Comparative Analysis of Holographic Display and Three-Dimensional Television

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ABSTRACT

Data visualization is a key component in a variety of high-impact fields: medicine, engineering, architectural design, intelligence, and many others. Current sensors used in these fields record multi-dimensional data sets, such as light detection and ranging (LiDAR) sensors, magnetic resonance imaging systems (MRI), and three-dimensional (3D) cameras. While these communities have a plethora of sensors to create data sets, the visualization of these data sets is lacking. The most common display modality is two-dimensional (2D), despite having data sets representing 3D geometries. Furthermore, additional dimensions such as time or a force measurement must be displayed in many situations. When using a 2D display, these additional dimensions must be compressed, or they are simply not displayed. The use of a 3D display alleviates many of these issues, by presenting the additional dimension naturally. A number of 3D display modalities are present in the market, with various strengths and weaknesses inherent in their designs. In this study, we compare a commercial 3D television which is a time-multiplexed stereoscopic display and an autostereoscopic holographic display. Participants in the study completed two tasks: a medical task and a tactical task. The tasks required them to identify certain landmarks in each data set, such as the tallest building or a particular anatomical structure. After the tasks, researchers gathered data on usability, visual perception, and cognitive load using the displays. Performance metrics for the medical and tactical task were also collected. The paper reports the study results and discusses the merits of the 3D display modalities, including recommendations of suitable use cases for both.

ABOUT THE AUTHORS

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INTRODUCTION

Data visualization is a key challenge in a number of fields. Diverse data sets require unique visualization strategies, especially as the number of dimensions increase. Is compressing a 3D building into a 2D blueprint the best visualization strategy for an architect to plan construction of a building? Is viewing a 2D medical image the best way for a physician to search for tumors or other pathologies in a 3D region of the body? Currently, the cultural standard for these tasks and many others is 2D viewing. Two-dimensional representations have become ubiquitous, ranging from movies and televisions to modern computers. The vast majority of displays present data in 2D, and as a result humans have acclimated. However, as technology progresses, there comes a time when the question should be asked – does viewing certain data sets in 3D make more sense? If so, a complementary question arises – does the current technology support such a paradigm shift?

A number of studies have indicated that viewing items in 3D rather than 2D may result in performance improvements. In a recent study, results indicated three major findings: 3D stereoscopic displays 1) aid the detection of diagnostically relevant shapes, orientations, and positions of anatomical features, especially when monocular cues are absent or unreliable; 2) help novice surgeons orient themselves in the surgical landscape and perform complicated tasks; and 3) improve the three-dimensional anatomical understanding of students with low visual-spatial skills (Held & Hui, 2011). Additional studies have shown similar results regarding 3D anatomical understanding, all showing that the addition of the depth dimension increases spatial understanding (Miller, 2000; Garg et al., 2001). Tactical tasks have also shown similar results. The use of 3D holographic display technology has shown improved time and accuracy in identifying tactical and terrain-related features when compared to conventional 2D maps and imagery. Additional benefit was reported in situational awareness, planning, and decision making (Kalphat & Martin, 2009). A route-planning task using SWAT teams showed that the use of 3D holographic content improved route planning time and resulted in a more efficient route overall (Fuhrmann et al, 2011). In an effort to generalize human performance related to 3D displays, a study using abstract data sets was conducted, and the results show that stereo 3D displays fostered a significant increase in spatial understanding (Ware & Franck, 1996). In tasks specifically designed to test differences in spatial memory, it has been shown that 3D displays showed increased performance over 2D displays (Tavanti & Link, 2001). The overarching theme shows that 3D displays can show increased performance in individual areas, such as medicine, anatomy, or terrain understanding. Additionally, the concept seems to be generalizable, indicating that the presentation of diverse data sets in 3D results in better performance and understanding.

From a biological standpoint, the human visual system benefits from the use of 3D displays. When viewing a 2D representation of a 3D object, the brain and visual system must use monocular visual cues in order to achieve depth perception. These monocular cues include retinal image size, texture gradients, motion parallax, linear perspective, overlap, lighting and shading, and accommodation. The brain can process a great deal of depth information from these monocular depth cues, but the visual system is designed to fuse monocular and binocular depth cues. These binocular cues include stereopsis and convergence, and are summarized in Table 1 (Teittinen, 2014).

Table 1: Monocular and Binocular Depth Cues

Cue	Category	Definition
Retinal Image Size	Monocular	When the real size of the object is known, our brain compares the sensed size of the object to this real size, and thus acquires information about the distance of the object.
Texture Gradient	Monocular	The closer we are to an object the more detail we can see of its surface texture. So objects with smooth textures are usually interpreted being farther away.
Motion Parallax	Monocular	A monocular depth cue in which we view objects that are closer to us and moving faster than objects that are further away from us.
Linear Perspective	Monocular	A type of monocular cue in which parallel lines appear to converge at some point in the distance.
Overlap	Monocular	When objects block each other out of our sight, we know that the object that blocks the other one is closer to us.
Lighting and Shading	Monocular	When the location of a light source is known and objects casting shadows on other objects, we know that the object shadowing the other is closer to the light source.
Accommodation	Monocular	Accommodation is the tension of the muscle that changes the focal length of the lens of eye.
Convergence	Binocular	A binocular cue based on signal sent from muscles that turn the eyes. To focus on near or approaching objects, these muscles turn the eyes inward. The brain uses the signal sent by these muscles to determine the distance of the object.
Stereopsis	Binocular	The perception of depth produced by the reception in the brain of visual stimuli from both eyes in combination.

These cues are very important, and can be deleterious when they are in conflict or are missing data required for visualization. For example, the brain fuses accommodation and convergence to create an accurate idea of the distance of the object from the viewer. However, these two cues can conflict with one another when attempting to view a 3D image on certain 2 and some 3D displays. In such a case, accommodation constricts muscles to focus the lens of the eye at the ideal distance for viewing the object; however, the angle of convergence believes the object to be at a different distance. This conflicting information is known as convergence-accommodation conflict and can hinder visual performance and cause visual fatigue (Hoffman et al., 2008). In fields that require viewing of 3D imagery for extended periods of time, such as an intelligence analyst, this conflict becomes a serious problem. In addition to potential physical symptoms, the visual system often misses binocular depth cues, which can be used to overcome confusion when dealing with strictly monocular cues. For example, Figure 1 shows an illusion known as Ames' Room, which occurs when only monocular cues are available (Ames, 1954). The perception is that the person on the right is a much larger in size that the person on the left; when in fact the room is shaped to take advantage of monocular cues such as retinal image size. Binocular cues such as convergence and stereopsis would overcome the confusion of this illusion and give the viewer the appropriate depth perception. For these reasons, the lack of binocular depth cues and the potential for conflicting cues makes the case that the human visual system would benefit from 3D displays.

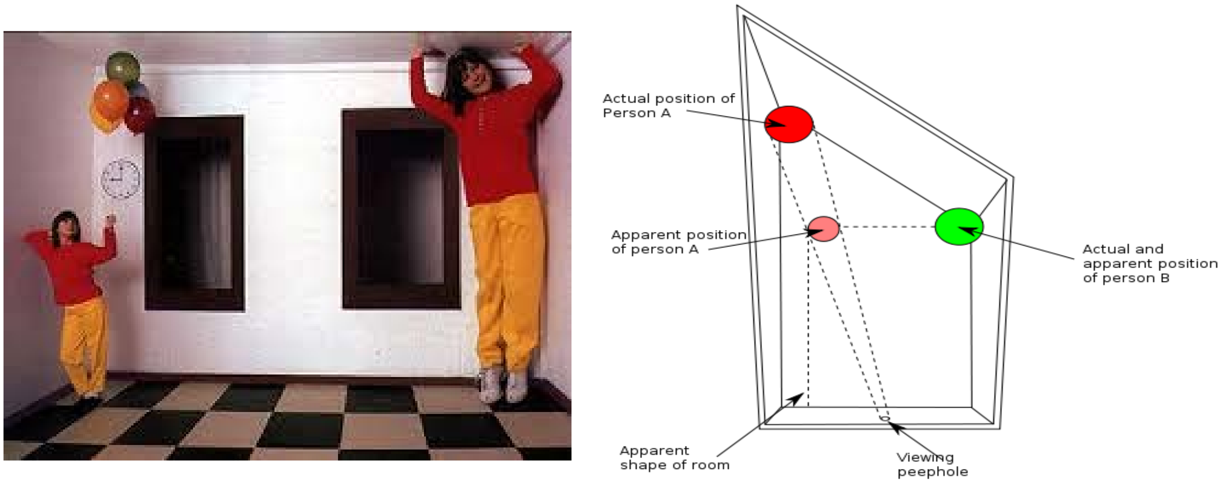

Figure 1: Ames' Room

While these studies, combined with the needs of our visual system, provide the rationale for 3D display use, the question of technological maturity remains. Are 3D displays currently good enough to be implemented into our day to day lives? A number of signs indicate that they may be. To begin, although falling short of high expectations, 3D television sales are still increasing. 3D televisions shipments totaled 41.45 million units in 2012, compared with 24.14 in 2011 and 2.26 in 2010, indicating an upward trend (Yonhap News Agency, 2013). In cinema, 3D films have seen a resurgence from the early 2000s, with high grossing films such as *Avatar*, *The Avengers*, *Cars 2*, and many more. In non-entertainment areas, 3D displays are also becoming widely used. Intelligence analysts commonly use 3D displays to view geospatial data (Keller, 2011). Areas including ground, undersea, and airspace visualization show frequent use of 3D display technology.

Unfortunately, the most commonly used 3D display are stereoscopic, meaning they require glasses to view the 3D effect. The majority of users do not wish to wear additional glasses when viewing a display, which has hindered adoption. Pushes in academia and industry have begun to create autostereoscopic displays using a variety of techniques (Pennington, 2014). Governmental agencies have also expressed interest in autostereoscopic displays, including a research effort by the Intelligence Advanced Research Projects Activity (IARPA) focused on a next generation holographic display (Keller, 2011). While the push of major research institutions is excellent, the question of current maturity still exists. This paper discusses an experiment aimed at quantifying the maturity of 3D television and holographic displays for use in the modeling and simulation (M&S) field. The results and discussion highlight identifying strengths and weaknesses in current 3D display technology, and discuss needed improvements in order to have 3D display technology mature to the point where it can provide substantial value within the M&S community.

METHODOLOGY

Materials

Two displays were used which are representative of the state of the art. A 60" Samsung LED SMART 3D television requiring active shuttering 3D glasses was used. The glasses alternate shutter times, thereby providing each eye with a unique view. The visual system and brain then combine the 2D views presented to each eye into a 3D image (Figure 2).

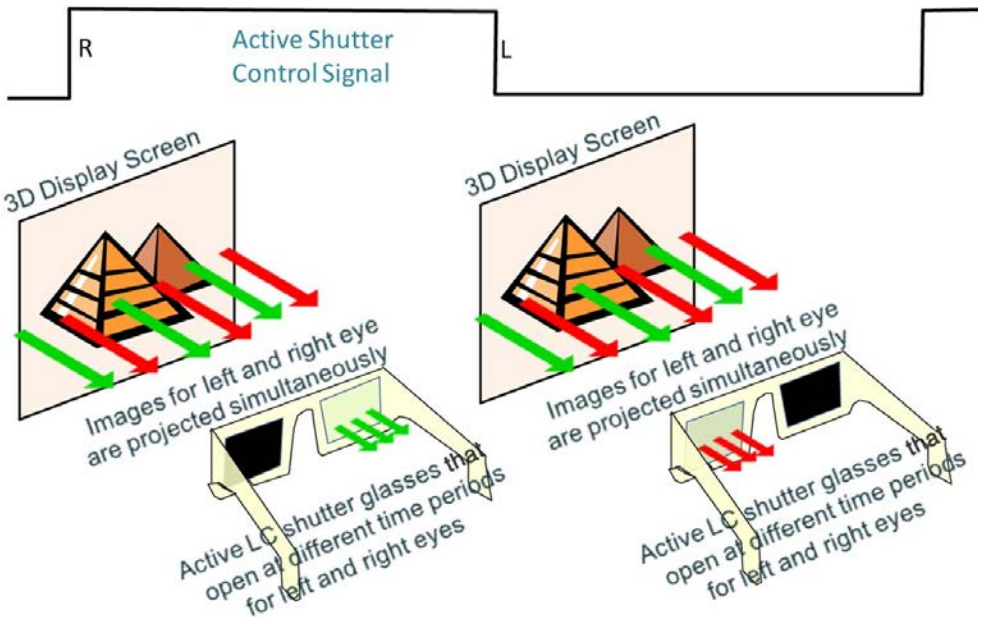

Figure 2: Time-Multiplexed stereoscopic displays (active shuttering glasses) (taken from Geng, 2013)

The second display used was a state-of-the-art holographic display created by Zebra Imaging, Inc. The holographic display is auto-stereoscopic, meaning no glasses are needed to view the 3D effect. The display was created during a DARPA funded research effort known as the Urban Photonic Sandtable Display (Figure 3). The display comprises 3 distinct layers. The first is a computational layer, which converts a 3D data set from a host computer to a holographic data set for use by the display. This changes a dataset of voxels, represented by the X, Y, Z coordinate system, into holographic elements (hogels) represented by X, Y, Z and two viewing angles. From here, the holographic data is passed to the light modulation layer, which generates the needed light using series of spatial light modulators. Lastly, an optics layer focuses the generated light into a light field which can be viewed by anyone observing the display (Klug et al., 2013). A summary of the both displays can be seen in the table below (Table 2).

Figure 3: Holographic Display

Table 2: 3D Display Characteristics

	Samsung 3D Television	**Zebra Imaging Holographic Display**
3D modality	Time-multiplexed stereoscopic	Light field display
Glasses	Active-shuttering	None; autostereoscopic
Size (diagonal)	60”	20”
Form Factor	Wall mounted	Table-top
Viewing angle	Approximately 60º left and right of the display	Fully parallax; viewable 360º
Resolution	1080p	2.5mm points (average) (Klug, 2013)

Experimental Design

The experiment consisted of seven total participants viewing content on both displays. Two sets of content were presented, and participants completed a series of simple tasks associated with each set. After completion of the tasks, participants were given surveys to gather their impression of the display. The presentation of content and display was counterbalanced, to ensure that the data wasn’t skewed as a result of the order in which information was presented. In other words, some participants viewed content on the holographic display first, while others began on the 3D television.

The first content set focused on anatomy and included two anatomical models: the heart and the brain. Each model was based on MRI scan data, which was reconstructed in 3D. The first model displayed was the brain. As participants studied the brain, researchers asked participants to estimate the dimensions of the brain in length, width, and depth. During this process, researchers recorded the time needed for task completion. This process was then repeated for the heart and surrounding vessels. Both the brain and the heart were displayed in a 1:1 scaling relative to the measurements of an average human.

The second content set was focused on an urban landscape. The cityscape presented a variety of buildings with a wide range of sizes and heights. All shadowing and texture were removed, in order to eliminate as many monocular cues as possible. This allows the results of the experiment to highlight how binocular cues present in 3D displays affect visual perception. The first task for this set required participants to locate the tallest building. Then, researchers asked participants to find the shortest buildings; within the data set there were 3 buildings which were equally low in height. Finally, the researchers asked participants to indicate the dimensions of the tallest building. All tasks were timed.

During the experiment, each participant viewed both sets of content on both displays. For example, a participant may have viewed 1) anatomy on the holographic display, 2) cityscape on the 3D TV, 3) anatomy on the 3D TV, and 4) cityscape on the holographic display. After each content session, participants were given a survey determining their cognitive load using a scale from 1-7, with 1 representing low mental effort, and 7 representing high mental effort. At the conclusion of all sessions, participants completed a final survey summarizing their feelings towards 3D displays.

RESULTS

The results showed no significant difference between displays for the time needed to complete the cityscape tasks. However, for the task of estimating the dimensions of anatomical structures, participants using the holographic display were significantly faster in both cases. For the heart dimension task, participants using the holographic display estimated dimensions with a mean time of 25.8±6.1s; when using the 3D TV participants had a mean time of 38.6±6.7s. Similar results occurred during the brain dimensions task; participants had a mean time of 23±6.1s using the holographic display and a mean time of 41.2±17s using the 3D TV (Figure 4). Using a student-t test, the difference between the two displays was significant ($p<0.5$).

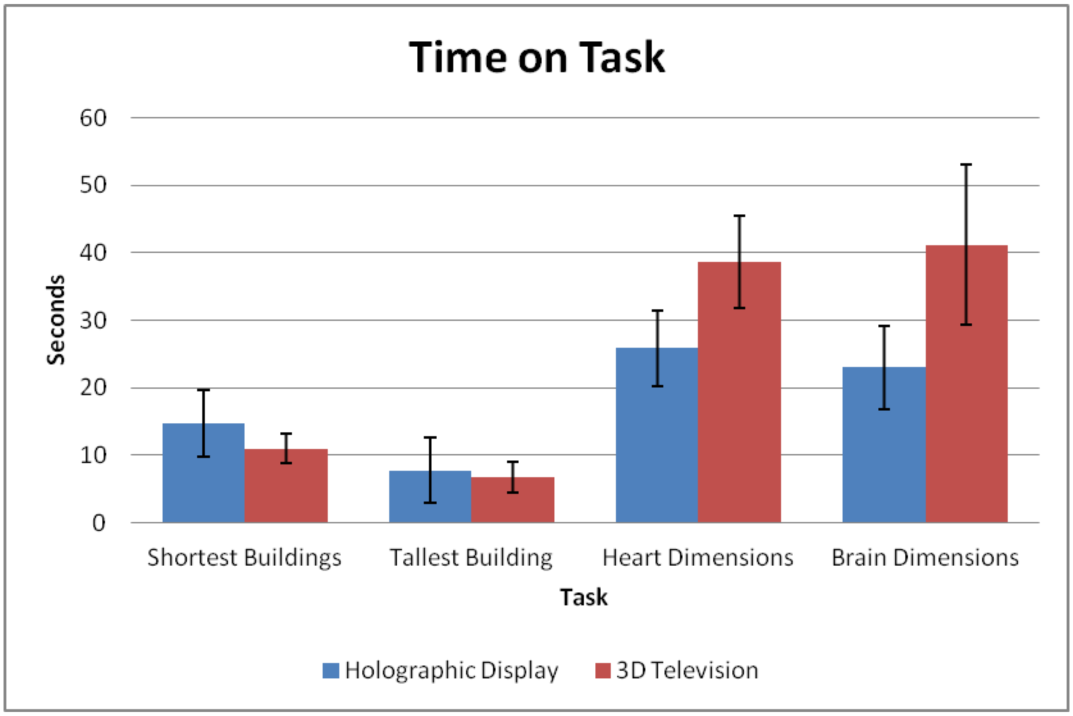

Figure 4: Time on Task

The next metric focused on quantifying perceived depth in the two displays. Using the average value of the depth dimensions provided for the heart, brain, and tallest building, the average depth was computed for each participant. The results indicated perceived depth was not significantly different for any of the data sets across displays (Figure 5).

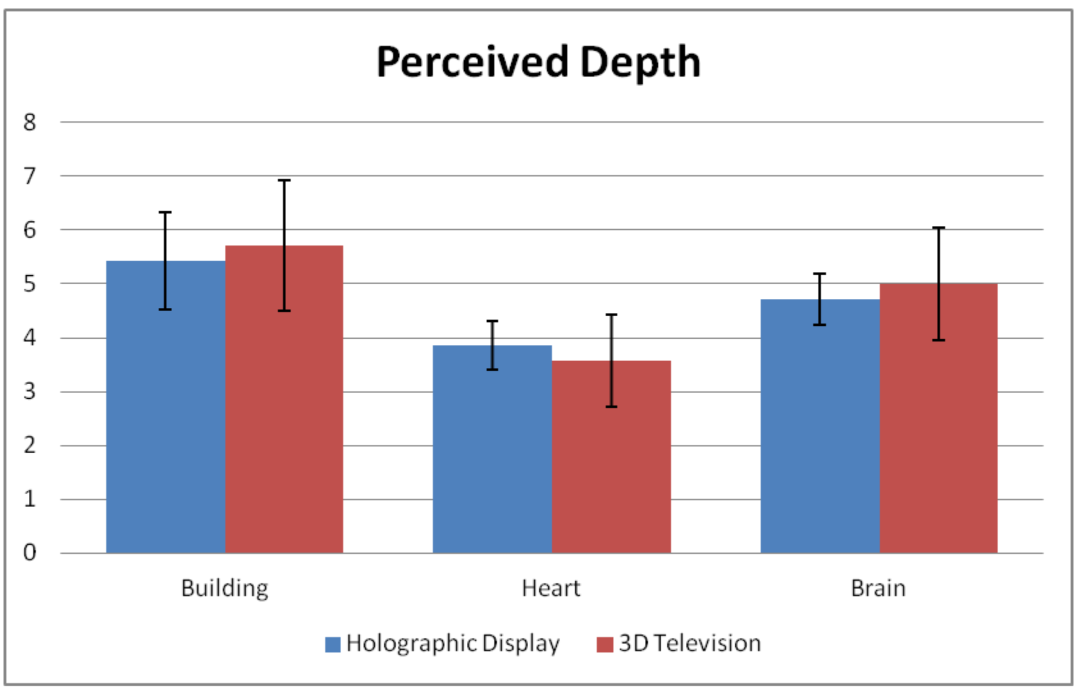

Figure 5: Perceived Depth of Display during Tasks

Researchers were also interested in the amount of mental effort needed to conduct the tasks, and whether the display modality had an effect. Averaging the mental effort for all tasks, the results indicate that the mental effort was nearly identical for both displays. Participants reported a mean mental effort of 4.2±1.05 while using the holographic display and a mean mental effort of 3.9±1.07 using the 3D television (Figure 6).

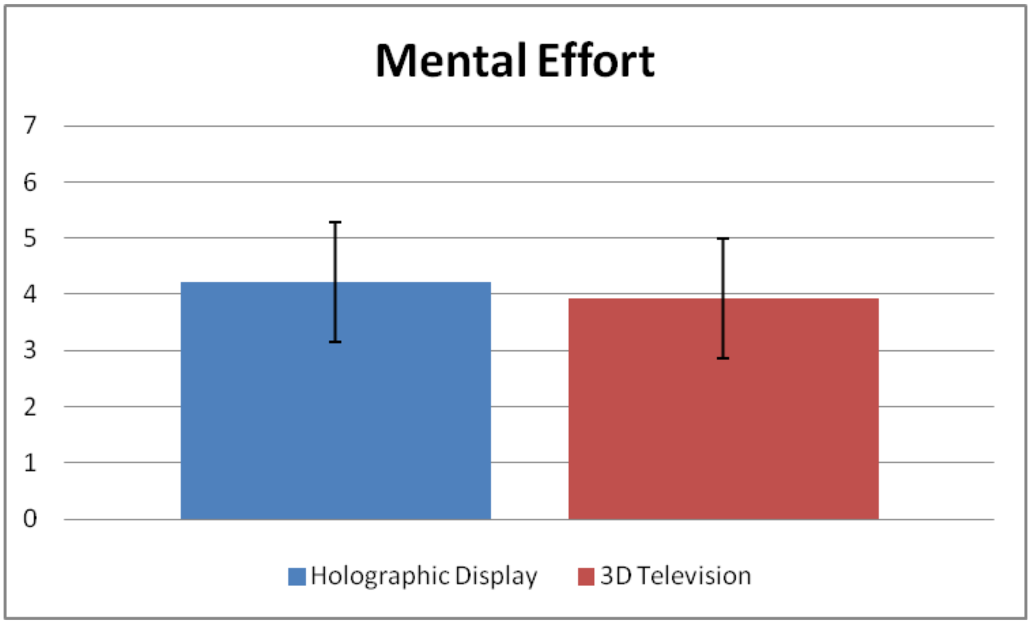

Figure 6: Mental Effort Associated with Display

While perceived depth and mental effort are important, perhaps the most important aspect of a display is the ability to convey information accurately. To assess this quantitatively, researchers used the dimensional data gathered from participants during the anatomy content sessions. Since the anatomy content was displayed using 1:1 scaling, by looking at the perceived size difference, researchers gain a metric for determining how accurately data was conveyed. Both displays resulted in skewed sizes, though the holographic display performed significantly better. The graphic shows the average size of the heart and brain as the leftmost image. Alongside this, the size of the heart and brain as participants judged from both displays, scaled according to the average size of a heart. For the heart, participants using the holographic display perceived the size to be an average 80% larger than a standard sized human heart; participants using the 3D television perceived nearly 200% larger (Figure 7). For the brain, participants were very accurate using the holographic display, estimating dimensions only 20% larger than a standard brain. When using the 3D television, the estimated difference in brain size was 102% larger than a standard brain (Figure 8).

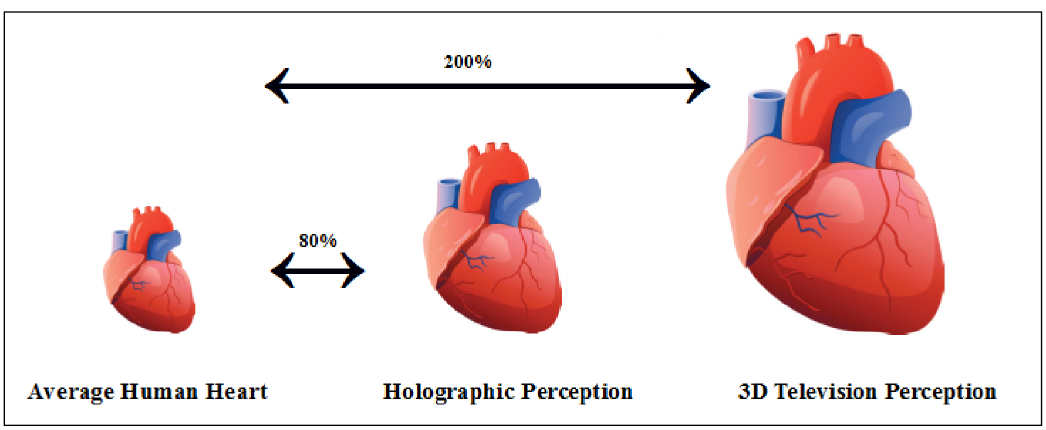

Figure 7: Heart Dimension Scaling based upon Participant Perception

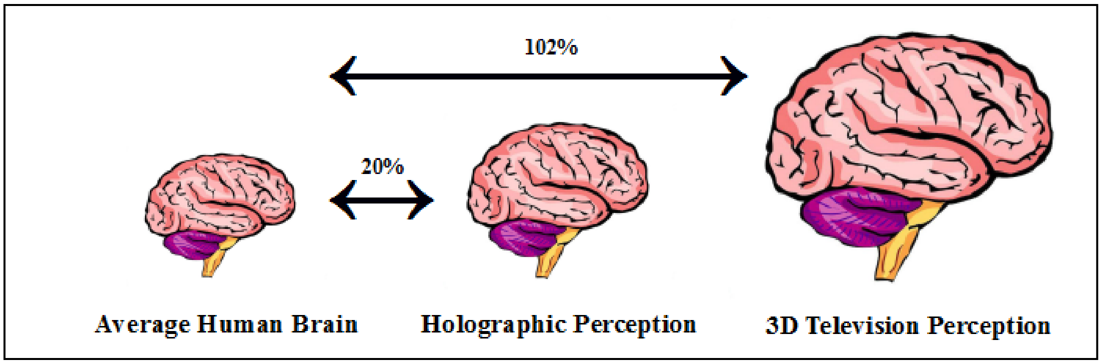

Figure 8: Brain Dimension Scaling based upon Participant Perception

Lastly, researchers used subjective data from surveys to determine the overall perception of the two displays. Participants indicated a few key points. The first: the resolution and clarity of a display was unanimously the most important feature of a display. Additionally, all participants felt that 3D displays were useful to the field of modeling and simulation. However, the majority of participants still preferred the traditional way of completing these tasks, such as using a map instead of viewing a cityscape on a 3D display. A summary of the results is seen in Figure 9.

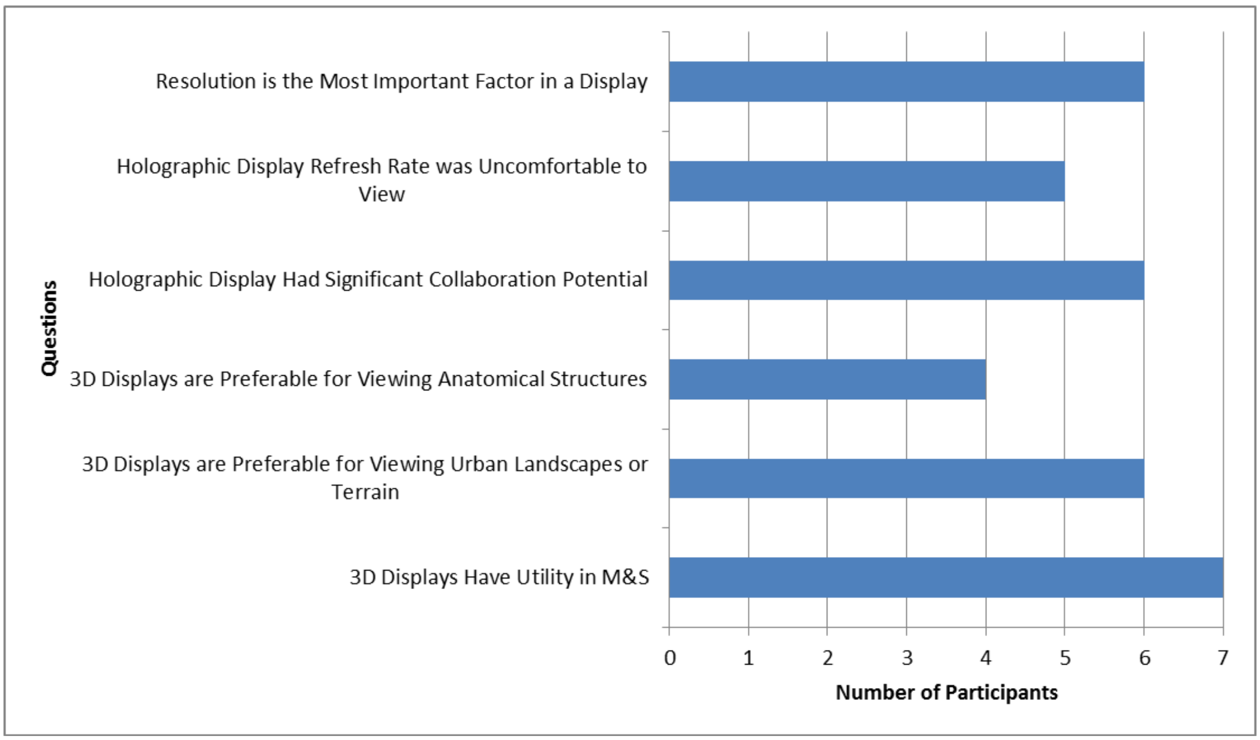

Figure 9: Summary of Subjective Survey Results

CONCLUSION

The experiment highlighted a number of interesting issues related to 3D visualization and 3D display technology. To begin, the data showed that users overwhelmingly believe that 3D visualization has an important role in modeling and simulation and in data visualization in general. This, added to earlier study findings, reinforces the notion that 3D displays are needed and desired tools for many tasks. While users hold the belief that 3D displays are important, the overall satisfaction in them was still quite low, especially for the holographic display. Due to the holographic display being hard on the eyes because of the refresh rate, users felt the display might not be ready to be widely used. This finding indicates that users may wish to use 3D displays, but still feel the technology is lacking in some areas.

The findings related to display performance are also valuable. To begin, the holographic display performed better than the 3D television in terms of conveying information quickly and accurately in terms of anatomical content. There are a few potential reasons for this. The first is form factor. Having the display as a table top may give users a more intuitive way of viewing anatomy. The second is the mechanism for producing the 3D effect may have had an impact. The holographic display presents depth both above and below the plane of the table. By doing this, the viewer can place their hand near the displayed heart or brain and get the impression of size easily. Because 3D televisions primarily have depth only into the display, this cannot easily be done with a 3D television. The results indicated that not only did users have a much better understanding of the size of anatomical structures, but users also were able to ascertain the dimensions more quickly using the holographic display. The reason for this may be related to wearing the glasses. A 3D television tricks the visual system by using active shuttering and exploiting the memory of our visual system to create a 3D image. The holographic display creates a lightfield image, which is processed the same way as a physically present object. Since the visual system is designed to process information in this fashion, the lightfield image of the holographic display may be the reason for the improved time on task and size accuracy participants demonstrated.

The results of this experiment highlight the strengths and weaknesses of current 3D display technology. First, a significant strength of 3D displays is the ability to accurately and quickly convey information, especially the holographic display. Another strength is the perception of utility by the user groups, which is an excellent predictor of overall technology acceptance (Davis, 1989). The primary weaknesses of the stereoscopic displays are the lack of depth coming out from the display and the need to wear glasses. The primary weaknesses of the autostereoscopic display, in this case holographic display, is that the refresh rate and resolution are still far too low for users to be able to effectively use the display for the majority of tasks. The path forward for this technology will be to focus on improving the highest impact display characteristics: resolution and refresh rate. The improvement of these characteristics will occur naturally through component improvement as well as system improvement through industry and academia. The overall results of this experiment indicate that 3D displays hold great promise but still require further research and development.

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