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Training Children to Reduce Motion and Increase Success of MRI Scanning

Woods-Frohlich, Lindsay; Martin, Toby; Malisza, Krisztina L.

Abstract: In this review, we outline interventions that can be used with children to prepare them for magnetic resonance imaging (MRI) and to limit their motion during medical imaging procedures. Children, especially those diagnosed with a developmental disability or other mental health challenges, may have difficulty remaining still for long periods of time.

Children also experience fear, anxiety and curiosity in the MRI environment due to the noise, size of the machines, and overall overwhelming experience. These difficulties can affect the ability of researchers and other professionals to perform clinical tests such as MRI, which require the child to remain motionless for the duration of the scan. A few studies have described methods used to prepare children for the MRI environment and train them for successful completion of the MRI scans. These include standard operating procedures as used in clinical scanning, such as appropriate information dissemination, standard physical restraint procedures and sedation. Other motion reduction techniques range from low-cost nontechnical but people heavy approaches, such as mock scanner training sessions, systematic desensitization and guided imagery techniques to more technical engineering type approaches, such as behavior feedback methods and the use of postprocessing motion correction algorithms.

Keywords: Motion, children, magnetic resonance imaging (MRI), systematic exposure.

INTRODUCTION

Magnetic resonance imaging (MRI) is a non-invasive technique that can be used to obtain images of soft tissue in the body. It does not require the use of harmful radiation or contrast agents, unlike Positron Emission Tomography (PET) and Single Photon Emission Computer Tomography (SPECT), and therefore is appropriate and can be safely used in research with a child population [1]. Additionally, functional magnetic resonance imaging (fMRI) allows researchers and clinicians to gather information about brain function by mapping activation within the brain [2]. The information gathered from these types of studies allows researchers to examine brain functions in subjects with neurocognitive impairments and can lead to a greater understanding of Central Nervous System (CNS) impairment. This information can then inform education, support, and intervention programs for these individuals [1].

There are a number of difficulties in imaging children, especially children with developmental delays or other neurocognitive issues. Children have difficulty staying still during imaging which frequently results in images that are unusable for research as well as clinical purposes. Head motion can produce artifacts and show erroneous areas of brain activity in fMRI, or can increase the “noise” in the data so that activity cannot be accurately mapped [2]. Children also experience fear, anxiety and curiosity in the MRI environment due to the size of the machine, noises, and overall experience (discomfort from being enclosed in the magnet bore). Children may also not understand the directions given to them during the MRI examination [3].

Since most subjects, especially children, tend to move somewhat during a series of images, such as those acquired during fMRI experiments, it is necessary to perform some type of post-processing motion correction. Motion correction algorithms estimate rigid body transformations relative to a reference image in the series and interpolate the data based on these motion parameters [4, 5]. These types of retrospective techniques, however, cannot correct through-plane motion, may introduce blurring, and rigid-body assumptions are violated by nonlinear effects of motion near areas of susceptibility-related distortions [6]. The use of motor tasks, a popular type of research in fMRI, can compound the problem of movement because the motion associated with the task (e.g. finger tapping or button pressing) can translate to the head [7]. Task-correlated motion is extremely difficult to deal with and result in artifacts even after post-processing for motion correction.

Frequently, psychologically- or behaviorally-affected individuals demonstrate greater motion problems. In one study [6], translational displacement was greater for a group of dyslexic children than for control children (both groups aged 7-13 years) or adults (18-25 years), and rotational displacement was greater for both groups of children compared to adults. Other researchers found no differences between patients with schizophrenia and matched control adults when looking at the degree of head motion, but concluded that direct comparison of motion parameters are essential to determine if additional corrective techniques are required [8].

Sedation to restrict motion and increase compliance has been used to obtain MR images in small children and older children with developmental delays, but clearly sedation cannot be used in fMRI studies where researchers are interested in brain function in response to different demands and tasks which require the child to remain awake and able to participate. In addition, sedation can alter neuronal function and change brain chemistry confounding the imaging data [1] and spectroscopic information in magnetic resonance spectroscopy (MRS) studies. Sedation also increases the risk of performing MRI, which by itself is a minimum risk procedure without sedation. Reducing the need for sedation also substantially reduces costs, such as additional nursing staff required during and following sedation, that are involved in performing the MR examination [9].

Physical restraints, such as bite bars and plastic moulds that restrain the subjects head can reduce motion during fMRI scanning, but can also cause subject discomfort and can lead to extra distress in child subjects [2]. Use of a head strap is not as uncomfortable and provides tactile feedback to the child if he or she moves while in the bore of the magnet. Most commonly-used restraints include foam pillows or padding, and vacuum padding to help immobilize the head. However, these are less restrictive and motion problems may persist. MRI-compatible weighted blankets placed over the body and legs can also help reduce motion that could be translated to the head. In our experience, this has the additional advantage of being comforting to certain children, especially those with behavioral or developmental delays, such as fetal alcohol spectrum disorders (FASD).

Alternatives to restraint and sedation for reducing children's motion during fMRI have included various environmental modifications and training procedures. These have generally involved either behavior feedback to reduce motion, or methods for reducing anxiety in the scanning

environment, thereby reducing a possible cause of unwanted motion. The following sections review interventions to achieve these outcomes.

TECHNIQUES TO REDUCE MOTION ARTIFACTS BY MINIMIZING ANXIETY

The extent of head motion during scans may depend upon the patient's level of anxiety. A randomized experimental study of clients undergoing nonemergency MRI [10] found that subjects who learned guided imagery and used it during their scan had lower state anxiety (as measured by the State-Trait Anxiety Inventory, or STAI) and also moved less frequently than did control subjects. The STAI is a standard measure of anxiety; the trait portion measures anxiety level in general, while the state portion measures current anxiety level. A subsequent investigation [11] found no differences in state anxiety levels in patients with motion artifacts and those without, but significant motion artifact increases were observed when the patients indicated they were worried about the technical apparatus. More recently [12], written information about MRI given to patients prior to their scans significantly reduced motion artifacts for those patients relative to a non-randomized control group, despite having no significant effect on STAI scores. The relationship between anxiety and motion during scans merits further study, but the evidence suggests that strategies to reduce head motion should include techniques that attempt to minimize patient anxiety.

INFORM THE PARENTS AND THE CHILD ABOUT THE PROCEDURES IN ADVANCE

Fear of the unknown contributes significantly to patient anxiety about MRI procedures [13]. A study including 120 adolescents undergoing imaging for the first time demonstrated that cooperation was inversely proportional to anxiety level [14]. It therefore stands to reason that providing sufficient information prior to imaging as well as increased interpersonal encounters [15] with the subjects or patients will help alleviate anxiety regarding the scanning and unwanted motion. In studies involving children, fear and lack of understanding of the procedures they need to complete and why can be major obstacles. The information provided should be suitable to each child's comprehension level. For example, video recordings of another child comfortably participating in the procedure have been used to help achieve a successful completion rate of approximately 81% with children aged 5 through 18 recruited for an fMRI protocol [16]. An illustrated storybook was part of another intervention (along with practice in a mock scanner unit) that saw 82% of children aged 4 through 16 years receive successful scans without sedation [17]. Other imaging procedures have demonstrated significantly lower distress ratings reported by subjects who received a photo-booklet explaining the imaging procedures and a letter with advice to parents on how to help the child through the process [18]. Each of these studies also included explicit opportunities for children to ask questions about any aspect of the procedure. Providing advance information is important for adults as well, although in two cases previously cited [11, 12] the information reduced unwanted motion without significantly affecting anxiety levels.

Dantendorfer *et al.* attempted to use an anxiety rating questionnaire prior to MRI examinations to predict occurrence of motion artifacts for 297 first time MRI patients [11]. While no differences were observed in anxiety state levels in patients with motion artifacts and those without,

significant motion artifacts were observed when the patients indicated they were worried about the technical apparatus [11]. This clearly supports the need to inform the patients and/or research subjects about the technical aspects of the MRI and procedures they will encounter prior to imaging. It is important for subjects to understand, in lay terms, how the MRI works, including the source of the noises, to alleviate concerns related to the system resulting in reduced motion artifacts.

PREPARE THE CHILD WITH A MOCK SCANNER

A realistic mock scanner provides several potential benefits when preparing children for real MRI. It is a less expensive and physically safer environment for preparation. The effects of training procedures such as contingent feedback for motion control [19, 20] and graduated exposure to reduce anxiety [3] are more likely to generalize to the real MRI if performed in a realistic setting. Finally, time spent around and in the mock scanner, combined with advance information and child-friendly environments, is itself an effective form of preparation to help children successfully complete diagnostic MRI scans without sedation [17, 21], as well as for research studies.

Epstein *et al.* have shown that practice in a mock scanner environment may also help to directly reduce unwanted motion in children and adults with and without attention deficit hyperactivity disorder (ADHD) [2]. Although the effect of mock scanner practice was not tested experimentally, dataloss during the real fMRI scans that followed training was less than 10%, compared to excessive motion on an average of 42% of training trials. Final scan motion levels did not differ significantly between the ADHD and non-ADHD groups for either children or adults.

Where a mock scanner is not available, it is important for the subject to explore the MRI scanning environment prior to imaging. Staff that work with pediatric populations conducting research using MRI, including physicians, technologists, and nursing staff suggest that MRI examinations in pediatric subjects require more preparation than do those with adults. This preparation requires time for familiarization of the child to the MRI environment and the establishment of rapport with those involved in the exam [3]. Rosenberg and colleagues note that children often want to inspect the magnet before being willing to participate. When a child's curiosity and anxiety are not attended to the child may not hold still during the study or may refuse to participate all together [3]. A first-hand examination of the scanner environment was a component of several of the successful interventions in studies cited previously [16, 17]. Byars *et al.* noted that this preparation took approximately one additional hour in the MRI environment and requires availability of sufficient scanner time to complete the preparation phase [16]. Use of a mock scanner for the orientation and training procedures would provide considerable savings in MR time and expense.

Play or rehearsal of scans can help children gain confidence in the imaging procedure and child life specialists, or play specialists can help children with behavioral or anxiety issues who do not respond to standard reassurance [3, 22]. Having a skilled child advocate or child life specialist with the child throughout the imaging will help alleviate stress and these caregivers can provide continuous gentle reminders or cues to keep still. Poldrack *et al.* suggest that in order to

minimize anxiety of the child, it is crucial that study staff are comfortable and experienced in dealing with children, guided progressive relaxation techniques are employed prior to entering the scanning room and external stimulation should be provided as soon as possible after the child enters the magnet [6].

In one MRI study, only 1 child in 169 children over 4 years of age who were referred to the Play department required the use of sedation [23]. Similarly, effective play preparation in young children who require other forms of intervention, such as radiotherapy, and frequently require immobilization, can reduce the need for sedation. In a study of 63 children, of whom 52 participated in play therapy, only 5 of the 52 children required sedation, while 90.4% did not [24]. In a similar study of 223 young cancer patients requiring radiotherapy, 21.4% of patients who did not receive intervention required anesthesia, while only 8.9% of those who received play therapy and interactive support needed anesthesia [25]. Custom-made videos and life-sized dolls can reduce or alleviate stress effectively [26]. Combining this information with preliminary visits to a mock scanner or a play therapy situation where the child can go through the procedure with a doll will help reduce anxiety before the actual motion training protocol begins.

If there are appropriate tools, such as a mock scanner, and time to allow for play, the reduction in motion and anxiety levels for children undergoing MRI examinations can provide a substantial economic benefit in ability to complete the MRI scans without motion artifacts and the use of sedation.

USE SYSTEMATIC EXPOSURE-BASED THERAPIES

When patients or subjects show considerable fear towards a situation, a more comprehensive method of familiarization may be needed. For example, a behavioral technique known as systematic desensitization involves inducing a relaxed state through deep breathing, progressive muscle relaxation, visual imagery, or comforting stimuli. Relaxation is evoked throughout a hierarchy of increasingly fearful approximations until the patient is comfortable with the previously feared situation [27]. Similar approaches have been successfully used to prepare both children and adults for surgery and other medical procedures. These procedures include fear of injections, dental treatment, radiation treatments and intravenous procedures [3, 27].

Slifer *et al.* applied a 10-step desensitization hierarchy to help 10 children aged 3 through 7 to undergo radiation treatment for malignancies [27]. Although the study did not involve an MRI setting, the techniques used would be readily transferable. The intervention differed from classical systematic desensitization in that the hierarchy was pre-planned and deliberate inducement of relaxation was de-emphasized in favor of praise and tokens for complying with the experimenter's requests. Nevertheless, 8 out of 10 children aged 3 to 5, and some older children with severe anxiety, behavior problems or developmental delays were able to complete their treatments without requiring sedation. Slifer later replicated the study with 11 additional children (9 of whom successfully completed treatment without sedation following training) and the use of a video display apparatus to promote relaxation [28].

A simulated scanner environment has been used to prepare pediatric subjects for successful completion of a diagnostic-quality MRI examination without the use of sedation [3]. Sixteen

healthy children and 16 children with obsessive compulsive disorder (OCD) received systematic desensitization. Ten healthy children also underwent an MRI scan, but without any prior intervention. All 32 children who underwent the simulation scanning experience (with or without sound) completed the actual MRI procedure. At the end of the training session the children had desensitized to a state that was maintained throughout the actual scanning session. Four children were still experiencing high levels of distress after the desensitization procedure was complete (3 OCD and one control) and asked that their parent accompany them while in the real scanner. The decrease in self-reported distress was greater for the OCD group than the control group, but the OCD group had significantly higher levels of self-reported distress at the beginning on the simulation experience than the control group.

The 9 children who did not undergo training had significantly higher initial heart rates and self-reported distress and a trend for higher heart rates at the end of the actual scanning procedure. One of the 10 children who was not trained in the simulation scanner experienced a claustrophobic reaction to being placed in the scanner and did not complete the study. These results indicate that a simulation scanner procedure for children can help to reduce anxiety and increase the possibility of a successful completion for the actual MRI without sedation. All children in this study benefited from decreased stress, although children with OCD appeared to benefit to a greater extent than controls [3].

USE GUIDED IMAGERY AND ALTERNATIVE SENSORY INPUT

Guided imagery, or the scripted visualization of pleasant images and instructions to relax, appears to be a very cost effective means of reducing anxiety and motion artifacts during MRI. In one study, a treatment group of adults used guided imagery before and during the MRI and a control group did not [10]. Subjects and the MR technician reported after the scan how many times during the scan the subject moved. Movement reports from the subjects and the MR operator correlated strongly, and a greater proportion of subjects who received the guided imagery (89%) were motionless compared to controls (62%). No significant differences were found in either mean trait or initial state anxiety measures. The experimental group showed significantly decreased STAI ratings following guided imagery training prior to the MRI, but the control group who only received the information regarding the MRI did not. However, the STAI ratings post MRI were similar between the guided imagery group and controls. The study suggests that guided imagery lowers anxiety levels prior to imaging reducing the risk of adverse psychological responses to the MRI. The cost of providing this type of imagery, which can be practiced at home prior to the MRI, is low. If the degree of motion during the MRI can be reduced by use of guided imagery, this can be a very cost effective intervention.

The presentation of video and/or audio stimuli using displays and headphones can reduce the need for sedation and decrease unwanted motion by promoting relaxation, distracting the child from unpleasant stimuli, and serving as a reward for appropriate behavior [3, 28, 29]. An MRI-compatible audio-visual system provided significant reduction in the need for sedation, with a 25% reduction in children aged 3-10 and 50% reduction in those over 10 years of age [9]. No effect was observed in children younger than three years. MRI-compatible video goggles were also part of a multi-component intervention that led to successful scanning without sedation for 170 of 209 (81%) 5- to 18-year-olds [16]. Most recently, the introduction of an audiovisual

system for 2110 patients, including 673 0- to 18-year-olds, led to a 15% reduction in the need for sedation. The system was evaluated positively by 84% of patients, and it controlled motion as effectively as sedation, as rated by independent radiologists [30].

BEHAVIOR FEEDBACK METHODS TO MINIMIZE HEAD MOTION

A simple sighting system that provides visual feedback to subjects based on head motion can effectively minimize motion during fMRI [31]. The system consists of a vertical mark made on the surface of the screen where tasks are projected, and a coil-mounted visor that places a dark horizontal thread over the subject's field of view. Correct visual alignment of the vertical screen mark and the horizontal thread indicates when the head is correctly positioned, and allows the subject to resume the correct position even after deliberate neck flexion. Six subjects who used the visor sighting system produced equivalent activation maps when deliberate head movements were and were not performed, after images from the periods of voluntary motion were removed. Motion was measured by tracking the signal intensity of a single voxel; intensity decreased markedly during deliberate flexions but was stable between flexions. Activation patterns did not differ significantly when the visor was present versus absent.

Visual feedback was also effective for 12 adult male subjects who were shown a four-way arrow display that was integrated with the projection of the cognitive task stimuli [32]. Motion was measured through real-time analysis of acquired image data, and changes in the arrow colors indicated the direction and magnitude of head movement to subjects while they performed common fMRI tasks. A statistically significant decrease in head motion was seen when the feedback system was used, yet neither cognitive task performance nor brain activation patterns were significantly affected by the system.

Display of a preferred video contingent upon staying still can effectively reduce motion during simulated MRI scans in children. In one study, four children aged 5 to 6 years received three conditions presented in a multiple baseline design [20]. In the baseline condition the environment was arranged according to usual clinical practice, meaning there was no entertainment or feedback during the simulated scan and the child was given a toy at the end of the scan. During the second condition, the modified MRI environment (or non-contingent cartoon) condition, the scanner was covered with a cartoon façade and the child could watch a preferred cartoon that was reflected on the head coil mirror. The soundtrack for the cartoon was played over headphones. Again, the child was given a toy at the end of the scan. The third condition was the modified MRI environment plus contingent feedback. A potentiometer string connected to the child's head by an adhesive patch measured motion and controlled video display. The child could view the cartoon as long as head movements were 2 mm or less per second. If the child exceeded this threshold then the video was automatically stopped for 3 seconds. When the child complied with the criterion immediate praise and edible items to be consumed after the scan were provided. The environmental modifications alone were not sufficient to reduce motion in three of the four subjects and movement actually increased for two subjects. The combined intervention (modified environment plus feedback) immediately reduced head movement to very low rates for all subjects.

These results were successfully replicated in a mock fMRI setting with four children aged 7 to 10, one of whom was diagnosed with ADHD, another of whom was diagnosed with ADHD and Fetal Alcohol Syndrome (FAS) [19]. Performances on the vigilance task increased and head movement decreased as a function of the reinforcement contingencies. Differential reinforcement successfully modified the children's task performance and head motion during the simulated fMRI scans. The authors noted that additional research is needed to determine if the procedures used in the mock scanner will result in more usable data from fMRI scans in children with brain disorders and/or assist with noncompliance [19].

A similar behavioral training approach was used to control motion in 10 children aged 3 to 7 years undergoing radiation treatment [27]. The full procedure involved desensitizing the child to the radiation equipment, staff and routines, motivating the child to cooperate with instructions, and teaching him or her to inhibit voluntary movement. The motion goal was achieved by rewarding the child for remaining briefly motionless for a "Polaroid picture", and then requiring longer and longer periods of stillness before the picture was taken. For example, the subject must hold still for a slow count from 1 to 10 out loud. Additional practice sessions were completed until the child was able to lie still for longer periods of time. The experimenter judged visually the extent of motion and provided verbal feedback as needed. Transition to the radiation equipment was facilitated by describing it as a larger camera. Additional practice trials were conducted *in situ* with the experimenter and parent outside the room watching on a closed circuit monitor and communicating *via* intercom. Following training, 8 of 10 children were able to fully cooperate with their daily radiation treatment procedure without sedation

Epstein *et al.* examined the use of a mock scanner training protocol for minimizing head motion in individuals with a diagnosis of ADHD [2]. This study included 12 parentchild dyads with ADHD (both parent and child currently met DSM-IV criteria for ADHD) and 12 matched control parentchild dyads. Head motion was measured by either a magnetic tracking system or mechanically by a potentiometer. Vacuum packing, foam padding, or plastic "reminder" clamps were used in the head coil to reduce motion. The subject watched a 5-min movie during which head motion data were collected. If cumulative head motion exceeded 2 mm the video would pause. If there were more than 6 abovethreshold movements within the 5-min span the task was repeated. If the participant made 6 or fewer head movements they moved on to the next task, in which head motion was measured but the video continued to play regardless of the magnitude of motion. A final task in the mock scanner included the participants practicing minimizing head movements while performing a cognitive task, similar to the one they would be performing while in the actual scanner. Across all mock scanner runs, 42.5% of the runs would have been excluded based on movement with the normal control parents having the least amount of movement and the youths with ADHD having the most amount of movement. In the actual scanner each subject underwent 5 runs of functional imaging data for a total of 225 runs. A total of 24 runs were excluded due to excessive motion, 9.2% of the ADHD participants' runs and 12.3% of normal control participants' runs.

Epstein *et al.* found that many participants had a distinct pattern of task-correlated motion [2]. The participants often made a nodding motion after an incorrect response. This appears to be a normal response to making an error (what the authors refer to as a "whoops" phenomenon). This effect was larger in adults than in children. Most head motion was in the same direction, with

little movement of the head side to side. This suggests that head restraint systems that reduce side to side motion are effective, but more consideration needs to be given to placing additional restraints at the top of the head or under the chin [2].

CONCLUSIONS

This review outlines several methods that can be used to successfully train children to remain still in an MRI environment. An important part of this process is familiarization of the environment and preparation of the children. Most studies have shown that when a child is introduced to the MRI scanning environment, apparatus, and procedures his or her level of anxiety decreases. When this is done in an unhurried and child-friendly manner it can help to alleviate fears and satisfy any curiosity the child may be experiencing. An opportunity to ask questions and explore is an important part of the preparation and should not be overlooked. If this introduction and preparation can be done in a mock scan environment then it is expected that substantial cost savings will result with respect to real scanner time and resources.

A second important element of preparing children for an MRI is the training needed to reduce motion, especially head motion, while in the MRI. Most studies reviewed relied upon the principle of behavior feedback. In these cases, head motion led to an environmental change that in turn reduced the amount of the motion. Some environmental changes used successfully include display/pausing a preferred video, verbal reminders (e.g. "stay as still as a statue"), and rewards such as stickers, toys, food and verbal praise. Simply representing the amount of motion to adult subjects can be sufficient to reduce motion; this method has not been studied with children to date but may be effective if the representation is clear and easily-understood.

The studies cited used a wide variety of systems to measure motion and to provide feedback, but in our view an optimal system has not yet emerged. Such a system should be affordable and should measure motion accurately and precisely. It should be able to present a variety of relevant ageappropriate consequences to subjects, and should be usable in a mock scanner training setting to reduce expensive magnet time. Ideally the feedback system should also be suitable for the real fMRI environment. Results from studies of adults and minimal visual feedback [31, 32] indicate that those systems can be used during fMRI scans without detriment to the quality of activation data obtained. This would obviously not be the case for systems that present full screen preferred videos as a consequence for stillness [2, 19, 20] that can be used for general MR imaging and spectroscopy studies. An important generalization challenge therefore remains: how should training be conducted in order to maximize the transfer of improved stillness to a setting where the training contingencies may not be applicable? This issue has received little study to date.

Most of the research conducted has included healthy control children and a few studies have included children with mental health conditions such as Obsessive Compulsive Disorder (OCD) and Attention Deficit Hyperactivity Disorder (ADHD). There is little research in this area on children with developmental delays or other neurocognitive disorders such as Fetal Alcohol Spectrum Disorders. This is an interesting finding as it has been speculated that this population are exceptionally hard to image in an MRI. More research needs to be conducted on children with developmental delays and neurocognitive issues to determine if they are more difficult to image, and how the techniques described should be tailored for these populations. Many of the

cited papers [2, 27, 28] describe combinations of techniques intended to improve scanning success. Analyzing the relative contributions of the intervention components would be a useful goal for future research.

More data are needed regarding procedures to increase scanning success by reducing stress and motion. Potential benefits include a huge potential financial savings as a result of improved image quality, reduction of required MRI scanner time and reduced need for sedation. Findings in this area should also be used to better inform the design and evaluation of fMRI protocols involving children, who will ultimately benefit most from the research.

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