KINEMATICS OF MULTI-TOUCH SCREEN USE IN A COLLABORATIVE WORK ENVIRONMENT

A Thesis

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Master of Science

by

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ABSTRACT

The objective of this research was to understand the ergonomic impact of multi-touch screen systems as well as space planning needs for using such systems in both single person and collaborative work environment. The impact of screen orientations and scenarios of use on the participants' head, neck and trunk postures when interacting with a simulated large multi-touch screen was analyzed based on the three dimensional kinematic data obtained through a video-based motion capture system. Sixteen participants took part in the experiment and performed three simulated tasks for three screen orientations (horizontal/ vertical/ self-adjusted) and two scenarios (single person/ collaboration).

Some kinematic concerns for using the simulated multi-touch screen were identified in this study. The vertical orientation was the best orientation in terms of head, neck and trunk kinematics. For horizontal orientation, in general mean trunk flexion range exceeded 20 degrees in the collaboration scenario and mean trunk axial rotation range was around 17 degrees. For self-adjusted orientation, trunk flexion and trunk axial rotation remained within an acceptable range; meanwhile it could offer more choices for the users. The participants' preferred screen tilted angles were analyzed and two possible fixed screen adjustments were suggested. Basic space planning needs were analyzed for interacting with the simulated multi-touch screen across screen orientations and single person/ collaborative use.

BIOGRAPHICAL SKETCH

Shuo Zhou grew up in Qinghuayuan in Beijing, China. She completed her secondary education at Middle School & High School Attached to Tsinghua University. Shuo entered Tsinghua University in 2006, and received her Bachelor of Science Degree in Automotive Engineering/Car Design in 2010. Upon completion of her undergraduate study in Tsinghua, Shuo came to Cornell University to continue her research in Human Factors and Ergonomics towards a Master's degree in the Department of Design and Environmental Analysis, College of Human Ecology. This thesis was completed as partial fulfillment of the requirements for the Degree of Master of Science which Shuo will receive in January, 2013.

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CHAPTER 1: INTRODUCTION

Design process in design industry involves exchanging ideas – traditionally using paper and sketching basis. However, specific advanced technologies are starting to replace these traditional tools now. Although multi-touch screen technology is not a new invention, it is seldom put into studio use due to high cost and other considerations. How can the design process be facilitated by this multi-touch screen technology which is currently being used more and more? Answering this question would provide needed kinematic guidelines to the design developers (and ultimately users) of such technologies.

Design is a very dynamic task which requires instant interaction, collaboration and sharing ideas during the whole process. One possible advantage of using digital media to share design ideas is that the timelines can be recorded simultaneously, therefore increasing the dynamics of this activity. With digital media, we could achieve this outcome since all the intermediate files are already kept in digital form. Among all the digital technologies that could be used to facilitate design process, a large multi-touch screen board is probably the most promising one. It benefits the collaborative work environment by delivering faithful rendering of high fidelity prototypes, instant feedback to design changes, and seamless connection to CAD/CAM equipment.

In a teamwork collaborative environment, whiteboard and markers are very common tools in a design company. With the development of multi-touch screen devices, such group work pattern could be changed. However, currently there are no general guidelines for planning and using large collaborative multi-touch screen systems. Questions remain unanswered, for example, how much space is needed to use the multi-touch screen? What are the ergonomic risks for using multi-touch screen boards? A targeted ergonomic study of simulated screen use can inform these space planning needs and address the kinematic concerns for prolonged use.

Recent studies are looking into the impact of multi-touch systems. One recent study focused on the viewing angles of two different touch screen tablets in four different sitting configurations (Young et al, 2012), but very little research has looked at large multi-touch screen boards tilted at different angles. Such large multi-touch screens usually require the users to be in a standing configuration and awkward head, neck and trunk postures under prolonged use in a standing configuration could cause neck pain and low back pain. Therefore, the effects of screen orientation of large multi-touch screens on the users' head, neck and trunk postures should be studied.

This study intended to provide some basic parameters of head and neck flexion, trunk flexion, and trunk axial rotation movements when using large multi-touch screens setting at different tilted angles. In this study, the three dimensional kinematic data of head, neck and trunk postures of the participants using a simulated multi-touch screen were obtained through a video-based motion capture system (Vicon Motus System, Version 9.2.0, Vicon Motion Systems, Inc., Centennial, CO).The subjects' preferred screen tilted angles were analyzed to see if there was an optimal preferred angle for the users. The impact of a collaborative working environment on the users' postures was discussed through analyzing the kinematic data. Potential space planning needs for using a simulated multi-touch screen in both single person and collaboration scenarios were discussed. Basic design guidelines and suggestions for further research were given in the end. This research contributed to the knowledge of kinematic risks related to multi-touch screen use and provided preliminary guidelines for designing space for multi-touch screen use.

CHAPTER 2: BACKGROUND

2.1 A Review in Head, Neck and Trunk Kinematics

Constrained head, neck and trunk postures have been associated with pain or discomfort in hands, arms, shoulders, neck and back in man-machine systems (Hunting et al, 1981; Keyserling et al, 1988). Studies concerning head, neck and trunk kinematics have been carried out concerning the use of traditional or non-traditional workstations, both with healthy subjects and patients/subjects with disabilities (Mathieu & Fortin, 2000; Vogt et al, 2001; Krebs et al, 1992; Al-Eisa et al, 2006; Keyserling et al, 2005).

Keyserling et al (1992) categorized trunk flexion into two groups: mild trunk flexion (between 20 degrees and 45 degrees) and severe trunk flexion (more than 45 degrees). Trunk flexion, rotation, and lateral bending have been proved to cause increased risk of back pain, increased discomfort in lower extremities, and decreased posture holding time as flexion angle increases (Punnett et al, 1991; Boussenna et al, 1982). And severe forward trunk flexion more than 45 degrees can be very stressful (Keyserling et al, 1992). Trunk rotation more than 20 degrees have been associated with back pain (Andersson, 1981; Punnett et al, 1991).

Keyserling et al (1992) also categorized neck flexion into mild neck flexion of between 20 degrees and 45 degrees, and severe neck flexion more than 45 degrees. Neck flexion has been associated with neck pain and stiffness (Grandjean et al, 1983a) and these symptoms would develop from prolonged exposure (Keyserling et al, 1992). Severe forward neck flexion can also cause pain in the upper back and arms (Harms-Ringdahl et al, 1986). And maximal neck flexion can cause pain and discomfort after only 15 minutes of exposure (Harms-Ringdahl et al, 1986).

Grandjean (1988) concluded that the forward head and neck flexion should not be more than 15 degrees; otherwise pain and fatigue are likely to occur. And the preferred sight line is on average between 10 degrees and 15 degrees below a horizontal plane and this corresponds very well to the preferred video display terminal (VDT) screen viewing angle (Grandjean, 1988).

Few gender related differences in patterns or ranges of motion on trunk kinematics was found in previous study (Crosbie et al, 1997). Though significant reduction in spinal range of motion during walking was found in this study with advancing age, the results suggested that these age-related differences are more likely to be due to walking speed effects than intrinsic aging effects.

2.2 Trunk Kinematics with Traditional Workstation

Recent studies started to examine trunk kinematics using motion analysis methods. One study (Mathieu & Fortin, 2000) used both EMG and motion analysis methods to examine trunk kinematics during a continuous trunk flexion/extensions task at four different periods (natural period chosen by each subject, 3, 2.25 and 1.5s periods) and a fatiguing task of 45 seconds at 1.5 s period. Ten healthy subjects participated in this study. The experiment results showed that varying the speed of continuous flexion/extension tasks did not reveal significant differences in trunk kinematics or EMG patterns from what was observed in the self-chosen natural period task.

Based on previous studies (Parnianpour et al, 1988; van Dieen et al, 1998), subjects who performed fatiguing flexion/extension tasks significantly reduced their range of motion in the sagittal plane while simultaneously increasing their lateral flexion and axial rotation. However, in Mathieu & Fortin's study, no statistically significant changes were found. The authors mentioned that the lack of significance could probably be due to that the fatigue test used in this study, which was designed for low back pain patients, was not demanding enough for healthy subjects. Nonetheless, these studies suggested that trunk flexion in the sagittal plane, lateral flexion and axial rotation during trunk movement are very likely related and should be combined to be considered.

Another study (Al-Eisa et al, 2006) described trunk kinematics in sitting position in comparison to standing position and found significant differences, but the study was mostly focused on patients with pelvic asymmetry and low back pain. A motion capture system was used to test the range of lateral flexion and axial rotation in both sitting and standing positions. Results showed that ranges of both lumbar and thoracic lateral flexion were significantly higher in standing whereas ranges of lumbar and thoracic axial rotation were higher in sitting positions. Trunk flexion in the sagittal plane of the subjects was not considered in this study.

In this study, a video based motion capture system was used to examine the trunk kinematics while performing simulated multi-touch screen related tasks.

2.3 Trunk Kinematics with Multi-Touch Devices

A recent study (Young et al, 2012) conducted an experiment on using touch screen tablets in four different user configurations. Fifteen subjects participated in this study. Head and neck flexion was measured by a marker based motion analysis system. Head flexion, neck flexion and cranio-cervical angle were measured as dependent variables and results showed that head and neck flexion varied significantly across the four configurations and across the two different tablets used in the experiment.

However, since the experiment was conducted in four relatively confined configurations, no standing position was considered. No trunk kinematics was considered in this study. Each of the two tablets was tested for two different angles since they were the only possible tilted angles possible for the tablets' cases. The results also showed that gaze angle (angle between the gaze vector and the horizontal plane) varied significantly between the two tablets.

To date, no study has focused on user preference of the tilted angle of a large multi-touch screen board. Therefore, more tilted angles in other configurations should be examined in future study.

2.4 Neck Flexion Angle with Traditional Workstation

Musculoskeletal discomfort in the neck and shoulder area is one of the biggest occupational health concerns for video display terminal (VDT) users and the vertical position of VDT and pronounced inclination of the head were identified among several ergonomics factors (Bergqvist, Wolgast, Nilsson & Voss, 1995; Hunting, Laubli & Grandjean, 1981).

Monitor height and location related to eyes are key parameters of workstation design in several studies, and viewing angles and screen inclination were also discussed (Grandjean, Hünting & Pidermann, 1983; Villanueva, Sotoyama, Jonai, Takeuchi, & Saito, 1996). The results showed the preferred viewing angles were nearly normally distributed, between -4 and -14 degree; and the majority of the subjects preferred a backward inclination of the screen between 91 and 100 degree. The preferred screen height had an effect on the preferred screen inclination; the lower the height of the screen, the greater is the preferred backward inclination of the screen (Grandjean et al, 1983b). But experiments in this study were conducted in a sitting position for a traditional VDT workstation, and no preference of the height and inclination of the screen were given for a standing position.

Another study (Villanueva et al, 1996) showed that the relationship of eye position and body posture suggested that body positions changed to complement the eye position in obtaining a better view of the visual target. Viewing angle was determined mainly by inclination of the neck and the eye. Viewing distance and trunk inclination showed significant correlation. This study was conducted in a sitting position with 10 subjects, five different screen height settings, 80, 90, 100, 110 and 120 cm, were used in the experiment.

2.5 Multi-Touch Screen Boards

A previous study (Wigdor et al, 2007) was carried out analyzing a subject who used a horizontal direct-touch tabletop as his primary computing environment for 13 months. The study included a structured interview with the user and an analysis of the touch and click locations when operating in the touch screen tabletop modes compared to the regular laptop desktop modes over a three week period. The experiment showed a striking result that a greater number of touch events were generated towards the bottom of the tabletop touch screen compared to using the laptop; however, upon further analysis, this could be due to the placement of the soft keyboard on the screen. Because of the limitation of the experiment method, we cannot conclude which part of the touch screen was being used most often. The size of the screen and the part of screen which was used most often would affect the users' trunk postures in both standing and sitting positions; therefore, more studies in this area should be brought up.

In this study, the height of the table was set so that it could be operated while either sitting or standing. Besides, the subject had choices of two different touch screen tables, one with a diagonal measurement of 81 cm and the other one of 107 cm. Although it was used as a single user tabletop, the subject preferred the larger tabletop because it provided a larger field of view.

For the size of the multi-touch screen, there has been little research in this area, so not much reference can be included. For a traditional table top workstation, Grandjean (1988) suggested that all materials, tools and controls should be placed within the space illustrated in Figure 2-1. The grasping distance (from shoulder to hand) should be about 55-65 cm and the working distance (elbow to hand) should be about 35-45 cm. However, Grandjean also mentioned that an occasional stretch up to distance of 70-80 cm can also be undertaken without ill-effects.

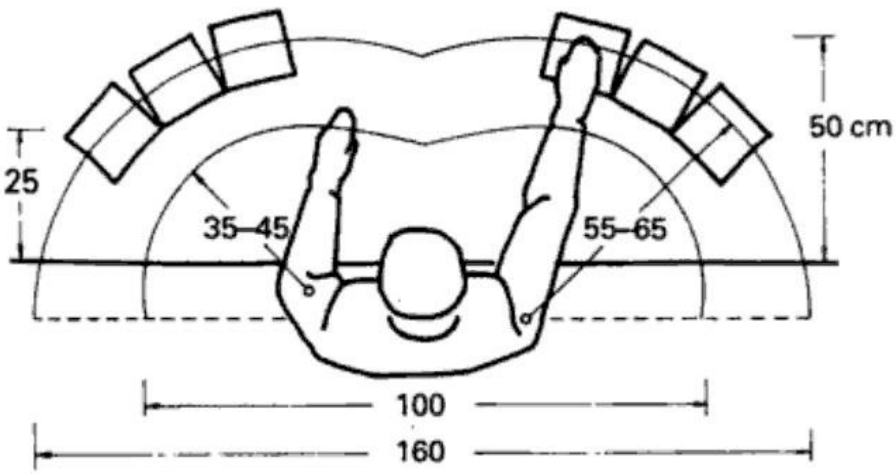

Figure 2- 1 Horizontal arc of grasp, and working area at table top height (Grandjean, 1988)

A horizontal multi-touch screen could be very similar to a traditional table top workstation, but still very little research on tilted table-top size can be referred here.

2.6 Single User Work Compared to Collaboration Work with Tabletops

One previous study (Ryall et al, 2004) focused on the issue of tabletop size, particularly the effect of group size and table size on the speed of performing a task, the work strategies among group members, social interactions within the group, issues of shared resources, and user preference for table size.

Groups of subjects assembled target poems using word tiles on the tabletop. The two tables of different sizes used for the experiment were rectangular devices having a 4:3 aspect ratio with touch surfaces measuring 80cm and 107cm diagonally. Results of this study showed that the size of the table had no significant effect on the task speed of assembling poems. There was no significant interaction effect between table size and group size. For larger groups, additional vertical displays for shared information might be needed. Further research on space planning needs is needed for tabletop collaboration work. Orientations of a tabletop design were not discussed in this study.

Another study (Scott et al, 2004) conducted two observational studies of traditional tabletop collaboration in both casual and formal settings to understand the interaction practices of tabletop collaboration. The results revealed that the subjects used three types of tabletop territories within the shared tabletop workspace: personal, group, and storage. From the observation results, although no group explicitly discussed reserving any areas for personal use, it seemed that social norms dictated that the tabletop area directly in front of someone were mostly reserved for use by that particular person. Thus, the use of personal territories might have an impact on how people physically interact with each other during collaboration work.

The insights of this study called for more research into this area, for example, how people interact with their collaborators on tabletops set at different tilting angles.

2.7 Research Rationale and Research Aims

The objective of this research was to analyze the head, neck and trunk posture when fulfilling three simulated multi-touch screen tasks. By analyzing the three dimensional kinematic data transformed by the video based Vicon Motus motion capture system, it was expected to identify some potential kinematic risks for prolonged use within this simulated multi-touch screen environment and also to evaluate the impact of a collaborative working environment on head, neck and trunk kinematics. The effects of screen orientations on head, neck and trunk kinematics were discussed. Space planning needs for using the simulated multi-touch screen board in both single person and simulated collaborative work environment was discussed.

The research aims for this study were to understand: 1) the impact of screen orientations (horizontal/ vertical/ self-adjusted) on users' head, neck and trunk movement and positioning; 2) the impact of scenarios of use (single person/ collaboration) on users' head, neck and trunk movement and positioning; 3) the users' preferred screen tilted angle for multi-touch screen use; 4) space planning needs across screen orientations and single person/collaborative use.

CHAPTER 3: METHODS

3.1 Apparatus

A repeated measure experiment was carried out and the motion capture system used in this study was the video-based Vicon Motus system. All experiments were conducted in a laboratory environment. A 36 inch by 24 inch whiteboard was used to simulate the multi-touch screen and magnetic shapes on the whiteboard were used for the task. Each magnetic shape used for the experiment was a 1.5 centimeter by 1.5 centimeter square.

3.2 Participants

Sixteen graduate students in Cornell University participated in this study. They were from different background and eight of them majored in a design related area (Interior Design, etc.). The subjects were aged from 23 to 29 years and the average age of the participants was 24.6 years old. Eight of them were male and eight were female. All participants were right handed. Each participant received 15 dollars as compensation for participating in this study.

3.3 Tasks

For each experimental condition, the participant was asked to perform three tasks which mimicked how multi-touch screen were used to simulate potential postures when interacting with such multi-touch screens. The first task was the Perimeter Task (Task 1). The subject was asked to move the magnetic shape on the board counter-clockwise along the perimeter of the whiteboard. The magnetic shape remained contact to the board during the trial and it moved within the area between the edge of the whiteboard and a drawn line which was a distance of 4 centimeters to the edge of the board.

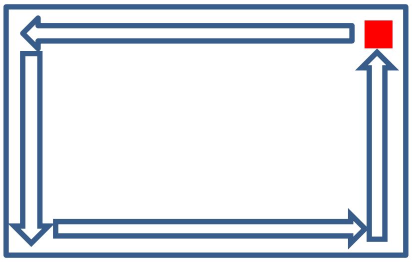

Figure 3- 1 Perimeter Task

The second task was the Rotation Task (Task 2). The participant was asked to simulate a rotation task on the whiteboard by moving one magnetic shape each hand on the board and rotating them counter-clockwise, both hands moving at the same time, as shown in the figure below. The initial locations of the two magnetic shapes were on the center line of the board, within the drawn line addressed before, 4 cm to the left and right edges. The magnetic shapes had to reach the uppermost and bottommost points of the whiteboard within the drawn line addressed before. Same as Task one, both magnetic shapes remained contact to the whiteboard during the trial.

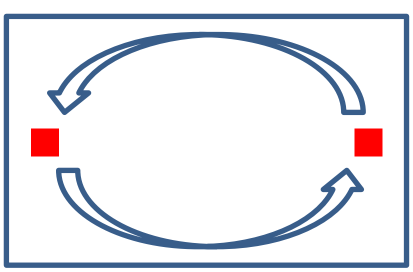

Figure 3- 2 Rotation Task

The third task was the Enlarge Task (Task 3). The participant was asked to hold one magnetic shape for each hand and then simulate an enlarge task on the whiteboard, as shown in the figure below. Started from the upper right corner and the lower left corner, the participant moved the two magnetic shapes to the center of the whiteboard and then moved them respectively to the upper left corner and the lower right corner. The participant then repeated these movements, moved the shapes back to the center, then back to the upper right and lower left corner. Both magnetic shapes remained contact to the board during the trial.

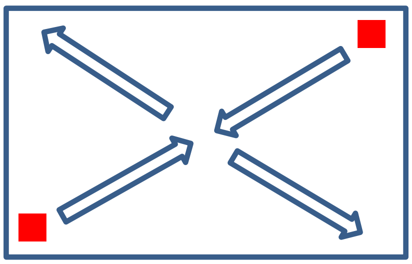

Figure 3- 3 Enlarge Task

3.4 Experiment Design

There were two independent variables. The first independent variable was the screen orientation, which consisted of three levels: the horizontal orientation, the vertical orientation and the self-adjusted orientation. The second independent variable was the scenarios of use, which consists of two levels: the single person scenario and the collaboration scenario. Each participant was asked to perform three tasks across the three screen orientation conditions and across the two scenarios of use. In total, each participant performed 18 trials for the experiment. The duration of each trial was 10 seconds. There was no specific demanding goal for each task.

3.5 Procedure

Followed the consent protocols approved by the Cornell Institutional Review Board, the experimenter measured the height and right arm length of the participant. Then the experimenter placed reflective markers to eight body landmarks on the participant: ectocanthus right, tragion right, C7, T5, two nominal landmarks below the two scapulae, PSIS left and right. (The experimenter also marked two landmarks on the right forearm: Lateral Humeral Epicondyle right and the midpoint of the Ulnar Styloid and Radial Stylion, right, and two landmarks on the right thigh.) The two nominal landmarks below the scapulae were chosen to avoid the possible effects of the movement of the scapulae during the experiments; each landmark was about 2 centimeters below the inferior angle point of each scapula.

Then the participant was asked to perform the three specifically designed tasks on the simulated multi-touch board. The participant performed in six trials. The first three trials were the single person scenarios, and the other three were the collaboration scenarios. In the single person scenarios, participants were asked to choose their standing point in the beginning of each trial. Their horizontal distances from the location of Acromion to the lower edge of the simulated board were measured right before the recording of each trial. They were permitted to move freely but had to remain within the camera view. In the collaboration scenarios, the participants' movements were restricted and a chair at thigh high was put up to the right side of the participant to act as a co-worker during the experiment recording and the participants were not allowed to move the chair nor walk across the chair area as shown in Figure 3-4 below.

Same as the single person scenario, in the beginning of each trial, participants were asked to choose a standing point. Their horizontal distances from the location of Acromion to the lower edge of the simulated board were also measured before the recording of each trial. The participants were allowed to move freely at his/her own side as long as they remained within the bounded area.

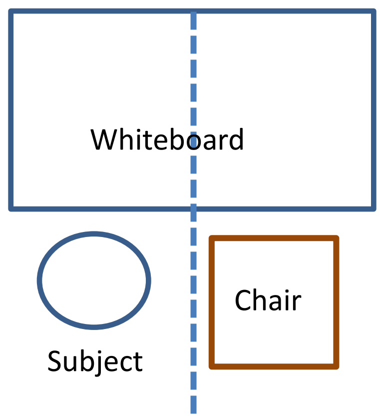

Figure 3- 4 Experimental Setting for the Collaboration Scenario

For both the single person and the collaboration scenario, there were three screen orientation conditions, the horizontal orientation, the vertical orientation and the self-adjusted orientation. The horizontal and vertical orientations were the first two conditions for the participant to get familiar with the system. The order of the static built environment (the horizontal and the vertical orientations) was counterbalanced. The self-adjusted environment was the last screen orientation. Before each experimental condition, the magnetic shapes used for the experiments were placed on the whiteboard at the initial location. Within each condition, the participants were asked to perform the three specific designed tasks one by one as described before. After each task, the participants were allowed to rest for about 60 seconds and then started the next task. The experimenter recorded the trial using the motion capture system.

For the horizontal orientation, the whiteboard (simulated multi-touch screen) was set up at 0 degree; for the vertical orientation, the whiteboard was set up at 90 degree. For the self-adjusted orientation, the participant set the whiteboard at their preferred tilted angle. The tasks were repeated across all three orientations.

For the horizontal orientation, the height of the screen was normalized at the participants' elbow height; for the vertical and self-adjusted orientation, the height of the screen's lower edge was normalized at the participants' elbow height.

Before the video recording of the single person scenarios, the participants were given 5 minutes to get familiar with the simulated multi-touch board and the magnetic shapes. They were encouraged to play with the shapes on board as much as they like and get familiar with the three tasks; their movements were not restricted.

For the collaboration scenarios, the three screen orientation conditions were the same as in the single person scenarios: horizontal/self-adjusted/vertical. Before the actual video recording, one of the experimenters moved and played using the magnetic shapes with the participant and encouraged the participant to get familiar with this collaboration scenario: the participant's movements were restricted due to the presence of a co-worker and they only operated at their own side. After practicing with the participant for 5 minutes, the experimenter left. A chair was placed at the experimenter's side at the participant's thigh height, to simulate the presence of a "co-worker". Then the participants were asked to act as if the experimenter (the co-worker) was still here and their movements were simulated to be restricted by the presence of the chair. They were asked to try to move the magnetic shapes as required for the task and not to walk across the chair's side. Then after warm-up for another two minutes, the experimenter started to record the trial. The three tasks were repeated as in the single person scenarios. In order for the participants to get familiar with the experimental conditions, each participant finished the single person scenario trials before they performed the collaboration scenario trials.

3.6 Dependent Variables

The primary dependent variables were head, neck and trunk postures captured by the motion analysis system, represented by the Head and Neck angle, Trunk Flexion angle and the Trunk Axial Rotation angle.

The Head and Neck angle was the vector angle between the line passing through the point of Ectocanthus and the point of Tragion, and the line passing through the point of Tragion and the point of C7. The Trunk flexion angle was the vector angle between the horizontal plane, and the line passing through the mid-point of the two nominal landmarks below the two scapulae and the mid-point of the PSIS left and the PSIS right. The Trunk Axial Rotation angle was the vector angle, projected to the horizontal plane, between the line passing through the two nominal landmarks below the two scapulae (defined in experimental procedure), and the line passing through the PSIS left and the PSIS right. These angles were calculated from the three dimensional head, neck and trunk kinematics data measured using the three dimensional motion capture system (Vicon Motus, Version 9.2.0, Vicon Motion Systems, Inc.).

The primary dependent variables used in the data analysis process were the range of motion for the trunk flexion in the sagittal plane, range of motion for the trunk axial rotation in the transverse plane, and the smallest head and neck flexion angle, which indicated the largest head and neck flexion. The head and neck flexion angle here was the Cranio-cervical angle, used as the combined head and neck angle.

For analyzing space planning needs, there were two dependent variables. As illustrated in Figure 3-1, although the participants' preferred total space for operating this human-screen system remained unknown, the actual space this system took could be calculated based on the current experiment data:

$$\text{Length} = \text{Distance to Board} + \text{Board Width} \times \cos \alpha$$

The subject's distance to board (the horizontal distance from the subject's Acromion to the lower edge of the simulated board) was measured before each trial and the board width was 61 cm (24 inch). The angle α was the screen tilted angle. For horizontal orientation, $\alpha = 0$ deg; for vertical orientation, $\alpha = 90$ deg; for self-adjusted orientation, α was the subject's preferred tilted angle.

Therefore, the subject' distance to board as well as the calculated Length of the space were used as two dependent variables when analyzing the space planning needs for this human-screen system.

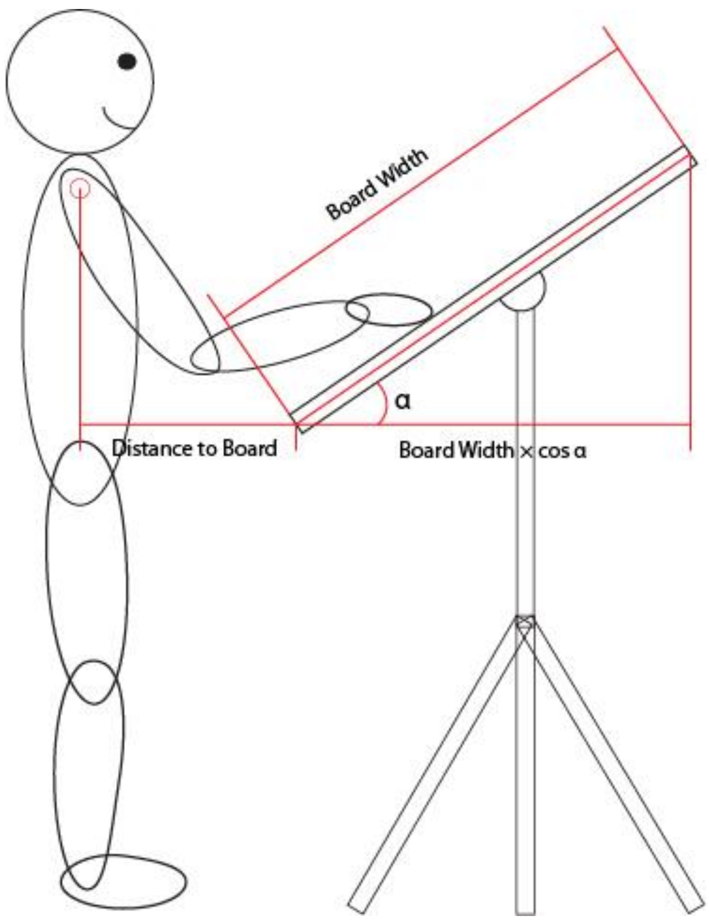

Figure 3- 5 Space Planning Needs Dependent Variables

3.7 Data Analysis

To test the research aims, a mixed model repeated measures ANOVA test was used in this study. The ANOVA test was calculated for the three simulated tasks, respectively. The screen orientations (horizontal; vertical; self-adjusted) and the scenarios (single; collaboration) as well as the orientation by scenario interaction were set as the fixed effects. The subject was set as a random effect. A post-hoc Tukey's HSD test was used for testing difference between each comparison for the three screen orientations and the two scenarios. Also a multiple comparison correction test (Bonferroni correction) was used to see whether there was a significant difference between the two comparisons. Nine comparisons were included in the test, therefore, using the multiple comparison correction (Bonferroni correction), if the p-value was smaller than 0.05/9 = 0.0056, then there was a significant difference between the two comparisons (0.05 was the level of significance and 9 was the number of comparisons included in the test).

During the experiment, for each subject, their heights, and their right arm lengths were measured, as well as their distances to the edge of the simulated board for each trial. The height, right arm length and the distance to the board edge were set as fixed effects in the mixed model at first to test whether there was any significant main effect. The statistic test results showed that for each task and for each dependent variable, there was no significant main effect for height, right arm length as well as the distance to board edge. Therefore, they were removed from the final mixed model.

Because the three simulated tasks used in this study was representative of three different kinds of movements when interacting with the simulated multi-touch board, kinematics results for each task were calculated respectively.

For analyzing space planning needs, a similar mixed model was used. The screen orientations and the scenarios as well as the orientation by scenario interaction were set as the fixed effects. The subject was set as a random effect. Since the subjects' distances to board and their screen tilted angles were the same for all three tasks within each trail, the results were calculated regardless of tasks.

All data analysis calculation was done using the JMP 9 software (SAS Institute, Cary, NC).

CHAPTER 4: RESULTS

4.1 Built Environment

4.1.1 Static Built Environment

The static built environment set up in this study was the horizontal and the vertical screen orientations. Horizontal and vertical orientations for large multi-touch boards are very commonly seen in industries. In a static built environment, the participants cannot adjust how the multi-touch screens are set up.

4.1.2 Self-Adjusted Environment

The self-adjusted environment in this study allowed the participants to choose their preferred screen tilted angle for the self-adjusted orientation. The mean preferred tilted angle was 39.25 degrees. Figure 1 showed the distribution of the preferred angles of all the participants. For all the screen orientations, the height of the simulated multi-touch board was normalized to the subjects' elbow height. Therefore, as shown in the figure below, the height of point O (origin) was normalized at the subject's elbow height and the largest preferred angle was 55 degrees and the smallest was 19 degrees, with a range of 36 degrees. The 0 degree line indicated the horizontal orientation and the 90 degree line indicated the vertical orientation.

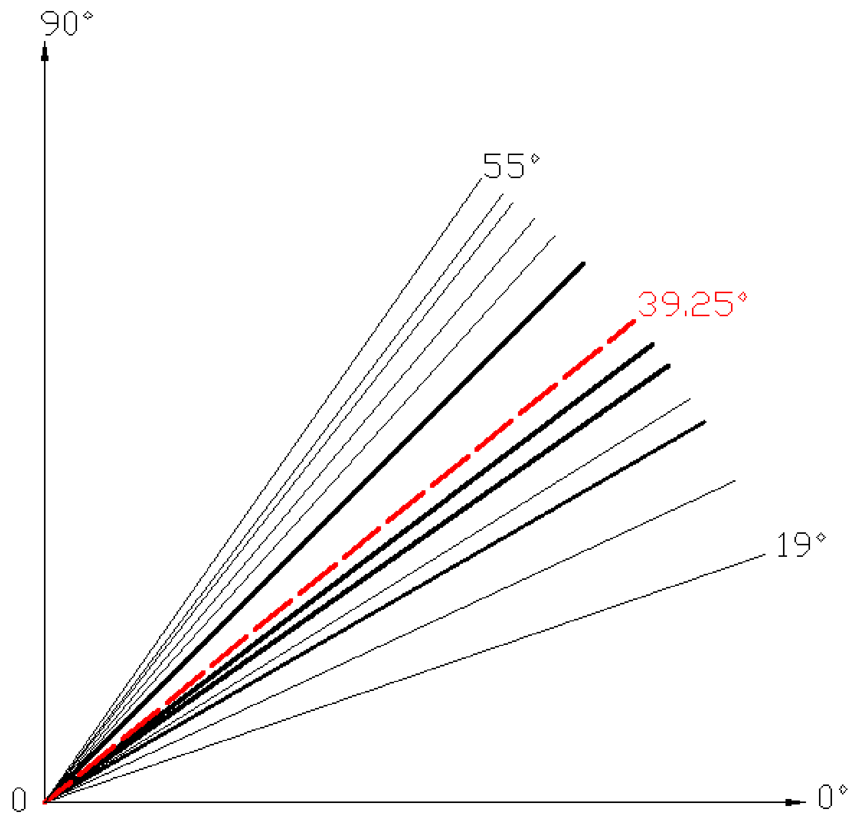

Figure 4- 1 Preferred Angle Distribution

In Figure 4-1, a thicker black line indicated two frequencies for the certain tilted angle. The red dashed line showed the mean preferred tilted angle, 39.25 deg.

4.2 Trunk Flexion

4.2.1 Perimeter Task

For the Perimeter task, trunk flexion range varied significantly across the three screen orientations (p-value < 0.0001). Trunk flexion range for the horizontal orientation (mean = 21.0 deg) was higher than the vertical orientation (mean = 7.8 deg) as well as the self-adjusted orientation (mean = 11.7 deg). Also, trunk flexion range for the collaboration scenario (mean = 15.4 deg) was significantly higher than the single person scenario (mean = 11.5 deg) with p-value < 0.0001.

Table 1 Least Squares Means Table (SE) for Perimeter Task, Trunk Flexion Range [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	21.0	1.1
Self [B]	11.7	1.1
Vertical [C]	7.8	1.1

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	15.4	1.0
Single	11.5	1.0

4.2.1.1 Single Person Scenario

Table 2 shows the least square's means and the standard errors for the single person scenario (3 screen orientations) for trunk flexion range.

Table 2 ANOVA Least Squares Means Table (SE) for Perimeter Task, Single Person Scenario, Trunk Flexion Range

Level	Least Sq Mean	Std Error
Single, Horizontal	16.0	1.4
Single, Self	10.5	1.4
Single, Vertical	8.2	1.4

Table 3 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 3 Least Squares Means Differences Tukey HSD for Perimeter Task, Single Person Scenario, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	7.7	1.6	<.0001*
S,Horizontal	S,Self	5.5	1.6	0.0090
S,Self	S,Vertical	2.3	1.6	0.6994

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

As the results showed, in the single person scenario, the trunk flexion range for the horizontal orientation was significantly higher than the vertical orientation. But when comparing the horizontal and the vertical orientation to the self-adjusted orientation respectively, there was no significant difference.

4.2.1.2 Collaboration Scenario

Table 4 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for trunk flexion range.

Table 4 ANOVA Least Squares Means Table (SE) for Perimeter Task, Collaboration Scenario, Trunk Flexion Range

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	26.1	1.4
Collaboration, Self	12.9	1.4
Collaboration, Vertical	7.3	1.4

Table 5 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 5 Least Squares Means Differences Tukey HSD for Perimeter Task, Collaboration Scenario, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	18.7	1.6	<.0001*
C,Horizontal	C,Self	13.1	1.6	<.0001*
C,Self	C,Vertical	5.6	1.6	0.0076

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that in the collaboration scenario, the trunk flexion range for the horizontal orientation was significantly higher than the vertical orientation as well as the self-adjusted orientation. But the vertical and the self-adjusted orientations were not significantly different according to the multiple comparison correction results.

Table 6 showed the results when comparing the single person and the collaboration scenarios together.

Table 6 Least Squares Means Differences Tukey HSD for Perimeter Task, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	S,Horizontal	10.1	1.6	<.0001*
S,Vertical	C,Vertical	0.9	1.6	0.9933
C,Self	S,Self	2.5	1.6	0.6149

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

For horizontal orientation only, the trunk flexion range for the collaboration scenario was significantly higher than the single person scenario. For vertical and self-adjusted orientation, the trunk flexion ranges for the collaboration scenario were not significantly different to the single person scenario.

4.2.2 Rotation Task

For the Rotation task, trunk flexion range varied significantly across the three screen orientations (p-value < 0.0001), but was not significantly different between the two single/collaboration scenarios (p-value = 0.5912). Trunk flexion range for the horizontal orientation (mean = 14.2 deg) was higher than the vertical orientation (mean = 8.9 deg) and the self-adjusted orientation (mean = 9.8 deg).

Table 7 Least Squares Means Table (SE) for Rotation Task, Trunk Flexion Range [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	14.2	1.3
Self [B]	9.8	1.3
Vertical [B]	8.9	1.3

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	11.2	1.2
Single	10.7	1.2

4.2.2.1 Single Person Scenario

Table 8 shows the least square's means and the standard errors for the single person scenario (3 screen orientations) for trunk flexion range.

Table 8 ANOVA Least Squares Means Table (SE) for Rotation Task, Single Person Scenario, Trunk Flexion Range

Level	Least Sq Mean	Std Error
Single, Horizontal	13.6	1.5
Single, Self	9.6	1.5
Single, Vertical	9.1	1.5

Table 9 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 9 Least Squares Means Differences Tukey HSD for Rotation Task, Single Person Scenario, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	4.5	1.4	0.0180
S,Horizontal	S,Self	4.0	1.4	0.0518
S,Self	S,Vertical	0.5	1.4	0.9988

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

For the single person scenario, although the trunk flexion range for the horizontal orientation was higher than the other two orientations, according to the multiple comparison correction result, there was no significant difference.

4.2.2.2 Collaboration Scenario

Table 10 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for trunk flexion range.

Table 10 ANOVA Least Squares Means Table (SE) for Rotation Task, Collaboration Scenario, Trunk Flexion Range

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	14.9	1.5
Collaboration, Self	10.0	1.5
Collaboration, Vertical	8.6	1.5

Table 11 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 11 Least Squares Means Differences Tukey HSD for Rotation Task, Collaboration Scenario, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	6.2	1.4	0.0003*
C,Horizontal	C,Self	4.8	1.4	0.0084
C,Self	C,Vertical	1.4	1.4	0.9056

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

For the collaboration scenario, the trunk flexion range for the horizontal orientation was significantly higher than the vertical orientation. And there was no significant difference between the self-adjusted and the vertical orientation.

Table 12 showed the results when comparing the single person and the collaboration scenarios together.

Table 12 Least Squares Means Differences Tukey HSD for Rotation Task, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	S,Horizontal	1.3	1.4	0.9306
S,Vertical	C,Vertical	0.5	1.4	0.9994
C,Self	S,Self	0.4	1.4	0.9996

[1] C means the Collaboration scenario; S means the Single Person scenario.
[2] * indicates there is a significant difference between the two comparisons.

The result showed no significant difference between the two single/collaboration scenarios for all three screen orientations.

4.2.3 Enlarge Task

Task 3 is the Enlarge task. Trunk flexion range varied significantly across the three screen orientations (p-value < 0.0001) and also between the two single/collaboration scenarios (p-value < 0.0001). Trunk flexion range for the horizontal orientation (mean = 17.4 deg) was higher than the self-adjusted orientation (mean = 10.6 deg) and the vertical orientation (mean = 4.8 deg). Also, trunk flexion range for the collaboration scenario (mean = 13.5 deg) was significantly higher than the single person scenario (mean = 8.4 deg).

Table 13 Least Squares Means Table (SE) for Enlarge Task, Trunk Flexion Range [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	17.4	1.0
Self [B]	10.6	1.0
Vertical [C]	4.8	1.0

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	13.5	1.0
Single	8.4	1.0

4.2.3.1 Single Person Scenario

Table 14 shows the least square's means and the standard errors for the single person scenario (3 screen orientations) for trunk flexion range.

Table 14 ANOVA Least Squares Means Table (SE) for Enlarge Task, Single Person Scenario, Trunk Flexion Range

Level	Least Sq Mean	Std Error
Single, Horizontal	11.9	1.2
Single, Self	9.1	1.2
Single, Vertical	4.2	1.2

Table 15 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 15 Least Squares Means Differences Tukey HSD for Enlarge Task, Single Person Scenario, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	7.7	1.3	<.0001*
S,Horizontal	S,Self	2.8	1.3	0.2330
S,Self	S,Vertical	4.9	1.3	0.0033*

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

In the single person scenario, trunk flexion range for the horizontal orientation was significantly higher than the vertical orientation, but there was no significant difference between the horizontal and the self-adjusted orientation. The self-adjusted orientation was also significantly higher than the vertical one.

4.2.3.2 Collaboration Scenario

Table 16 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for trunk flexion range.

Table 16 ANOVA Least Squares Means Table (SE) for Enlarge Task, Collaboration Scenario, Trunk Flexion Range

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	22.9	1.2
Collaboration, Self	12.0	1.2
Collaboration, Vertical	5.5	1.2

Table 17 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 17 Least Squares Means Differences Tukey HSD for Enlarge Task, Collaboration Scenario, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	17.4	1.3	<.0001*
C,Horizontal	C,Self	10.8	1.3	<.0001*
C,Self	C,Vertical	6.6	1.3	<.0001*

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

In the collaboration scenario, trunk flexion range for the horizontal orientation was significantly higher than the self-adjusted orientation, which was also significantly higher than the vertical orientation.

Table 18 showed the results when comparing the single person and the collaboration scenarios together.

Table 18 Least Squares Means Differences Tukey HSD for Enlarge Task, Trunk Flexion Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	S,Horizontal	11.0	1.3	<.0001*
C,Vertical	S,Vertical	1.3	1.3	0.9166
C,Self	S,Self	3.0	1.3	0.1869

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that, when set as the horizontal orientation, the trunk flexion range for the collaboration scenario was significantly higher than the single person scenario.

4.3 Trunk Axial Rotation

4.3.1 Perimeter Task

The trunk axial rotation range varied significantly across the three screen orientations (p-value < 0.0001). Trunk axial rotation range for the horizontal orientation was 17.1 deg; the range for the self-adjusted orientation was 16.9 deg and the vertical orientation 12.7 deg. Trunk axial rotation range varied significantly between the single person scenario (mean = 17.1 deg) and the collaboration scenario (mean = 14.1 deg) with p-value < 0.0001.

Table 19 Least Squares Means Table (SE) for Perimeter Task, Trunk Axial Rotation Range [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	17.1	1.2
Self [A]	16.9	1.2
Vertical [B]	12.7	1.2

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	14.1	1.1
Single	17.1	1.1

4.3.1.1 Single Person Scenario

Table 20 shows the least square's means and the standard errors for the single person scenario (3 screen orientations) for trunk axial rotation range.

Table 20 ANOVA Least Squares Means Table (SE) for Perimeter Task, Single Person Scenario, Trunk Axial Rotation Range

Level	Least Sq Mean	Std Error
Single, Horizontal	18.3	1.3
Single, Self	18.3	1.3
Single, Vertical	14.6	1.3

Table 21 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 21 Least Squares Means Differences Tukey HSD for Perimeter Task, Single Person Scenario, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	3.7	1.1	0.0143
S,Horizontal	S,Self	0.1	1.1	1.0000
S,Self	S,Vertical	3.7	1.1	0.0171

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference across the three screen orientations in the single person scenario.

4.3.1.2 Collaboration Scenario

Table 22 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for trunk axial rotation range.

Table 22 ANOVA Least Squares Means Table (SE) for Perimeter Task, Collaboration Scenario, Trunk Axial Rotation Range

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	15.8	1.3
Collaboration, Self	15.6	1.3
Collaboration, Vertical	10.9	1.3

Table 23 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 23 Least Squares Means Differences Tukey HSD for Perimeter Task, Collaboration Scenario, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	4.9	1.1	0.0004*
C,Horizontal	C,Self	0.2	1.1	0.9999
C,Self	C,Vertical	4.7	1.1	0.0007*

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

As shown in Table 23, in the collaboration scenario, trunk axial rotation range for the horizontal orientation was significantly higher than the vertical orientation. Axial rotation range for the self-adjusted orientation was also significantly higher than the vertical one. But there was no significant difference between the horizontal and the self-adjusted orientation.

Table 24 showed the results when comparing the single person and the collaboration scenarios together.

Table 24 Least Squares Means Differences Tukey HSD for Perimeter Task, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	C,Horizontal	2.5	1.1	0.2244
S,Vertical	C,Vertical	3.7	1.1	0.0144
S,Self	C,Self	2.7	1.1	0.1674

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

No significant difference was found between the single person and the collaboration scenarios for all the three screen orientations.

4.3.2 Rotation Task

The trunk axial rotation range varied significantly across the three screen orientations (p-value < 0.0001). Trunk axial rotation range for the horizontal orientation was 12.3 deg; the range for the self-adjusted orientation was 10.2 deg and the vertical orientation 8.7 deg. There was no significant difference between the collaboration scenario (mean = 10.8 deg) and the single person scenario (mean = 10.0 deg) with p-value = 0.2084.

Table 25 Least Squares Means Table (SE) for Rotation Task, Trunk Axial Rotation Range [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	12.3	0.8
Self [B]	10.2	0.8
Vertical [B]	8.7	0.8

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	10.8	0.8
Single	10.0	0.8

4.3.2.1 Single Person Scenario

Table 26 shows the least square’s means and the standard errors for the single person scenario (3 screen orientations) for trunk axial rotation range.

Table 26 ANOVA Least Squares Means Table (SE) for Rotation Task, Single Person Scenario, Trunk Axial Rotation Range

Level	Least Sq Mean	Std Error
Single, Horizontal	11.6	1.0
Single, Self	10.6	1.0
Single, Vertical	7.7	1.0

Table 27 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 27 Least Squares Means Differences Tukey HSD for Rotation Task, Single Person Scenario, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	3.9	1.1	0.0097
S,Horizontal	S,Self	1.0	1.1	0.9509
S,Self	S,Vertical	3.0	1.1	0.1030

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results in Table 27 showed that there was no significant difference between each comparison for the single person scenario.

4.3.2.2 Collaboration Scenario

Table 28 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for trunk axial rotation range.

Table 28 ANOVA Least Squares Means Table (SE) for Rotation Task, Collaboration Scenario, Trunk Axial Rotation Range

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	13.0	1.0
Collaboration, Self	9.8	1.0
Collaboration, Vertical	9.6	1.0

Table 29 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 29 Least Squares Means Differences Tukey HSD for Rotation Task, Collaboration Scenario, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	3.3	1.1	0.0456
C,Horizontal	C,Self	3.2	1.1	0.0619
C,Self	C,Vertical	0.1	1.1	1.0000

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results in Table 29 showed that there was no significant difference between each comparison for the collaboration scenario.

Table 30 showed the results when comparing the single person and the collaboration scenarios together.

Table 30 Least Squares Means Differences Tukey HSD for Rotation Task, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	S,Horizontal	1.4	1.1	0.8329
C,Vertical	S,Vertical	2.0	1.1	0.5034
S,Self	C,Self	0.9	1.1	0.9736

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results in Table 30 showed that there was no significant difference between the single person scenario and the collaboration scenario for each screen orientation.

4.3.3 Enlarge Task

The trunk axial rotation range varied significantly across the three screen orientations (p-value < 0.0001). Trunk axial rotation range for the horizontal orientation (mean =17.3 deg) was significantly higher than the self-adjusted orientation (mean = 13.3 deg) and the vertical orientation (mean = 7.7 deg). There was no significant difference between the collaboration scenario (mean = 13.2 deg) and the single person scenario (mean = 12.3 deg) with p-value = 0.2115.

Table 31 Least Squares Means Table (SE) for Enlarge Task, Trunk Axial Rotation Range [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	17.3	1.1
Self [B]	13.3	1.1
Vertical [C]	7.7	1.1

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	13.2	1.1
Single	12.3	1.1

4.3.3.1 Single Person Scenario

Table 32 shows the least square’s means and the standard errors for the single person scenario (3 screen orientations) for trunk axial rotation range.

Table 32 ANOVA Least Squares Means Table (SE) for Enlarge Task, Single Person Scenario, Trunk Axial Rotation Range

Level	Least Sq Mean	Std Error
Single, Horizontal	16.9	1.2
Single, Self	13.0	1.2
Single, Vertical	7.2	1.2

Table 33 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 33 Least Squares Means Differences Tukey HSD for Enlarge Task, Single Person Scenario, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	9.7	1.1	<.0001*
S,Horizontal	S,Self	3.8	1.1	0.0135
S,Self	S,Vertical	5.9	1.1	<.0001*

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

In the single person scenario, trunk axial rotation range for the horizontal orientation was significantly higher than the vertical orientation. Trunk axial rotation range for the self-adjusted orientation was significantly higher than the vertical orientation. No significant difference existed between the horizontal and the self-adjusted orientation.

4.3.3.2 Collaboration Scenario

Table 34 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for trunk axial rotation range.

Table 34 ANOVA Least Squares Means Table (SE) for Enlarge Task, Collaboration Scenario, Trunk Axial Rotation Range

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	17.7	1.2
Collaboration, Self	13.6	1.2
Collaboration, Vertical	8.1	1.2

Table 35 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 35 Least Squares Means Differences Tukey HSD for Enlarge Task, Collaboration Scenario, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	9.6	1.1	<.0001*
C,Horizontal	C,Self	4.1	1.1	0.0067
C,Self	C,Vertical	5.5	1.1	<.0001*

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

As shown in Table 35, in the collaboration scenario, trunk axial rotation range for the horizontal orientation was significantly higher than the vertical orientation. No significant difference between horizontal and self-adjusted orientation. Axial rotation range for the self-adjusted orientation was significantly higher than the vertical orientation.

Table 36 showed the results when comparing the single person and the collaboration scenarios together.

Table 36 Least Squares Means Differences Tukey HSD for Enlarge Task, Trunk Axial Rotation Range [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	S,Horizontal	0.9	1.1	0.9721
C,Vertical	S,Vertical	1.0	1.1	0.9514
C,Self	S,Self	0.6	1.1	0.9943

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that for each orientation, no significant difference existed between the two scenarios.

4.4 Cranio-Cervical Angle

4.4.1 Perimeter Task

The results showed that there was no significant difference across the three screen orientations, neither between the two single/collaboration scenarios. And there was no orientation by scenario interaction.

Table 37 Least Squares Means Table (SE) for Perimeter Task, Cranio-cervical Angle [1]

Level	Least Sq Mean	Std Error
Vertical [A]	125.0	3.5
Self [A]	123.5	3.5
Horizontal [A]	120.6	3.5

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	124.2	3.0
Single	121.9	3.0

4.4.1.1 Single Person Scenario

Table 38 shows the least square's means and the standard errors for the single person scenario (3 screen orientations) for the smallest cranio-cervical angle, which indicates the largest head and neck flexion.

Table 38 ANOVA Least Squares Means Table (SE) for Perimeter Task, Single Person Scenario, Cranio-cervical Angle

Level	Least Sq Mean	Std Error
Single, Horizontal	124.3	4.5
Single, Self	121.1	4.5
Single, Vertical	120.3	4.5

Table 39 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 39 Least Squares Means Differences Tukey HSD for Perimeter Task, Single Person Scenario, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	S,Vertical	4.0	5.8	0.9832
S,Horizontal	S,Self	3.3	5.8	0.9933
S,Self	S,Vertical	0.7	5.8	1.0000

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference between each comparison for the single person scenario.

4.4.1.2 Collaboration Scenario

Table 40 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for the smallest cranio-cervical angle.

Table 40 ANOVA Least Squares Means Table (SE) for Perimeter Task, Collaboration Scenario, Cranio-cervical Angle

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	117.0	4.5
Collaboration, Self	126.0	4.5
Collaboration, Vertical	129.7	4.5

Table 41 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 41 Least Squares Means Differences Tukey HSD for Perimeter Task, Collaboration Scenario, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Vertical	C,Horizontal	12.8	5.8	0.2560
C,Self	C,Horizontal	8.9	5.8	0.6435
C,Vertical	C,Self	3.8	5.8	0.9864

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference between each comparison for the collaboration scenario.

Table 42 showed the results when comparing the single person and the collaboration scenarios together.

Table 42 Least Squares Means Differences Tukey HSD for Perimeter Task, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	C,Horizontal	7.4	5.8	0.8023
C,Vertical	S,Vertical	9.4	5.8	0.5978
C,Self	S,Self	4.8	5.8	0.9615

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

As shown in Table 42, there was no significant difference between the single person and the collaboration scenarios for all three screen orientations.

4.4.2 Rotation Task

The ANOVA results showed that there was no significant difference across the three screen orientations, neither between the two single/collaboration scenarios. And there was no orientation by scenario interaction.

Table 43 Least Squares Means Table (SE) for Rotation Task, Cranio-cervical Angle [1]

Level	Least Sq Mean	Std Error
Self [A]	128.3	2.4
Vertical [A]	125.5	2.4
Horizontal [A]	124.0	2.4

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	127.2	2.0
Single	124.7	2.0

4.4.2.1 Single Person Scenario

Table 44 shows the least square's means and the standard errors for the single person scenario (3 screen orientations) for the smallest cranio-cervical angle.

Table 44 ANOVA Least Squares Means Table (SE) for Rotation Task, Single Person Scenario, Cranio-cervical Angle

Level	Least Sq Mean	Std Error
Single, Horizontal	119.1	3.1
Single, Self	129.2	3.1
Single, Vertical	125.8	3.1

Table 45 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 45 Least Squares Means Differences Tukey HSD for Rotation Task, Single Person Scenario, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Vertical	S,Horizontal	6.7	4.1	0.5842
S,Self	S,Horizontal	10.0	4.1	0.1540
S,Self	S,Vertical	3.4	4.1	0.9630

[1] S means the Single Person scenario.
[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference between each comparison for the single person scenario.

4.4.2.2 Collaboration Scenario

Table 46 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for the smallest cranio-cervical angle.

Table 46 ANOVA Least Squares Means Table (SE) for Rotation Task, Collaboration Scenario, Cranio-cervical Angle

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	128.8	3.1
Collaboration, Self	127.5	3.1
Collaboration, Vertical	125.2	3.1

Table 47 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 47 Least Squares Means Differences Tukey HSD for Rotation Task, Collaboration Scenario, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	C,Vertical	3.7	4.1	0.9466
C,Horizontal	C,Self	1.3	4.1	0.9995
C,Self	C,Vertical	2.3	4.1	0.9928

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference between each comparison for the collaboration scenario.

Table 48 showed the results when comparing the single person and the collaboration scenarios together.

Table 48 Least Squares Means Differences Tukey HSD for Rotation Task, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Horizontal	S,Horizontal	9.7	4.1	0.1810
S,Vertical	C,Vertical	0.6	4.1	1.0000
S,Self	C,Self	1.7	4.1	0.9986

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

As shown in Table 48, there was no significant difference between the single person scenario and the collaboration scenario for all three screen orientations.

4.4.3 Enlarge Task

The ANOVA results showed that there was a significant difference across the three screen orientations with p-value = 0.0008. The cranio-cervical angle for horizontal orientation (mean = 118.9 deg) was significantly smaller than the self-adjusted orientation (mean = 127.6 deg) and the vertical orientation (mean = 130.8 deg). But the self-adjusted orientation was not significantly different with the vertical one. No significant difference between the two single/collaboration scenarios. And there was no orientation by scenario interaction.

Table 49 Least Squares Means Table (SE) for Enlarge Task, Cranio-cervical Angle [1]

Level	Least Sq Mean	Std Error
Vertical [A]	130.8	2.9
Self [A]	127.6	2.9
Horizontal [B]	118.9	2.9

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	125.8	2.6
Single	125.7	2.6

4.4.3.1 Single Person Scenario

Table 50 shows the least square’s means and the standard errors for the single person scenario (3 screen orientations) for the smallest cranio-cervical angle.

Table 50 ANOVA Least Squares Means Table (SE) for Enlarge Task, Single Person Scenario, Cranio-cervical Angle

Level	Least Sq Mean	Std Error
Single, Horizontal	119.1	3.6
Single, Self	128.6	3.6
Single, Vertical	129.4	3.6

Table 51 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 51 Least Squares Means Differences Tukey HSD for Enlarge Task, Single Person Scenario, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Vertical	S,Horizontal	10.3	4.4	0.1875
S,Self	S,Horizontal	9.5	4.4	0.2624
S,Vertical	S,Self	0.8	4.4	1.0000

[1] S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference between each comparison for the single person scenario.

4.4.3.2 Collaboration Scenario

Table 52 shows the least square's means and the standard errors for the collaboration scenario (3 screen orientations) for the smallest cranio-cervical angle.

Table 52 ANOVA Least Squares Means Table (SE) for Enlarge Task, Collaboration Scenario, Cranio-cervical Angle

Level	Least Sq Mean	Std Error
Collaboration, Horizontal	118.6	3.6
Collaboration, Self	126.6	3.6
Collaboration, Vertical	132.1	3.6

Table 53 shows the results for the post-hoc Tukey's HSD test used for testing difference between each comparison.

Table 53 Least Squares Means Differences Tukey HSD for Enlarge Task, Collaboration Scenario, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
C,Vertical	C,Horizontal	13.5	4.4	0.0336
C,Self	C,Horizontal	8.0	4.4	0.4600
C,Vertical	C,Self	5.5	4.4	0.8077

[1] C means the Collaboration scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results showed that there was no significant difference between each comparison for the collaboration scenario.

Table 54 showed the results when comparing the single person and the collaboration scenarios together.

Table 54 Least Squares Means Differences Tukey HSD for Enlarge Task, Cranio-cervical Angle [1, 2]

Level	- Level	Difference	Std Err Dif	p-Value
S,Horizontal	C,Horizontal	0.5	4.4	1.0000
C,Vertical	S,Vertical	2.7	4.4	0.9899
S,Self	C,Self	2.1	4.4	0.9971

[1] C means the Collaboration scenario; S means the Single Person scenario.

[2] * indicates there is a significant difference between the two comparisons.

The results in Table 54 showed that there was no significant difference between the single person scenario and the collaboration scenario for each screen orientation.

4.5 Space Planning Needs

4.5.1 Distance to Board

Table 55 showed that the subjects' distances to board varied significantly across the three screen orientations (p-value < 0.0001). Distances to board for the vertical orientation (mean = 47.3 cm) was larger than the self-adjusted orientation (mean = 30.6 cm) and the horizontal orientation (mean = 23.3 cm) was the smallest. The distances to board for the collaboration scenario (mean = 33.3 cm) was not significantly different with the single person scenario (mean = 34.1 cm) with p-value = 0.2664. And there was an orientation by scenario interaction with p-value = 0.0022.

Table 55 Least Squares Means Table (SE) for Distance to Board [1]

Level	Least Sq Mean	Std Error
Vertical [A]	47.3	1.0
Self [B]	30.6	1.0
Horizontal [C]	23.3	1.0

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	33.3	0.9
Single	34.1	0.9

Table 56 shows the least square's means and the standard errors for the six levels (2 scenarios by 3 screen orientations) for the subjects' distances to board. For the vertical orientation, although the results showed the single person scenario was significantly different to the collaboration scenario, the actual difference in distances was not large. For both self-adjusted and horizontal orientation, subjects' distances to board for single person and collaboration scenarios were not significantly different.

Table 56 ANOVA Least Squares Means Table (SE) for Distance to Board [1]

Level	Least Sq Mean	Std Error
Vertical, Single [A]	49.4	1.2
Vertical, Collaboration [B]	45.1	1.2
Self, Single [C]	30.6	1.2
Self, Collaboration [C]	30.6	1.2
Horizontal, Single [D]	22.3	1.2
Horizontal, Collaboration [D]	24.3	1.2

[1] Levels not connected by same letter are significantly different.

4.5.2 Space Length

Figure 4-2 illustrated how the subject interacted with the simulated multi-touch screen during the experiment and how the length of the space was calculated:

$$\text{Length} = \text{Distance to Board} + \text{Board Width} \times \cos \alpha$$

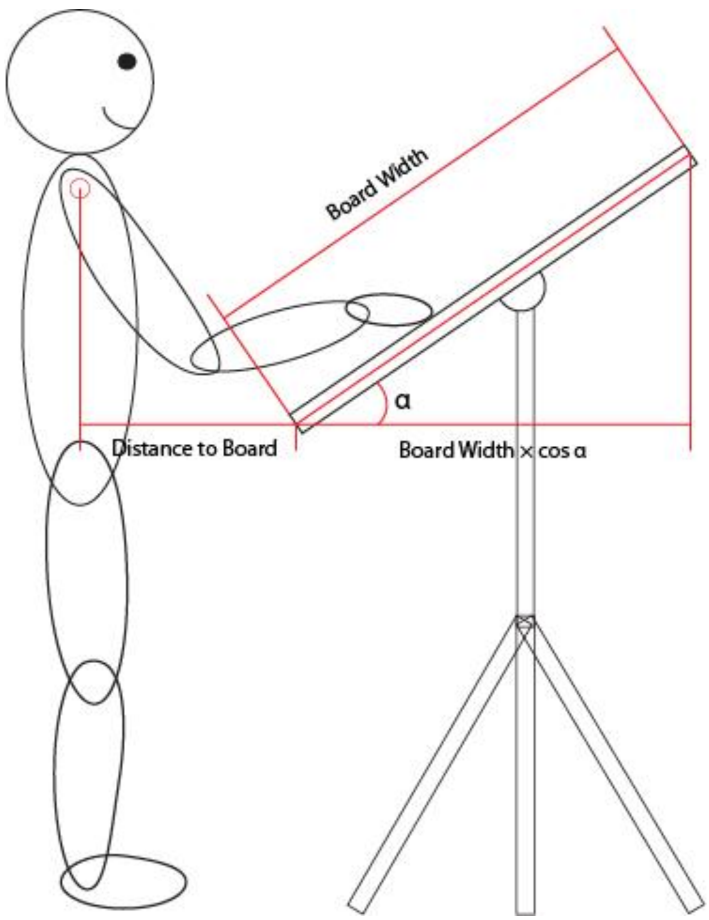

Figure 4- 2 Space Length Calculation

Table 57 showed that the space length varied significantly across the three screen orientations (p-value < 0.0001). Space length for the horizontal orientation (mean = 84.3 cm) was larger than the self-adjusted orientation (mean = 77.0 cm) and the vertical one (mean = 47.3 cm) was the smallest. Space length for the collaboration and single person scenarios were not significantly different with p-value = 0.3649. And there was also an orientation by scenario interaction with p-value = 0.0155.

Table 57 Least Squares Means Table (SE) for Space Length [1]

Level	Least Sq Mean	Std Error
Horizontal [A]	84.3	1.3
Self [B]	77.0	1.3
Vertical [C]	47.3	1.3

[1] Levels not connected by same letter are significantly different.

Level	Least Sq Mean	Std Error
Collaboration	69.1	1.2
Single	69.9	1.2

Table 58 shows the least square's means and the standard errors for the six levels (2 scenarios by 3 screen orientations) for space length. For all three orientations, space length for the single person and the collaboration scenarios were not significantly different.

Table 58 ANOVA Least Squares Means Table (SE) for Space Length [1]

Level	Least Sq Mean	Std Error
Horizontal, Single [A]	83.3	1.5
Horizontal, Collaboration [A]	85.3	1.5
Self, Single [B]	77.1	1.5
Self, Collaboration [B]	77.0	1.5
Vertical, Single [C]	49.4	1.5
Vertical, Collaboration [C]	45.1	1.5

[1] Levels not connected by same letter are significantly different.

CHAPTER 5: DISCUSSION

5.1 Self-Adjusted Environment

Figure 5-1 showed the preferred screen tilted angle distribution. The tilted angles seemed to fall into two groups, as indicated by the two areas surrounded by the red contour. The two purple dashed lines indicate the average angles for the two groups. The first group consists of 9 angles and they range from 19 degrees to 37 degrees with an average of 31.1 degrees. The second group consists of 7 angles and they range from 45 degrees to 55 degrees with an average of 49.7 degrees. The mean of all preferred angles was 39.25 degrees, which did not fall within either of the two groups.

For all participants, the self-adjusted orientation was the last experimental condition so that he/she would get familiar with the vertical and horizontal orientation at first and then chose their preferred angle. The order of the first two screen orientation conditions (the horizontal and the vertical) was counterbalanced for the 16 participants. In order to test if the participants' preferred tilted angle were affected by the last screen orientation condition, a two sample t-test was used to test if there was any difference between participants whose last orientation condition was horizontal before the self-adjusted one and participants whose last orientation condition was vertical before the self-adjusted one. The two sample t-test results showed no significant difference between these two groups of participants with p-value = 0.135. A non- parametric Mann-Whitney U test showed no significant difference, either, with p-value = 0.155.

The reason why the participants' preferred tilted angles showed a tendency of falling into two groups remained unclear. Besides the order of experimental conditions, no significant relevance was found associated with the participants' height and right arm length, either.

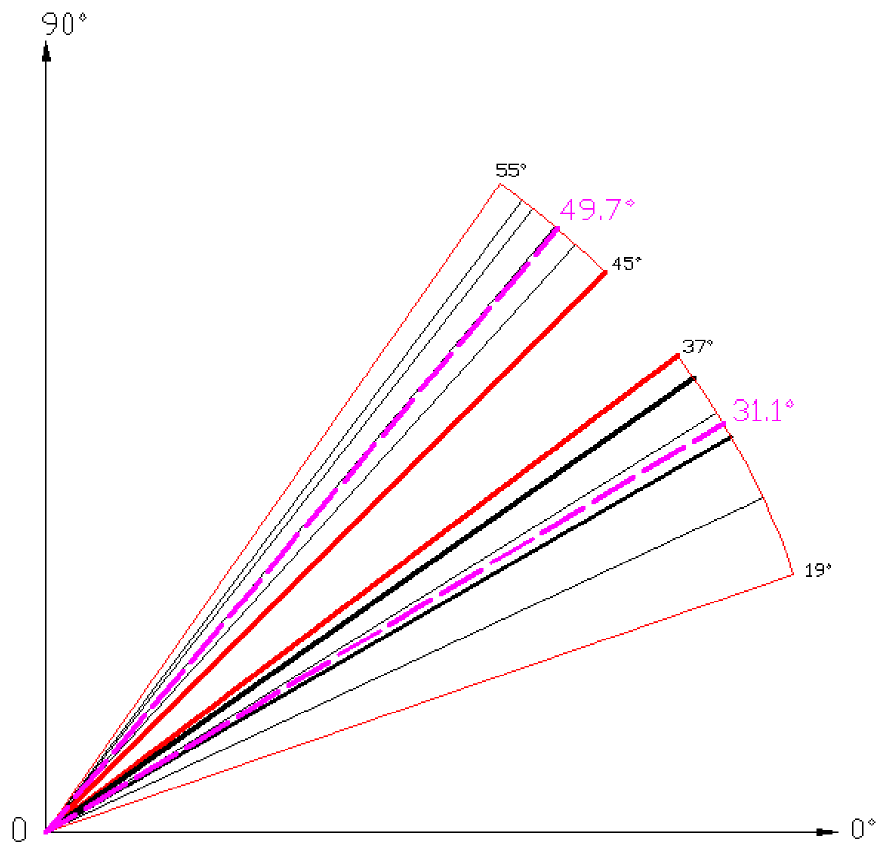

Figure 5- 1 Preferred Angle Distribution [1, 2]

[1] A thicker line indicates two frequencies for the certain tilted angle

[2] The two purple dashed lines indicate the average angles for the two groups

The two mean angles indicated by the two purple dashed lines for the two groups shown in Figure 5-1 might be better representatives for the mean preference of the users. There has been no research carried out in the field concerning preferred angles for large multi-touch boards, thus no reference can be given here. Therefore, two possible tilted angle adjustments were recommended here based on the results in this study: one was around 30 degrees and the other one was around 50 degrees, as suggested by the mean angles for the two groups, respectively. Compared to one fixed tilted angle, a multi-touch screen could be made with two fixed adjustments to provide the users more choices for optimal screen tilted angles. And building a large multi-touch screen with a few fixed adjustments could also be easier and save cost for industry use compared to a continuous adjustment for screen angle.

Future study in this area could consider 30 degrees and 50 degrees as two possible options and more adjustments could be tested in order to find the most suitable adjustment options for multi-touch screen users. And more head, neck and trunk kinematic experiments could be carried out to test the difference between the two recommended angles. If more participants could be recruited and more data collected, a prediction model on user's preference for screen tilted angle might be built; the users' height and arm length could be included in the prediction model.

5.2 Trunk Flexion

For the Perimeter task, in general, the trunk flexion range for the horizontal orientation was significantly higher than the other two orientations, and trunk flexion range for collaboration scenario was significantly higher than the single person scenario. Especially for the horizontal orientation, the trunk flexion range for the collaboration scenario (26.1 deg), which was the highest, was 10.1 degrees higher than the single person scenario. According to previous studies stated before (Keyserling et al, 1992), this could be categorized as mild trunk flexion and trunk flexion at this range with or without external loading could both cause increased risk of back pain and discomfort in the lower extremities, etc (Punnett et al, 1991; Boussenna et al, 1982).

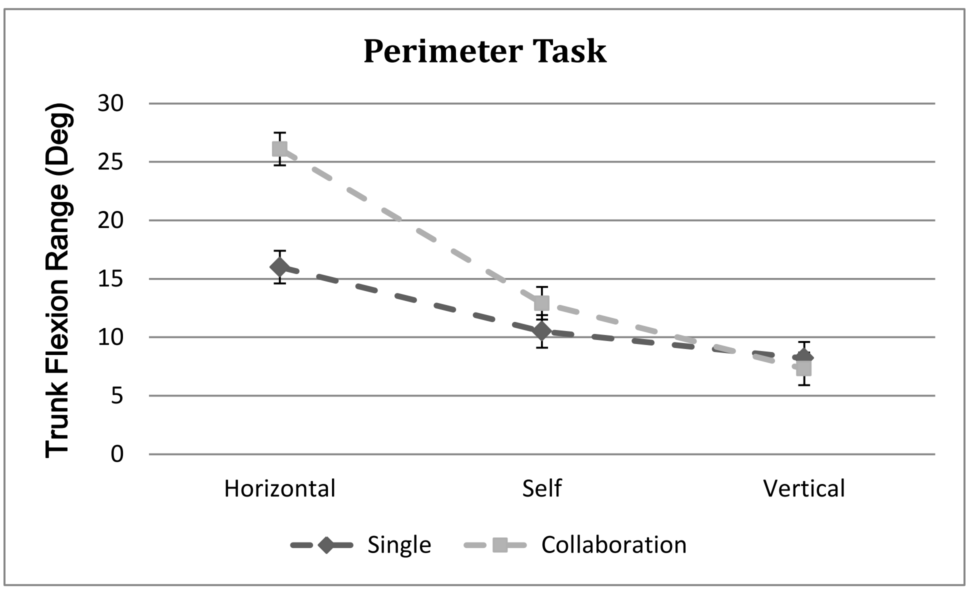

Figure 5- 2 Trunk Flexion Range, Perimeter Task

Results for the Perimeter task suggested the vertical orientation was the best orientation with the least trunk flexion range. The trunk flexion range for the self-adjusted orientation, although still significantly higher than the vertical, was smaller than the horizontal orientation. The impact of a collaborative environment on trunk kinematics was only significant for the horizontal orientation. This result suggests that if a certain task requires collaboration work on a large multi-touch screen and requires the users to maintain a mild trunk flexion posture for a prolonged time, the board should not be mounted horizontally in order to avoid potential risk of discomfort in back and the lower extremities.

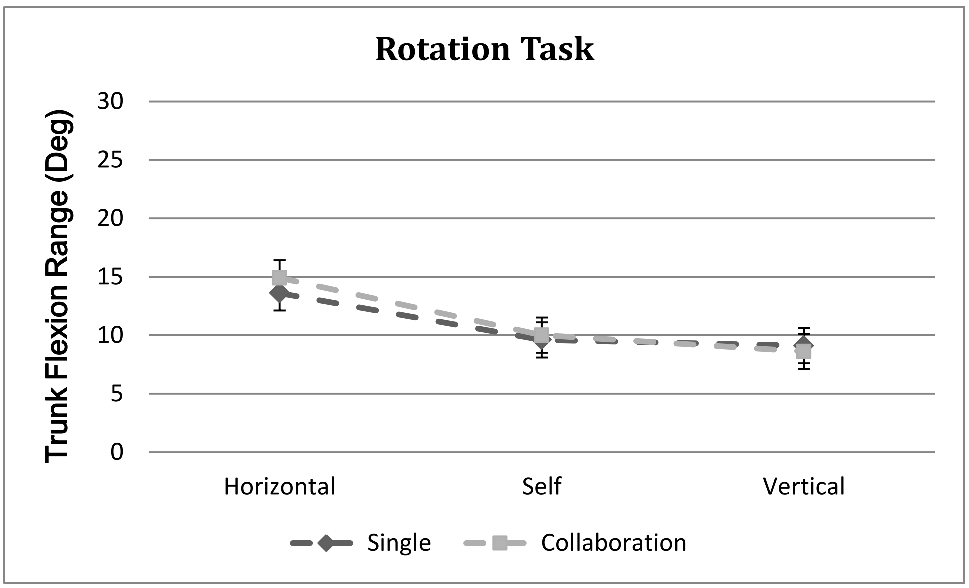

Figure 5- 3 Trunk Flexion Range, Rotation Task

For the Rotation task, the trunk flexion range for the horizontal orientation was also significantly higher than the self-adjusted and the vertical orientation. But the impact of the collaborative environment was not significant. The trunk flexion range for rotation task was smaller than the range for the perimeter task, and this could be due to less range of motion for the rotation task so that the participant's trunk flexion range was smaller than for the previous task.

The trunk flexion range for the Enlarge task revealed a similar pattern as the Perimeter task, with the trunk flexion range for the collaboration scenario in general significantly higher than the single person scenario, and especially for the horizontal orientation (22.9 deg). This range of flexion could also be categorized as mild trunk flexion and could cause back pain in prolonged exposure (Keyserling et al, 1992). The results also suggested that the vertical orientation could be the best for a collaborative working environment, with the horizontal orientation being the worst condition concerning trunk flexion.

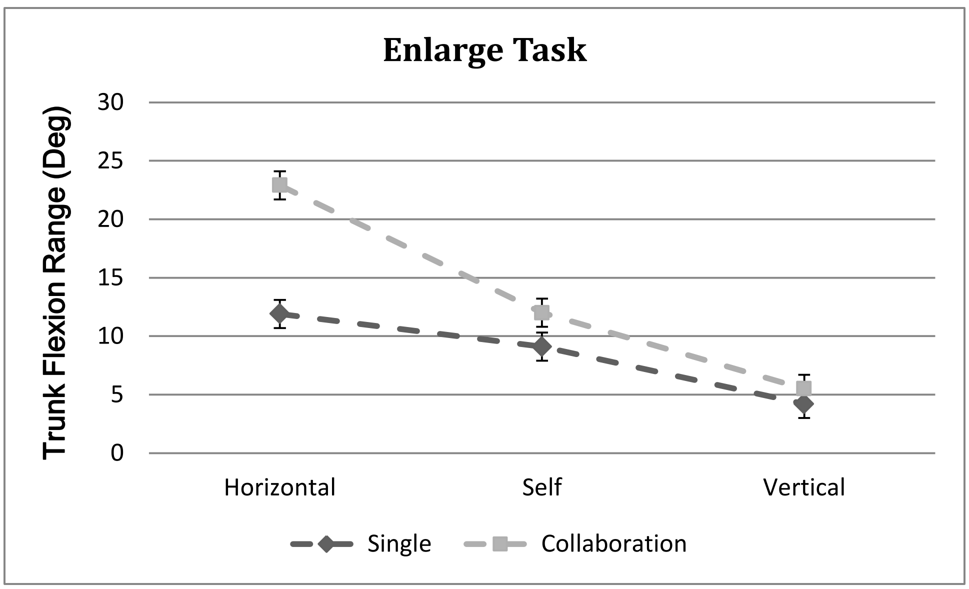

Figure 5- 4 Trunk Flexion Range, Enlarge Task

In all, vertical orientation was the best condition concerning trunk flexion, especially for a collaborative work environment. However, when the vertical orientation was not possible concerning the given space, the self-adjusted orientation could also be considered, since the flexion range for self-adjusted orientation was in general significantly smaller than the worst horizontal orientation and the range was smaller than 20 degrees which was not categorized as mild trunk flexion. Same as the vertical orientation, the trunk flexion range of the self-adjusted orientation for collaboration scenario was not significantly higher than the single person scenario. Meanwhile, the self-adjusted environment could offer more choices for users concerning their personal preference for screen tilted angles, when compared to a fixed vertically mounted multi-touch screen. Therefore, it was suggested that the self-adjusted orientation could be used when vertical orientation was not possible and it could offer more options for the users without much trade-off in trunk flexion range.

5.3 Trunk Axial Rotation

The Perimeter task was the only task for which the trunk flexion range of the single person scenario was significantly higher than the collaboration scenario. This could suggest that one user working alone might require more trunk rotation movement than two users working collaboratively. And this could be due to the standing location of the subjects. For the single person scenario, subjects were standing in the middle facing the screen directly; but for the collaboration scenario, subjects were standing at one side and they were facing the screen with an angle. This standing location could result in reducing the trunk rotation range when they were performing the task. However, for the other two tasks, the axial rotation ranges for the two scenarios were not significantly different. Therefore, more future research in this area should be carried out in order to examine the impact of a collaborative environment on trunk axial rotation movements.

As shown in Figure 5-5, for Perimeter task, the trunk axial rotation ranges for the horizontal and the self-adjusted orientation were not significantly different for both the single person and the collaboration scenario. The trunk axial rotation ranges for the horizontal and self-adjusted orientation of single person scenario were the highest and they reached 18.3 degrees. Although this range did not surpass 20 degrees, it was very close and might also cause back pain under prolonged exposure. The vertical orientation had the smallest axial rotation range in both scenarios. In general, the vertical orientation required the least trunk rotation movements (12.7 deg).

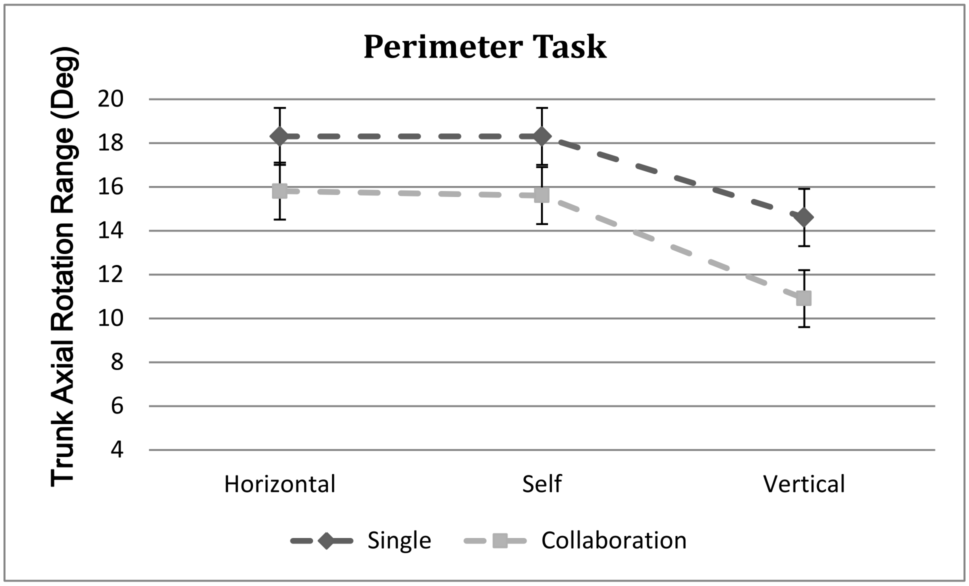

Figure 5- 5 Trunk Axial Rotation Range, Perimeter Task

The trunk axial rotation range for the Rotation task and the Enlarge task revealed a similar pattern. Compared to these two tasks, in general the trunk axial rotation for the perimeter task was the highest, which suggested that the perimeter task covered the largest range of motion and rotation.

Same for Rotation task and Enlarge task as shown in Figure 5-6 and Figure 5-7, the vertical orientation has the smallest trunk axial rotation range. For the Enlarge task, the trunk rotation range for the horizontal orientation also reached 17.3 degrees on average, which though did not surpass the 20 degrees lower bound associated with back pain (Andersson, 1981; Punnett et al, 1991), were very close and could cause serious problems if the subject maintains this posture for a considerable long time.

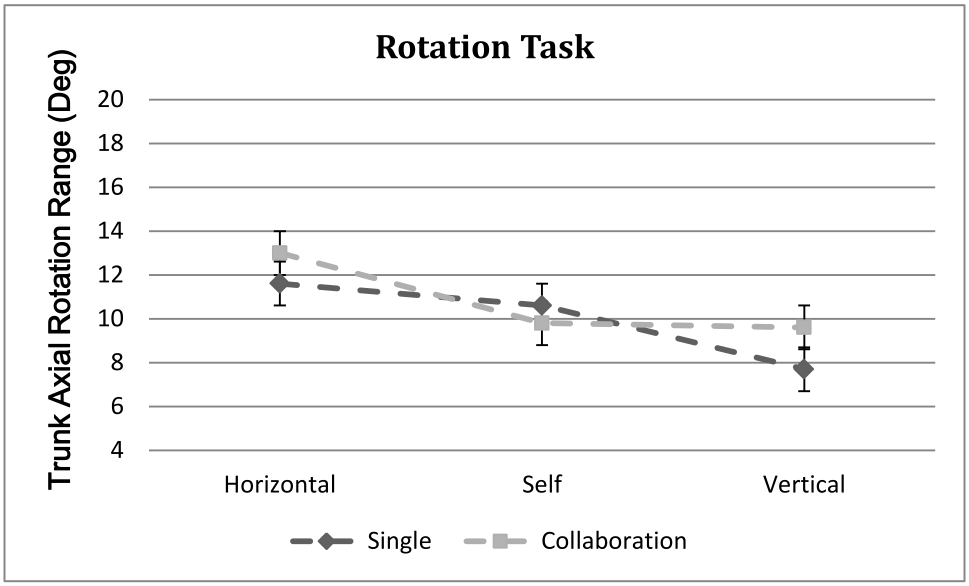

Figure 5- 6 Trunk Axial Rotation Range, Rotation Task

For the Rotation task, the trunk axial rotation range for the self-adjusted orientation, although higher than the vertical orientation, was not significantly different. Therefore, in the future, more tilted angle adjustments could be included in the experiment to test the difference between the self-adjusted and vertical orientation in reducing trunk axial rotation.

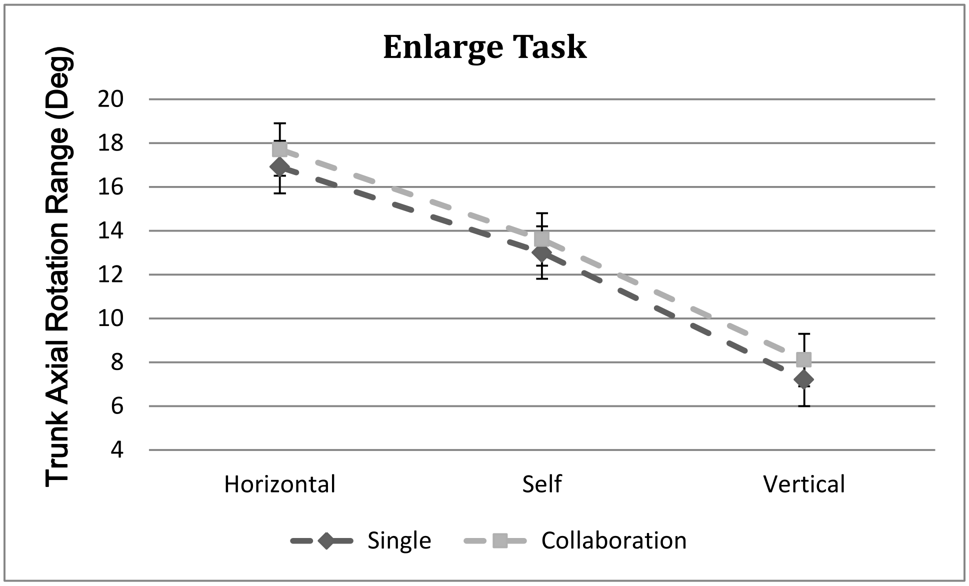

Figure 5- 7 Trunk Axial Rotation Range, Enlarge Task

5.4 Cranio-cervical Angle

Figure 5-8, 5-9, and 5-10 showed the Cranio-cervical angles for the three tasks. For both the Perimeter task and the Rotation task, there was no significant difference across the three screen orientations, neither between the two scenarios of use. And there was no orientation by scenario interaction.

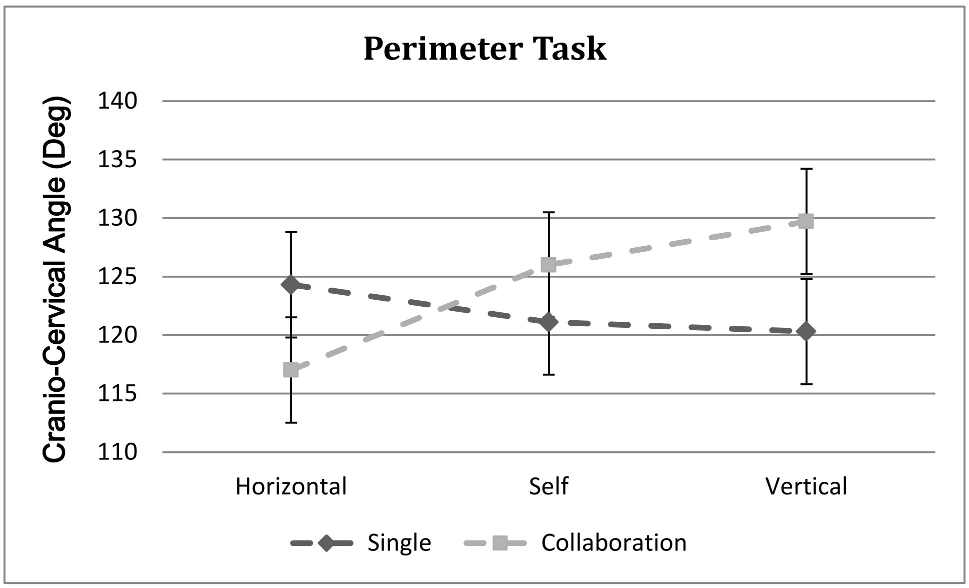

Figure 5- 8 Cranio-cervical Angle, Perimeter Task

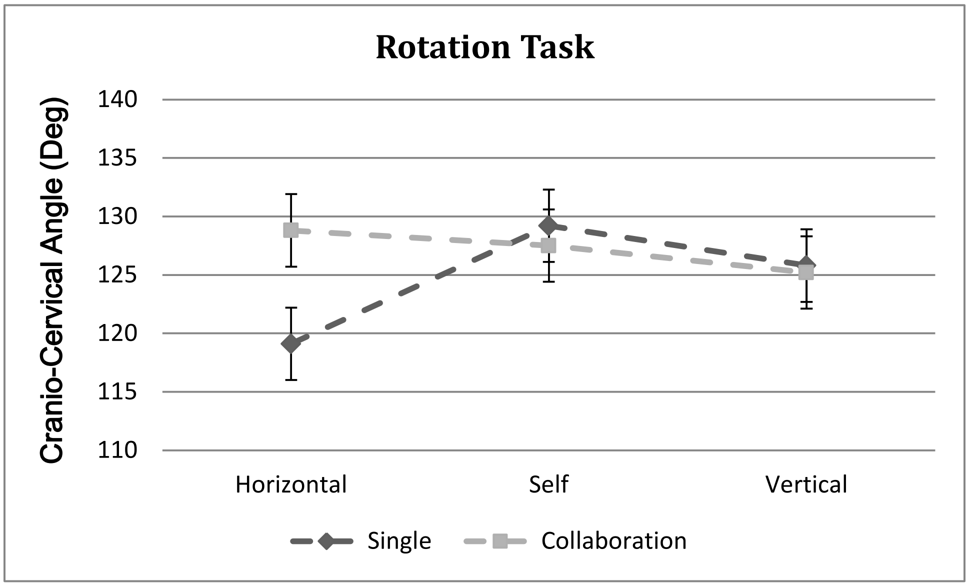

Figure 5- 9 Cranio-cervical Angle, Rotation Task

For the Enlarge task, the cranio-cervical angle for horizontal orientation was significantly smaller than the other two orientations, which indicated a greater head and neck flexion. The mean cranio-cervical angle for the horizontal orientation was 118.9 degrees. In Young et al's research (2012), the cranio-cervical angle for all four conditions were within the 130 degrees to 140 degrees range, and there were no significant difference across the two tablets tested. Compared to this study (Young et al, 2012), the mean 118.9 degrees was at least 10 degrees smaller.

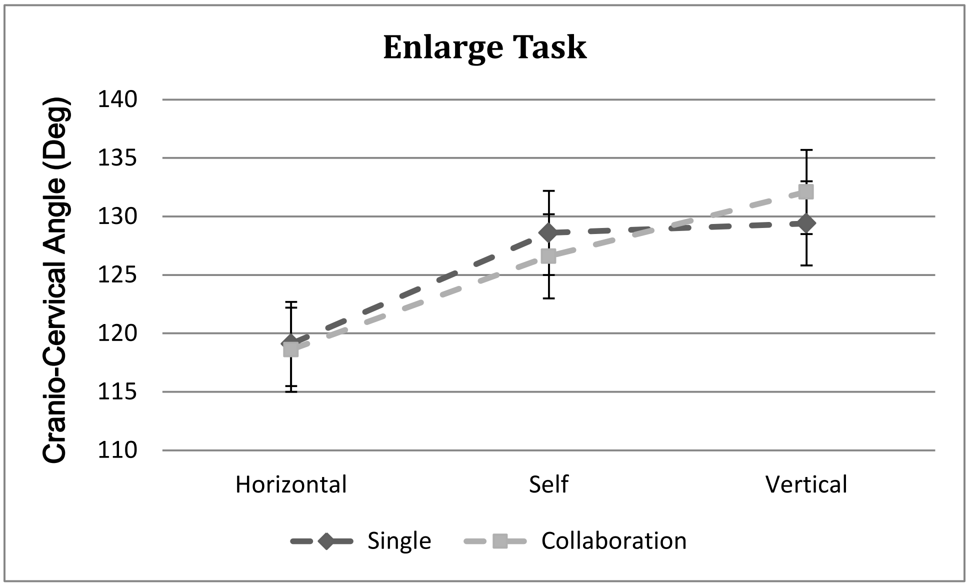

Figure 5- 10 Cranio-cervical Angle, Enlarge Task

The lack of significance in the results could be due to the limitation of the system and the experimental process. The measuring of the cranio-cervical angle was intended to capture the head and neck movement in the sagittal plane. However, in order to obtain the most natural postures during the process, the participants' movements were not controlled. And, since the three tasks required very dynamic interactions with the simulated screen, there could be slight head rotation movements when the participants were performing the tasks. This kind of movements was not captured in the analysis process and could lead to a lack of significance in the results for cranio-cervical angle.

5.5 Tasks

During the experiment, we noticed that the results for the perimeter task, as we expected, covered the largest range compared to the other tasks, indicating that it required the participants to reach full range of motion. Therefore it was suggested to be the most effective task in this study. Although we expected that the Rotation task would generate more trunk axial rotation movements compared to the other two tasks, this task did not act as effective as it was expected to be. When completing the Enlarge task, the participants were observed to perform trunk rotation movements on some level, but might not be able to cover the full possible trunk axial rotation range when interacting with the simulated multi-touch screen. Therefore, in order to examine the trunk rotation movement, the Perimeter task or a re-designed combined task is recommended in potential future studies in the field of trunk kinematics.

For the area of head and neck kinematics, none of the three tasks used in this study showed a very compelling result. This could be partially due to the limitation of the system and also the experimental process. However, the three tasks used in this study could also have limitations. A new task designed specifically for examining head and neck kinematics should be suggested for future research. This task should try to avoid possible head rotation movements.

5.6 Screen Size

The simulated screen used in this study was 36 inch (91cm) by 24 inch (61cm) with a diagonal measurement of relatively 109 cm. In one previous study (Wigdor et al, 2007) where two direct-touch tabletops were tested, the subject preferred the larger table with a diagonal measurement of 107 cm. Grandjean (1988) suggested that for a traditional table top workstation, the table top should be within a certain space with a width of 50 cm, and the grasping distance (from shoulder to hand) was about 55-65 cm and an occasional stretch up to distances of 70-80 cm could be undertaken without detrimental effects. The width of the board used in this study was 61 cm. For a horizontal orientation, this was roughly the suggested range according to Grandjean. However, for the vertical and self-adjusted orientation, no previous studies in the area of screen size can be referred.

The size of the multi-touch screen could affect the users' head, neck and trunk flexion. If a screen is too large, the user might have a much larger trunk flexion range and trunk axial rotation range. But a larger screen could offer the user a better field of view. The screen size could also affect the total space required for using the multi-touch screen system. Therefore, an optimal screen size should reach a balance for all the factors mentioned above. More screen size choices should be tested in future studies and the users' preferred screen size could be a very important parameter for studying space planning needs of using multi-touch screens.

5.7 Space Planning Needs

The results in Figure 5-11 showed that the screen orientation had a main effect on the subjects' distances to board. For the horizontal orientation, subjects tended to stand closer to the screen (23.3 cm) and for the vertical orientation, subjects tended to stand the most further away (47.3 cm). For future research in this area, if more participants could be recruited and more data collected, it could be examined whether there is any linear relationship between the tilted screen angles and the users' preferred distances to board.

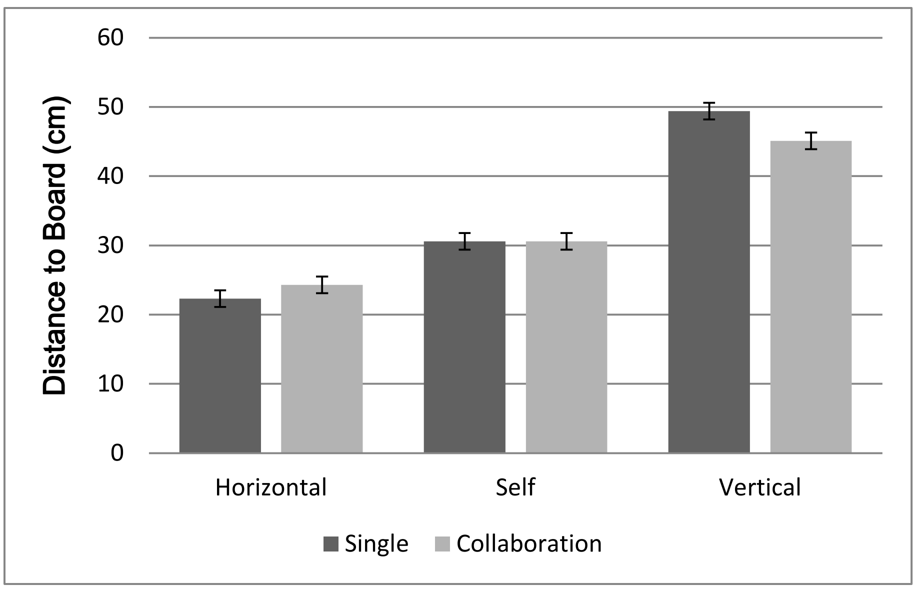

Figure 5- 11 Distance to Board

There was no significant difference for the single person and the collaboration scenario. However, since for the collaboration scenario, a chair was used to simulate the presence of a "co-worker", this could be the reason why there was no significant difference. If the user were to cooperate with a real person, he/she might be interacting with the board differently. Therefore, the impact of a collaborative working environment on the subjects' preferred distances to the board remains unknown.

In this study, the participants were not asked about their preferred total space size for interacting with the simulated multi-touch board. Only the length of the actual space this human-screen system took was calculated. The results in Figure 5-12 showed that the screen orientation had a main effect on the space length defined in this study. As the opposite of the subjects' distances to board, the space length was the smallest for the vertical orientation (47.3 cm), larger for the self-adjusted orientation (77.0 cm), and was the largest for the horizontal orientation (84.3 cm). And there was no significant difference between the single person and the collaboration scenario across all three orientations.

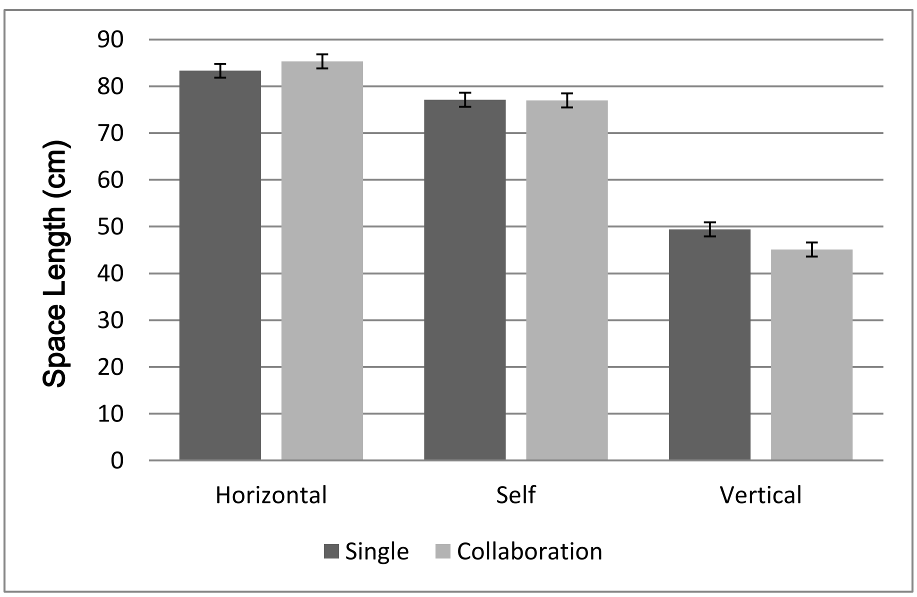

Figure 5- 12 Space Length

These results suggested that for a horizontal orientation, the total space size a user prefers might be the largest since the actual space length defined in this study was the largest for the horizontal orientation. However, the length defined here would not be truly representative of the total space size the user prefers, since the width of the space was not measured in this study. And if a simulated multi-touch screen of a different size were used, the results could be different. Therefore, further research is needed in this area.

In future research, it is suggested that moveable walls could be used to test the users' total space size preference. For example, plastic walls with wheels can be placed around the subjects and the simulated screen they are interacting with. During the experiment, the subjects can adjust the space they need by pushing the moveable walls away or dragging the walls towards themselves. Their preferred total space size then can be measured. One limitation of this moveable wall design is that the walls might block the camera views if a video-based motion capture system is to be used.

5.8 Limitations and Future Research

In this study, the movements of the participants' arms and hands were not measured. Although the results showed the vertical orientation was the best experimental condition regarding head, neck and trunk kinematics, the results could be different if arm movements were included.

There was a lack of significance in the results for the cranio-cervical angles. The measurement of cranio-cervical angels were intended to capture the movement in the sagittal plane, therefore head rotation movements in the transverse plane were not included in the analysis process. However, for the three simulated tasks used in this study, slight head rotation was inevitable, and this could result in a lack of significance in the final results. In order to further examine the head and neck flexion in a dynamic interactive environment, another way of measurement should be suggested to measure movements only in the sagittal plan.

In the future, if more participants could be recruited, a prediction model for users' preferred screen tilted angles could be built. More research in this area is required to validate the current two adjustments suggested based on results in this study.

Due to the limitation of the video-based system used in this study, a chair was used to simulate the two-worker shared working environment. For future studies, a real interactive collaborative environment with two or more workers should be applied to the experiment. The current simulated experimental condition only focused on two-worker interaction and multiple users' conditions should be studied. For specific experimental design, the Perimeter Task, when used in the single person scenario and the simulated collaboration scenario, was shown to be the most effective task which covered the largest range of motion, therefore it is suggested for further studies with two or more real collaborators.

In order to evaluate the users' total preferred space when interacting with a multi-touch screen, plastic movable walls are suggested to be used in future study. And movable walls may also be applied to conditions with multiple users. Under such conditions, three or more workers in the collaborative environment will agree upon the total space they need for fulfilling the task and then push or drag the plastic walls to determine the boundaries of the needed space.

In this study, only the length of space was measured. The width of the space was not measured and this might have resulted in a lack of significance between the single person and the collaboration scenario. More screen sizes should be tested in future research.

A future research in the same experiment settings with a genuine multi-touch screen board is suggested. If similar results are gained, then the way of building a low-fidelity simulated multi-touch screen board as in this study could be recommended for other studies in related areas, since a low-fidelity simulated board is fast and easy to be built and costs less.

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CHAPTER 6: CONCLUSIONS

6.1 Head, Neck and Trunk Kinematics

This study identified some kinematic concerns when interacting with a simulated multi-touch screen. In general, trunk flexion range for horizontal orientation was larger than self-adjusted and vertical orientations. Trunk flexion range for the collaboration scenario was larger than the single person scenario. For horizontal orientation in the collaboration scenario, the mean trunk flexion range exceeded 20 degrees for both Perimeter task and Enlarge task, which could be defined as mild trunk flexion.

Trunk axial rotation range for vertical orientation was smaller than self-adjusted and horizontal orientations. For horizontal orientation, the mean trunk axial rotation range was around 17 degrees for both Perimeter task and Enlarge task. For cranio-cervical angle, only for the Enlarge task, the angle for the horizontal orientation was significantly smaller than the self-adjusted and vertical orientations, which indicated a larger head and neck flexion. No significant difference was found among other conditions for cranio-cervical angle.

Therefore, the vertical orientation was the best orientation in terms of head, neck and trunk kinematics with the smallest trunk flexion range, smallest trunk axial rotation range, and a larger cranio-cervical angle. The horizontal orientation, being the worst condition, is not suggested if the users are required to interact with the multi-touch screen continuously for a considerable long time. For self-adjusted orientation, the trunk flexion range and trunk axial rotation range both remained within an acceptable range. Therefore, when installing a vertical screen is not possible, a self-adjusted multi-touch screen is suggested and it can provide the users more choices for screen tilted angles.

The screen tilted angle results in this study were measured for single person use only. The mean preferred angle was 39.25 degrees. The distribution of the participants' preferred tilted angles fell into two groups. Therefore, instead of a continuous adjustment or one fixed adjustment for screen tilted angle, the two mean tilted angles for the two groups (30 degrees and 50 degrees) were suggested as two possible fixed adjustments for potential design implications.

The present study was the first to measure user's preferred screen tilted angles and it provided two tilted angle adjustments as preliminary guidelines for designing self-adjusted large multi-touch screens. Future studies in this area should continue to examine kinematic concerns specifically for the two suggested angles and more possible adjustments should be tested. Basic standards for designing multi-touch screens could be established based on the kinematic results in this study.

6.2 Space Planning Needs

Basic space planning needs for using a multi-touch screen were identified in this study. Screen orientation was found to have a main effect on the subjects' distances to board as well as the defined length of space in this study. Participants tended to stand most far away for the vertical orientation (47.3 cm). The horizontal orientation requires the largest length of space

(84.3 cm), while the vertical orientation requires the least. No significant difference between the single person and the collaboration scenario was found for both the subjects' distances to board and the defined length of space.

Design guidelines suggested in this study include: when designing a workspace involving use of a vertically mounted multi-touch screen, more space in front of the screen should be reserved compared to a horizontal or a self-adjusted screen; in general, more total space should be reserved for using a horizontally mounted multi-touch screen.

This study provided basic guidelines for designing space when implementing large multi-touch screens in workplaces. It is the first study to look at space needs for using multi-touch screens in a collaborative work environment. Results in the present study could be used to establish primary design standards and they are especially useful for multi-touch screen manufacturers, end users of such devices, as well as workplace designers.

APPENDIX A: EXPERIMENT RAW DATA

ID	Orientation	Treat ment	Task	Trunk Flexion Range (deg)	Trunk Rotation Range (deg)	Smallest Head Angle (deg)	Height (cm)	Right Arm Length (cm)	Distance to Board Edge (deg)	Screen Tilted Angle (deg)
1	Horizontal	S	1	8.6	10.8	139.2	169	78	23	0
1	Horizontal	S	2	7.5	4.8	120.1	169	78	23	0
1	Horizontal	S	3	7.2	7.1	119.0	169	78	23	0
1	Horizontal	C	1	20.2	8.0	134.1	169	78	21	0
1	Horizontal	C	2	13.8	7.3	125.8	169	78	21	0
1	Horizontal	C	3	11.3	6.9	139.8	169	78	21	0
1	Vertical	S	1	4.8	8.2	148.9	169	78	54	90
1	Vertical	S	2	8.0	2.8	139.3	169	78	54	90
1	Vertical	S	3	2.8	4.3	138.1	169	78	54	90
1	Vertical	C	1	6.8	5.5	145.5	169	78	50	90
1	Vertical	C	2	13.8	7.4	138.3	169	78	50	90
1	Vertical	C	3	6.0	4.3	141.9	169	78	50	90
1	Self	S	1	7.8	7.5	134.4	169	78	31	37
1	Self	S	2	7.1	6.7	137.8	169	78	31	37
1	Self	S	3	4.7	5.1	140.2	169	78	31	37
1	Self	C	1	6.5	5.1	139.2	169	78	34	37
1	Self	C	2	16.5	5.8	140.4	169	78	34	37
1	Self	C	3	8.3	5.0	132.0	169	78	34	37
2	Horizontal	S	1	30.7	9.0	116.5	156	63	16	0
2	Horizontal	S	2	20.9	8.9	113.0	156	63	16	0
2	Horizontal	S	3	11.3	16.7	114.4	156	63	16	0
2	Horizontal	C	1	35.6	9.8	102.9	156	63	18	0
2	Horizontal	C	2	15.1	14.1	127.7	156	63	18	0
2	Horizontal	C	3	34.4	17.3	49.1	156	63	18	0
2	Vertical	S	1	8.1	10.6	69.5	156	63	49	90
2	Vertical	S	2	5.0	5.3	134.6	156	63	49	90
2	Vertical	S	3	5.2	8.5	132.5	156	63	49	90
2	Vertical	C	1	4.3	7.4	128.3	156	63	38	90
2	Vertical	C	2	2.9	11.2	123.6	156	63	38	90
2	Vertical	C	3	3.1	5.0	127.2	156	63	38	90
2	Self	S	1	8.0	18.0	119.7	156	63	25	52

2	Self	S	2	4.1	3.4	132.1	156	63	25	52
2	Self	S	3	4.6	10.5	132.4	156	63	25	52
2	Self	C	1	14.0	10.3	126.2	156	63	24	52
2	Self	C	2	11.5	10.0	128.1	156	63	24	52
2	Self	C	3	9.5	7.5	133.0	156	63	24	52
3	Horizontal	S	1	26.4	18.1	139.1	164	72	19	0
3	Horizontal	S	2	16.5	6.0	93.7	164	72	19	0
3	Horizontal	S	3	17.1	20.1	126.3	164	72	19	0
3	Horizontal	C	1	28.8	16.2	138.9	164	72	23	0
3	Horizontal	C	2	17.0	13.1	135.2	164	72	23	0
3	Horizontal	C	3	30.5	15.7	129.1	164	72	23	0
3	Vertical	S	1	11.9	11.7	106.1	164	72	43	90
3	Vertical	S	2	6.8	5.0	128.0	164	72	43	90
3	Vertical	S	3	5.0	6.4	136.3	164	72	43	90
3	Vertical	C	1	7.0	12.7	150.5	164	72	38	90
3	Vertical	C	2	9.4	13.8	129.7	164	72	38	90
3	Vertical	C	3	6.8	8.4	127.7	164	72	38	90
3	Self	S	1	10.1	17.0	149.0	164	72	27	45
3	Self	S	2	13.8	11.8	131.0	164	72	27	45
3	Self	S	3	8.0	13.7	122.3	164	72	27	45
3	Self	C	1	7.5	17.4	148.2	164	72	26	45
3	Self	C	2	6.0	9.1	137.7	164	72	26	45
3	Self	C	3	10.1	12.7	135.9	164	72	26	45
4	Horizontal	S	1	13.9	11.3	102.8	165	73	25	0
4	Horizontal	S	2	11.4	8.5	125.6	165	73	25	0
4	Horizontal	S	3	6.3	8.9	128.1	165	73	25	0
4	Horizontal	C	1	25.4	16.3	78.9	165	73	21	0
4	Horizontal	C	2	7.8	8.6	123.3	165	73	21	0
4	Horizontal	C	3	16.4	10.9	109.0	165	73	21	0
4	Vertical	S	1	6.0	10.7	134.6	165	73	48	90
4	Vertical	S	2	6.1	6.3	132.7	165	73	48	90
4	Vertical	S	3	5.5	3.6	126.1	165	73	48	90
4	Vertical	C	1	5.3	12.2	130.9	165	73	43	90
4	Vertical	C	2	9.1	7.7	128.5	165	73	43	90
4	Vertical	C	3	4.4	5.3	136.1	165	73	43	90
4	Self	S	1	9.2	15.6	135.3	165	73	34	45
4	Self	S	2	3.9	10.1	132.0	165	73	34	45
4	Self	S	3	8.7	7.3	131.2	165	73	34	45

4	Self	C	1	6.9	11.4	118.8	165	73	29	45
4	Self	C	2	7.1	6.6	132.7	165	73	29	45
4	Self	C	3	8.3	8.3	130.6	165	73	29	45
5	Horizontal	S	1	12.8	12.8	138.7	171	74	22	0
5	Horizontal	S	2	21.3	11.2	97.4	171	74	22	0
5	Horizontal	S	3	15.4	9.9	127.2	171	74	22	0
5	Horizontal	C	1	27.5	24.5	93.3	171	74	20	0
5	Horizontal	C	2	30.5	19.8	114.6	171	74	20	0
5	Horizontal	C	3	23.9	20.5	128.1	171	74	20	0
5	Vertical	S	1	9.5	12.0	133.7	171	74	50	90
5	Vertical	S	2	16.8	4.6	130.7	171	74	50	90
5	Vertical	S	3	3.0	2.1	133.7	171	74	50	90
5	Vertical	C	1	11.2	7.7	140.4	171	74	44	90
5	Vertical	C	2	16.3	11.4	120.9	171	74	44	90
5	Vertical	C	3	4.2	4.7	124.6	171	74	44	90
5	Self	S	1	15.5	17.1	136.4	171	74	23	30
5	Self	S	2	14.8	14.4	135.0	171	74	23	30
5	Self	S	3	12.6	12.6	132.4	171	74	23	30
5	Self	C	1	18.0	13.7	103.0	171	74	20	30
5	Self	C	2	19.4	7.9	113.3	171	74	20	30
5	Self	C	3	10.3	12.7	93.1	171	74	20	30
6	Horizontal	S	1	9.5	16.4	131.6	163	70.5	17	0
6	Horizontal	S	2	9.0	11.0	127.1	163	70.5	17	0
6	Horizontal	S	3	13.4	13.4	115.9	163	70.5	17	0
6	Horizontal	C	1	24.7	14.0	123.7	163	70.5	26	0
6	Horizontal	C	2	7.6	7.9	132.3	163	70.5	26	0
6	Horizontal	C	3	21.1	13.3	125.7	163	70.5	26	0
6	Vertical	S	1	4.8	11.8	114.1	163	70.5	44	90
6	Vertical	S	2	6.1	3.3	128.8	163	70.5	44	90
6	Vertical	S	3	2.3	4.6	125.2	163	70.5	44	90
6	Vertical	C	1	4.1	7.1	124.5	163	70.5	46	90
6	Vertical	C	2	5.2	4.6	125.7	163	70.5	46	90
6	Vertical	C	3	4.2	4.0	132.6	163	70.5	46	90
6	Self	S	1	8.1	18.1	127.9	163	70.5	28	37
6	Self	S	2	9.3	8.4	131.3	163	70.5	28	37
6	Self	S	3	13.2	9.5	127.2	163	70.5	28	37
6	Self	C	1	15.1	14.5	128.7	163	70.5	36	37
6	Self	C	2	6.6	6.8	134.3	163	70.5	36	37

6	Self	C	3	13.3	12.9	124.7	163	70.5	36	37
7	Horizontal	S	1	19.9	22.7	130.5	168	70.5	19	0
7	Horizontal	S	2	15.2	8.4	124.1	168	70.5	19	0
7	Horizontal	S	3	20.5	13.3	132.5	168	70.5	19	0
7	Horizontal	C	1	26.3	13.3	115.3	168	70.5	27	0
7	Horizontal	C	2	11.9	11.5	129.2	168	70.5	27	0
7	Horizontal	C	3	28.1	17.1	123.5	168	70.5	27	0
7	Vertical	S	1	17.6	11.8	133.2	168	70.5	42	90
7	Vertical	S	2	6.8	10.3	125.5	168	70.5	42	90
7	Vertical	S	3	9.3	8.2	131.5	168	70.5	42	90
7	Vertical	C	1	7.7	8.8	129.8	168	70.5	43	90
7	Vertical	C	2	5.5	6.4	127.7	168	70.5	43	90
7	Vertical	C	3	8.4	12.7	134.8	168	70.5	43	90
7	Self	S	1	16.3	15.4	135.0	168	70.5	28	35
7	Self	S	2	9.6	5.4	123.0	168	70.5	28	35
7	Self	S	3	13.4	12.2	121.5	168	70.5	28	35
7	Self	C	1	13.1	14.4	134.1	168	70.5	30	35
7	Self	C	2	6.6	12.5	110.1	168	70.5	30	35
7	Self	C	3	22.0	10.9	128.7	168	70.5	30	35
8	Horizontal	S	1	17.8	20.2	123.3	168	71	18	0
8	Horizontal	S	2	10.3	9.9	134.6	168	71	18	0
8	Horizontal	S	3	13.7	15.0	119.7	168	71	18	0
8	Horizontal	C	1	29.3	15.9	109.9	168	71	23	0
8	Horizontal	C	2	10.8	13.3	136.3	168	71	23	0
8	Horizontal	C	3	22.8	17.9	131.5	168	71	23	0
8	Vertical	S	1	9.4	15.6	103.2	168	71	50	90
8	Vertical	S	2	9.3	6.3	125.8	168	71	50	90
8	Vertical	S	3	3.6	4.6	141.9	168	71	50	90
8	Vertical	C	1	10.5	11.4	84.9	168	71	51	90
8	Vertical	C	2	6.8	5.4	73.2	168	71	51	90
8	Vertical	C	3	7.9	7.0	139.7	168	71	51	90
8	Self	S	1	12.7	20.1	95.5	168	71	37	55
8	Self	S	2	4.5	9.2	139.6	168	71	37	55
8	Self	S	3	8.0	10.1	134.7	168	71	37	55
8	Self	C	1	12.1	13.3	133.2	168	71	37	55
8	Self	C	2	5.7	10.3	127.6	168	71	37	55
8	Self	C	3	15.4	13.9	139.6	168	71	37	55
9	Horizontal	S	1	15.5	20.9	135.8	170	70	31	0

9	Horizontal	S	2	9.1	12.1	127.3	170	70	31	0
9	Horizontal	S	3	8.3	25.6	126.2	170	70	31	0
9	Horizontal	C	1	26.3	19.0	128.0	170	70	29	0
9	Horizontal	C	2	10.0	8.8	115.9	170	70	29	0
9	Horizontal	C	3	19.7	25.4	123.8	170	70	29	0
9	Vertical	S	1	10.7	14.9	117.6	170	70	54	90
9	Vertical	S	2	6.7	9.3	133.9	170	70	54	90
9	Vertical	S	3	2.3	11.5	138.2	170	70	54	90
9	Vertical	C	1	5.8	12.4	135.5	170	70	49	90
9	Vertical	C	2	7.7	14.5	131.4	170	70	49	90
9	Vertical	C	3	2.9	7.6	123.7	170	70	49	90
9	Self	S	1	7.8	15.9	124.1	170	70	32	32
9	Self	S	2	7.3	11.6	132.8	170	70	32	32
9	Self	S	3	13.5	20.2	128.5	170	70	32	32
9	Self	C	1	12.1	18.9	121.7	170	70	32	32
9	Self	C	2	4.4	9.3	128.5	170	70	32	32
9	Self	C	3	6.6	16.7	124.5	170	70	32	32
10	Horizontal	S	1	9.6	15.9	73.3	178	77	18	0
10	Horizontal	S	2	6.8	11.8	107.8	178	77	18	0
10	Horizontal	S	3	10.0	11.9	93.4	178	77	18	0
10	Horizontal	C	1	14.6	12.9	111.3	178	77	22	0
10	Horizontal	C	2	14.2	11.7	130.1	178	77	22	0
10	Horizontal	C	3	15.7	14.3	119.4	178	77	22	0
10	Vertical	S	1	5.9	16.9	127.6	178	77	53	90
10	Vertical	S	2	12.7	23.6	123.8	178	77	53	90
10	Vertical	S	3	3.2	9.3	130.6	178	77	53	90
10	Vertical	C	1	4.8	12.1	125.2	178	77	48	90
10	Vertical	C	2	3.8	8.7	133.8	178	77	48	90
10	Vertical	C	3	4.9	12.8	129.6	178	77	48	90
10	Self	S	1	8.4	13.6	112.2	178	77	25	19
10	Self	S	2	7.8	9.3	99.2	178	77	25	19
10	Self	S	3	6.6	13.8	122.3	178	77	25	19
10	Self	C	1	10.0	25.5	118.7	178	77	30	19
10	Self	C	2	8.7	9.8	112.8	178	77	30	19
10	Self	C	3	7.0	17.6	99.7	178	77	30	19
11	Horizontal	S	1	16.1	24.8	129.0	173	72.5	26	0
11	Horizontal	S	2	23.1	18.4	130.0	173	72.5	26	0
11	Horizontal	S	3	15.6	21.3	119.9	173	72.5	26	0

11	Horizontal	C	1	27.6	17.8	129.4	173	72.5	30	0
11	Horizontal	C	2	23.2	14.0	131.3	173	72.5	30	0
11	Horizontal	C	3	32.5	14.8	126.7	173	72.5	30	0
11	Vertical	S	1	7.7	21.8	120.1	173	72.5	59	90
11	Vertical	S	2	12.7	5.4	119.0	173	72.5	59	90
11	Vertical	S	3	5.7	9.1	135.1	173	72.5	59	90
11	Vertical	C	1	10.4	13.8	135.0	173	72.5	57	90
11	Vertical	C	2	22.3	15.4	127.8	173	72.5	57	90
11	Vertical	C	3	4.8	14.4	133.1	173	72.5	57	90
11	Self	S	1	12.7	17.1	114.5	173	72.5	36	35
11	Self	S	2	21.7	11.7	113.7	173	72.5	36	35
11	Self	S	3	9.3	11.2	127.4	173	72.5	36	35
11	Self	C	1	20.4	18.3	102.8	173	72.5	40	35
11	Self	C	2	26.7	14.9	124.1	173	72.5	40	35
11	Self	C	3	23.6	19.6	128.9	173	72.5	40	35
12	Horizontal	S	1	27.8	18.7	111.7	175	74	29	0
12	Horizontal	S	2	26.2	10.9	110.2	175	74	29	0
12	Horizontal	S	3	10.0	15.0	76.5	175	74	29	0
12	Horizontal	C	1	39.9	15.5	113.0	175	74	32	0
12	Horizontal	C	2	24.1	11.1	134.3	175	74	32	0
12	Horizontal	C	3	22.6	21.4	93.0	175	74	32	0
12	Vertical	S	1	4.1	13.0	96.2	175	74	51	90
12	Vertical	S	2	5.7	4.7	67.6	175	74	51	90
12	Vertical	S	3	2.9	5.7	67.8	175	74	51	90
12	Vertical	C	1	4.3	12.5	107.3	175	74	45	90
12	Vertical	C	2	8.5	10.5	125.3	175	74	45	90
12	Vertical	C	3	6.2	9.5	129.6	175	74	45	90
12	Self	S	1	16.3	17.7	118.1	175	74	31	30
12	Self	S	2	17.9	8.0	128.8	175	74	31	30
12	Self	S	3	6.7	11.7	124.9	175	74	31	30
12	Self	C	1	19.9	15.3	108.9	175	74	32	30
12	Self	C	2	10.0	7.7	124.3	175	74	32	30
12	Self	C	3	11.0	10.0	126.3	175	74	32	30
13	Horizontal	S	1	9.3	18.2	134.5	173	75	21	0
13	Horizontal	S	2	10.3	15.7	114.0	173	75	21	0
13	Horizontal	S	3	6.1	14.0	128.2	173	75	21	0
13	Horizontal	C	1	13.4	12.7	134.0	173	75	22	0
13	Horizontal	C	2	7.5	12.3	125.1	173	75	22	0

13	Horizontal	C	3	10.7	11.7	117.4	173	75	22	0
13	Vertical	S	1	6.0	12.5	121.6	173	75	49	90
13	Vertical	S	2	10.5	9.4	124.3	173	75	49	90
13	Vertical	S	3	2.8	5.5	127.7	173	75	49	90
13	Vertical	C	1	9.4	13.7	132.8	173	75	43	90
13	Vertical	C	2	4.1	5.4	129.9	173	75	43	90
13	Vertical	C	3	4.8	8.8	140.1	173	75	43	90
13	Self	S	1	6.8	16.1	133.3	173	75	30	50
13	Self	S	2	3.3	13.3	133.4	173	75	30	50
13	Self	S	3	8.1	14.9	130.9	173	75	30	50
13	Self	C	1	4.3	14.1	131.0	173	75	26	50
13	Self	C	2	4.0	8.5	131.3	173	75	26	50
13	Self	C	3	7.2	15.1	138.2	173	75	26	50
14	Horizontal	S	1	9.3	33.4	134.9	168	70	22	0
14	Horizontal	S	2	10.4	20.5	115.5	168	70	22	0
14	Horizontal	S	3	12.1	31.2	123.5	168	70	22	0
14	Horizontal	C	1	22.9	23.6	124.4	168	70	20	0
14	Horizontal	C	2	10.5	19.1	130.4	168	70	20	0
14	Horizontal	C	3	19.5	34.0	122.9	168	70	20	0
14	Vertical	S	1	6.3	29.0	134.8	168	70	47	90
14	Vertical	S	2	12.2	10.8	125.3	168	70	47	90
14	Vertical	S	3	4.3	12.0	130.4	168	70	47	90
14	Vertical	C	1	7.3	19.7	134.5	168	70	40	90
14	Vertical	C	2	3.6	10.6	126.2	168	70	40	90
14	Vertical	C	3	4.5	10.6	128.3	168	70	40	90
14	Self	S	1	6.3	32.9	129.2	168	70	29	53
14	Self	S	2	9.1	17.8	130.2	168	70	29	53
14	Self	S	3	4.8	19.9	126.0	168	70	29	53
14	Self	C	1	8.7	25.8	133.9	168	70	31	53
14	Self	C	2	4.0	15.3	123.0	168	70	31	53
14	Self	C	3	9.9	23.5	128.4	168	70	31	53
15	Horizontal	S	1	17.0	24.6	132.9	171	69	24	0
15	Horizontal	S	2	11.8	16.5	143.4	171	69	24	0
15	Horizontal	S	3	16.8	24.5	137.8	171	69	24	0
15	Horizontal	C	1	31.3	21.5	117.6	171	69	29	0
15	Horizontal	C	2	26.2	21.0	145.2	171	69	29	0
15	Horizontal	C	3	35.8	22.6	145.1	171	69	29	0
15	Vertical	S	1	10.3	16.3	149.1	171	69	45	90

15	Vertical	S	2	14.0	12.0	147.5	171	69	45	90
15	Vertical	S	3	6.3	10.5	149.3	171	69	45	90
15	Vertical	C	1	15.4	11.3	150.3	171	69	45	90
15	Vertical	C	2	13.1	12.0	137.9	171	69	45	90
15	Vertical	C	3	9.3	6.8	141.9	171	69	45	90
15	Self	S	1	13.3	26.9	46.6	171	69	33	25
15	Self	S	2	9.2	18.5	140.5	171	69	33	25
15	Self	S	3	16.8	21.9	134.6	171	69	33	25
15	Self	C	1	32.4	19.5	145.2	171	69	32	25
15	Self	C	2	16.5	13.1	148.4	171	69	32	25
15	Self	C	3	25.4	17.3	143.3	171	69	32	25
16	Horizontal	S	1	11.1	15.3	115.7	178	71	27	0
16	Horizontal	S	2	7.3	11.2	122.1	178	71	27	0
16	Horizontal	S	3	6.5	21.7	117.1	178	71	27	0
16	Horizontal	C	1	23.2	12.3	116.7	178	71	25	0
16	Horizontal	C	2	7.6	13.8	124.8	178	71	25	0
16	Horizontal	C	3	21.5	19.8	113.6	178	71	25	0
16	Vertical	S	1	8.2	17.0	115.3	178	71	52	90
16	Vertical	S	2	5.8	3.7	126.0	178	71	52	90
16	Vertical	S	3	2.7	8.7	126.2	178	71	52	90
16	Vertical	C	1	2.9	6.0	120.0	178	71	42	90
16	Vertical	C	2	5.6	9.3	122.7	178	71	42	90
16	Vertical	C	3	5.0	8.2	122.7	178	71	42	90
16	Self	S	1	8.0	22.8	125.8	178	71	41	48
16	Self	S	2	10.3	10.2	126.5	178	71	41	48
16	Self	S	3	6.1	13.6	121.7	178	71	41	48
16	Self	C	1	5.7	12.0	120.9	178	71	30	48
16	Self	C	2	6.8	8.8	123.4	178	71	30	48
16	Self	C	3	4.8	14.4	118.3	178	71	30	48

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