Designing a Decision Support System for Neurosurgery

Visualizing information with 2D vs 3D

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ABSTRACT

Visualization technology is constantly developing and works as a powerful tool for understanding complex data. Neurosurgeons at St. Olavs Hospital spend a lot of their time analyzing anatomical structures and tumor characteristics by using flat 2D imaging. This article draws on literature review within the field of neurosurgery, 3D visualization tools, human factors and realization of 3D displays. Methods were based on interviews, observation and usability tests with a low-fidelity prototype. The purpose was to explore how to use data visualization support tools in best possible way in order for neurosurgeons to be able to make secure decisions. Interacting with a three-dimensional object can be necessary for reducing the cognitive load, rather than constructing a mental model from two-dimensional images. Although 3D can be perceived as a superior solution to 2D, this is not always the case. Visualizations are often easier to integrate in a 2D system, and as 2D is a part of a 3D space, some elements in a 3D space are often better visualized in 2D. 2D and 3D highlights different aspects of relevant information. They are demonstrated to complete each other and together create an optimal view of the situation.

Keywords: neurosurgery, human factors, St. Olavs Hospital, visualization tools, 2D imaging, MRI, interactive 3D space

1. INTRODUCTION

Advanced technology is constantly developing, and the pace of innovation is only getting more impressive with time. New and advanced technology has made enormous improvements and impacts every part of our daily life in different ways. There are many advantages to the use of technology, and as for the communication society we live in today, technology continually changes our ways of sharing information, ideas and knowledge. Visual representation of data is a powerful way to make it easier to understand. Visualization works as a cognitive tool for your mind to create visual images. By imitating reality, information visualization functions as an external tool to acquire insight, understanding problems, notice hidden data and making good decisions (Ware, 2013).

1.1 Medical visualizations

Visual representation of quantitative analysis of complex data in medical context is crucial for understanding spatial relations. Visualization gives valuable support to tasks like diagnosis and planning possible treatments (Preim, Spindler, Oldhafer & Peitgen, 2001). Flat 2D imaging is currently the most familiar tool in radiology, but three-dimensional displays have over the last decade been tested, refined and applied. Complex data is believed to be described more efficiently in three dimensions (Reichelt, Häussler, Fütterer & Leister, 2010). However, acceptance of three-dimensional

(3D) displays and human factors are among issues to consider in 3D display technologies.

This paper is written in relation to my project with SINTEF Technology and Society dept. of health research and neurosurgeons at St. Olavs Hospital, Trondheim University Hospital, Norway. This article will be based on how St. Olavs Hospital share known data and plan treatments for brain tumors in their multidisciplinary team meetings (MDT) with neurosurgeons, oncologists, pathologists and radiologists.

Currently, these MDT meetings at St. Olav are based on a presentation of 2D magnetic resonance images (MRI), segmented in order to build a static 3D volume. The purpose of this paper is to discuss in which cases it would be beneficial to use interactive visualization methods like 3D versus flat 2D imaging for more efficient interpretation of complex data like pathological structures (e.g. tumors) and important anatomical structures at risk.

2. BACKGROUND

2.1 Neurosurgery

Neurosurgery involves treatments given for injuries to the nervous system, particularly the brain and the spinal cord (Schichtling & Dietrichs, 2016). Neurosurgeons are doctors specialized within neurosurgery, and they treat, among other, head and neck injuries, intracranial hemorrhage (bleeding within the brain), tumors, infections, epilepsy, etc. Their main tasks are to examine symptoms, diagnose, evaluate risky procedures, treat diseases, operate patients and give advice and guidance. Together with being responsible, careful, encouraging and motivational, keeping up with medical and technological development is an important requirement for neurosurgeons (Utdanning.no, 2017)

2.2 Brain Cancer

Brain tumors occur when abnormal cells grow and form a mass of tissue. A brain tumor can be primary, when cancer starts in the brain, or secondary, when cancer has spread to the brain from another area. A malignant tumor is more aggressive than a benign tumor, as it often grows irregularly into surrounding tissue and can spread to remote areas of the body. Some of the symptoms of brain tumors include headaches, nausea, balance and walking problems, personality changes, memory problems, numbness in the legs. There exist many different types of brain tumors, and they are usually divided into grades from I to IV based on prognostic factors. The grade of malignancy increases with grade II, III and IV. A grade IV tumor is usually defined as a *glioblastoma multiforme*. This kind of brain tumor has a very aggressive growth pattern, is badly delimited from surrounding structures and difficult to remove surgically (Roald, 2016).

2.3 MDT Meetings

The study by Friedland et al compared the outcomes between MDT and non-MDT patients by analyzing 726 cases. They found that survival was improved for stage IV patients managed in a MDT meeting compared to non-MDT patients (Bozic, 2011). The study by Lanceley et al., explore different influences on multidisciplinary team decision-making. They find that discussions often are dominated by the more experienced surgeons/doctors. Also, routine presentation of all cases limits the input from others, weakens the patient-centered focus and thus does not fulfill the purpose of an MDT meeting (Lanceley, Savage, Menon & Jacobs, 2008). MDT meetings became mandatory in Norway a couple of years ago, and is necessary to decide the course of treatment for patients.

2.4 Virtual Environments

Virtual Environments, also called VEs, can be useful tools for surgical simulation, as these are dangerous tasks to train in the real environment. Any surgical procedure has a slight risk of complications, and VEs can offer an immersive and realistic way to practice procedures and manage complications that may occur (Vicentini & Botturi, 2009). To generate a clear visual image of the reality, it is necessary that the VEs are well established. In surgical context, the different applications need to be developed in a way that includes all the details for it to be a highly effective training tool.

2.5 Building a Cognitive Model

It is beneficial for neurosurgeons to be able to build a mental model of their patient's brain based on the information they have available. Visualizing in 3D can help reduce the cognitive load of the viewer. Koike investigates the role of another spatial dimension in software visualization, where he, among other things, discusses how to help users construct a mental model efficiently. A lot of information placed in a 2D space will help users create a mental model, but in a way that might be unproductive. In addition, a large amount of complex information may result in different creations of a mental model, depending on the viewer. 2D displays integrated into one 3D framework can reduce the cognitive load, and can literally be the viewer's mental model. From this, the 3D representation will have each 2D image as viewpoints.

However, a 3D representation with an increased number of graphic elements and colours can be confusing and result in cognitive overload. In that case, it might be necessary to have the opportunity to isolate and display the different instances you want to see (Koike, 1993).

2.6 Depth perception

3D displays are expected to give the perception of depth as naturally as in our daily life. However, the visual ability to identify the real world in 3D is still a challenging task to accomplish. There are varieties of cues for depth perception. Displays of data in space deliver depth-cue information to give an exact perception of space (Reichelt et al., 2010). Visual cues are classified into different categories according to whether they require one (monocular) or two eyes (binocular). Structure-from-motion is a depth cue within monocular dynamic, which involves moving pictures. Motion-based cues like motion parallax and kinetic depth effect are important information for depth perception. The outcome of a 3D shape projected into a screen is a two-dimensional object, but once it is rotated, the three-dimensional shape becomes apparent (Reichelt et al., 2010). This is the kinetic depth effect, and it illustrates how to make sense of depth and distances, especially with complex shapes and objects pictured on top of each other which can seem to collide.

Reichelt et al. highlights in their article on depth cues the oculomotor cues, subdivided into accommodation and convergence. With accommodation, we mean how the human eye manage to hold objects at different distances as well as the ability to compute the size of objects that are depicted in close to you (Ware, 2013). Convergence involves how both eyes converge to a certain degree determined to the fictitious distance of the fixated object. The *vergence* angle obviously differs as the eyes fixate on objects nearby or far away (Reichelt et al., 2010). Based on the review by Reichelt et al., motion cues and oculomotor cues of convergence and accommodation are crucial for a pleasant 3D viewing experience. Together with the oculomotor cues, structure-in-motion provides a fast and reliable estimate of depth. However, the accommodation-convergence relationship works best with displays with short distance to observer, like for example a desktop monitor (Ware, 2013). Dalgarno, Hedberg and Harper find that among multiple visual cues, accommodation and vergence are insignificant if objects are more than 1 meter away from the observer, while motion-based cues gets less useful if objects are more than 10 meters away (Dalgarno, Hedberg & Harper, 2002). Thus, these cues, together with other visual cues, provide a comfortable desktop 3D view if the object is very close to the viewer.

2.7 Implementation of 3D in educational context

The study by Huk tested the level of understanding interactive three-dimensional visualizations within learning environments. The study turned out to give different results, depending on the students' spatial ability levels. Students with high spatial ability remained within their cognitive capacity by the presence of 3D models, whereas students with low special ability experienced a cognitive overload (Huk, 2006).

Studies have shown that navigating in virtual environments on desktop is not too different from navigating in the real world, which support the idea that students can develop their spatial ability by training in a 3D environment. They would practice their perception ability in 3D from an early stage, and together with 2D views, a 3D environment would work as a necessary supplement to form cognitive models and improve the understanding (Dalgarno et al., 2002).

2.8 3D slicer

3D-slicer have been demonstrated and proven to be an efficient tool in clinical research. A 3D construction made of MRIs are helpful to investigate the tumor mass and reveal the unseen. A 3D slicer has the potential to make the analyzation more accurate and exciting and might provide better possibilities for extracting tumor shape and position (Tayade, Patil & Sonawane, 2016). 3D slicer creates a productive way to work for advanced medical imaging. It offers the flexibility to examine from different viewpoints and navigate through a 3D modelled shape to see complex information, which both is not physically possible. Gering et al found that users needed to vary their focus between 2D images and the equivalent 3D shape, and with the use of a 3D slicer, multiple hazard could be seen simultaneously (Gering et al., 1999).

2.9 3D printing

3D printing has started to show potential as rapid prototyping in medical context. From a 3D computer model, a 3D printer machine can read the CAD data set and produce a physical model equivalent to the computer model. Examining a solid free form in hand is often better than 2D or 3D visualization tools, even though it can't simulate tissue and surrounding structure (Rengier et al., 2010). Dr. Sloane Guy recently changed his opinion on 3D printed models being a gimmick. Once he held a 3D-printed model of the heart of one of his patients, the defect was easy to see, and the traditional approach had to be rejected. He admitted that without a physical model to manipulate, he never would have realized what was the right decision to make (Rogers, 2017). Another example is Dr. Darin Okuda, who also discovered the benefits of 3D-printed models for diagnosing and understanding brain tumors. With a physical 3D form, it was easier to characterize their shape and surface, which is not as clear from a simple scan (Coldewey, 2017).

3. METHOD

In relation to my project on designing an interface prototype of a decision support system, I have used different methods to gain insight in how an MDT meeting takes place. First, I needed to identify what information to include in order for neurosurgeons to be able to make secure decisions. Second, I explored how to use data visualization tools in the best possible way to make sense of information available. Findings were based on interviews, observation and usability tests of low-fidelity prototypes. 2D imaging and interactive 3D interfaces were tested and compared with the tools I had available.

3.1 Interview

Semi-structured interviews were mainly performed to gain as much information as possible on neurosurgery and brain cancer diagnosis and treatment. A semi-structured interview combines some feature from both unstructured and structured interviews (Rogers, Sharp & Preece, 2011). A basic interview script was created in advance. Follow-up questions were generated along the way to let new and relevant information come forth.

3.2 Usability testing

Usability testing is the most efficient way to figure out how your target user experience the product. If the user can't complete the assigned tasks, there are obviously something that needs to be changed (Usability First, 2015).

The usability tests were based on me giving mission tasks which basically followed the user through all pages of a decision support interface. The user was encouraged to constantly self-report his thoughts and reasons behind the choices that were made. Along the way, the user characterized the tumor from the information he had available. At the end a decision was made whether this patient needed treatment or not.

Together with 2D MRIs, the user also had access to a brain 3D model on an interactive screen display. The brain was transparent, in which you could see the outer structure and a colored tumor inside. As I observed, his mission was to characterize the tumor by rotating and zooming. He was then handed a low fidelity model of the same 3D shape, only this time it was a static image which was unable to interact with. The static 3D model could also visualize the different areas in the brain if wished for.

As the participant performed a pre-planned task, I acted more as a "fly on the wall". I observed how the user interacted with the 3D model to gain understanding for their context, tasks and goals. Next, I needed to evaluate how my prototype supported these tasks and goals.

4. RESULTS

From interviews, the neurosurgeon vaguely expressed an opinion that an interactive 3D system works more like a "fancy" tool in addition to 2D images. However, they do already use 3D sometimes in the analyzing stage.

In my work in observing how the neurosurgeon interact with an interactive 3D model, the immediate feedback was positive. The user liked how the brain and tumor was visualized. The unfamiliarity of a touchable device was clear to me as the user was very careful on interacting with the model at begin with. After a while he gained more confidence with the interaction and were able to tell me the position of the tumor. Obviously, he had more experience with navigating on a computer display with a mouse.

When looking at the static 3D shape, users had a hard time perceiving depth. As discussed earlier, depth perception is depended on structure-in-motion. You need to be able to rotate a 3D shape to be able to build a cognitive model in your mind. Their expertise and habits, however, still lies within analyzing 2D MRIs. An interesting observation was how segmentation of tumor caught the users interest. It visualized the same segmented tumor in 3D and its growth pattern over time. Notes like preoperative, postoperative or other treatments were provided as well as a different prognosis. The user found this interesting, and could see the potential of a simpler characterization of the tumor itself. Although, this would probably be a helpful tool for oncologists, as this is within their expertise. Neurosurgeons are basically more interested in the neuro anatomical relationships.

5. DISCUSSION

Multidisciplinary team meetings at St. Olavs Hospital are based on presenting patients with the support of MR images. They use the software called SECTRA to scroll through MRIs segmented in order to build static 3D volumes.

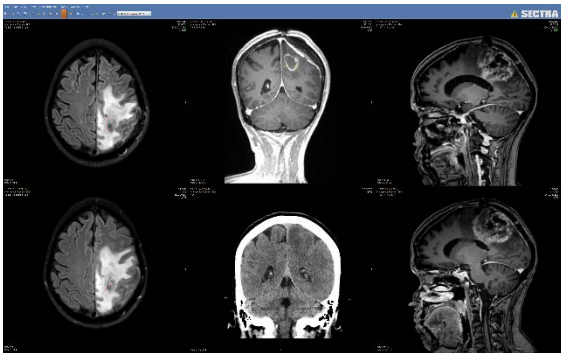

Figure 1 At St. Olavs hospital they use SECTRA to scroll through MRIs segmented in order to build static 3D volumes.

As 3D could be seen as a superior solution to 2D, this might not always be the case. The human brain is created to navigate and interact in 3D space, as we live in a three-dimensional world. Although, visualizing a 3D environment on an interactive media is a difficult task to accomplish. Visualizations are often easier to integrate in a 2D system, and as 2D is a part of a 3D space, it is safe to say that some elements of a 3D space are often better visualized in 2D.

In learning situations regarding treatment of brain cancer, 3D environments have a lot of potential and can improve a conceptual understanding. Spatial cognitive representation and the ability to form a cognitive 3D object in your mind are desirable in this case.

From interviews, usability testing and literature review, findings say that there is potential in interactive 3D displays for St. Olavs Hospital. The use of interactive 3D displays in medical context does already exist in different parts of the world. The process of going from 2D to interactive 3D might seem beyond their comfort zone and expertise at first, but keeping up with new technology is crucial in which case it is beneficial. Known data should be visualized in a way that benefits all participants to fulfill the requirements of an MDT meeting and to come up with a good decision together.

An interactive 3D object could work as a helpful tool for finding hidden patterns in data. By rotating a 3D modelled shape, you enable the structure-in-motion cue, together with a better perception of depth. The accommodation-convergence relationship is known to be difficult to accomplish in a good way unless objects are less than 1 meter away from the observer. As examining a brain tumor and its surrounding structures require the object to be close, it should be achievable in our case.

Findings have made me conclude that having an interactive 3D brain supported by MRIs could be expedient. In my opinion, both 2D and 3D navigation can highlight different elements and together create an optimal view of the situation. By viewing important anatomical areas and structures in a 3D model, it is simple to notice what the tumor affects. It could be an efficient tool in pre-planning of a surgery, as to see where surgeons might be able to reach and remove the tumor without harming healthy tissue and structures. Tracts are on example that have potential in being visualized within a 3D model. Tracts are like threads and are connected to different human functions, like speech, balance, etc. There are loads of them, and there might be efficient to isolate and view different types of tracts to analyze what the tumor might affect and what to avoid during a surgical procedure. Being able to get a clearer view of the situation and plan a surgical path to avoid affecting tracts and functions. Segmentation of tumor might be an advantageous tool for the oncologists present in these meetings. I also see possibilities in obtaining 2D MRIs from all angles, using a clipping plane from the concept of a 3D slicer. Viewpoints should be experimented with, whether they would like to set the tumor in the middle, etc.

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