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Collaborative View Configurations for Multi-user Interaction with a Wall-size Display

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Abstract

This paper explores the effects of different collaborative view configuration on face-to-face collaboration using a wall-size display and the relationship between view configuration and multi-user interaction. Three different view configurations (shared view, split screen, and split screen with navigation information) for multi-user collaboration with a wall-size display were introduced and evaluated in a user study. From the experiment results, several insights for designing a virtual environment with a wall-size display were discussed. The shared view configuration does not disturb collaboration despite control conflict and can provide an effective collaboration. The split screen view configuration can provide independent collaboration while it can take users' attention. The navigation information can reduce the interaction required for the navigational task while an overall interaction performance may not increase.

CCS Concepts

•***Human-centered computing*** → *Collaborative interaction; User interface design; Computer supported cooperative work;*

1. Introduction

This paper explores view configurations for face-to-face collaboration on visualization tasks with wall sized displays and evaluates them. Traditionally, visualization systems are designed for a single user on a desktop computer and collaborative visualization (or multi-user visualization) systems have extended the traditional concept of visualization in order to support multiple users but Collaborative visualization also incorporates research from other fields such as distributed computing, human-computer interaction, and computer-supported cooperative work [IES*11] to support multi-user collaboration. While collaborative visualization benefits from work in these disciplines, there are many challenge that are unique to the intersection of collaborative work and visualization. These include human-centered interactive visualization, fatigue for multi-user interaction, and coordinating user input in collaborative visualization systems among others.

There are many ways to categorize collaborative visualization, however, the space-time matrix is often broadly used [Bae93]. This classifies collaborative systems according to space (distributed or co-located) and time (synchronous or asynchronous). Our research is focused on co-located synchronous collaboration. In this case, several people standing in front of, and interacting with, visualization on a large wall sized display at the same time.

Research on co-located collaborative visualization with a wall-size display has been conducted to support seamless, effective and natural multi-user interaction [SFB*87] [SGH*99] [JFW02] [IBR*03] [PST04] [WJF*09]. Researchers have mostly employed a shared view that enables users to access the whole space on the screen together. Several studies [TSB*07] [LHS*14] evaluated their interfaces by comparing a shared view and a split screen. McGill et al. discussed [MWB14] the advantages and disadvantages of a shared view and a split screen view configuration for multi-user interaction. McGill et al. [MWB15] also evaluated view configuration for multiple users, but they did not provide equitable control interfaces in these setups.

Overall, there have not been many study on how different view configurations influence multi-user interaction. This is important because wall-size displays are increasingly using a number of different view configurations. Therefore, there is an opportunity to evaluate view configurations for multi-user visualization with a wall-size display in order to investigate the effect of view configurations and the relationship between view configurations and multi-user interaction.

In addressing this topic, our research has the following aims:

- To learn how multiple users interact with a wall-size display depending on the view configurations.
- To investigate the difference between a shared view and a split screen view configuration in terms of usability workload, and ability to collaborate.

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- To investigate if additional information such as navigation information can affect multi-user interaction.

In the remainder of this paper, first, we review the related work including other similar approach on view configurations for multi-user interaction. Then, the designed and implemented view configurations for collaborating on a wall-size display are explained in detail. Next, the experimental conditions and procedure are described to evaluate the interaction performance, usability, and preference of the view configurations. Finally, the experimental results are discussed and conclusions are presented.

2. Related Work

Our research is based on earlier work in the areas of face to face collaboration, table-top displays, comparison of multiple display setups and wall-size displays. In this section, we review key related work from each of these areas, and show how our research extends this earlier work.

The responsive workbench was one of the earliest visualization systems for co-located collaboration around a large horizontal surface [KBF*95]. It provided a Virtual Reality(VR) environment that displayed shared 3D scenes via shutter glasses to people standing around the table. Vernier et al. [VLS02] developed a multi-user round interactive table-top display based on radial tree layouts and two different fisheye interfaces to support multi-user collaborative works. The system facilitated user interaction for relocation, reorientation, scaling and layout on a circular table. UbiTable developed by Shen et al. [SER03] provided spontaneous, walk-up-and-use functionality to share data, such as photos and notes.

Tse et al. [TSB*07] explored how three different display setups could be used in a single collaborative system. In this case, a multi-modal independent display, shared display, and True groupware display (remote display) on a table-top interface. They offered a generalized approach for each setup. The independent display setup provides separable interaction, the shared display supports rich awareness for each user, and the True groupware display allows remote users to work in parallel on a large screen.

Recently, Permulin integrated a set of interaction and visualization techniques for multiple users using a table-top display and a shutter display to support co-located collaboration [LHS*14]. This system provided not only private views but also a shared view, and additional gesture interaction allowed users to independently control each view. They evaluated the prototype system by comparing it to a conventional table-top setup and a split screen configuration. From the evaluation, they found that the Permulin setup enables users to unobtrusively share information and to support private work. However, the system is basically a multi-view system, which may not be optimal for collaboration with a large-scale display in terms of sharing information.

Compared to the table top display for collaboration, several wall-display systems have also been developed. The Collab system was one of the first to provide a collaborative environment for people to work together face-to-face or remotely on multiple desktops and a large display wall [SFB*87]. Dynamo supported the ability to transfer users' media to a wall-size shared display [IBR*03]. Digital furniture and interaction techniques were designed to support spontaneous collaboration using the InteractTable, Dyna Wall, and CommChairs interfaces [SGH*99] [PST04]. Using these systems users could interconnect laptops and furniture components to construct ad hoc collaborative spaces. The iRoom was designed to provide a seamless interactive environment [JFW02]. WeSpace was a collaborative workspace that integrated a large data wall with a multi-user multi-touch table for small groups for data exploration and visualization [WJF*09]. In their studies and development, they employed a single shared view and the research mainly focused on the development of user interfaces and interaction between interfaces and users or between interfaces.

Rogers and Lindley made several observations from user studies comparing vertical and horizontal interactive displays in a city tour planning task [RL04]. Users with the table display were more encouraged to switch roles, explore ideas and follow closely what each user was doing. In contrast, users found that a wall display is socially awkward for collaboration. Tan et al. [TGC05] showed that large displays can improve productivity in spatial tasks, and Ball and North [BN05] showed the potential performance benefits of large displays in low-level navigation and visualization tasks. Hou et al. [HNPL12] found that the larger displays were suitable for increasing immersion. They discovered that large displays increase the sense of self-presence more than smaller displays and a user sacrifices many benefits of larger displays to indulge in using a personal device. They suggested that if possible the shared utilization of the screen would be preferable than the use of personal devices.

There are several studies for view configurations with a wall-size display.

The proxemic approach was suggested by Ballendat et al. [BMG10]. The interaction technique was demonstrated with dynamic visualization on a shared view using proxemic information, location, and user view directions. The system varied the view configurations such as the shared view and the multi-screen based on multiple users' behavior.

Wallace et al. [WSS*09] presented a user study to investigate differences between single display and multi-display configuration as well as between interface configurations. They used the Job Shop Scheduling task [TGC05] and three difference interface-access schemes (shared, negotiated (manual switch), and fixed access) to evaluate the two display configuration (single display configuration and multi-display configuration). They showed that the multi-display configuration provides advantages for performing individual tasks, while the single display configuration offers advantages in coordinating access to shared resource. In single display configuration, the shared access scheme showed the best task completion time, task efficiency, and low error rate compared to manual and fixed access schemes. However, the result of the task optimality with the shared access scheme was lower than the other schemes.

McGill et al. compared a multi-view display with a shared view display and two individual displays [MWB15]. To assess the advantages of a multi-view display, they conducted a user study with a loosely coupled task (independently searching for entertainment and deciding on one movie). They found that the multi-view display was preferable to the shared view display. They also revealed that there was different awareness between multiple displays and the multi-view display because the multi-view display requires additional interaction to view partner activities. However, in the user study, a single controller was given to the users in the shared view condition and an individual controller was given for multiple displays and a multi-view display, which is an unfair comparison to evaluate each view configuration in terms of a control interface. These different control interfaces may affect the results.

Although researchers have developed special purpose interaction components to mitigate the spatial interference in a shared single display, the fact that the interference was not high in a shared single display was found [THSG04]. Tse et al. studied how co-located people partitioned their collaborative drawing activities within a shared single display environment [THSG04]. The result of the experiment revealed that people tend to avoid interfering with their partners by spatially separating their actions in the workspace.

In summary, there have been many applications and interaction techniques on co-located collaborative display interfaces to support seamless, effective and natural multi-user interaction. They mostly employed a shared view that enables users to access the whole space on the screen together or a multi-view that provided independent views. Also, many researchers developed novel display interfaces and evaluated their interfaces by comparing a shared view. However, there has been only brief discussion on the advantages and disadvantages of a shared view and a split screen view configurations.

In this paper, we designed and built the three different view configurations to explore the effect of view configurations and the relationship between view configurations and multi-user interaction. Novelty of this paper is that we compare between three view configurations in terms of the relationship between view configurations and multi-user interaction.

3. Collaborative View Configurations

In this section, we explain the three collaborative view configurations of a wall-size immersive display that were designed and implemented for the experiment. The first, two view configurations are widely used in multi-user interaction with a wall-size display; a shared view and a split screen. The third setup includes navigation information in addition to the split screen.

3.1. Shared View

A shared view is commonly used for a shared large-scale display either composed of a single display or multiple displays. In this configuration, users share the same view and interact with the visualized information at the same time. The advantages of a shared view are that whole display can be used for visualization and interaction and that it increases the collaborative experience. On the other hand, one of the disadvantages of the shared view is a control conflict between users. Because the users can access the environment at the same time, users can interfere others' interaction. Therefore, several control interfaces or strategies have been developed to reduce the control conflict such as negotiated access (requiring an additional action such as 'click' to hand over control) and fixed access (a system assigns control to each user automatically) [GG98] [WSS*09].

3.2. Split Screen

A split screen configuration is another common configuration for a shared wall-size display where the screen space is split into multiple view regions dedicated to each user. This provides an independent view and separate control to each user which increases the user's interaction freedom. However, this setup does not guarantee private views like in a multi-view display and users can also lose their focus on their own view when they look at other user's screens. As this configuration splits the whole screen, the size for each user is reduced. Finally, due to the independent views, it can be hard for each user to recognize the locations and viewing direction of the other users in VR exploration or manipulation tasks.

3.3. Split Screen with Additional Navigation Information

The third setup is a split screen with additional information. This overcomes a disadvantage of the split screen by adding additional information such as navigation information(NI) in order to provide a common reference frame for the location of users. The NI can provide additional information on the location of users in relationship to each other and facilitate shared exploration and manipulation.

One of the main problems of a split screen with a shared display is that it is hard for users to know where they are in the displayed virtual environment and how to reach a certain place. For example, in a pilot study, the participants used a shared view and a split screen for the manipulation tasks in the experiment. The participants had a problem with finding their location and the route to reach a certain location. For instance, when the participants needed to rotate -30 degrees to complete the task, they rotated 330 degrees in opposite direction because they did not know the direction to the shortcut. Complementing the split view on this problem, NI could help to find locations of users and a faster route, even if it occupies additional screen space.

4. Experiment

The aim of this study was to design, develop and evaluate collaborative view configurations on a wall-size display for multi-user interaction. With a wall-size display, we investigated how view configurations facilitate or impede multi-user interaction. To investigate the effects of view configurations, the control interfaces were restricted and not used for personal visualization.

In order to accomplish these aims, we designed and implemented three different view configurations mentioned in the previous section. This experimental system has the capability to allow two users to interact with the systems using individual tablet computers. We used a wall-size projection based immersive visualization display (2.8m by 1.8m) (see Figure 1). A set of markers attached to stereo glasses is tracked by the ART tracking camera system [ART] to obtain position and rotation of two participants. For 3D stereoscopic visualization, we employed passive circular polarization filters on the projectors and on the glasses.

For the experiment, a tablet computer was provided to each user for manipulating 3D virtual objects in the virtual environment. The tablet computers were only used as touch input devices and did not

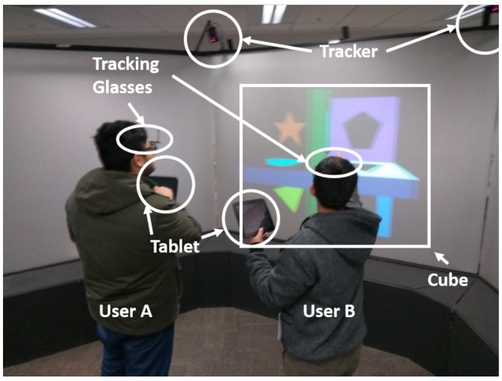


Figure 1: *Experimental Setup.*

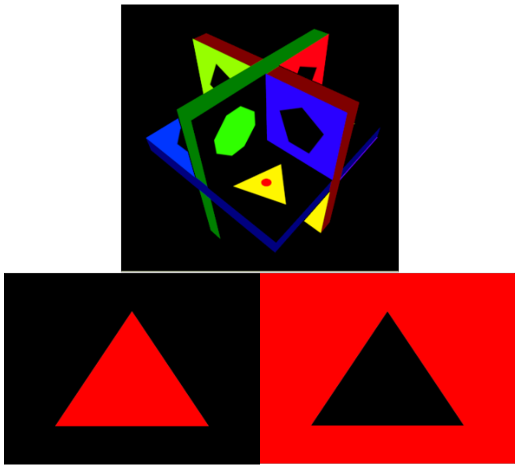


Figure 2: *An example of a 3D object for the experiment (top), red triangle shape (bottom left) and black triangle shape with red background (bottom right) as matching shapes*

display any visualization or graphic user interface to take attention from the large screen. Using a tablet computer screen as an additional personal display was excluded for the purpose of this study to make fair comparison between view configurations. The tablet interface provided users with two different modes (manipulation and cursor mode) and four touch gestures (double tap, swiping, pinching in/out, and tap-and-hold). The manipulation mode and cursor mode can be switched between using the double tap gesture. In the manipulation mode, the participants can rotate the 3D object on the screen with a swiping gesture, and zoom in/out with a pinching in/out gesture. In the cursor mode, each participant could select a shape on the 3D object using their cursors. The participants could also move their own cursors with the swiping gesture and select an object with tap-and-hold gesture.

At the beginning of each condition, the two participants were asked to stand at marked locations on the floor, at each center of the split screen (See Figure 1). When the experiment started, a large 3D object comprised of 24 images was displayed on the large screen. Each surface of the object contained 4 images and each edge of the object was reentrant to minimize the number of images that the participants could view at once (See Figure 2). This encouraged the participants to manipulate the object more. Each image was a color-filled shape or black-colored shape with a colored background. For the tasks in the experiment, the participants were asked to find the matching shapes, as shown in Figure 2.

4.1. Experimental Conditions

The experiment compared the following three conditions:

1. Shared view (SV): A comparative baseline for typical multi-user interaction with a shared large-scale display and tablet computers as control interfaces provided to each user.
2. Split screen (SS): The screen space split into half and allocated to each user to view and interact with the system independently. The same control interfaces are provided as in the baseline condition
3. Split screen with navigation information and two control interfaces (SSNI): The same as the split screen configuration, except a small portion of the screen is allocated for showing navigation information which provides the location of each user's point of view. The same control interfaces are provided as in the baseline condition.

In the shared view condition, both participants could move their cursors over the entire screen in the cursor mode. In the manipulation mode, the participants could have a conflict to rotate or to zoom in/out the object. To avoid this, they needed to coordinate with their partner to manipulate the object or needed to make their strategies. For example, only one participant rotates the object. In the split screen condition, each user had an independent workspace. At all times the participants could manipulate the object shown on their view and independently move their own cursors. In the cursor mode, their cursors could not cross over to the partner's workspace. The split screen with navigation information condition provided navigation information in addition to the split screen condition. The NI was displayed at the bottom of the screen. Users could use the NI for finding a faster route or advising the route or the location for their partner. Figure 3 shows the differences between each condition.

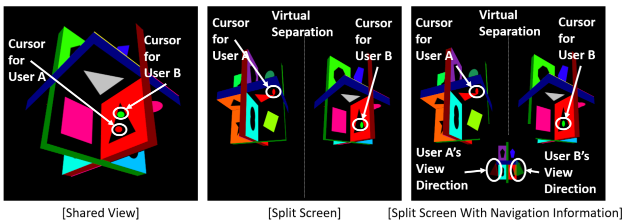


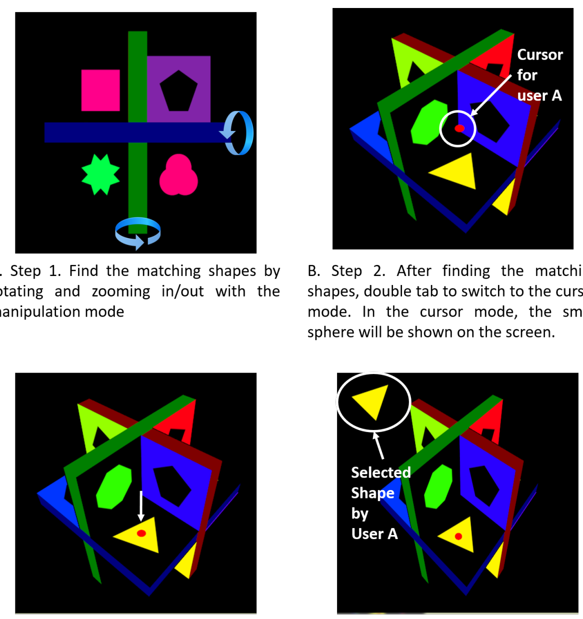
Figure 3: *Three display conditions employed in the experiment*

4.2. Experimental Procedure

A single task in the experiment was similar to a block matching game. If one participant selected the color-filled shape, his/her partner needed to select the same shape in black with the background in the same color as the matching shapes. For example, if one participant selected the red triangle shape, his/her partner needed to select the black triangle shape with a red background (see Figure 2).

The experiment consisted of two parts; manipulation for finding matching shapes and selection of matching shapes. With the SS and SSNI conditions, participants could manipulate the 3D object and select the matching shape individually. With the SV condition, the participants could manipulate the 3D object together and each participant had to individually select the matching shapes. This was to prevent only one participant finishing the whole task.

The detailed procedure for each single task is shown in Figure 4. When the experiment started, the large screen displayed a large 3D object in one of the view configurations (SV, SS or SSNI). The participants were asked to find the matching shapes in the 3D object by rotating it and zooming in/out using the manipulation mode (Step 1 in Figure 4). After identifying the matching shapes, the participants were asked to use the double tap gesture to change the mode from the manipulation mode to the cursor mode (Step 2 in Figure 4). In the cursor mode, a small colored sphere was shown as a cursor. Each user could switch to the cursor mode independently and participants had their cursor in a different color. User A, who stood at the left side of the screen, had the red cursor and User B, who stood at the right side of the screen, had the green cursor. After changing to the cursor mode, the participant had to place his/her cursor on a shape with the swiping gesture (Step 3 in Figure 4). In step 4, the participants were asked to select the shape by using a tap gesture. As shown in step 4 in Figure 4, the selected shape was displayed on the top left (for User A) or the top right (for User B) corner of the screen.



A. Step 1. Find the matching shapes by rotating and zooming in/out with the manipulation mode

B. Step 2. After finding the matching shapes, double tab to switch to the cursor mode. In the cursor mode, the small sphere will be shown on the screen.

C. Step 3. Place the sphere cursor on the shape by swiping gesture in the cursor mode.

D. Step 4. Hold tab on the image and the selected shape will be display on the left or right top.

Figure 4: *The detailed procedure of a single task*

In the shared view condition, participants could follow the steps simultaneously or take turns one by one depending on the location of the matching shapes. For example, if the matching shapes were shown in the view at the same time, the participants could move their cursors and select the matching shapes at the same time. If not, one participant needed to select the shape and then another participant could select the matching shape to complete the task after rotating the object. In the SS and the SSNI condition, the participants could perform the task procedure independently.

The participants were asked to find as many matching shapes as possible within 5 minutes in each condition. Note that the procedure and the task goal for all three conditions were basically the same, and the difference between the shared view condition and the split screen conditions was independency between participants. With the shared view, the participants could select matching shapes either together or sequentially. With the split screen, participants could independently find and select the matching shapes.

The study recruited 42 participants (21 pairs, 22 males and 20 females) aged 21 to 38 years old (Mean (M) = 26.67, Standard Deviation (SD) = 4.97). 57% of the participants had experienced large-scale virtual environments such as CAVE-like systems.

4.3. Experimental Measures

To investigate the effects of the view configurations on users' abilities to effectively collaborate, the study collected the average task completion time per task (*tct*), and touch distance that participants used to interact with mobile tablets via touch gestures (swiping and pinching in/out). The study also measured the workload for each view configuration using the NASA-TLX survey [HS88] and usability using the System Usability Scale (SUS) [B*96]. After completing all conditions, participants were asked to rank the three conditions based on their preference and to write comments about their experiences.

A repeated measures ANOVA ($\alpha = 0.05$) was employed using SPSS for analyzing the effect of different view configurations on *tct*, touch distance, NASA-TLX, and SUS. A non-parametric Friedman test was applied in order to analyze preference with α level of 0.05. Post-hoc tests using Wilcoxon signed-rank tests with the Bonferroni correction ($\alpha = 0.017$) were applied.

5. Results

5.1. Interaction Performance

Figure 5 shows the average task completion time per task *(tct)* and average touch distance for the three experimental conditions. A repeated measures ANOVA test with a Greenhouse-Geisser correction showed that there was a significant difference between conditions ($F(1.983, 39.662) = 12.099$, $p < 0.001$). Post hoc tests using the Bonferroni correction revealed that collaboration with the SV condition was faster than other conditions, which was statistically significantly different from SS ($p = 0.001$) and SSNI ($p = 0.002$).

There was significant difference between view configurations ($F(1.346, 26.921) = 13.577$, $p < 0.001$) in touch distance. A post hoc test showed that the SV condition required significantly less touch gesture interaction compared to the SS condition ($p < 0.001$) and the SSNI condition ($p = 0.042$). In addition, navigation information reduced the touch distance from 1998.6 pixels to 1562.9 pixels, which was significantly different from the SS condition ($p = 0.049$).

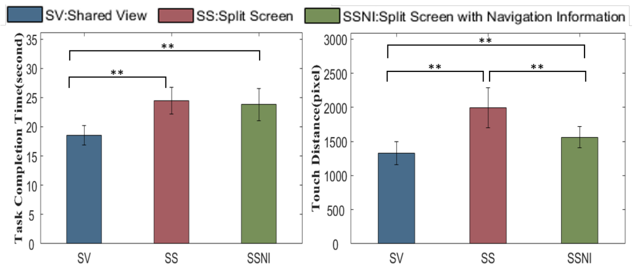


Figure 5: *The results of the tct and touch distance.(Bar represents SD)*

5.2. System Usability Scale & NASA-TLX

Figure 6 illustrates the experimental results of SUS score and average NASA-TLX score and for the three conditions. The results of SUS and overall NASA-TLX were very similar. A repeated measures ANOVA found no significant difference between the conditions (SUS: $F(1.944, 38.883) = 0.071$, $p = 0.927$ and NASA-TLX: $F(1.553, 31.055) = 1.026$, $p = 0.353$).

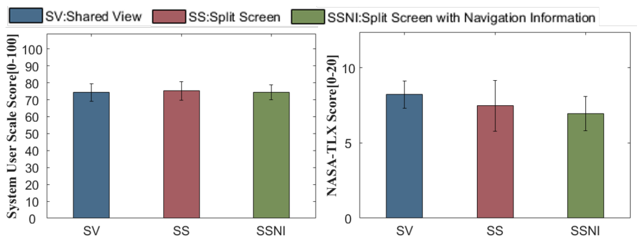


Figure 6: *Average SUS (left) and overall NASA-TLX scores (right). (Bar represents SD)*

Figure 7 illustrates the experimental results of subscales of NASA-TLX and average overall score for the three conditions, respectively. A repeated measures ANOVA test showed that the results of mental demand (MD) and frustration (FR) did differ significantly between the conditions (MD: $F(1.893, 37.850) = 4.013$, $p = 0.028$, FR: $F(1.384, 27.688) = 3.785$, $p = 0.049$). A post hoc test revealed that splitting a screen significantly reduced MD ($p = 0.049$) and navigation information did not have a significant effect on MD, although it increased slightly ($p = 0.596$). According to the post hoc tests, neither split screen ($p = 0.445$, between the SV and SS conditions) nor adding navigation information ($p = 0.717$, between the SS condition and the SSNI condition) significantly affected on users' the frustration. When both split screen and navigation were applied together, it reduced frustration ($p < 0.001$).

5.3. User Preference

Figure 8 shows the average user preference response for three view configurations. A Friedman test revealed that there was a significant

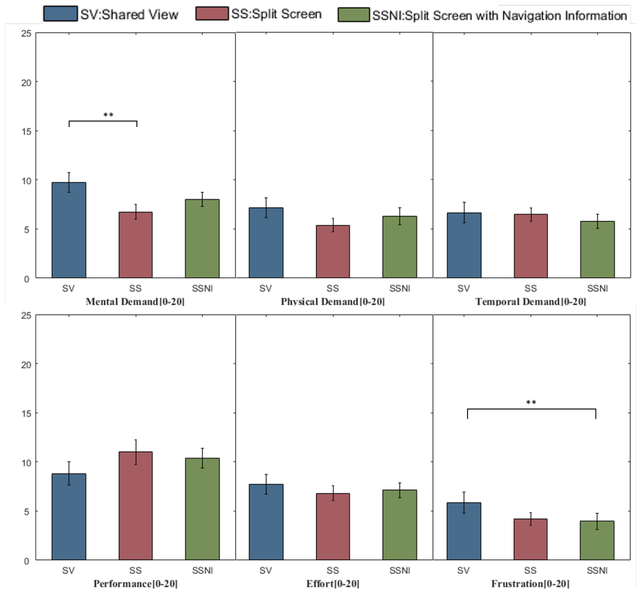


Figure 7: *The results of the NASA-TLX subscales.(Bar represents SD)*

difference between view configurations ($X^2 = 16.419$, $p = 0.001$). The post-hoc analysis with the Wilcoxon Signed-rank tests (Bonferroni correction applied) found that the result for the SSNI condition differed significantly from both the SV ($Z = -2.856$, $p = 0.004$) and SS ($Z = -2.408$, $p = 0.016$) conditions while the result of the SS condition was not significantly different from the SV condition ($Z = -1.471$, $p = 0.141$).

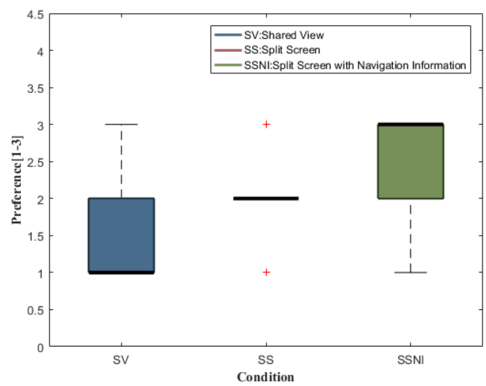


Figure 8: *Average preference scores for all conditions (High score means more preferred).*

6. Discussion

The results of the preference showed that participants felt that the SSNI condition was preferable over the SV and SS conditions. Most participants voted the SV condition as the worst view configuration because of the physical bottleneck of sharing the control. The two main reasons for the preference result were independency and performance, which we hypothesized. However, the performance with the split screen setup(either with the navigation information or not) was not superior to that with the SV condition. When the number of completed tasks were revealed to the participants after the experiment, most participants were surprised and they thought that they would have completed more tasks with the SS condition. The results imply that the split screen view configuration could increase the users' confidence level although further investigation would be needed.

The results of the task performance revealed that the shared view could increase performance in collaboration. The interaction with the shared view provided the best performance compared to the other view configurations. The users had less misunderstanding such as wrong pointing (Confused with which screen the partner mentioned) because the participants could search matching shapes and discuss it while looking at the same view. Therefore, they were able to finish the tasks faster.

On the other hand, interaction in the SS and SSNI conditions took more time than in the SV condition. We observed that the participants spent more time looking at their partner's view to search and match the shapes. If more information was available that helped to solve the problem, such as the partner's view and the navigation information, the participants tried to use it. The participants did not use a simple "peeking" action that the previous works discussed [MWB15], rather it was more of "reading" or "understanding" actions in collaboration as they stopped rotating the 3D object and tried to match their partner's shapes and their own shapes. The participants also occasionally missed the matching shapes on their own individual views due to the reading action. While the participants were more confident with more information, but they spent more time using the information. Although the participants also spent more time to see all of the views in the SSNI condition, but the navigation information help reducing the *tct*.

From the touch distance results, we found NI reduced the amount of input required for navigation since it provided information about faster routes. From the participants' feedback, the NI was helpful in some cases, although not always when the matching shapes were shown in the view at the same time. The results of *tct* and touch distance implied that the navigation information could reduce amount of efforts required to navigate using touch interaction. However, the SSNI condition did not provide the best performance because the participant's attention was split between multiple views and they needed more time to understand the information.

The result of the SUS score showed that the view configurations did not affect the usability. The average SUS score of the conditions is greater than 70, which is a C grade in the rage of a "good" usability score. In previous research [MWB15], a shared view had an F grade, which is a "poor" score. The SUS scores in this study were similar between SV and SS conditions while the result was different from the previous study [MWB15]. As the task in this study is very similar to that of the previous study, it might not have affected the usability score. Providing controllers to each individual user could have contributed to this improved result compared to previous study where the participants needed to share one controller. We postulate that providing each user with his own individual input device appears to be increasing usability even though they could not interact with the system at the same time.

The participants had higher mental demand and more frustration when they collaborated using the shared view according to the NASA-TLX subscale results. The participants felt less frustration in the SSNI condition compared to the other view configurations. From the result, both the split screen and navigation information reduced frustration while each single component did not reduce the frustration level. However, the overall aggregated NASA-TLX result showed that the mental demand and the frustration did not have a significant effect on the overall workload.

From these results, there are several design considerations that can be made on collaborative view configurations for a wall-size display:

- The split screen setup increases independency although users may lose attention and spend more time with it.
- The shared view setup can provide more effective interaction and collaboration while it has control conflict.
- Navigation information can increase users' confidence level.
- The split screen setup together with navigation information can reduce frustration level.
- Collaborative view configurations may not have a big impact on usability and workload.

7. Conclusion and Future work

In this paper, three different collaborative view configurations for wall-size immersive displays were introduced and evaluated. From the experiment results, several considerations for designing a virtual environment with a shared wall-size display were suggested. The experimental results showed that the shared view configuration does not critically disturb collaboration. Rather, it can provide an efficient environment for collaboration. The split screen configuration can provide independent collaboration while it can take cost in attention and require more time to collaborate. Divided attention in the split screen may also lead into misunderstandings such as wrong pointing. The navigation information can reduce the amount of interaction required for navigational task, but an overall performance increase may not be guaranteed.

Further experiments need to be carried out in the future to explore the effect on collaboration with the higher number of users. The workspace for each user will be reduced in the split screen configuration and users would lose attention more. Also, there would be more control conflict in the shared view configuration. The higher number of users may be different from the reported results.

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