



Case report

MRI acoustic noise-modulated computer animations for patient distraction and entertainment with application in pediatric psychiatric patients

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ABSTRACT

Purpose: To reduce patient anxiety caused by the MRI scanner acoustic noise.

Material and methods: We developed a simple and low-cost system for patient distraction using visual computer animations that were synchronized to the MRI scanner's acoustic noise during the MRI exam. The system was implemented on a 3T MRI system and tested in 28 pediatric patients with bipolar disorder. The patients were randomized to receive noise-synchronized animations in the form of abstract animations in addition to music ($n = 13$, F/M = 6/7, age = 10.9 ± 2.5 years) or, as a control, receive only music ($n = 15$, F/M = 7/8, age = 11.6 ± 2.3 years). After completion of the scans, all subjects answered a questionnaire about their scan experience and the perceived scan duration.

Results: The scan duration with multisensory input (animations and music) was perceived to be ~15% shorter than in the control group (43 min vs. 50 min, $P < 0.05$). However, the overall scan experience was scored less favorably (3.9 vs. 4.6 in the control group, $P < 0.04$).

Conclusions: This simple system provided patient distraction and entertainment leading to perceived shorter scan times, but the provided visualization with abstract animations was not favored by this patient cohort.

1. Introduction

Magnetic resonance imaging (MRI) is a versatile noninvasive and radiation-free imaging modality. Over 60 million MRI scans are performed worldwide each year [1]. MRI is generally considered a safe imaging modality. However, the MRI scan environment is less than patient friendly. The confined space of the magnet and the loud repetitive acoustic noise generated during the scan [2,3] are two major factors that promote anxiety in the MRI environment. Anxiety-related reactions during MRI occur in 2–30% in the general population, resulting in early scan termination in 1–5% of patients [4–7].

The MRI acoustic noise arises as a result of rapid-switching of electrical currents in the gradient coils, which causes vibrations in the coils and the surrounding structures [8]. The resulting noise pressure levels may exceed 100 dB(A) [9,10], which necessitates the use of hearing protection such as earplugs and headphones [8,11,12]. While hearing protection significantly attenuates the sound level, acoustic noise remains a source of anxiety that adversely affects the patient experience with MRI scanning [13].

It has been recognized that the perception of a stimulus depends on

the presence of other stimuli in the environment due to the multisensory integration nature of the brain [14–17]. Hence, the perception of loud repetitive MRI noise could be modulated by the introduction of other sensory inputs. Thus, patients undergoing MRI scanning are often provided with music or radio through headphones. The audio material serves as a distraction from the MRI environment and attenuates the perception of the scanner noise.

Multisensory studies suggest that vision dominates our sensory input and can bias the perception of other stimuli [17]. Thus, visual input may have better distracting effects than acoustic stimulus on the patient. Typical video distraction in MRI, when available, is provided in the form of conventional multimedia content (e.g. movies). However, acoustic noise remains as an external source that interferes with the audio/video material provided for distraction. On the contrary, presenting sensory inputs modulated by the MRI acoustic noise has been suggested to improve patient experience [18,19], and preliminary studies has shown promise in healthy adults [19].

We hypothesized that computer-generated animations synchronized to the MRI acoustic noise may provide a favorable modulation of the perception of the loud repetitive auditory stimulus for patients, and

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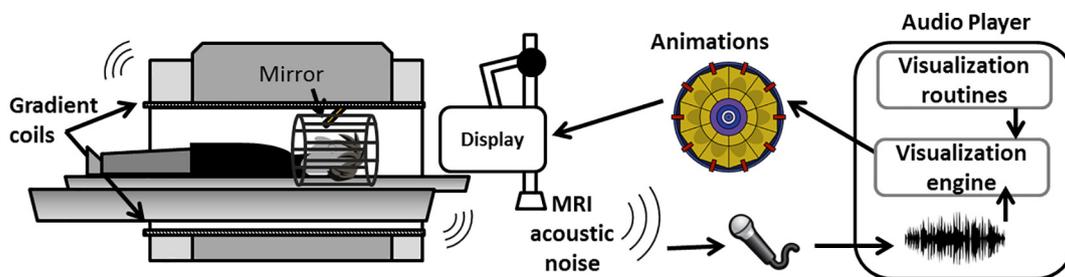


Fig. 1. System for patient distraction and entertainment using MRI acoustic noise-synchronized visualization. The acoustic noise from MRI scanning is detected using a sensitive microphone. The noise is fed as the input to a computer audio player equipped with a visualization engine. The engine generates an animated scene that is modulated by the sound signal according to the specified visualization routines. The animated scene is displayed on a monitor placed at one end of the scanner magnet, and projected to the patient using a system of mirrors mounted on top of the head coil.

could even turn the acoustic noise into a form of entertainment that engages the patient and shifts his/her focus from the MRI environment. In this work, we investigated this hypothesis in a population of pediatric patients with bipolar disorder undergoing routine clinical MRI scanning.

2. Material and methods

2.1. System setup

A preliminary system for patient distraction/entertainment (Fig. 1) was built and interfaced to a 3.0 Tesla MRI system (Philips Healthcare, Best, The Netherlands) [19]. The system employed a microphone placed adjacent to the MRI examination room to pick up the scanner's acoustic noise. The noise was fed as the input to a computer program that modulated animated visualization routines using the sound signal. The animated scene was displayed on a monitor placed at one end of the scanner magnet, and projected to the patient using a system of mirrors mounted on top of the head coil.

2.2. Sound-modulated visualization routines

The input noise signal from the microphone was fed as the input to the computer media player Winamp v5.666 (Nullsoft Inc., www.winamp.com). Winamp comes equipped with the MilkDrop2 visualization plugin (www.geisswerks.com/milkdrop), which was used to generate the sound-modulated animations. MilkDrop2 uses a hardware-accelerated engine that runs animation scripts (called presets). These presets manipulate the animation scene depending on the sound frequency (bass, midrange and treble) and amplitude. A sample preset file is provided as supplementary material. A large number of pre-programmed visualization routines were available. However, not all routines were suitable for use with patients undergoing MRI. Hence, a strategy was defined for selecting from among existing routines. We selected few visualization routine that we identified to satisfy the following requirement: (i) be reasonably responsive to the audio signal such that the patient can easily associate the animations with the acoustic noise; (ii) use an eye-friendly color scheme, avoiding very bright colors which might be startling to the patient; (iii) avoid very rapid scene transitions; and (iv) employ entertaining animations that engage the patient. In addition to these characteristics, the visualization paradigm included a set of visualization routines that cycled through the study to prevent boredom. Based on these criteria, we selected a set of six visualization routines to cycle through the scan, and each routine was displayed for 1 min before it was replaced by the next routine.

2.3. MRI studies

The study included 28 pediatric patients with bipolar disorder. The demographics of these patients are listed in Table 1. Patients referred to

Table 1

Demographics of the study groups.

	Visualization group	Control group
Number of participants	13	15
Females/males	6/7	7/8
Age in years (mean \pm SD) (range)	10.9 \pm 2.5 (7–16)	11.6 \pm 2.3 (8–15)

the study were randomized to receive only musical entertainment, or both music and acoustic noise-synchronized visual animations. The study was approved by our Institutional Review Board, and informed consents were obtained from parents and verbal consent from the children.

The study duration was approximately 1 h, and the imaging protocol included one imaging session that employed the following pulse sequences: localizer, 3D T1w images with magnetization-prepared rapid gradient echo (MP-RAGE), resting-state functional MRI using echo-planar imaging (EPI), 3D FLAIR (fast spin echo), diffusion tensor imaging with spin echo EPI, and 3D T2w (fast spin echo). Visualization was used in all sequences except in the initial localizer and resting-state fMRI scans.

2.4. Patient feedback

After completion of the imaging study, all subjects were asked to complete a questionnaire about their MRI scan experience. The questionnaire included questions about overall scan experience, comfort, loudness of the scanner, enjoyment of the audio and visual materials (if applicable), and scan experience relative to prior scans (if applicable). The patients were also asked to estimate their perception about the scan duration. The questionnaire and the scales used for the answers are shown in Table 2. The parents were allowed to assist the children in completing the questionnaire. The Mann-Whitney test was used to compare the ratings between the two patient groups.

3. Results

Fig. 2 shows examples of screenshots from the computer animations used in this study. Video clips of the animations with different pulse sequences are provided in the supplementary material.

The distribution of the scores from the study participants are shown in the box plot in Fig. 3. Significant differences ($P < 0.05$) were observed between the two groups (music only and music + computer animations) in four categories. The overall scan experience was rated less favorably by the group receiving the visualization (3.9 vs. 4.6 in the control group, $P < 0.04$), as was the enjoyment of the audio (music) material (4.1 vs. 4.5, $P < 0.04$). Recommendation of the scan was also lower (3.7 vs. 4.3, $P < 0.01$). The perceived scan duration was significantly shorter for the visualization group (43 min vs 50 min, $P < 0.05$), although the actual scan durations were approximately

Table 2
The patient response questionnaire.

Question	Scale
1 How do you rate your overall MRI scan experience?	(1: very unsatisfied, 5: very satisfied)
2 How comfortable were you inside the scanner?	(1: very uncomfortable, 5: very comfortable)
3 How loud was the scanner?	(1: very quiet, 5: very loud)
4 How much did you enjoy the audio material?	(1: not at all, 5: very much)
5 How much did you enjoy the visual material?	(1: not at all, 5: very much)
6 How long do you think you actually stayed inside the MRI scanner (minutes)?	10, 15, 20, 25, 30, 40, 50, 60, 70, 90
7 If you underwent MRI scan(s), how do you rate today's experience relative to your previous scan(s)?	(1: much worse than previous scans, 5: much better)
8 How likely you will recommend the audio/visual materials to others?	(1: very unlikely, 5: very likely)

equal (60 vs 58 min, $P=NS$). The group receiving the visualization rated an average score of 3.82 ± 1.27 for the visual material.

4. Discussion

Significant efforts have been made to reduce the impact of MRI acoustic noise. These include methods to modify the design and insulation of the gradient coils [20–22] and use of “quiet” or “silent” imaging pulse sequences that reduce the degree of gradient switching [23–26]. Another approach aimed to alter the perception of the noise by modifying the gradient pulses to play a musical note [27]. These approaches require modifications of the MRI scanner hardware or changes to the MRI pulse sequences, both are beyond the reach of most MRI imaging facilities.

This work introduces a simple and low-cost approach to alter the patient perception of the scanner acoustic noise. The approach can be readily implemented on current clinical MRI systems. It does not need any alteration of the scanner hardware/software or the imaging pulse sequences. The requirements for this system are a sensitive microphone and audio cables (\$20–80), an MRI-compatible display medium, and a low-end computer (~\$300) with media player and visualization software (no cost). While MRI-compatible display monitors are expensive (several thousand dollars), these are widely available in many MRI suites that provide support for functional MRI studies and video entertainment. Another possible display medium could be through image projection on the scan room walls or the MRI bore itself. The MRI console computer or other computers in the room may be used to host the media player software. A variety of media player software and visualization engine are freely available in the public domain. Installation of the system requires little technical knowledge. Thus, the system may cost approximately \$350 (computer, microphone, and cables) in supplies. Installation and testing may take approximately 2–4 h.

While the acoustic noise-modulated visualization resulted in

perceived shorter scans (~7 min shorter compared to the music-only group), it appears that pediatric psychiatric patients did not prefer this approach, as reflected in the lower scan experience scores. Several factors may have contributed to this result. First, the patient group in this study comprising children with bipolar disorder may be particularly vulnerable to the additional visual stimulus. Despite being enjoyable by healthy volunteers [19], the animations may have been perceived as another annoying stimulus in the confined MRI environment. Another difficulty with this patient group was their young age (7–16 years old) which made it difficult for some children to understand and answer the study questionnaire without assistance from their parents. Besides the study population, other experimental design choices such as the visualization routines possibly negatively affected patient experience. These routines were basically abstract animations, and while entertaining for many adults, were perhaps inadequate or unsuitable for entertaining children. In addition, the questionnaire may have been too difficult for the relatively younger children.

This initial implementation of the system may be improved in several ways. Instead of abstract animation, more interesting animation routines such as cartoon or animations incorporating familiar movie themes and characters may improve the overall experience of the patients. In addition, customizing the animations to the individual patient may improve engagement with the animation. A large set of animations may be developed and each patient be given the option to select a preferred subset of one or more animation routines. The generated animations may further be projected to the patient using MRI-compatible goggles. The goggles immerse the patient into the animated visual scene, and help the patient avoid the anxiety of being in the confined space. Stereo goggles will also allow three-dimensional animations. Finally, incorporating noise-modulated audio/music effects, combined with the modulated visual animations, could be more entertaining.

The results from the questionnaire reflected the overall experience of all visualization routines which cycled through the entire study. This

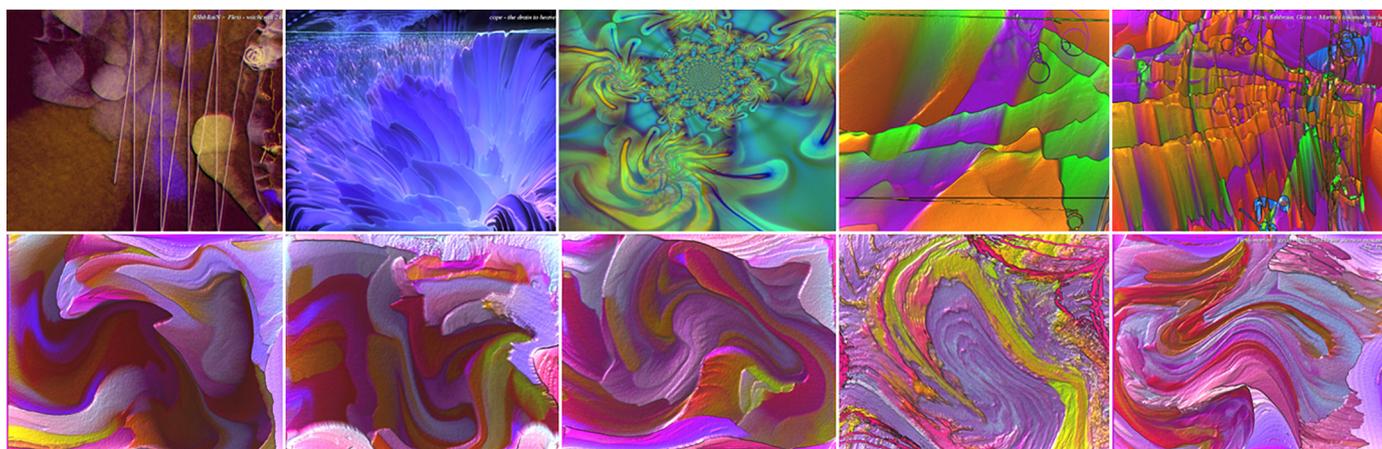


Fig. 2. Examples of screenshots of the MRI acoustic noise-synchronized animations. The upper row shows still images from five different visualization routines. The lower row shows frames from a visualization routine at different time points during a pulse sequence.

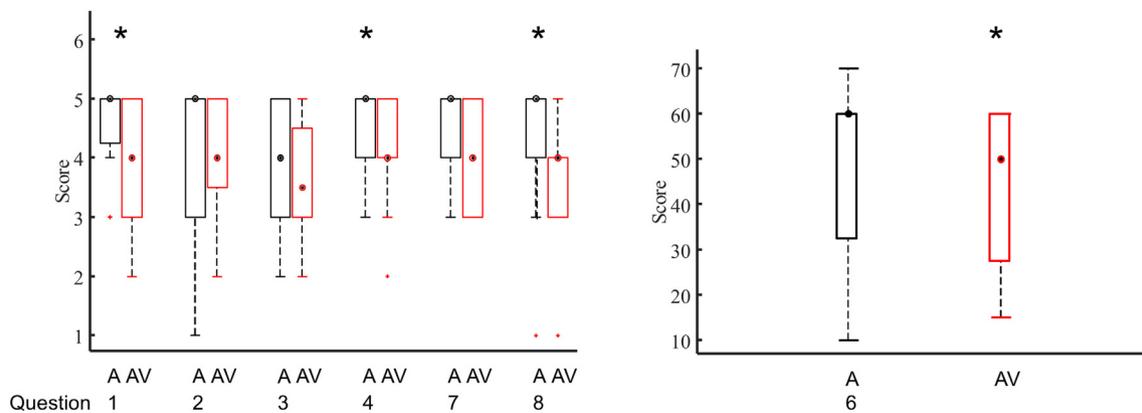


Fig. 3. Box plot of patient ratings for the survey questions. The questions numbers indicate overall scan experience (1), comfort (2), loudness (3), enjoying audio (4), experience relative to previous scans (7), and recommendation to others (8) with audio-only (A, black) and audiovisual (AV, red) stimuli. The perceived scan time (question 6) is shown in the right plot. The key to the ratings are shown in Table 2. Asterisks denote statistically significant differences ($P < 0.05$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

did not allow evaluation of the individual routines. It is possible that the young age of few participants may have affected their understanding of the questionnaire. However, age was not used a covariate in the analysis since we believe that the sample size is small to statistically assess age dependence. Future studies will record physiological parameters such as blood pressure, heart rate, and respiration as objective measures of anxiety.

In conclusion, acoustic-noise animations provide a simple distraction and entertainment tool. While the scores indicated unfavorable reception of abstract animations by this group of psychiatric pediatric patients, we anticipate that more lively and customized animations, MRI goggles, 3D animations, and noise-modulated audio stimuli could further improve the patient experience and reduce the level of anxiety associated with MRI procedures. These possibilities will be explored in future studies. Larger studies including both adults and children with various disorders are currently planned.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.mri.2019.05.014>.

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References

- [1] Sutton R, Kanal E, Wilkoff BL, Bello D, Luechinger R, Jenniskens I, et al. Safety of magnetic resonance imaging of patients with a new Medtronic EnRhythm MRI SureScan pacing system: clinical study design. *Trials* 2008;9:68.
- [2] Hedeén RA, Edelstein WA. Characterization and prediction of gradient acoustic noise in MR imagers. *Magn Reson Med* 1997;37:7–10.
- [3] Winkler SA, Schmitt F, Landes H, de Bever J, Wade T, Alejski A, et al. Gradient and shim technologies for ultra high field MRI. *Neuroimage* 2018;168:59–70.
- [4] Quirk ME, Letendre AJ, Ciotone RA, Lingley JF. Anxiety in patients undergoing MR imaging. *Radiology* 1989;170:463–6.
- [5] Meléndez JC, McCrank E. Anxiety-related reactions associated with magnetic resonance imaging examinations. *JAMA* 1993;270:745–7.
- [6] Eshed I, Althoff CE, Hamm B, Hermann KG. Claustrophobia and premature termination of magnetic resonance imaging examinations. *J Magn Reson Imaging* 2007;26:401–4.
- [7] Katznelson R, Djaiani GN, Minkovich L, Fedorko L, Carroll J, Borger MA, et al. Prevalence of claustrophobia and magnetic resonance imaging after coronary artery bypass graft surgery. *Neuropsychiatr Dis Treat* 2008;4:487–93.
- [8] McJury PhD M, Shellock PhD FG, McJury M, Shellock FG. Auditory noise associated with MR procedures: a review. *J Magn Reson Imaging* 2000;12:37–45.
- [9] Price DL, De Wilde JP, Papadaki AM, Curran JS, Kitney RI. Investigation of acoustic noise on 15 MRI scanners from 0.2 T to 3 T. *J Magn Reson Imaging* 2001;13:288–93.
- [10] Counter SA, Olofsson A, Borg E, Bjelke B, Häggström A, Grahn HF. Analysis of magnetic resonance imaging acoustic noise generated by a 4.7 T experimental system. *Acta Otolaryngol* 2000;120:739–43.
- [11] McJury M, Stewart RW, Crawford D, Toma E. The use of active noise control (ANC) to reduce acoustic noise generated during MRI scanning: some initial results. *Magn Reson Imaging* 1997;15:319–22.
- [12] Brummett RE, Talbot JM, Charuhas P. Potential hearing loss resulting from MR imaging. *Radiology* 1988;169:539–40.
- [13] McNulty JP, McNulty S. Acoustic noise in magnetic resonance imaging: an ongoing issue. *Radiography* 2009;15:320–6.
- [14] Shimojo S, Shams L. Sensory modalities are not separate modalities: plasticity and interactions. *Curr Opin Neurobiol* 2001;11:505–9.
- [15] Stein BE, Stanford TR, Rowland BA. The neural basis of multisensory integration in the midbrain: its organization and maturation. *Hear Res* 2009;258:4–15.
- [16] Macaluso E, Driver J. Multisensory spatial interactions: a window onto functional integration in the human brain. *Trends Neurosci* 2005;28:264–71.
- [17] Witten IB, Knudsen EI. Why seeing is believing: merging auditory and visual worlds. *Neuron* 2005;48:489–96.
- [18] Gillies MF, Van Ee R, Elswijk V, Franciscus GA, Tijs TJW. System and method for distraction of patient during scanning. 2013.
- [19] Gabr RE, Narayana PA. Patient distraction and entertainment system for magnetic resonance imaging using visual effects synchronized to the scanner acoustic noise. 13th Int. Jt. Conf. Comput. Vision, Imaging Comput. Graph. Theory Appl., Rome, Italy. 2016. p. 60.
- [20] Edelstein WA, Hedeén RA, Malozzi RP, El-Hamamsy S-A, Ackermann RA, Havens TJ. Making MRI quieter. *Magn Reson Imaging* 2002;20:155–63.
- [21] Edelstein WA, Kidane TK, Taracila V, Baig TN, Eagan TP, Cheng YN, et al. Active-passive gradient shielding for MRI acoustic noise reduction. *Magn Reson Med* 2005;53:1013–7.
- [22] Katsunuma A, Takamori H, Sakakura Y, Hamamura Y, Ogo Y, Katayama R. Quiet MRI with novel acoustic noise reduction. *Magn Reson Mater Physics, Biol Med* 2001;13:139–44.
- [23] Heismann B, Ott M, Grodzki D. Sequence-based acoustic noise reduction of clinical MRI scans. *Magn Reson Med* 2015;73:1104–9.
- [24] Idiaytullin D, Corum C, Park J, Garwood M. Fast and quiet MRI using a swept radiofrequency. *J Magn Reson* 2006;181:342–9.
- [25] Ott M, Blaimer M, Breuer F, Grodzki D, Heismann B, Jakob P. Acoustic noise reduction in T1- and proton-density-weighted turbo spin-echo imaging. *Magn Reson Mater Physics, Biol Med* 2016;29:5–15.
- [26] Liebig P, Heidemann RM, Hensel B, Porter DA. Accelerated silent echo-planar imaging. *Magn Reson Imaging* 2019;55:81–5.
- [27] Ma D, Pierre EY, Jiang Y, Schluchter MD, Setsompop K, Gulani V, et al. Music-based magnetic resonance fingerprinting to improve patient comfort during MRI examinations. *Magn Reson Med* 2016;75:2303–14.