average	18.01	21.83	29.00	10.83	7.13	6.57

TABLE IX. AVERAGE YAW ANGLE (DEGREE) OF THE PARTICIPANTS' HEADS IN EACH TASK

Group size	Pictures without directionality		Pictures with directionality		character string	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
2	156.85	157.71	153.24	154.43	158.65	154.03
3	104.05	153.21	120.47	153.61	127.21	151.60
4	91.81	149.98	91.70	150.21	108.11	149.60
5	89.04	147.54	94.65	147.67	107.94	147.36
6	81.75	143.30	87.14	145.08	106.03	146.29
Average	96.72	148.51	109.32	149.09	122.35	148.93

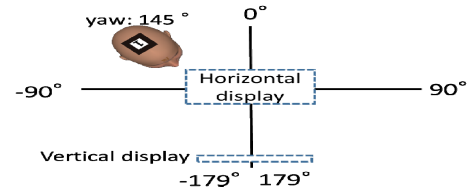


Fig. 9 Camera coordinate system (viewed from ceiling).

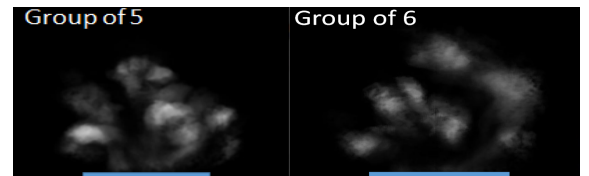


Fig. 10 Heat maps around the vertical display

and six. Around the horizontal display, the participants' positions were relatively more fixed than around the vertical display. When classifying the text cards, participants tended to gather on one side but would not get too close to each other. Fig. 11 shows the differences between groups of three and four around the horizontal display.

From this information we inferred that around the horizontal display the participants preferred to maintain a certain distance from others to "hold their own territory" as much as possible, which caused the fixed positions. They preferred to turn their heads in the same direction rather than rotate the cards so as to compensate for the effect of the directional properties and maintain a common perspective for all the group members.

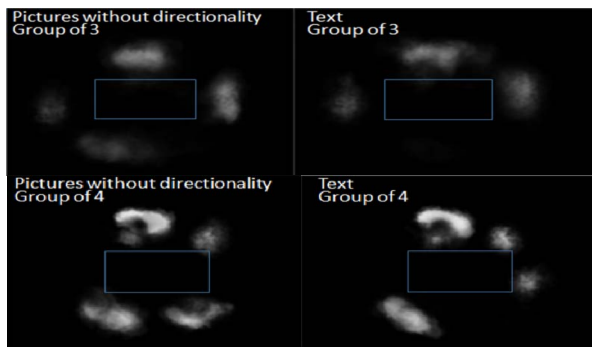


Fig. 11 Heat maps around the horizontal display.

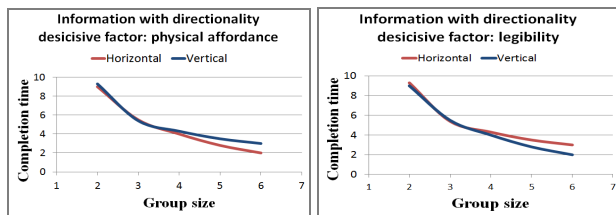


Fig. 12 Completion time determined by three factors.

B. Completion Time / Directional Properties / Group Size

Observing the processes for all the tasks led us to assume that there are three important factors that greatly affect the completion time in our card classification task: legibility, the group's idea generation ability, and the physical affordance of the display. By legibility, we mean the display's affordance to facilitate the process of perception and interpretation of information. The vertical display offers better support for legibility of information with directionality because it can provide the same angle of view for all the group members. The group's idea generation ability differs with the individuals making up the group and rises with the group size. Consequently, for a small group it will be the main factor affecting the completion time. For a large group the main factor will be the physical affordance of the display. The horizontal display can offer better support for physical affordance because it allows more users to touch displays simultaneously.

Considering the combination of the three factors, we assume that the completion time for information without directionality would decline as the group size increases. In particular, the vertical display curve would be flatter than the horizontal display one. For information with directionality, we assume the slopes of the two curves would be determined by both legibility and the physical affordance of the display (see Fig.12). We expect to test this hypothesis in future experiments.

VII. CONCLUSION AND FUTURE WORK

Our results show that, during the card classification task, more eye contact instances were detected around the horizontal display but no difference in verbal participation was found between the two environments. Members of large groups moved more around a vertical display while members of small groups moved more around a horizontal display. We also discovered that around the horizontal display, participants preferred to turn their heads in the same direction rather than rotate the cards so as to compensate for the effect of the

directional properties. They also preferred to maintain a certain distance from others. Around the vertical display, members in a group of four or more persons stood in two or more layers and preferred to stand a certain distance from the screen to get an overview.

In future work we will revise the contents of the text cards and conduct an additional experiment with groups of up to eight or more persons. If the additional experiment reveals further verification possibilities we will then conduct a large-scale experiment to collect more evidence to test our hypotheses.

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