Quantitative Comparison of Interaction with Shutter Glasses and Autostereoscopic Displays

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ABSTRACT

In this paper we describe experimental measurements and comparison of human interaction with three different types of stereo computer displays. We compare traditional shutter glasses-based viewing with three-dimensional (3D) autostereoscopic viewing on displays such as the Sharp LL-151-3D display and StereoGraphics SG 202 display. The method of interaction is a sphere-shaped "cyberprop" containing an Ascension Flock-of-Birds tracker that allows a user to manipulate objects by imparting the motion of the sphere to the virtual object. The tracking data is processed with OpenGL to manipulate objects in virtual 3D space, from which we synthesize two or more images as seen by virtual cameras observing them. We concentrate on the quantitative measurement and analysis of human performance for interactive object selection and manipulation tasks using standardized and scalable configurations of 3D block objects. The experiments use a series of progressively more complex block configurations that are rendered in stereo on various 3D displays. In general, performing the tasks using shutter glasses required less time as compared to using the autostereoscopic displays. While both male and female subjects performed almost equally fast with shutter glasses, male subjects performed better with the LL-151-3D display, while female subjects performed better with the SG202 display. Interestingly, users generally had a slightly higher efficiency in completing a task set using the two autostereoscopic displays as compared to the shutter glasses, although the differences for all users among the displays was relatively small. There was a preference for shutter glasses compared to autostereoscopic displays in the ease of performing tasks, and glasses were slightly preferred for overall image quality and stereo image quality. However, there was little difference in display preference in physical comfort and overall preference. We present some possible explanations of these results and point out the importance of the autostereoscopic "sweet spot" in relation to the user's head and body position.

Keywords: Autostereoscopic displays, interactive displays, 3D interaction, benchmarking, stereo display, interaction modeling.

1. INTRODUCTION

Research and development in systems for the display of information in three dimensions has been an active topic for more than a century. Traditional stereo three-dimensional (3D) displays use shutter glasses, polarizing filters or other techniques to provide different images to the left and right eyes. Recently, several types of autostereoscopic (no-glasses) displays have been developed that provide 3D viewing experience without the use of external glasses. 3D displays recently became available commercially from many different companies. Research conducted by iSuppli/Stanford Sources [1] reported that 2 million 3D display units were shipped in 2003 and that by 2010 this number will quadruple and reach 8.1 million units. These projections suggest that 3D displays may soon become a common part of everyday life and could significantly impact how we view and interact with new media content.

Recently, several techniques for human manipulation and interaction with stereo displays have been developed [2]. In this paper we investigate human interaction with three different types of stereo displays, including one requiring glasses and two autostereoscopic displays. Users interact with displayed information using a sphere shaped "cyberprop" containing an Ascension Flock of Birds tracking device [3]. This tracking device uses pulsed DC magnetic tracking to find position and orientation. To compare the systems we performed a 3D interactive object manipulation benchmarking experiment. This benchmarking application focuses on the capture of human interaction performance on an object manipulation task using a set of standardized and scalable block configurations. In this task, the user is presented with a pair of identical block configurations (in different orientations) and is required to manipulate one set of blocks into superimposition with the target configuration using a specified interaction device (see Fig. 1). Performance measures for this task include time to successful superimposition and efficiency of movement path.

This experiment compared three different 3D displays: a standard CRT monitor using Crystal Eyes shutter glasses; a Sharp LL-151-3D autostereoscopic display; and a StereoGraphics SG202 display. We chose to compare these displays because they all use a different technique to achieve the 3D effect. We characterize these methods in Table 1. We evaluate the advantages and disadvantages of these display systems and compare the effectiveness of stereoscopic interaction in glasses versus autostereoscopic methods.

	Number of Viewers	Number of Views	One Eye Resolution (percentage of full vertical and horizontal resolution)	Sweet Spot	Comfortable Depth Range
Shutter glasses	Multi	Single time multiplexed	Full vertical and horizontal	No	Largest
LL-151-3D	Single	Two	Full vertical and 1/2 horizontal	Yes	Large
SG202	Multi	Nine	1/3 vertical and 1/3 horizontal	Yes	Smallest

Table 1. Comparison of stereoscopic methods and effects for different displays.

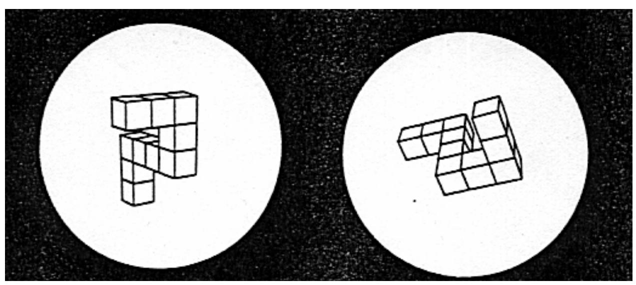

Figure 1. Shepard and Metzler [5] block configuration stimuli.

2. THE MENTAL ROTATIONS TEST

Our benchmarking measures were based on the Mental Rotations Test (MRT) [4]. This test investigates the mental rotation ability of individuals. Mental rotation (MR) is a dynamic imagery process that involves "turning something over in one's mind" [5]. Many day-to-day tasks and situations in life depend on one's ability to use imagery to turn over or manipulate objects mentally. Examples include automobile driving judgments, organizing items in limited storage space, using a map, sports activities, and many other situations in which one needs to visualize the movement and ultimate location of physical objects in 3D space.

Initially, thirty years ago, Shepard and Metzler [5], presented pairs of two dimensional perspective drawings to subjects and asked them to make judgments as to whether the 3D objects they portrayed were the same or different (see the example in Fig. 1). Traditional 2D measures for the assessment of mental rotation have produced intriguing findings, yet lack the precision needed to better understand this spatial ability. The most common test uses two-dimensional image stimuli that portray 3D objects and requires mental processing of the stimuli without any motoric involvement [4].

Rizzo et al. [6]-[10] investigated MRT via a manual virtual reality spatial-rotation task (VRSR) that required subjects to manipulate and superimpose block configurations within a virtual environment (VE). The use of VR for the assessment of visuospatial abilities allows for greater control and description of 3D stimuli along with more precise measurement of responses. The methodology and the inner workings of the VRSR are described extensively in the references.

3. THE EXPERIMENT

In this section we describe the experiment to evaluate the three different 3D displays and their effectiveness with 3D manipulation tasks.

3.1. Procedure

In our experiment we used fifteen male and fifteen female subjects from the University of Southern California Electrical Engineering Department, including students, staff and faculty. The males ranged in age from 19 to 51 (M = 29.7, SD = 7.6). The females ranged in age from 20 to 47 (M = 27.5, SD = 6.9). Before beginning the experiments, each subject completed a background questionnaire. The results of the questionnaire are given in Table 2.

Following the background questionnaire, we described the mental rotation block matching task to each subject and allowed them to familiarize themselves with it using a 2D training version of the task. This training phase was presented on an ordinary 2D display and used 12 simple block configurations selectable as a multiple-choice test via mouse clicks. Next, each subject was given time to use the Flock-of-Birds tracker with simple 2D images on an ordinary display.

Before starting the actual test using the 3D displays, we familiarized each subject with them and confirmed that they could see a sample 3D image on each display without artifacts. The two autostereoscopic displays have a preferred viewing position for an optimum stereo viewing experience. This so-called "sweet spot" is the best head position and body location to see the 3D image. We asked the subjects to maintain their viewing position in the sweet spot before starting the experiments.

	Yes			No		
	Male	Female	Total	Male	Female	Total
College education	3	6	**9**			
Graduate education	12	9	**21**			
Right handed	12	14	**26**	3	1	**4**
Uses corrective eye glasses	9	9	**18**	6	6	**12**
Used a 3D tracker before	1	4	**5**	14	11	**25**
Played 3D computer games before	10	9	**19**		4	**10**
Watched 3D stereoscopic movies or seen 3D stereoscopic images before	11	14	**25**	4	1	**5**
Worked with 3D displays before	1	5	**6**	14	10	**24**

Table 2. Results of subject background questionnaire.

Figure 2 shows an example of a subject manipulating the blocks with different displays. Subjects manipulate the control object by grasping and moving a sphere-shaped "cyberprop," which contains an Ascension Flock-of-Birds tracker. The motion of the sphere is imparted upon the control object. After successful superposition of the control and target objects, a "correct" feedback tone is presented, and the next task begins. The new control object appears attached to the sphere, and the new target appears a short distance away. This interaction method does not require users to press any buttons or select any objects. Control objects simply appear to be attached to the sphere for users to manipulate.

Figure 2. Examples of subjects during the experimental procedure. In a)., the subjects are first given a 2D training version of the mental rotation test on an ordinary display which they complete as a multiple choice experiment using mouse clicks. In b)., another subject is trained to use the Flock-of-Birds tracker with simple 2D images. In c). through e). the subject performs the experiment with more complex objects using different displays. Notice that while subject is doing the experiment with one display the other two are behind a black curtain. As the subject moves, the tracking device is placed at the same position relative to the display.

In order to reduce the learning effects on the subject performance we counterbalanced the display order across subjects. The display order varied as:

Test 1. Glasses, SG202, LL-151-3D
Test 2. LL-151-3D, Glasses, SG202
Test 3. SG202, LL-151-3D, Glasses

3.2. Displays and Interaction System

For glasses-based viewing we used StereoGraphics Crystal Eyes shutter glasses and a 20" CRT display. The autostereoscopic displays were the Sharp LL-151-3D and StereoGraphics SG202 displays. Both were driven by a 3GHz Pentium 4 Windows XP computer and NVidia Quadro4 900 XGL graphics card with 128MB memory. We used DDD's TriDef OpenGL SDK for real-time image interlacing [11]. The same Ascension Flock-of-Birds tracker was used for 3D interaction with all three displays.

We carefully arranged the experimental viewing conditions for the three displays to be as identical as possible. The active displays areas were made equal and set to 800 by 600 pixels surrounded by a black border extending to the maximum viewable area of the display screen. We asked the experimental subjects to position their head in front of the three displays to achieve similar angular field of view.

3.3. Evaluation

We collected both qualitative and quantitative data for analysis purposes. Subjects completed the same manipulation task set at each display. Each task set consisted of ten different manipulation tasks. During the tests, we recorded the speed of completion and efficiency of each subject for each task. We define efficiency as the ratio of the shortest path possible for matching controlled block and target block to the path taken by the user in matching the blocks. Efficiency is inversely proportional to the amount of travel (rotations and translations) the user-controlled block makes before correctly being superimposed on the target block, so that higher efficiency factors are better.

After finishing the tasks using all the displays, we asked subjects to fill out a questionnaire and evaluate their experiences with the displays. Specific questions asked them to rank the displays in terms of making their task easier, image quality, stereoscopic image quality, physical comfort and overall display preference.

4. RESULTS

Figures 3 through 6 summarize our results. Figure 3 shows that on the average, performing the tasks using shutter glasses required less time as compared to using the autostereoscopic displays. While both male and female subjects performed almost equally fast with shutter glasses, there were mixed results in comparing the male-female completion time between the two autostereoscopic displays. Comparing the two autostereoscopic displays, the male subjects performed better with the LL-151-3D display, while female subjects performed better with the SG202 display.

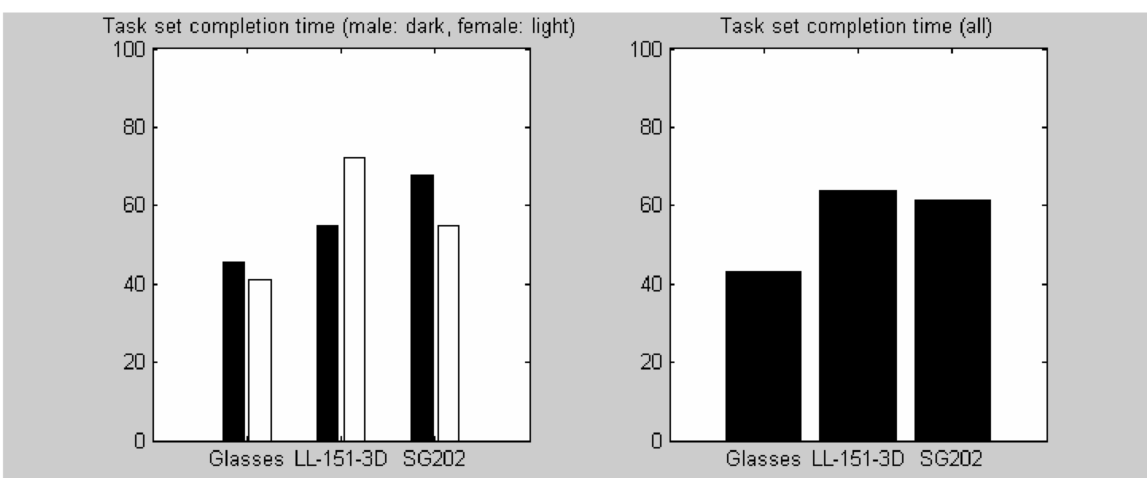

Figure 3. Average time of task set completion. The graph on the left shows the task set completion time for males and females. The graph on the right shows the average time of task set completion for all the users using different displays. Each task set has ten tasks.

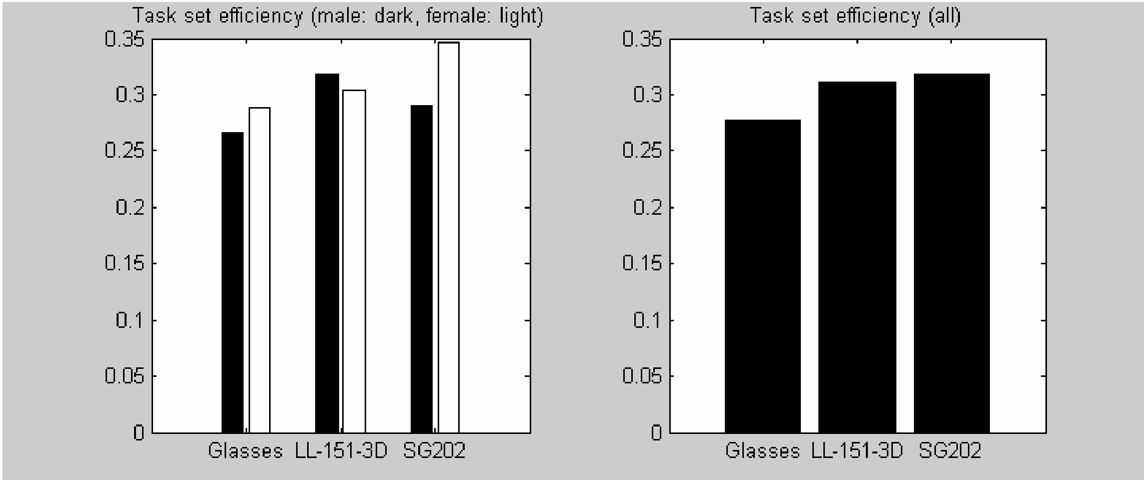

Figure 4. Average efficiency in task set completion. The graph on the right shows the task set completion efficiency of males and females. The graph on the right shows the average task completion efficiency of all users using different displays. Each task set has ten tasks.

Comparing the efficiency of completing a task set, it is interesting to note that on the average, users had a slightly higher efficiency score using the two autostereoscopic displays as compared to the shutter glasses (Fig. 4b). However, the differences for all users among the displays are relatively small. As with the completion time as shown in Fig. 3, there were mixed results in comparing the male-female efficiency between the two autostereoscopic displays

Figures 5 and 6 summarize the results of our end of experiment questionnaire. Most subjects indicated that shutter glasses made their task easier compared to the autostereoscopic displays. The shutter glasses were slightly preferred for overall image quality and stereo image quality, and there was little difference in display preference in the other categories. There was also little difference in the responses from men and women.

We performed a series of analysis of variance (ANOVA) *F*-statistic hypothesis tests to determine the likelihood of significant differences in the completion time and efficiency among the three displays. Table 3 lists the *p*-values for these tests.

	Completion time	Efficiency
Overall	0.0065	0.2049
Males	0.0328	0.2883
Females	0.0197	0.2597

Table 3. *P*-values from *F*-statistic hypothesis tests.

Using the accepted .05 level of significance, the *p*-values for *completion time* for all participants, males alone and females alone, were all less than that value, indicating that there were significant differences in their performance speed across the three displays. On the other hand, the *p*-values for the *efficiency scores* were all greater than 0.05, indicating a low likelihood of significant differences on this measure of performance across displays conditions.

5. INTERPRETATION OF RESULTS

A possible explanation for the differences in time of completion may be due to the comfortable stereoscopic depth range subjects experienced with the displays. As the depth range increases it becomes easier to manipulate objects in 3D. However, in the post-experiment questionnaire some subjects noted that it was difficult for them to move the cyberprop ball and also keep their head in the sweet spot of the autostereoscopic displays at the same time. Staying in the sweet spot was more difficult with the LL-151-3D as compared to the SG202. We can explain the differences in time of completion for males and females by the way they interacted with the objects on the screen. During the experiment we observed that as the users moved their hands with the tracker, their bodies move sometimes too.

There were no large differences in task efficiency across different displays. Subjects also did not show a clear preference for any display in the physical comfort category in general. We explain this in terms of the time it takes to finish an experiment. The average time required to finish the whole experiment with the displays is about 3 minutes for each subject. Results show that a few minutes at each display does not have a significant influence on the comfort level of the user. Thus, tests of a longer duration may be more effective in comparing these displays.

On the average, while females did not show a clear preference to any of the displays in the post experiment questionnaire, males showed a clear pattern of preference. Males preferred glasses in general and they liked the LL-151-3D more than the SG202. When we compare individual displays, the males did not prefer the SG202 as much as females in any of the categories. In order to clarify this we looked at the open-ended answers of the questionnaire. Males rated the SG202 image quality lower than the LL-151-3D, while females preferred the SG202 because it is easier to stay in the sweet spot compared to LL-151-3D.

The results of the post experiment questionnaire showed that in general, subjects preferred to use shutter glasses for 3D manipulation tasks, at least for the short duration tasks in this experiment.

6. CONCLUSION

Our experiment revealed some important results in general and male vs. female preferences in particular for 3D manipulation tasks using different 3D display methods. Our results indicate that staying in the sweet spot of a 3D display while doing 3D manipulation is important. Therefore, any 3D interaction method should take into account the movements required by a user to do the manipulation. For autostereoscopic displays these movements must be accurate and small enough so that the user can comfortably do the manipulation while staying in the sweet spot.

The comfortable depth range is another important variable because as this range increases, the task becomes easier. This becomes especially important when it is difficult to tell the differences in depth by traditional 2D depth cues such as perspective and size difference. In this experiment, the background was black and it was difficult to tell the size difference of the blocks in the useful depth range. In this experiment the only helpful 2D depth cue is occlusion. Therefore, the subjects had to rely on stereoscopic depth perception in order to make better depth judgments.

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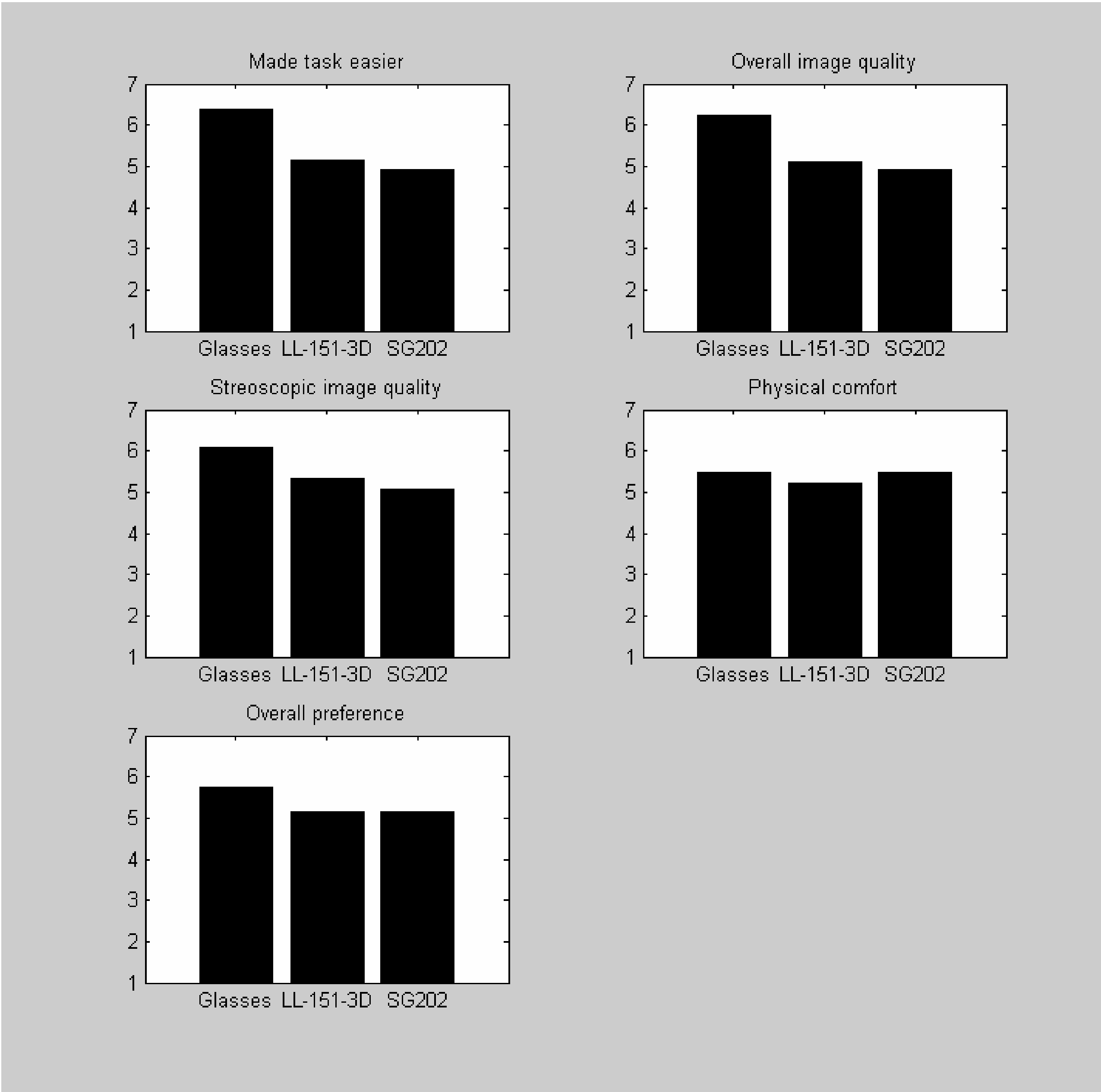

Figure 5. These graphs show the overall average of user responses for the post experiment questionnaire.

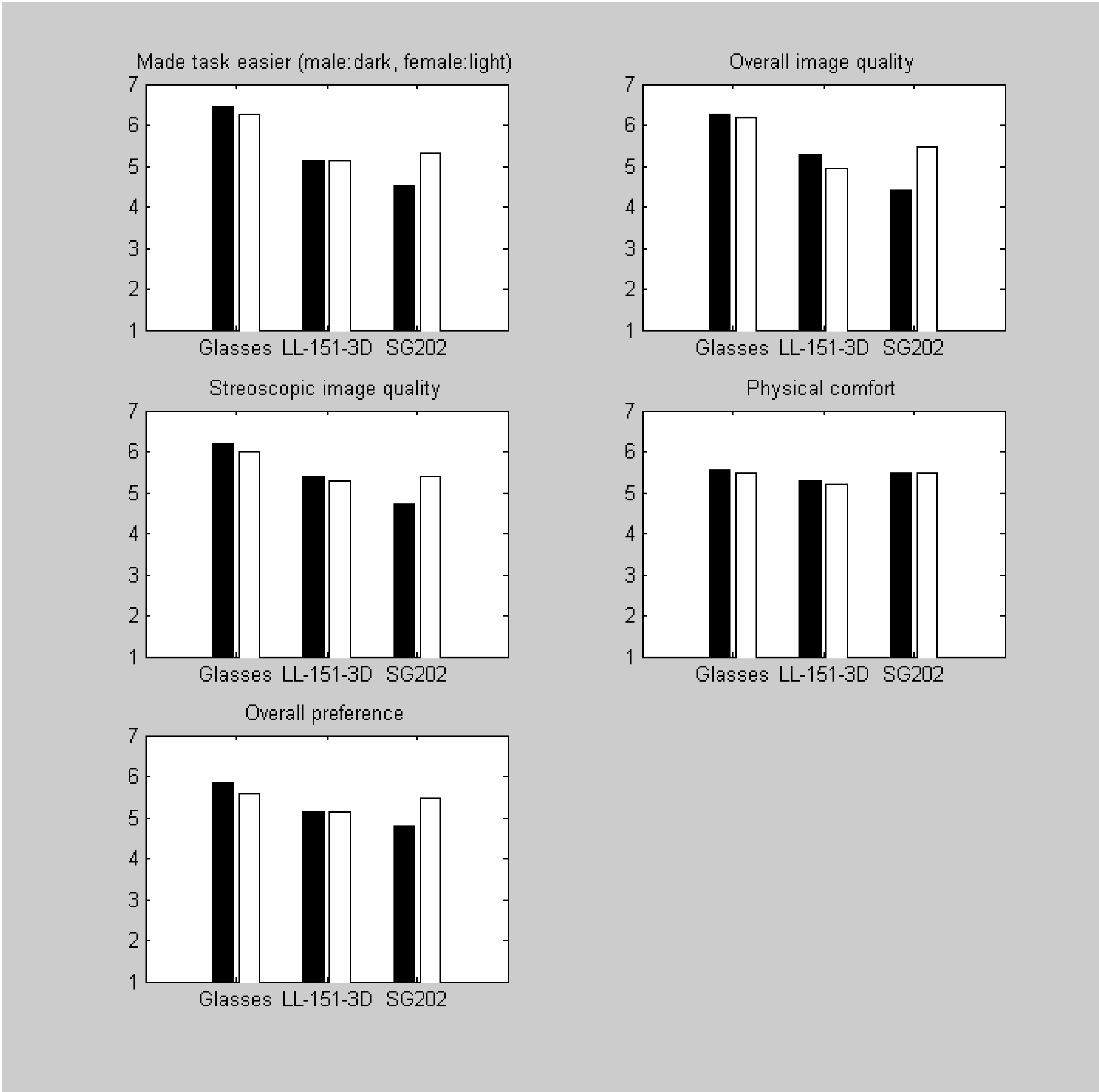

Figure 6. These graphs show the male and female averages of user responses for the post experiment questionnaire.