

Head-mounted displays in ultrasound scanning

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1. Introduction

Ultrasound imaging, which is also called ultrasound scanning or sonography, is conducted by exposing part of the body to high-frequency sound waves to produce a visualization of the inside of the body. Ultrasound scanning is non-invasive, so it is usually painless. It is also widely available, easy-to-use and less expensive than other imaging methods. Because ultrasound imaging uses no ionizing radiation it is safer for the patients and medical staff.

Ultrasound is often used for the diagnosis and monitoring of pregnant women and the unborn infant (Dudley, 2004). In Finland, an ultrasound scan is performed on mothers twice during pregnancy, the first in weeks 12+0 to 13+6 and the second after 19+0 to 20+0 weeks. The purpose of the screening is to check that the fetus is developing well and there are no abnormalities. As approximately 60 000 births occur per year, the total annual number of normal/routine fetus screenings is about 120 000. If mother has some illness, like diabetes, there is a reason to do more check-ups for the developing fetus.

The ultrasound scanning is based on a transducer that is located in a probe held by a sonographer and moved over the patient. The working position with the probe is often difficult, as it can cause a twisted position on users back, upper limbs and neck. For example, when investigating patient's heart, the patient is on the left side and the sonographer is doing sonography over the patient's body, which causes an abnormal working position (Morton & Delf 2007). The poor working position can cause tension to the neck, which could lead to uncomfortable feelings and headache.

Further problems can be created by the display of the sonographic machine, which is always placed on the top of the device. In most machines, the display is placed too high and when the gaze of the user changes between the patient and the display, the midwife must constantly look at either the display or the patient. This can place strain on the neck and other upper body muscles and can be uncomfortable during a long working day.

The situation can be especially problematic if the user has presbyopic vision and uses progressive lenses, because the user has to tilt his/her head to a very uncomfortable position, which can cause extra strain both to the neck and head (Figure 1.). An HMD could

be used to reduce this strain, as the scanning result is constantly visible in the visual field of the midwife and the need to turn the head would be reduced.



Fig. 1. Working position at the ultrasound machine with a normal display. The midwife must look at the display to see the results of scan, but has to turn her head toward the patient when repositioning the probe.

To avoid excessive work strain, special attention has been given to the work schedule of midwives. For example, at the Maternity Hospital of the Helsinki University Central Hospital there is a thirty-minute time for every ultrasound screening, so that gives to possibility to take a little break between the patients.. Furthermore, only two full working days with ultrasound screening tasks can be done sequentially. After that three resting days in other duties are required.

The most typical problems in ultra-sound scanning are musculoskeletal injuries and suffering of visual problems (Fernando, 1996). In a study focusing on the prevalence and causes musculoskeletal injuries among sonographers Morton & Delf 2007 report that experiences of pain and discomfort among sonographers is quite frequent, as 63.0% to 98.7% of the sonographers report some symptoms. Table 1 shows that shoulders, neck and upper back are quite often affected (Morton & Delf 2007). Visual discomfort among sonographers has been investigated less frequently, but some findings indicate that scanning work can

cause eyestrain and a headache which can be related to eyes, neck or upper limbs (Fernando, 1996).

	Miles, 2005	Pike et al, 1997	Necas, 1996
Neck	66 %	73 %	76 %
Upper back	45 %	60 %	53 %
Middle back	29 %	40 %	---
Lower back	48 %	65 %	46 %
Shoulder	67 %	73 %	66 %
Upper arm	34 %	38 %	---
Forearm	29 %	35 %	33 %
Wrist	47 %	65 %	61 %
Hands/fingers	43 %	60 %	47 %
Elbow	32 %	---	33 %

Table 1. Findings of anatomical areas which are affected by pain and discomfort. (adapted after Morton & Delf 2007).

As there has been many suggestions of using a head-mounted display in medicine, and the results have been generally positive, we wanted to test the usability of a HMD in ultrasound scanning task (Howarth, 1994 ; Koesveld et al, 2003; Letterie, 2002 ; Ormerod et al. 2002; Ross & Naluai-Cecchini, 2002; Rosenthal et al, 2002; Reisman et al, 2002; Ryndin et al, 2005; Satava, 1994; Satava & Jones, 1998; Schuhaiber, 2004; Rosenthal et al, 2002; Reisman et al, 2002).

However, there are also a number of possible problems related to the using an HMD in an ultrasound scanning task. Firstly, earlier studies related to head-mounted displays have indicated subjective visual strain symptoms in users (Häkkinen et al., 2004; Hiatt et al, 2002: Mon-Williams et al. 1993; Howarth & Costello, 1997), although other studies have suggested that the symptoms are similar to those when using an ordinary display (Peli, 1998; Rushton et al., 1994; Sheedy & Bergström, 2002). Secondly, an HMD might occlude parts of the visual field and thus make the performance of the scanning task more difficult. We took these issues into account when creating the experimental setup.

2. Purpose of the study

In the present study the purpose was to investigate the issue of attention shifting in an ultrasound scan task, where a midwife has to alternately observe the patient and the display showing the scan results. We wanted to determine how midwives with previous experience of conventional ultrasound scanning would experience using an HMD in an ultrasound scan task. We also compared two different head-mounted display types in the scan task. The participants performed an abdominal ultrasound scan with a see-through Sony Glasstron in experiment 1 and with Micro-Optical SV-6 PC viewer in experiment 2.

The participant had to find, mark, identify and measure different abdominal organs. The organs were the uterus or prostate, depending on patients' sex, the both of the kidneys and the bladder. Each organ was measured linearly and crosswise and the volume of the bladder was also determined. Each of the identified organs was documented by printout. The task lasted 20 minutes. During the task the experimenter observed the user from behind. The

experimental starting times were randomly distributed in the morning (9 am – 11 am) so that the existing eye strain would not affect the results. The participants did not know the ultrasound machine used in the experiment beforehand but they were able to familiarize themselves with the machine before the experiment.

2.1 Participants

Twenty-four registered midwives (mean age 43.1 years) with normal or corrected-to-normal vision participated in the two experiments: 13 in Experiment 1 (mean age 41.6 years) and 11 in Experiment 2 (mean age 44.8 years). The age of the youngest participant was 33 years and oldest 52 years. All participants were female and already had several years of experience of ultrasound methods in fetus scanning; 42.0% worked in a local hospital, 33.5% in Helsinki University Central Hospital, 17.0% in central hospitals, 4.0% in a healthcare centre and 4.0% of them were returning to working life, so they had no current working place.

2.2 Apparatus

We used two head-mounted displays: a see-through Sony Glasstron head-mounted virtual display in experiment 1 and a monocular Micro-Optical SV-6 PC viewer in experiment 2. The resolution of both displays was set to 640x480 pixels in both experimental conditions. The virtual image was at a distance of 1.4 meters with both displays. We placed a monocular display in front of the leading eye measured with the target aiming method (Figure 2.). We used a Vivid 3 ultra sound machine where we connected displays one at a time.



Fig. 2. Ultrasound scanning with the monocular display. The midwife can see the ultrasound scanning image in her left visual field and simultaneously follow the location of the probe with both eyes.

2.3 Procedure

In the main experiment the participant first completed a background questionnaire that contained general questions regarding the health of the participant. They described their head-mounted display and virtual reality experience, daily near-work time, computer-gaming frequency, motion-sickness frequency, headache frequency and handedness. We also asked when was the last time they had eaten and taken any medicines that made them more susceptible to nausea (sedatives or tranquilizers, decongestants, anti-histamines, asthma medicine or alcohol). Finally, the participants described their preconceptions and opinions about head-mounted displays. After completing the background questionnaire the participants began to do the task. After the task we gave the participants a questionnaire in which they described their opinions about the head-mounted display as well as the level of sickness symptoms they experienced after the use of the head-mounted display.

The participants performed an abdominal ultrasound scan with a see-through Sony Glasstron in experiment 1 and with Micro-Optical SV-6 PC viewer in experiment 2. The participant had to find, mark, identify and measure different abdominal organs. The organs were the uterus or prostate, depending on patients' sex, the both of the kidneys and the bladder. Each organ was measured linearly and crosswise and the volume of the bladder was also determined. Each of the identified organs was documented by printout. The task lasted 20 minutes. During the task the experimenter observed the user from behind. The experimental starting times were randomly distributed in the morning (9 am - 11 am) so that the existing eye strain would not affect the results. The participants did not know the ultrasound machine used in the experiment beforehand but they were able to familiarize themselves with the machine before the experiment.

3. Results

In the open questions the participants were asked about their positive and negative opinions about using the HMD. There were 18 positive and 22 negative responses in experiment 1 and 13 positive and 24 negative responses in experiment 2. The responses were diverse, but there were some issues that were brought up more frequently (Table 2). Only response categories with three or more answers are reported in the table, so the total number of answers in the table is less than in the complete experiment. 33.3 % of all the participants told in the post-experimental questionnaire that the ergonomics was better while using the HMD. In the answers the better ergonomics meant for example that using the HMD allowed the participants to move more and helped them to find out better working position. This matched their pre-task expectations, as the same number of participants expected better ergonomics before the task (positive pre-task answers in Table 2). The positive expectations meant that the participants expected to have a better working position and less strain in their neck and upper limbs with the HMD.

The image quality was also regarded as important, as 16.6% of the participants mentioned that the image quality was better with the HMD than with the ultrasound machine (positive post-task answers in Table 2). Interestingly, the participants expected this, as some had already mentioned this before the experiment (positive pre-task answers in Table 2). Focusing to the patient was also a significant issue, as 16.6% of all participants liked the

opportunity to be able to focus to the patient. This was visible in the pre-task expectations, so it was an issue that the participating nurses did not regard as important when considering the use of a head-mounted display.

The negative post-experimental findings were more divided (Table 2). Difficulties in wearing the display were most commonly mentioned negative post-task opinions (Table 2). Also, difficulties in communication with the patient and reduced visibility in the visual field due to the occluded areas were often mentioned. Interestingly, the sickness symptoms that were often mentioned in the pre-task questionnaire were not regarded as problematic in the post-task questionnaire.

If the two displays are compared, there are no clear differences in the post-task opinions (Tables 3 and 4).

However, certain display-specific issues were found to be disturbing. With the Glasstron the difficulty in wearing the display, the reduced visibility and difficulties in communicating with the patient were emphasized (Table 3). On the other hand, with the MD-6 the main problems were related to difficulties in keeping the display stationary in the correct position in front of the eye, the small size of the display and perceptual problems related to binocular vision experienced by the participants (Table 4). Positioning the display was especially difficult for the participants who used progressive or bifocal spectacles.



Fig. 3. Ultrasound scanning with the see through biocular display. The midwife can see the ultrasound scanning image in her visual field and simultaneously follow the location of the probe through the see-through display.

Positive pre-exp	Freq	Negative pre-exp	Freq
Ergonomics will be better	8	Adverse symptoms	8
Don't know	6	Decreased contact patient	6
Better display quality	3	Lack of eye contact	6
Total	17		20
Positive post-exp	Freq	Negative post-exp	Freq
Ergonomics was good	8	Difficult to maintain contact to patient	4
Good image	4	Reduced visibility	4
Focus to the patient	4	Too much weight	4
Total	16		12

Table 4. The most frequent positive and negative post-task response categories in experiment 2 (MD-6).

Positive post-task	freq	Negative post-task	freq
Focus on patient	4	Difficult to wear the display	4
Ergonomics were good	4	Reduced visibility	3
Better concentration on examination	3	Difficult to communicate with the patient	3
Total	11	Total	11

Table 3. The most frequent positive and negative post-task response categories in experiment 1 (Glasstron).

Positive post-task	Freq	Negative post-task	Freq
Ergonomics were good	4	Difficult to keep the display in correct position	3
Good quality of image	3	Small working area through the display	3
Focus on patient	3	Problems with vision	3

Table 4. The most frequent positive and negative post-task response categories in experiment 2 (MD-6).

4. Conclusions

The use of head-mounted displays in medicine is in a preliminary stage and further research is needed to evaluate its long-term clinical impact on patients, nurses, doctors and hospital administrators. Other studies have shown that the use of a head-mounted display can be more precise than the use of a conventional desktop system. It also allows better accuracy and safety of clinical decisions based on images. However, psychological factors have a strong effect on the acceptance of the new technology. The widespread use and the universal transfer of such technology will remain limited until there is a better understanding of user experience issues related to this application.

Our results indicate that midwives regarded head-mounted displays as acceptable accessories to an ultrasound scanning task. Using the monocular head-mounted displays

prompted slightly fewer negative comments than the use of a binocular see-through display. The reason for the differences might be related to the fact that the small monocular display disturbed the users less than the see-through display, which decreases the contrast of the visual scene and occludes peripheral vision.

The results showed both positive and negative ergonomics issues. The positive issues were related to the better working position made possible by the head-mounted display. In other words, using a HMD requires less body rotation and less stretching out of the hands during scanning. This could ease adverse physical symptoms of sonographers in the long run. Furthermore, this might prevent the development of a musculoskeletal injury.

The negative ergonomics issues were complaints of difficulties in wearing the display and keeping the display stationary in front of the eye. In the long term, such issues might greatly decrease the satisfaction of users, so attention should be paid to the design of the displays so that wearing the display would be effortless and the display would remain stationary on the head in all work situations.

Generally our results suggest that the use of head-mounted displays is feasible during ultrasound scan. However, improvements in image quality as well as the design of the head-mounted display are necessary before the headset can be recommended for general use during ultrasound scanning. The test population in our experiment was fairly small, so it is difficult to generalize the results. A larger study will be needed to evaluate the possible trends in user performance over single sessions and over longer time periods. There may also be significant variability between users in accuracy and fatigue effects.

In the future, we are going to continue studies with the sonographers. Interesting questions are, for example, how a presbyopic person manages to use head-mounted display with the spectacles in the working situation. Also, we plan to investigate whether there are any differences with users who wear progressive lenses, normal single power lenses or contact lenses.

From an ophthalmological point of view there are also several interesting research topics, like the possible relation of head-mounted display use and intraocular pressure (IOP) of the eye and the effect of HMD use to the dry-eye syndrome (Schaumberg et al, 2003).

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