Video Article

Making MR Imaging Child's Play - Pediatric Neuroimaging Protocol, Guidelines and Procedure

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Abstract

Within the last decade there has been an increase in the use of structural and functional magnetic resonance imaging (fMRI) to investigate the neural basis of human perception, cognition and behavior [1, 2]. Moreover, this non-invasive imaging method has grown into a tool for clinicians and researchers to explore typical and atypical brain development. Although advances in neuroimaging tools and techniques are apparent, (f)MRI in young pediatric populations remains relatively infrequent [2]. Practical as well as technical challenges when imaging children present clinicians and research teams with a unique set of problems [3, 2]. To name just a few, the child participants are challenged by a need for motivation, alertness and cooperation. Anxiety may be an additional factor to be addressed. Researchers or clinicians need to consider time constraints, movement restriction, scanner background noise and unfamiliarity with the MR scanner environment[2,4-10]. A progressive use of functional and structural neuroimaging in younger age groups, however, could further add to our understanding of brain development. As an example, several research groups are currently working towards early detection of developmental disorders, potentially even before children present associated behavioral characteristics [e.g.11]. Various strategies and techniques have been reported as a means to ensure comfort and cooperation of young children during neuroimaging sessions. Play therapy [12], behavioral approaches [13, 14,15, 16-18] and simulation [19], the use of mock scanner areas [20,21], basic relaxation [22] and a combination of these techniques [23] have all been shown to improve the participant's compliance and thus MRI data quality. Even more importantly, these strategies have proven to increase the comfort of families and children involved [12]. One of the main advances of such techniques for the clinical practice is the possibility of avoiding sedation or general anesthesia (GA) as a way to manage children's compliance during MR imaging sessions [19,20]. In the current video report, we present a pediatric neuroimaging protocol with guidelines and procedures that have proven to be successful to date in young children.

Video Link

The video component of this article can be found at https://www.jove.com/video/1309/

Protocol

We have incorporated general experimental testing guidelines as well as MRI specific approaches [12-23] into one complete neuroimaging protocol intended to guide researchers and clinicians during neuroimaging sessions with awake children as young as four years of age. First, we aim to emphasize general testing guidelines adapted for MRI examinations. Second, we provide a hands-on, step-by-step description of our neuroimaging protocol. In our experience, a single session of approximately 2.5 hours (including a maximal imaging time of 45-60 minutes) is sufficient to train and guide a child through a neuroimaging session.

General Guidelines

As in every testing session with pediatric populations, general guidelines and recommendations for how best to work with young children should be considered [24]. We highlight comfort, appropriateness and motivation (**CAM**) and provide definitions of these concepts.

(**C**) Comfort: *Comfort is defined as the emotional state of a young participant involved in an imaging session where the feeling of threat is minimized and security is maximized.*

Environment: In line with other research groups [19,20], we consider the mock scanner area an ideal place to start a neuroimaging session. Ideally, a mock scanner area replicates the actual MRI room and MR scanner to the greatest extent possible (e.g. including a mock MR scanner mirroring an actual MR scanner's appearance and the sounds produced) [20]. This room provides the same equipment (e.g. response tools) as the actual MRI room. Without a static magnetic field, it is a safe place to familiarize the child with the imaging procedure in a child-appropriate way. The mock scanner area can be designed in a child-friendly manner by adding stuffed animals, placing a few toys in the room (not too many because this could be distracting), having parents and siblings sit on child-size chairs and table, and providing some parent-approved snacks and drinks. We further provide the child with a sticker chart, a CD with the child's structural brain images, and a treasure chest with a gift certificate and other small prizes.

Family & Friends: One way to facilitate active participation during a neuroimaging session is to encourage the participating children to invite their family, siblings and friends or to bring their own stuffed animals or toys. In addition, children and their parents should be allowed to choose whether they prefer to have one parent be present in the MRI room during the fMRI experiment.

Clothing: Clothing with no metallic pieces (e.g., buttons or zippers) is mandatory. Children may prefer to wear their own clothing. However, appropriate attire (e.g. hospital gowns) should be available if needed. As training and MRI rooms can be cold, a blanket may offer the child additional comfort.

(**A**) Appropriateness: *Appropriateness describes the frameworks and contexts used to present activities and materials during the neuroimaging session in relation to the age group studied.*

Terminology: The terminology and practices used during pediatric neuroimaging sessions should be carefully chosen. Doing so can avoid misconceptions or a frightening atmosphere. Inappropriate terms, for example, include the following: "*it is really loud, but it will not hurt you"* or *"how are you doing inside the machine?*. It is recommended to use positive language that is easily understood by children and to address potential issues directly. Avoiding certain phrases can be advantageous for the session and a child-appropriate choice of technical terms is recommended (e.g. "*brain camera*" instead of "*MRI machine*", "*camera click*" instead of "*scanner noise*", etc.).

Misconceptions: One important goal is to clarify the child's misconceptions about imaging as early as possible during the neuroimaging session. An easily understandable study description should be communicated prior to the visit and may be repeated at the beginning of the neuroimaging session.

Response Tools: Using specific response tools appropriate to the age of the participant has proven to be beneficial [25]. As an example, when using various instruments (e.g. headphones, response buttons, eye tracker, etc.), it is important to use those that are child-appropriate in size and shape. These instruments should be carefully positioned so that the child does not wiggle and move in an attempt to reach the response devices.

Affective State: As in every testing session, it is essential to be sensitive to the affective state of the participant. Children may not always express their feelings readily, but anxiety, boredom or frustrations need to be recognized and dealt with promptly [7,24]. Concerns need to be addressed directly and questions need to be posed in a child-appropriate manner.

Flexible Approach: It is highly recommended to account for the specific needs of each child and to allow sufficient time to make a flexible approach possible (e.g. optional help depending on the child, additional training sessions, allowing enough time for the neuroimaging session, etc.).

(**M**) Motivation: *Motivation describes the willingness of a participant to actively cooperate within a given research setting.*

Child-Friendly Themes: We recommend using a fun theme that guides children throughout the neuroimaging session (e.g. an adventure story). By doing so, the children become invested and engaged in the sequence of the activities. Furthermore, a theme can give the research team an opportunity to build all experiments and task paradigms in a child-friendly way (e.g. using cartoon characters).

Traditional & Virtual Sticker Charts: Sticker charts are well known as tools to help motivate children to complete different experiments within one session. A virtual sticker chart is analogous to the traditional sticker chart, but it can be shown (via projector) to the child when inside the MR scanner. As an example, we use a virtual sticker chart modeled after the children's game "*Chutes and Ladders*", where the participants have to find their way home (this can only be achieved by completing the experimental tasks). Not only is this fun for the child, but it gives the research team time after each run (image acquisition time for one experimental task) to prepare for the next.

Course of Action

Pediatric Neuroimaging Session I: Preparation

1) Before the neuroimaging session: In preparation for the neuroimaging session, the participating families are provided with information through print or online media, which contain age-appropriate descriptions offering a preview of the study content and details.

Pediatric Neuroimaging Session II: Training (approximately 1 hour)

2) Welcome & paperwork: The pediatric neuroimaging session starts in the mock scanner area, where the research team welcomes the participating child, family and friends. Institutional review board (IRB) forms (e.g., consent and assent forms), MR scanner screening forms, and reimbursement procedures are reviewed and it is ensured that the scope of the neuroimaging session is clear for the child and the parents.

3) (f)MRI introduction: The mock scanner area is introduced to the child and the parents including a short description of the mock scanner, the response tools and additional material used during the neuroimaging session. A digital camera can be used to explain how a regular camera takes pictures and how a "brain camera" (MRI scanner) works. Examples of sharp and blurry pictures demonstrate the impact of motion on the quality of the photos or pictures (see Figure 1). Movement restriction may be illustrated through the use of optional games, such as the "Freezing-Game" or "Statue-Game". These games require the child to stay very still (e.g. as an ice sculpture or statue) for a short period of time.

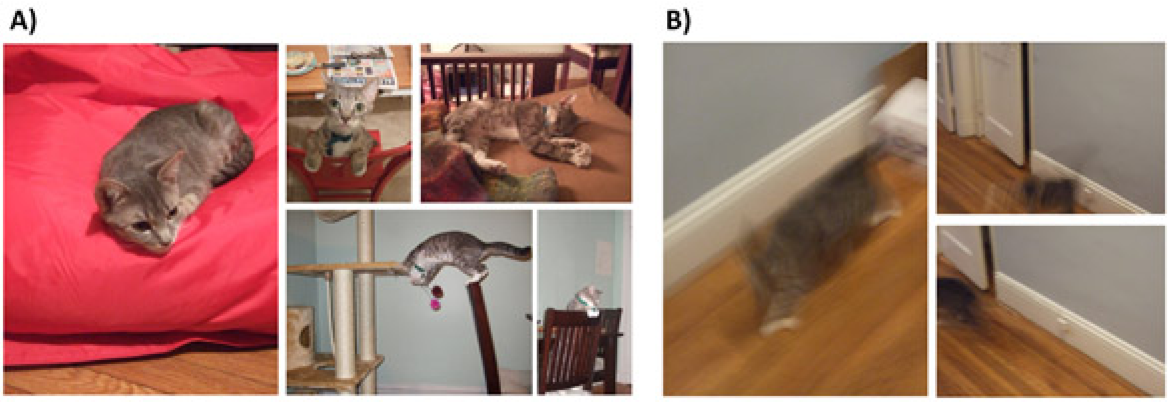

Figure 1. (A) Sharp and **(B)** blurry pictures may be used to demonstrate the impact of motion on picture quality.

4) Introduction to experiment: Before introducing the experimental tasks one can start with a short enjoyable activity. Next, the use of the mock scanner is slowly incorporated.

5.1) Short movie: For this experiment a child friendly theme is added to the neuroimaging session. The children take part in a spaceship adventure game which is introduced by a short movie; the main characters guide the child through all experiments.

5.2) Experimental tasks / "games": The use of the mock scanner is incorporated step-wise: **(1)** instructions are shown while the child is sitting on the mock scanner bed; **(2)** the instructions are repeated using printed cards which mirror a computer screen; **(3)** the first few examples are solved with the help of the research team; **(4)** training items are then presented in real time; **(5)** as a next step the child is offered the use of headphones and pre-recorded scanner background sounds are played back during the presentation of the training items; **(6)** finally, the child is allowed to play the game inside the mock scanner. The research team ensures understanding of the experimental tasks.

If using more than one response tool, such as one button in each hand, it is important to define which response tool corresponds to which answer. A child may not know the difference between left and right. A stuffed animal (e.g. a monkey) can be placed next to one side of the child. Instead of the instructions *"press the right button"*, the instructions are changed to *"press the monkey button"*.

5) Rules of communication: During the training the child is taught that a gentle hand press on their leg signals that they are moving too much. This signal serves as a means of communication possibility between the research team and the child during the actual fMRI experiment. It is explained to the child that speech should be avoided during image acquisition as it could interfere with the experimental task performance and impact data quality.

6) Short break / dice game: During a break, dice may be used to determine a random order in which the games will be played during the fMRI experiment. This ensures randomization across participants.

7) Repetition of main points: Before starting the fMRI experiment it is recommended that the researcher repeat the most important rules for the neuroimaging session to the child. In order to minimize memory demands on young children, it is helpful to summarize critical information in a few main points and to reiterate those throughout the session.

8) Trouble shooting: When a child hesitates in taking part in the training session or fMRI experiment, researchers are advised to **(1)** act immediately; **(2)** offer to take a break; **(3)** address concerns and assure that participation is voluntarily; and depending on the child's choice the session is either stopped early or **(4)** game strategies as recommended by play therapists [12,26] are used to help a more anxious child get comfortable with the new environment. It is important to use flexible approaches that allow a child to participate at a pace that is comfortable for them. However, the child's choice in participation needs to be evident.

9) MRI training without mock scanner: If researchers or clinicians do not have access to a mock scanner area, game strategies as used by play therapists are highly recommended [26]. For example, a neuroimaging session can be simulated by using pictures or a model of an MR scanner [12]. Furthermore, behavioral approaches using desensitization and operant behavioral techniques [13-15,17,23] have helped to reduce distress in children and increase the number of children successfully completing their neuroimaging session.

Pediatric Neuroimaging Session III: Break and Metal Screening

10) Metal screening: Before entering the MRI room, every participant and parent must fill out and sign an MRI screening form. Additionally, the child needs to be checked for ferrous objects. A hand held metal detector or a magnet can be used to introduce the screening playfully (e.g. "pretend we are at the airport").

Pediatric Neuroimaging Session IV: fMRI Experiment (45 to 60 min)

General: During the fMRI experiment, the biggest challenge for many children is to stay very still for a long period of time. It is recommended to keep each experiment as short as possible or to divide the experiment into two experimental runs. In our experience, run imaging times with a maximum of five to seven minutes have proven accomplishable by children elementary school age or younger. The total length of the imaging session should also be considered. However, it is easier for a child to go through a long imaging session with several short experimental runs than to complete a shorter session with longer experimental runs. Neuroimaging experiments often employ a block design in which different experimental task conditions are presented in a series of subsequent blocks. Children can easily get confused by changing task demands within one experimental run and therefore it is recommended to keeping task conditions separated (e.g., by sampling two different task conditions in two subsequent experimental runs with a break in between).

11) Facilitate transition: To facilitate the child's transition to the actual MRI room, the child is accompanied by a research staff member and may choose to bring along a parent and the child's favorite stuffed animal, as long as the toy does not contain any ferrous parts. Additionally one research team member is recommended to accompany the child.

12) Equipment check: Screen and mirror positioning (for visual experiments), sound volume (for auditory experiments), and response tools need to be checked and ear protection (e.g., ear plugs) should be provided for attendants in the MRI room. Check the response tools and settings with applied examples (e.g. play questions for the child to test audio settings and have the child answer them). The research team must ensure that every family member present in the MRI room received information on appropriate behavior and rules, especially concerning safety.

13) fMRI / experimental task performance: Task instructions should be repeated before the start of each game (experimental task). After each game, the virtual sticker chart rewards the child's cooperation. While in the MR scanner, the child's comfort and movement must be monitored. The presence of a research team member in the MRI room has proven to be highly advantageous; the child's well-being and behavior can be observed, and essential communication and motivating feedback can be given directly to the child. Head movement of the child may be observed by the research team member present in the MRI room or by the researcher monitoring the image acquisition outside of the MRI room. A gentle hand press practiced during the training session signals to the child that they are moving too much. For experiments with several experimental runs, a short break half way through the neuroimaging session maintains comfort. As a motivational factor during the break, the child can be shown his or her own brain images.

14) Structural image acquisition: Finally structural MR image acquisition requires the participant to lie still without performing any experimental task. The child can be entertained by watching a short movie during this time. Recommended examples of appropriate movies are animal movies or documentaries as they are enjoyable and unlikely to induce laughing which may lead to head movements during image acquisition. The child handles movement restriction during the time of image acquisition more easily if told that pictures acquired during this time will be presented to them as a gift to take home, such as a CD with the child's brain pictures.

15) Closing: Once image acquisition is complete the reimbursement procedure follows including gifts, prizes and a CD with acquired brain pictures for the child to take home.

Representative Results

The use of appropriate preparation protocols and child-friendly imaging procedures positively influences cooperation, motivation and the experience of our participating children and their families. Use of this protocol reduces overall movement and thereby increases the chance of obtaining high quality images without the use of sedation or GA.

Using the current protocol we have recently obtained functional and structural brain imaging data for a group of pre-school aged children (ages 4.9 to 6.3 years / average age 5.5 years). Over 95% of all children have been able to complete a neuroimaging session including mock scanner training and fMRI experiment. The guidelines and procedures presented in this protocol were designed for pediatric neuroimaging sessions. However the general principle and many of the described tools can be applied to pediatric imaging sessions in general such as image acquisition of other body parts.

Discussion

The emergence of functional and structural MRI to study the human brain has facilitated possibilities of examining typical as well as atypical brain structure and functions and therefore holds great promise for both research and clinical purposes [6]. However, MRI studies in younger age groups remain less numerous when compared to those of adults, adolescents or infants, which is mainly due to technical and practical difficulties when performing pediatric neuroimaging sessions. The current video-protocol presents hands-on solutions addressing the main practical challenges that may have prevented research groups from performing (f)MRI experiments in young children.

Challenges of pediatric neuroimaging are numerous, but researchers agree that the two main obstacles to overcome are: level of anxiety/distress and participant's movement [2,4,7,25]. Anxiety and distress are commonly reported in clinical patients undergoing imaging procedures. It is estimated that 4 to 20% of all patients refuse to undergo the MRI session or terminate an imaging session before completion [27]. An incomplete clinical imaging session can have serious implications because it may delay proper diagnosis and possible treatment [22]. MRI sessions in children have been reported to impose even higher levels of anxiety/distress [7,18]. However, Rosenberg et al., (1997) could show that distress in children aged 6 to 17 can be significantly reduced by careful subject preparation, including the use of mock scanners.

The intense scanner noise generated by the shifting of gradient coils during conventional continuous image acquisition is one potential cause for anxiety or discomfort [28]. This scanner background noise (SBN) may not only cause anxiety and discomfort in the participant, but can potentially interfere with experimental paradigms (e.g. during auditory or attention tasks [29,30]. One way to circumvent the exposure to the SBN is to use interleaved data acquisition designs such as the behavior interleaved gradient (BIG) technique [31,32] or sparse temporal sampling [29,30,33-36] (see Gaab et al. 2007 for a detailed discussion on advantages and disadvantages of 'silent' imaging designs).

As an additional obstacle to overcome, movement restriction is necessary to obtain high quality and diagnostically relevant data. In clinical practice, children below a certain age (usually between 6 to 8 years) are often imaged using sedation or general anesthesia (GA) [20]. However, besides possible risks to the child, GA and sedation both lead to increased imaging time and higher costs due to the use of external staff, equipment and medications [23]. Sedation or GA is not used during fMRI due to its potential influence on the blood level dependency contrast (BOLD contrast) [1]. Furthermore, many neuroimaging tasks require the child to be alert and responsive.

It has been shown that play therapy, simulation and behavioral approaches (e.g. cognitive behavioral therapy, behavioral reinforcement) are successful methods to reduce anxiety, reduce overall movement and to allow MRI without sedation in children as young as 3 years of age [23,14]. The current protocol incorporates ideas and elements of the main behavioral management techniques to date into one complete neuroimaging protocol and thereby aims to offer researchers as well as clinicians hands-on guidelines to design and conduct imaging sessions with awake, young children. The use of the current protocol has proven to increase the number of children able to successfully complete a neuroimaging session. The use of a child-friendly and age appropriate pediatric neuroimaging protocol may also allow clinicians to reduce the use of sedation or GA in children undergoing imaging procedures and is expected to increase the emergence of pediatric imaging studies in younger age groups.

Disclosures

The authors have nothing to disclose.

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