Patient Distraction and Entertainment System for Magnetic Resonance Imaging using Visual Effects Synchronized to the Scanner Acoustic Noise

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Abstract: Acoustic noise is a major source of discomfort for patients undergoing magnetic resonance imaging (MRI) examination. Loud noise is generated from fast gradient switching during MRI scanning. The noise level is reduced by wearing hearing protection devices, but the noise cannot be entirely avoided. Patient distraction techniques can shift the attention away from the annoying noise. We implemented a simple and low-cost system for patient distraction using visual effects that are synchronized to the gradient acoustic noise. This multisensory approach for patient distraction is implemented on a 3.0T scanner and tested in six healthy adult volunteers. After the scan was completed, the volunteers were asked about their scan experience with visualization, rating their preference on a 0-10 scale. The images were visual inspected for any artifacts. All volunteers indicated improved experience with the proposed visualization system with an average score of 6.3. The image quality was not affected by visualization.

1 INTRODUCTION

Magnetic resonance imaging (MRI) is a powerful diagnostic technique, with approximately 60 million scans performed worldwide each year (Sutton et al., 2008). MRI provides excellent soft tissue contrast without using ionizing radiation, making it a preferred technique among many patient populations, including children. Unfortunately, the MRI environment suffers from multiple factors that make it less patient friendly. These include the confined environment inside the magnet bore and the loud acoustic noise generated by the scanner.

Acoustic noise in MRI arises from the rapid alterations in the current flowing in the gradient coils when executing an imaging protocol. The large currents in the presence of the strong magnetic field produce large Lorentz forces, which cause the vibrations of the gradient coils. The vibrations generate loud tapping, knocking, or chirping sounds (McJury and Shellock, 2000).

Acoustic noise can reach dangerous levels, with the sound pressure level exceeding 100 dB(A) (Counter et al., 2000; Price et al., 2001), where the units dB(A) account for the frequency-dependence of the human ear. Earplugs, headphones, and active noise cancellation (McJury et al., 1997) can significantly reduce the noise level and improve hearing protection and patient safety (Brummett et al., 1988). However, acoustic noise is not completely avoidable, and noise remains a factor that adversely affects the patient experience in MRI (McNulty and McNulty, 2009).

A recent approach to reduce the perceived noise it to play the gradient pulses in a fashion that produces music (Ma et al., 2015). This approach can improve the patient experience, but requires special programming requirements to change the way MRI pulse sequences are performed. This is beyond the reach of most MRI centres.

The loud noise of MRI represents an intense auditory stimulus. However, the intensity of a sensory stimulus is one of multiple factors that determine the tolerance of that stimulus. The perception of the stimulus also depends on the presence of other stimuli in the environment, and on the multisensory integration capabilities of the brain (Macaluso and Driver, 2005; Shimojo and Shams, 2001; Stein et al.. 2009; Witten and Knudsen, 2005). Hence, the perception of the loud noise of MRI can

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be modulated by the introduction of other sensory inputs (Gillies et al., 2013). Multisensory studies suggest that vision dominates our sensory input and can bias the perception of other stimuli (Witten and Knudsen, 2005). We investigated whether visual effects in the form of animated graphics that are synchronized with the scanner acoustic noise could change the patient's perception of the loud noise of the scanner. Moreover, by using pleasing and engaging visual effects, this approach may provide an entertaining environment that could further improve the patient comfort and experience.

In this paper we describe the implementation of a novel, simple, low-cost, and practical patient distraction system based on audio-visual integration, and demonstrate its performance in a clinical MRI system.

2 METHODS

2.1 System Setup

All developments were carried out on a 3.0 T Philips Ingenia MRI system (Philips Healthcare, Best, The Netherlands). Figure 1 shows the schematic of the patient distraction and entertainment setup. A sensitive microphone is placed in the MRI operator room adjacent to the MRI examination room. The MRI scanner's noise is picked up by the microphone and is fed as the input audio signal to a music player with sound-modulated visualization capabilities. The visualization is projected back to a display monitor placed at one end of the scanner magnet. The display is projected to the patient eyes using a system of mirrors mounted on top of the head coil. MRI-compatible goggles, if available, can be used in place of the display monitor and the mirrors.

The Winamp media player software v5.666 (Nullsoft Inc., available at www.winamp.com) was used to play the input noise signal from the microphone. Other players with comparable functionality can be similarly used. Winamp includes multiple visualization plugins, including MilkDrop 2 (www.geisswerks.com/milkdrop), which was used in all experiments in this work. MilkDrop is a hardware-accelerated environment for running visualization routines (called presets) defined by a scripting language.

A large number of visualization routines are available in MilkDrop. However, not all routines are suitable for use with patients. Based on experimentation we identified the following criteria for an MRI-friendly visualization routine. First, the visualization routine must be reasonably responsive to the audio signal such that the patient can easily associate the animation with the acoustic noise. Second, the routine must use an eye-friendly color scheme, avoiding very bright colors. Third, the routine should avoid very rapid transitions. Finally, the routine should contain entertaining animations that engage the patient. Based on a consensus of the authors and two MRI technologists, the visualization routine selected in this work was the "Flexi, martin + geiss - dedicated to the sherwin maxawow". This preset displays a two-dimensional color-changing flowing pattern which is modulated by the input audio signal. This preset satisfied all the four criteria we identified for a patient-friendly visualization routine (Fig. 2).

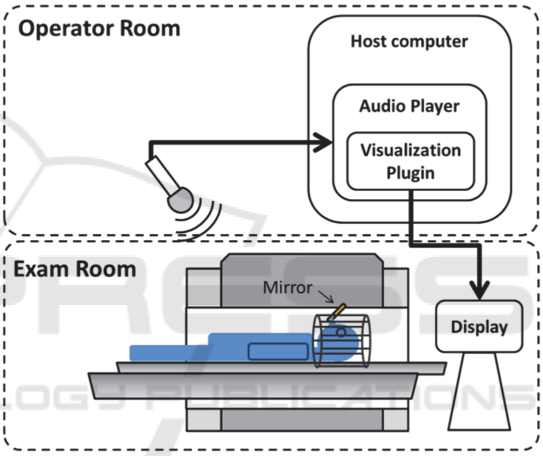

Figure 1: The MRI acoustic noise-synchronized visualization system. The mirror mounted on the head coil helps the patient to view the display.

2.2 MRI Experiments

Six healthy adult volunteers (5 males, 1 female, age = 42±13 years) participated in this study. The volunteers were told that they will be watching video material during the scan, but no clue was provided about how the visualization worked or that it was triggered by sound.

All six subjects were scanned twice using the same protocol but with the visualization feedback used in only one imaging session. Imaging in the two sessions used a routine MRI brain protocol including a survey scan, field calibration scan, diffusion weighted imaging (DWI), three-dimensional magnetization-prepared T1-weighted (3D T1), multi-slice dual-echo turbo spin echo (2D TSE) and multi-slice fluid-attenuated inversion recovery (2D FLAIR) pulse sequences. These scans are typically used in routine clinical examination. The total scan time for each imaging session was ~16 min. Note that the intensity and the pattern of the scanner noise directly depend on the type of the pulse sequence used and its scan parameters. The scan parameters of all pulse sequences are listed in Table 1.

Immediately after the imaging study, the volunteers were asked whether they prefer the scan with or without visualization, and were asked to rate their preference on a scale from 0 to 10, with 0 being no preference for either options (with or without visualization), and 10 being highest preference. To reduce possible bias on scoring, half of the subjects underwent the visualization experiment in the first part of the study, while the other half had the visualization in the second part of the scan.

To investigate whether the visualization feedback could increase the degree of volunteer involuntary motion, corresponding image sets in the two sessions were compared side-by-side for any possible motion artifacts.

Table 1: The MRI protocol and the scan parameters used in the study. GRE, gradient-recalled echo; SE, spin echo; EPI, echo planar imaging; FOV, field-of-view; TR, repetition time; TE, echo time; TI, inversion time.

Protocol	**2D Survey**	**2D DWI**	**3D T1**	**2D TSE**	**2D FLAIR**
Sequence type	GRE	SE + EPI	GRE	SE	SE
TR / TE [ms]	11 / 4.6	5807 / 88	8.0 / 3.7	6800 / (9.5, 90)	10,000 / 80
TI [ms]	800	NA	1068	NA	2600
Flip angle [°]	15	90	6	90	90
FOV [mm]	300 x 300	240 x 240	256 x 256	256 x 256	256 x 256
Slice Thickness [mm]	10	3	1	3	3
Matrix	308 x 128	200 x 118	256 x 256	256 x 208	256 x 238
Plane	3-plane	Axial	Sagittal	Axial	Axial
Pulse train length	64	59	256	12	16
b-value [s/mm^2]	NA	1000	NA	NA	NA
Scan time [min:sec]	0:31	2:02	5:05	3:24	4:20

3 RESULTS

Figure 2 shows screenshots taken from the visualization preset while playing out an MRI pulse sequence. The visualization provided a sound-responsive modulation of the flow pattern that is pleasant for the observer. Table 2 lists the preference and the scores reported by the six volunteers. All volunteers preferred visualization, with average score 6.3±1.2.

The images acquired in the two sessions (with and without running the visualization) showed no noticeable differences, indicating that the visualization feedback did not affect the image quality (Fig. 3). In one subject, motion artifacts were observed on the dual echo scan as a result of patient coughing in the middle of the scan. The scan was not repeated.

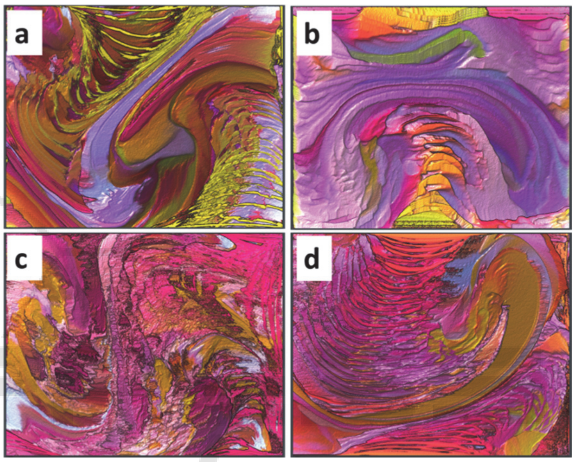

Figure 2: Screenshots of the MRI acoustic noise-synchronized visualization at four moments during the execution of a T1 pulse sequence. The first two images (a,b) are from a quiet period in the sequence, while the last two (c,d) are recorded at a gradient-intensive period.

Table 2: Scores given by the volunteers for their scan preference. 0=no preference, 10=most preference.

Volunteer	**Prefer Visualization? (Yes/No)**	**Score [0-10]**
1	Yes	7
2	Yes	5
3	Yes	8
4	Yes	5
5	Yes	7
6	Yes	6
All		**6.3 ± 1.2**

4 DISCUSSION

The high preference score reported by the volunteers for the visualization indicates that visual effects synchronized to the scanner's acoustic noise improved the patient experience during MRI examination. All volunteers indicated that they were entertained by the visualization. One volunteer indicated that the visualization kept him awake during the study when in fact he preferred to take a nap. This case demonstrates that the visualization may not be suitable for all subjects and that it is better suited for certain categories of patients. This approach for patient distraction and entertainment may be particularly beneficial for scanning children.

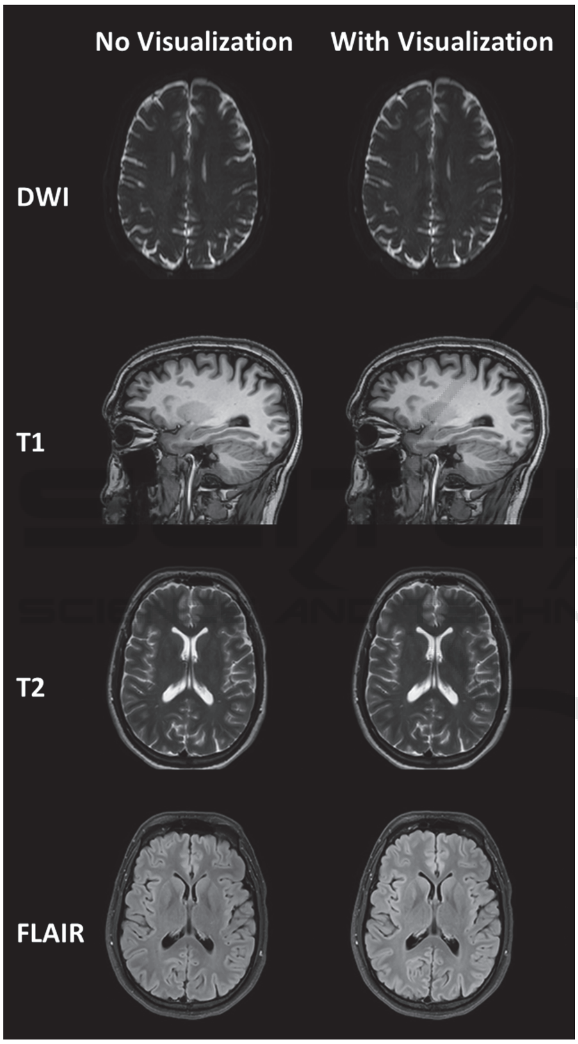

Figure 3: MRI images acquired from one volunteer with and without the visualization. No differences in image quality are observed between the two datasets.

All experiments were performed with a single visualization routine for the relatively short 16-min scan. Nevertheless, one volunteer expressed that after approximately five minutes the visualization scheme was not as entertaining as it was at the beginning of the study. Multiple and interleaved routines should thus be incorporated and cycled through in the visualization program to prevent boredom from longer scans.

Very bright colors or rapid animations corresponding to periods of fast-switching gradients may be startling to the patient and cause involuntary motion. We did not notice any effect on the image quality from turning on the visualization routine used in this preliminary study. A larger study is recommended to study the effect of this technology on patient motion with different types of visualization routines.

The developed system for patient distraction and entertainment in MRI is a simple, low-cost (costs only the price of a sensitive microphone), and easy to build around any MRI system without the need for specialized pulse sequences. MRI-compatible display monitors or goggles are required in this approach. However, MRI-compatible display monitors are widely available in many MRI suites as they are needed for functional MRI studies.

We anticipate that optimized or even patient-customized visualization routines may further improve the patient experience and reduce the level of anxiety associated with MRI procedures. These possibilities will be explored in future studies.

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