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Acoustical analysis of functional magnetic resonance imaging

A literature review and exploratory measurements

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In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

An acoustical analysis of a magnetic resonance imaging (MRI) scanner was performed to characterize the noise during functional scanning. This work was performed in the interest of implementing auditory stimuli in future studies, and assessing the risk to participants for overexposure to noise. The noise level during functional scanning was 113.9 dBA, with the greatest energy between 1 and 2 kHz. This frequency range should be avoided in the design of auditory cues to ensure that they are clearly audible. With proper use of hearing protection, participants can be exposed to functional scanning noise for about one hour according to the Canada Labour Code limit. These results form the basis for the design of auditory stimuli for future functional MRI (fMRI) studies, and provide guidance for the maximum length of fMRI experimental protocols.

Résumé

Une analyse acoustique d'un appareil d'imagerie à résonance magnétique (IRM) a été réalisée afin de caractériser le bruit durant un balayage fonctionnel. Ces travaux ont été effectués en vue de la mise en oeuvre de stimuli audio dans des études ultérieures ainsi que pour évaluer le risque de surexposition des participants au bruit. Le niveau de bruit durant le balayage fonctionnel était de 113,9 dBA, avec l'énergie la plus élevée entre 1 et 2 kHz. Il est donc souhaitable d'éviter cette gamme de fréquences dans la conception des stimuli auditifs afin que ceux-ci soient clairement audibles. L'utilisation d'une protection auditive appropriée permet d'exposer les participants au bruit du balayage fonctionnel pendant environ une heure en respectant la limite établie dans le *Code canadien du travail*. Ces résultats établissent une base qui servira à la conception de stimuli audio pour de futures études d'imagerie à résonance magnétique fonctionnelle (IRMf). Ils donnent également des indications sur la durée maximale des protocoles expérimentaux d'IRMf.

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Executive summary

Acoustical analysis of functional magnetic resonance imaging: A literature review and exploratory measurements

Ann Nakashima; Oshin Vartanian; DRDC Toronto TR 2013-088; Defence R&D Canada – Toronto; August 2013.

Introduction or background: The high levels of noise that are produced during functional magnetic resonance imaging (fMRI) scanning create a challenging environment for neurocognitive studies, particularly if auditory stimuli are to be used. In addition, the noisy environment can be a source of discomfort for study participants and potentially pose a risk for overexposure to noise. An acoustical analysis of an MRI scanner was performed in the interest of 1) designing an easily detectable auditory stimulus that can be used in fMRI studies, and 2) assessing the noise environment for risk of overexposure to noise.

Results: The noise level during functional scanning was 113.9 dBA, with the greatest energy between 1 and 2 kHz. This suggests that the main component of an auditory cue should be outside this frequency range to be clearly audible. A test participant achieved 100% detection for a 500 Hz tone presented at levels of 81 to 92 dB SPL. With proper use of hearing protection, a participant could undergo functional scanning for approximately one hour without exceeding the noise exposure limits imposed by the Canada Labour Code.

Significance: These results form the basis for the design of auditory stimuli for future fMRI studies. A limit on the duration of functional scanning (i.e., length of the experimental session) to avoid overexposure to noise has been defined.

Future plans: In future fMRI studies, the participants will be instructed on how to properly insert the earplugs and the experimental protocol with be limited to one hour or less to avoid overexposure to noise. The knowledge of the fMRI noise environment opens up new possibilities for neurocognitive studies involving communication and auditory perception.

Sommaire

Acoustical analysis of functional magnetic resonance imaging: A literature review and exploratory measurements

Ann Nakashima; Oshin Vartanian ; DRDC Toronto TR 2013-088 ; R & D pour la défense Canada – Toronto; août 2013.

Introduction ou contexte : Le fort bruit produit lors d'un balayage d'imagerie à résonance magnétique fonctionnelle (IRMf) crée des difficultés pour les études neurocognitives, particulièrement s'il faut utiliser des stimuli audio. De plus, le milieu bruyant peut être désagréable pour les participants et créer un risque de surexposition au bruit. Une analyse acoustique d'un appareil d'IRM a été réalisée afin de (1) concevoir un stimulus auditif facilement détectable qui puisse être utilisé dans les études d'IRMf et (2) évaluer le bruit ambiant pour déterminer le risque de surexposition au bruit.

Résultats : Le niveau de bruit durant le balayage fonctionnel était de 113,9 dBA, avec l'énergie la plus élevée entre 1 et 2 kHz. Il serait donc souhaitable que la composante principale d'un stimulus audio se trouve hors de cette gamme de fréquences pour être clairement audible. Un participant à l'essai a obtenu un taux de détection de 100 % pour une tonalité de 500 Hz présentée à des niveaux de 81 à 92 dB SPL. L'utilisation d'une protection auditive appropriée permet d'exposer les participants au bruit du balayage fonctionnel pendant environ une heure en respectant la limite établie dans le Code canadien du travail.

Importance : Ces résultats établissent une base qui servira à la conception de stimuli audio pour de futures études d'IRMf. Une limite de la durée du balayage fonctionnel (c'est-à-dire de la longueur de la séance expérimentale) visant à éviter la surexposition au bruit a été définie.

Perspectives : Dans des études d'IRMf ultérieures, les participants recevront des instructions sur la façon correcte d'insérer les bouchons d'oreille; la durée du protocole expérimental sera d'au plus une heure afin d'éviter une surexposition au bruit. La connaissance de l'environnement sonore de l'IRMf ouvre de nouvelles possibilités d'études neurocognitives portant sur la communication et la perception auditive.

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1 Background

Functional Magnetic Resonance Imaging (fMRI) is used to study the neural response of participants while they are engaged in a cognitive task. Previous fMRI studies by scientists at Defence Research and Development Canada – Toronto (DRDC Toronto) have used a variety of neurocognitive tasks to study higher cognition processes such as risky choice (Vartanian et al, 2011), deception (Vartanian et al 2012), and divergent thinking (Vartanian et al, 2013). The neurocognitive tasks that have been used to date have been administered using stimuli presented exclusively in the visual modality. It has been shown that bimodal audio-visual cues can provide an advantage over unimodal visual cues during multitasking in noise (Chan and Chan, 2006; Nakashima and Crebolder, 2010); therefore, it is of interest to explore the use of auditory stimuli, particularly for neurocognitive tasks that require a cued response. However, the use of auditory stimuli in an MRI scanner is complicated by its extreme noise environment. Therefore, it is critical to characterize the noise environment of the scanner in order to design an auditory cue that is audible, but does not impose a risk with respect to hearing damage. In addition, it is important to evaluate the noise levels of the scanner to ensure that study participants are not at risk for overexposure to noise from the scanner alone.

This document presents a brief review of the literature on fMRI noise and an analysis of noise measurements that were taken inside a scanner that has previously been used by DRDC Toronto scientists.

2 Literature Review

2.1 Noise Measurements

There are a number of sources in an imaging room that contribute to the background noise level even when images are not being captured. These include pumps used to supercool the magnet, fans used to supply ventilation to the patient and air-handling equipment for the room (Ravicz et al, 2000). During scanning, intermittent noise is produced during image acquisition. Magnetic field gradients are created by supplying current to coils inside the imager bore. The resulting forces on the coils cause them to flex and vibrate, producing substantial amounts of acoustic energy (Ravicz et al, 2000). The rapid gradient switching (approximately 1 kHz) that occurs during echo-planar imaging (EPI) that is used for functional imaging produces the highest levels of noise.

The noise levels have been shown to vary depending on the magnet strength and the imaging protocol that is used. Price et al (2001) measured levels ranging from 82.5 dBA on a 0.23T system to 118 dBA on a 3T system during rapid imaging. A spectral analysis of gradient noise in 1.5T and 3T scanners showed peak levels of 115 dB SPL at 1 kHz and 131 dB SPL at 1.4 kHz, respectively, for each of the systems (Ravicz et al, 2000). More et al (2006) measured peak levels of 120 to 130 dB SPL inside a 4T scanner. These noise levels clearly present a concern for the risk of overexposure to noise.

2.2 Noise Exposure

The need for hearing protection for patients and workers in MRI environments has been well documented (e.g., McJury and Shellock, 2000). In Canada, the occupational noise exposure limit for 8 hours (a typical working day) is 85 to 90 dBA, depending on the jurisdiction (Canada Labour Code, 1985). Earmuffs and earplugs are conventional hearing protection devices. Earmuffs are difficult to use inside the scanner due to limited space inside the head coil. Therefore, it is common practice to provide a study participant with earplugs, which they insert themselves with minimal or no instruction. The typical attenuation that is achieved by conventional earplugs in the laboratory is 10 to 20 dB at low frequencies and 30 to 40 dB at middle and high frequencies (1 kHz and above). However, the same earplug will typically only provide 33% of the laboratory-measured attenuation in the field (NATO, 2010). This is largely due to improper insertion of the earplugs by the user. Previous studies have indicated potential hearing damage even with earplug use. Radomskij et al (2002) found decreased otoacoustic emission (OAE) levels after MRI scanning in participants who had worn earplugs. Decreased OAE levels can be an early indication of cochlear dysfunction (Desai et al, 1999).

The noise levels produced by an MRI scanner depend on the type of scanner and the scanning protocol. The amount of noise exposure that is experienced by a participant depends on the length of time spent inside the scanner, and the level of hearing protection that is provided. These factors will determine the maximum length of the experimental protocol, in terms of protecting the participants from overexposure to noise.

2.3 Use of Auditory Stimuli

If auditory stimuli are to be used in an fMRI study, the signals must be clearly audible in the presence of the scanner noise. Both the level and the spectral content of the signal must be considered. For example, one spectral analysis of noise during functional scans in a 3T scanner showed spectral peaks at 1.4 kHz and 2.8 kHz (Ravicz et al, 2000). It would be best to avoid these frequencies in the design of the auditory stimuli to reduce the effects of masking. Because masked signals are more difficult to detect, they also increase the cognitive load. Without knowledge of the spectrum of noise produced by the scanning protocol, the inclination would be to simple make the stimulus as loud as possible. This would result in saturation of the cortical response (Hall et al, 2001) and interfere with the neural response to the experimental task. It is thus essential to characterize the noise environment of the scanner prior to designing the auditory stimulus to be used in the study.

2.4 Noise Mitigation

Sparse imaging protocols have been developed for studies involving speech and auditory processing. Such protocols use a repetition time (TR) that is longer than the acquisition time (TA), allowing for a silent period between the acquisition of consecutive volumes (e.g., Hall et al, 2001). Auditory stimuli such as speech can be presented during the silent period without the interference of the EPI noise. However, sparse imaging reduces the temporal resolution of the data, and therefore is not sufficient to capture the neural response for event-related designs requiring short inter-trial intervals (Mueller et al, 2010). Previous fMRI studies conducted by DRDC Toronto scientists have used an imaging protocol with a TR of 2s (Vartanian et al., 2011, 2012, 2013), while sparse imaging protocols use a TR of about 10 to 11s (Hall et al, 2001; Peelle et al, 2010; Mueller et al, 2011).

Exploratory research on the use of active noise control (ANC) has shown promising results for reducing the spectral peaks by up to 35 dB at the ear. However, the cancellation of noise from a perceptual standpoint was limited to about 13 dB due to sound transmission to the cochlea through bone conduction (Hall et al, 2009). ANC is generally not effective at higher frequencies due to the accumulation of phase shift with frequency (Elliott and Nelson, 1993) and therefore is less useful for rapid EPI protocols where the spectral peaks occur at frequencies above 1 kHz.

Because the noise environment changes depending on the scanner model, magnet strength, scanning protocol and other noise sources in the scanning room, an acoustical analysis of the exact experimental setup is required prior to the design of any auditory stimuli. An acoustical analysis will also determine the requirements for the level of hearing protection that is required for the participants and any other noise mitigation strategies that may be necessary.

3 MRI Scanner Measurements

3.1 Apparatus

A 3T MRI scanner with an 8-channel head coil (Discovery MR750, 22.0 software, GE Healthcare, Waukesha, WI), located at Sunnybrook Health Sciences Centre (Toronto, ON) has been used for previous experiments conducted by DRDC Toronto scientists (Vartanian et al., 2012, 2013), and will continue to be used in the future. Noise levels were captured using a pre-calibrated Optimic™ 1155 fibre-optic microphone (Optoacoustic, Moshav Mazor, Israel, Figure 1), which is safe for use in the scanner. It is capable of measuring noise levels up to 130 dB SPL with a frequency response of 10 to 15000 Hz. The microphone signals were recorded with LMS SCADAS mobile data acquisition hardware and LMS Test.Xpress software (LMS International, Leuven, Belgium) running on a Dell laptop. The hardware was placed outside the scanner room. The laptop was used to present the auditory stimuli to a test participant inside the scanner. The stimuli were presented to the participant through the Avotec Silent Scan 3100 system (Avotec Inc, Stuart, Fl) using a non-headset (Figure 2). The non-headset is an MR-compatible set of earphones with the transducers embedded in foam inserts. An auditory detection task programmed in E-Prime 2.0 (Psychology Software Tools, Sharpsburg, PA) was presented to the test participant through the laptop and Avotec system.

Figure 1: Optimic™ 1155 microphone (photo by Optoacoustics).

Figure 2: Avotec Silent Scan 3100 and non-headset. Photos by Avotec Inc.

3.2 Measurement Procedure

The optical microphone was pre-calibrated and rated with a self-noise level of 34.5 dBA. Prior to taking the scanner measurements, the response of the optical microphone was tested and compared with a calibrated 0.5 inch free-field condenser microphone (PCB Piezotronics model 377B02, Depew, NY). Measurements of 74 dB SPL pink noise were taken inside the Noise Simulation Facility at DRDC Toronto, as well as background noise measurements inside a quiet office.

A test participant was chosen so that the scanner measurements could be taken at the ear. The participant gave informed consent as per an experimental protocol that was previously approved by the DRDC Human Research Ethics Committee and the Sunnybrook Research Ethics Board. The test participant had normal hearing levels from 125 to 8000Hz (< 20dB HL). The participant inserted earplugs (EAR Classic, 3M Personal Safety Division, St. Paul, MN) and the microphone was placed outside the earplug on the left ear, held in place with medical tape. The non-headset

was placed over the ears. Measurements were only taken at the left ear due to limited time with the scanner.

The scanner measurements were taken inside the 3T scanner at Sunnybrook Health Sciences Centre on September 12, 2011. The noise was measured under three conditions: scanner off (background noise only), structural scanning and functional scanning. T1 anatomical volume images (.86 × .86 × 1.0 mm voxels) were acquired. Structural and anatomical scans for each participant are always taken prior to functional scanning. The structural scans take about seven minutes and the anatomical scan lasts about one minute. For functional imaging, T2*-weighted gradient echo spiral-in/out acquisitions were used to produce 26 contiguous 5 mm thick axial slices (repetition time [TR] = 2000 ms; echo time [TE] = 30 ms; flip angle [FA] = 70°; field of view [FOV] = 200 mm; 64 × 64 matrix; voxel dimensions = 3.1 × 3.1 × 5.0 mm), positioned to cover the whole brain.

During functional imaging, the test participant completed a simple auditory detection task. Two screens were shown in succession with the same fixation (a series of three plus signs: +++). In one of the screens, the fixation was accompanied by a 500 Hz tone. After both screens were shown, the participant was asked to indicate which screen had the tone by pressing a button. All five levels of tones were presented ten times each, in random order, for a total of 50 trials. The levels of the test tones emitted from a laptop computer through the Avotec SS-3100 system were measured outside of the detection task. The Avotec output was fixed at level 5 with a gain multiplier of 10. The laptop volume was set to maximum.

The noise recordings are summarized in Table 1. For each recording, the data were analyzed in terms of Leq (equivalent sound level, in dB SPL and dBA), fast fourier transform (FFT; 512 lines from 0 to 25600 Hz) and 1/3 octave bands (20 to 20000Hz).

Table 1: Summary of noise measurements.

Noise Type	Duration (s)	Number of samples
Background	30	1
Localizer scan	60	1
Anatomical scan	60	6
Functional scan	60	5
500 Hz test tones	15	5

4 Results

The responses of the optical microphone (Optimic) and the calibrated condenser microphone (PCB) are shown in Figure 3. The Optimic measured higher levels than the PCB at frequencies above 800 Hz, indicating that the noise floor of the Optimic is too high to accurately measure the relatively low noise levels at these frequencies (~20 dB SPL). However, the Optimic showed good agreement with the PCB for 74 dB SPL pink noise. Based on the literature, it was expected that the noise of the scanner would be above 74 dB SPL. The Optimic was thus deemed sufficiently accurate for the noise measurements in the scanner.

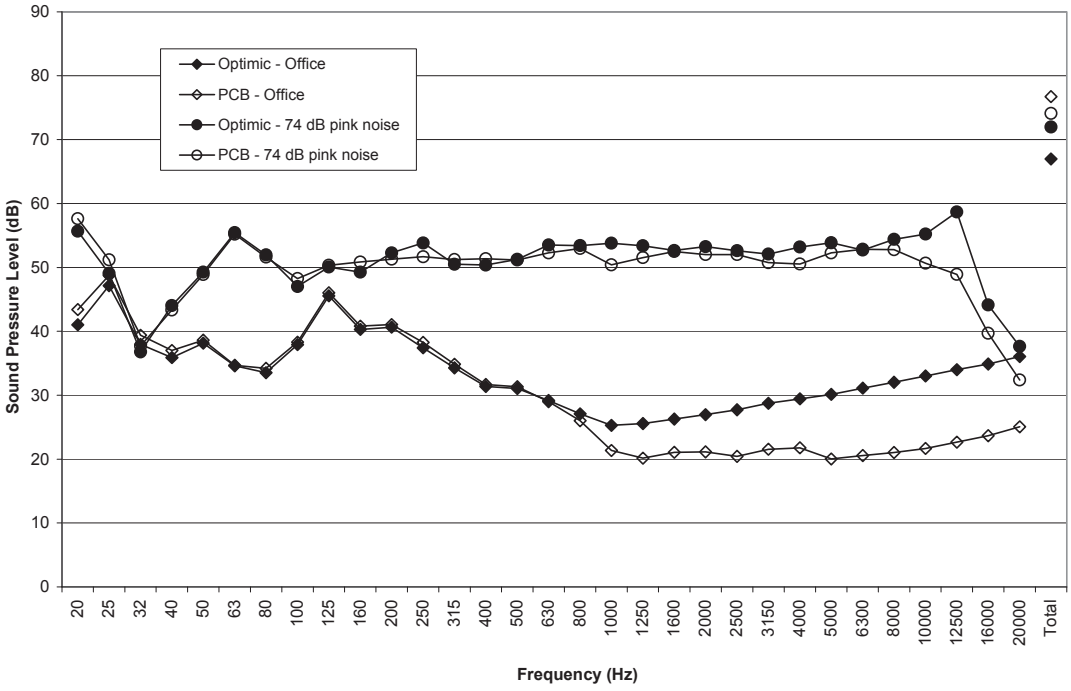

Figure 3: Comparison of the optical (Optimic) and condenser (PCB) microphones at a low noise level and 74 dB SPL pink noise.

The overall noise levels (Leq) for each scanning condition are shown in Table 2. The noise levels during the different types of scanning ranged from 97.4 to 113.4 dB SPL. The A-weighted levels differed by 0.5 dB or less from the unweighted levels.

Table 2: At-ear noise levels during scanning (microphone was placed between the earplug and the headset).

Scanning Condition	Noise level (dB SPL)	Noise level (dBA)
Background noise	78.4	64.6
Localizer scan	97.4	96.7
Anatomical scan	101.3	100.6
Functional scan	113.4	113.9

The 1/3 octave band levels for each of the scanning conditions are shown in Figure 4. The anatomical scan noise contained local maxima at 125 and 250 Hz, and most of the noise energy was contained in the range of 125 to 1600 Hz. The noise during functional scanning was concentrated in the 1 to 2 kHz range.

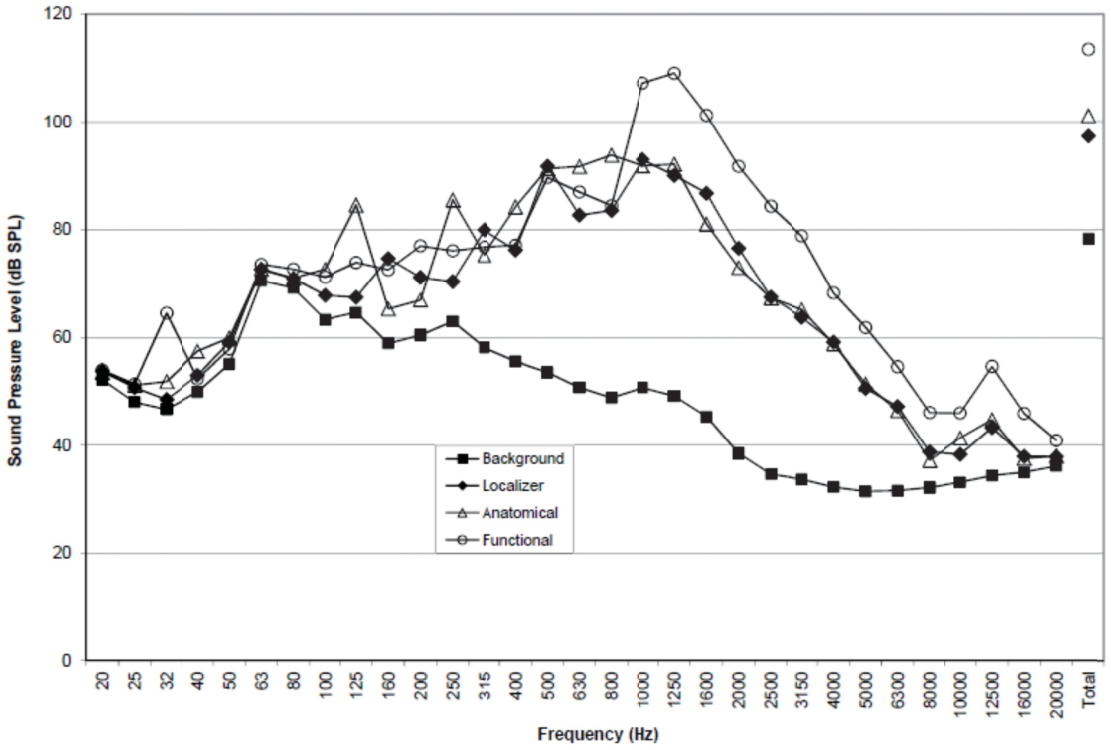

Figure 4: 1/3 octave band spectra of the background noise and three scanning conditions.

The levels of the 500 Hz test tones are shown in Table 3. The test participant achieved 100% accuracy on the auditory detection task, indicating that all the levels of the 500 Hz tone were clearly audible through the scanner noise during functional imaging. There was a trend for the response time to increase as the level of the tone increased, but not enough trials were completed to perform a statistical analysis (10 trials at each tone level for a total of 50 trials).

Table 3: Response time for the auditory detection task. The test tone was 500 Hz.

Tone level (dB SPL)	Response Time (ms)	Standard Deviation
81.1	403	165
85.4	406	176
88.5	493	218
90.8	503	196
92.1	582	250

The 500 Hz tone at the third volume level (88.5 dB SPL) is shown in Figure 5 with the noise spectra of all of the scanning conditions. The level of the tone is clearly above the noise level at 500 Hz for all conditions.

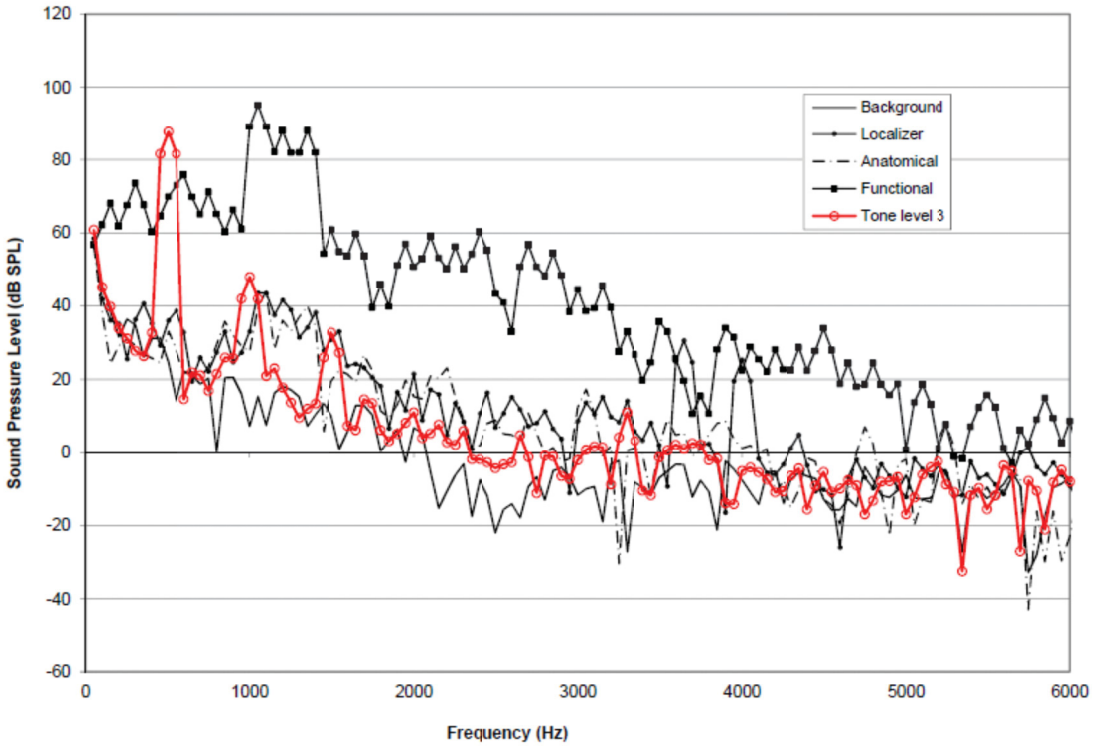

Figure 5: Comparison of the 500 Hz tone with the noise spectra for all scanning conditions.

5 Discussion

5.1 Noise Exposure

The microphone was placed under the non-headset, outside of the earplug worn by the test participant at the left ear. The noise levels that were measured are therefore representative of the levels at the ear with the use of the non-headset. The non-headset does not act as a noise-attenuating earmuff. An earmuff usually consists of earcups that are held in place with a connecting headband that creates a seal over each ear by applying force to the sides of the head. The low-profile foam design of the non-headset does not create a seal over the ears, and therefore offers minimal attenuation. Measurements were only taken at the left ear due to limited time with the scanner. It has been shown that while the noise spectra at the left and right ears are not identical, the overall levels are similar (More et al, 2006). Therefore, it is assumed that the discussion of noise exposure here can be applied to both ears.

Table 4: Noise exposure limits for exposure time as per the Canada Labour Code, referenced to 87 dBA with a 3 dB exchange rate.

Maximum Permitted Exposure Level (dBA)	Maximum Permitted Duration of exposure
87	8 h
90	4 h
93	2 h
96	1 h
99	30 min
102	15 min
105	7.5 min
108	3.75 min
111	< 2 min
114	< 1 min

The Canadian Standards Association recommends the use of hearing protection for exposure to noise levels above 85 dBA. The use of the A-weighting in the calculation of the total noise level reflects the sensitivity of the human ear over the range of audible frequencies (CSA, 2002). The background noise in the room, measured inside the bore of the scanner before images were acquired, was substantial at 64.6 dBA, but not high enough to require the use of hearing protection. The A-weighted noise levels during functional and anatomical scanning were 96.7 dBA and 100.6 dBA, respectively. Occupational noise exposure limits in Canada range from 85 to 90 dBA for 8 hours of exposure, depending on the jurisdiction. The federal limit is 87 dBA with a 3dB exchange rate, allowing for a 3 dB increase in the noise level for a halving of the exposure time (see Table 4). A participant could thus be safely exposed to a level of 99 dBA for 30 min and 102 dBA for 15 min. The typical durations of the localizer and anatomical scans are 1 and 7 min, respectively, so the participant was not overexposed to noise, although the use of hearing protection is recommended. During functional scans, the noise was 113.9 dBA, which is a level that unprotected ears can only be exposed to for less than one minute (see Table 4). Therefore, a test participant must wear hearing protection during a functional scan. It can

reasonably be assumed that a participant achieves 20 dB of noise attenuation after fitting earplugs under supervision (see, for example, Berger, 1983). With the use of earplugs, then, the approximate noise exposure during functional scanning is about 94 dBA. The duration of exposure (i.e., the total duration of the experimental tasks during a session) should therefore be limited to about one hour to avoid overexposure to noise. This is an important limit to consider not only in the design of the fMRI experimental protocols, but also for possible re-scans during a session in the case of interruptions. Previous fMRI studies performed by DRDC Toronto scientists have involved functional scanning of up to approximately 35 min in duration (Vartanian et al., 2011, 2012, 2013), which is within the noise exposure limit.

5.2 Auditory Detection

The levels of the 500 Hz test tones, recorded at different gain levels, ranged from 81.1 to 92.1 dB SPL. The test participant achieved 100% on the detection task, indicating that all of the tone levels were clearly audible in the presence of noise during functional scanning. MIL-STD 1472G (2012) indicates that an auditory alarm should be 15 dB above the background noise for a caution alarm, and 20 dB above in the critical band for a warning signal (i.e., greater urgency). The test tones here were about 10 to 20 dB above the functional scanner noise at 500 Hz (see Figure 5). In the interest of using an auditory stimulus in an fMRI study, it is important to present the stimulus at a level that is easily audible, but not so intense that it causes saturation of the cortical response. For this example of using a simple tone as an auditory cue, a level of about 15 dB above the background noise is appropriate.

It should be noted that individuals with hearing loss will likely have trouble detecting an auditory stimulus, particularly in the presence of high background noise (Abel et al, 1990). Therefore, it is imperative that individuals are screened for normal hearing thresholds prior to their participation in a study involving auditory stimuli.

6 Summary

The noise levels during functional scanning in the 3T scanner at Sunnybrook Health Sciences Centre were recorded and analyzed in the interest of 1) assessing the risk of overexposure to noise and 2) testing the detectibility of a simple auditory stimulus. With proper use of hearing protection, participants are not at risk for overexposure to noise, provided that functional scanning is limited to about one hour. A 500 Hz tone presented at 81 to 92 dB SPL (i.e., 10 to 20 dB above the background noise at 500 Hz) was clearly audible to the test participant. These results form a basis for the design of auditory stimuli for future fMRI studies using this scanner.

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List of symbols/abbreviations/acronyms/initialisms

ANC	Active Noise Control
dB SPL	Sound Pressure Level, in Decibels
dBA	Sound Pressure Level, A-weighted
CSA	Canadian Standards Association
DND	Department of National Defence
DRDC	Defence Research & Development Canada
EPI	Echo Planar Imaging
FA	Flip Angle
FFT	Fast Fourier Transform
fMRI	Functional Magnetic Resonance Imaging
FOV	Field of View (for imaging protocols)
Hz	Hertz (unit of frequency)
kHz	Kilohertz (unit of frequency)
Leq	Equivalent Sound Level (integrated over the measurement period)
ms	Milliseconds
MIL-STD	Military Standard (United States)
MRI	Magnetic Resonance Imaging
NATO	North Atlantic Treaty Organisation
OAE	Otoacoustic Emission
S	Seconds
T	Tesla (unit of magnetic field strength)
TA	Acquisition Time (for imaging protocols)
TE	Echo Time (for imaging protocols)
TR	Repetition Time (for imaging protocols)

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An acoustical analysis of a magnetic resonance imaging (MRI) scanner was performed to characterize the noise during functional scanning. This work was performed in the interest of implementing auditory stimuli in future studies, and assessing the risk to participants for overexposure to noise. The noise level during functional scanning was 113.9 dBA, with the greatest energy between 1 and 2 kHz. This frequency range should be avoided in the design of auditory cues to ensure that they are clearly audible. With proper use of hearing protection, participants can be exposed to functional scanning noise for about one hour according to the Canada Labour Code limit. These results form the basis for the design of auditory stimuli for future functional MRI (fMRI) studies, and provide guidance for the maximum length of fMRI experimental protocols.

Une analyse acoustique d'un appareil d'imagerie à résonance magnétique (IRM) a été réalisée afin de caractériser le bruit durant un balayage fonctionnel. Ces travaux ont été effectués en vue de la mise en oeuvre de stimuli audio dans des études ultérieures ainsi que pour évaluer le risque de surexposition des participants au bruit. Le niveau de bruit durant le balayage fonctionnel était de 113,9 dBA, avec l'énergie la plus élevée entre 1 et 2 kHz. Il est donc souhaitable d'éviter cette gamme de fréquences dans la conception des stimuli auditifs afin que ceux-ci soient clairement audibles. L'utilisation d'une protection auditive appropriée permet d'exposer les participants au bruit du balayage fonctionnel pendant environ une heure en respectant la limite établie dans le *Code canadien du travail*. Ces résultats établissent une base qui servira à la conception de stimuli audio pour de futures études d'imagerie à résonance magnétique fonctionnelle (IRMf). Ils donnent également des indications sur la durée maximale des protocoles expérimentaux d'IRMf.

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