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Evaluation of monoscopic and stereoscopic displays for visual–spatial tasks in medical contexts

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ABSTRACT

In the medical field, digital images are present in diagnosis, pre-operative planning, minimally invasive surgery, instruction, and training. The use of medical digital imaging has afforded new ways to interact with a patient, such as seeing fine details inside a body. This increased usage also raises many basic research questions on human perception and performance when utilizing these images. The work presented here attempts to answer the question: How would adding the stereopsis depth cue affect relative position tasks in a medical context compared to a monoscopic view? By designing and conducting a study to isolate the benefits between monoscopic 3D and stereoscopic 3D displays in a relative position task, the following hypothesis was tested: stereoscopic 3D displays are beneficial over monoscopic 3D displays for relative position judgment tasks in a medical visualization setting. 44 medical students completed a series of relative position judgments tasks. The results show that stereoscopic condition yielded a higher score than the monoscopic condition with regard to the hypothesis.

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1. Introduction

Visualizing and understanding digital medical data is a complex yet critical process involved in diagnosis, pre-operative planning, minimally invasive surgery, instruction and training in the medical field. The information generated from CT, MRI, and other medical imaging technologies can be high in volume, highly detailed and complex. Translating this data into usable information is difficult, yet of the uttermost importance to patients' care [1]. At 28.6%, diagnostic errors are the leading type of medical paid claim in the United States. Diagnostic errors leading to death or permanent injury range from 80,000 to 160,000 patients annually [2]. Diagnostic errors occur because: (1) physician cognitive bias, for example when a physician focuses in a single diagnosis without considering all the diagnostic possibilities and (2) Limited information, medical imaging data is not always available in diagnosis [3]. It is crucial that medical imaging data is represented and used in such a way as to minimize diagnostic errors.

Visualization tools and applications are being developed to minimize the complexity of medical data. One of the proposed solutions is the use of both monocular and binocular cues for depth perception, as in the case of stereoscopic applications. Depth perception is used to determine the shapes of objects in the world, and the spatial position of these objects [4]. The ability to see depth is so important that the Human Visual System (HVS) has redundant cues to detect it. Monocular depth cues can be acquired by only one eye, and these types of cues can be present in conventional displays. Monocular depth cues include perspective projection, occlusion, familiar size, object motion, and motion parallax [5–7]. If monocular depth cues are degraded or absent in traditional displays then depth perception and performance may also degrade. Stereoscopic technology can provide more robust, natural, and accurate depth perception cues in image representations.

Stereopsis is a binocular depth cue that consists of processing the disparity between the unique images presented to each eye. Human eyes are separated slightly horizontally and receive a unique perspective of the world. The brain fuses the left and right images, and from the differences between the two images, the brain extracts depth information [5]. The disparity of information obtained from the two unique images is processed to the point that the HVS can differentiate between an object 1.0 m away and a second object 1.2 mm away [6].

Even if stereoscopic applications use the most sensitive depth cue, and theoretically offer advantages over monoscopic monitors when displaying depth information to the HVS, the adoption of

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stereoscopic applications in medicine will not occur until a clear advantage of stereoscopic applications over monoscopic applications is demonstrated.

The work presented here attempts to study the how the stereoscopic depth cue affect a visual spatial task over a traditional monoscopic 3D display.

2. Background

Even though stereopsis applications offer the most robust and complete set of depth cues they are not widely adopted in the medical field. There are three main aspects contributing to barriers of adopting stereoscopic displays: (1) negative physiological displays associated with stereoscopic displays, (2) additional costs in hardware, and (3) the unclear understanding of the advantages of stereoscopic displays over monoscopic displays.

The first contributing factor against the adoption of stereoscopic displays is the association of stereoscopic displays and physiological effects. It is estimated that around two to three million persons in the US cannot see stereopsis and when presented with stereoscopic applications they experience negative reactions, such as headaches, blurred vision, and dizziness when using stereoscopic displays [1,8].

The second contributing factor to the adoption of stereoscopic displays is cost. Stereoscopic systems require additional equipment such as glasses, special displays, and even specialized tracking systems. In some cases the computing requirements are more demanding than regular displays [6]. However, processing power has increased, and simultaneously decreased in cost, such that a stereoscopic display can be acquired for little more than a standard desktop computer.

The third contributing factor slowing the adoption of stereoscopic displays is whether they have clear advantages over monosocopic displays. Many of the studies that compare monoscopic and stereoscopic applications have yielded mixed results [1]. It is important to further the study of stereoscopic applications with basic research questions to understand their advantages and limitations.

2.1. Stereoscopic applications in medicine

Many stereoscopic applications have been developed to address current short-comings of traditional display technologies. Current stereoscopic medical applications can be divided into four areas: diagnosis, pre-operative planning, minimally invasive surgery, and teaching/training [1,9].

Diagnosis aims to identify anatomical structures and abnormalities inside the human body. Currently most diagnosis applications use a mixture of 2D views and monoscopic 3D views. By making use of stereopsis to separate the background object from the object of interest, stereoscopic applications could help to reduce false positives and false negatives during diagnosis. Several stereoscopic applications have been developed for diagnostic purposes, including applications in mammography [10–12].

Pre-operative planning finds the optimal surgical path for a procedure based on pre-operative images obtained from the patient. Pre-operative planning can improve surgical precision, reduce the time of an intervention, and reduce possible complications. Similarly to diagnosis, pre-operative planning uses a mixture of 2D and monoscopic 3D views. The 2D views help to assess the distances and angles of the surgical path, while 3D views help to understand and label the anatomical structures. Several stereoscopic [13,14] applications have been developed for pre-operative planning. For example, Reitinger [13] developed a stereoscopic liver surgery planning that allows the user to analyze the data, and conduct measurements utilizing pre-operative planning.

Minimally invasive surgery (MIS) is another potential application for stereoscopic displays. MIS surgery is conducted from outside the body by minimizing the size of the incisions. MIS has been proven to lower the recovery times for the patient [15]. MIS is challenging for the surgeon because visual information is restricted. The operative space cannot be seen directly, as it is only available through a camera placed through one of the incisions, called the laparoscope. The image obtained from the laparoscope is restricted to a 2D flat monitor and lacks many of the depth cues associated with open surgery.

Computer simulations and visualizations have often been used to facilitate training. These simulations offer an alternative to cadavers, which are expensive and do not represent living tissue. Real patients are often not an option while training. Stereoscopic applications could aid in training by providing a better spatial understanding of anatomical features. Several studies show an advantage of stereoscopic applications to monoscopic applications for training [16,17]. Luursema [16] conducted a study in which participants were exposed to either a monoscopic or a stereoscopic training condition for an anatomical learning module. Participants with the stereoscopic condition performed better in answering anatomical questions.

While the many possible stereoscopic applications may highlight the benefits of stereoscopic displays, the majority of studies conducted to this day have yielded mixed results. Kickuth [18] conducted a study for the classification of fractures using monocular 3D and stereo 3D displays and did not find any benefits or disadvantages of stereo 3D over mono 3D. Out of the 62 images used for the identification fractures, 40 of those images had artificially created fractures by a surgeon. Kickuth commented that some of the artificial fractures were of atypical shape, which may have increased the level of difficulty of the task. Hanna conducted a study in which four specialized operators conducted 60 tasks in 2D and stereoscopic 3D displays and no differences between the conditions. This study had four experienced participants that could have been using monocular depth cues to complete the tasks. For these users stereopsis might not offer an advantage due to their vast experience. However, this study did not show that stereopsis performed worse than the 2D condition, so while other monocular cues can be used in surgical tasks, using stereopsis as a cue does not lead to worse results.

These studies have been important in paving the way to evaluate the differences between monoscopic and stereoscopic 3D displays, but in order to assess the relevance of stereoscopic applications in a medical context additional research is necessary.

McIntire et al. [19] conducted a review of all the stereoscopic studies available in literature today. Out of the 162 publications and 182 experiment reviews, they found that 60% had positive stereoscopic results, 15% showed unclear benefits, and 25% showed no benefits.

While much research has been done to study stereoscopic applications, it is still unclear as to precisely when they benefit a user the most over a monoscopic application. This becomes even more murky when considering this in the medical field as many studies are not run using medical tasks or imagery. It is important to understand the limitations of stereoscopic displays. The study presented in this paper was conducted under several controlled conditions to understand how these conditions affect performance in a medical context. Distances, orientations, and colors were independent variables used to assess the performance of a visual spatial task under monoscopic and stereoscopic conditions.

Based on surveyed literature the purpose of this work is to test the following hypothesis (null hypothesis for statistical purposes): Adding stereopsis as a depth cue will have an overall positive effect on a visual spatial task in a medical context. The benefits of stereoscopic displays will be complex and dependent on task difficulty and view angle.