Functional Magnetic Resonance Imaging (fMRI) and virtual reality: adding brain imaging to your virtual reality repertoire

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1. INTRODUCTION

Investigating the neural bases of human behavior is a remarkably complex process. In the 20th century, the traditional tools available to researchers have typically involved studying behavioral changes following a brain injury or lesion, as well as a number of physiology measures such as recording and stimulating brain areas (either inter-operatively or chronically during medical telemetry, often implemented to localize epileptic foci). Each of these has made unique contributions in providing insights into brain and behavior relations. However, such studies are invasive, and are not ideal for most purposes.

Within the last couple of decades, a variety of noninvasive brain imaging techniques have been developed and implemented to add to the arsenal of tools available to study brain function. Most notably, functional brain imaging has emerged as a method to examine correlates of brain activity. The term "functional brain imaging" typically refers to any technique that examines brain function noninvasively such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), electroencephalogram (EEG or event-related potentials – ERP), magnetoencephalography (MEG), or near infra-red spectroscopy (NIRS). For the purpose of this paper, the focus will be on fMRI because most of the problems and solutions that apply to fMRI will generalize to any of the other techniques.

This paper is designed for the VR researcher who has interest in using functional brain mapping during VR research, but who is unsure of the various issues that are involved in such a venture. Included are some of the main factors that one should consider in starting VR/fMRI experiments, and common solutions to problems that arise are provided. This primer can be used by anybody, ranging from the new graduate student with no research funds available to a full professor with generous available funds and unlimited staff.

2. SCANNER

The first item necessary is a scanner. An fMRI scanner is no different than the standard MRI scanner found in most hospitals. In fact, most scanners are used interchangeably to do both MRI and fMRI. The difference between the two is that for standard MRI, the scanner is tuned to be sensitive to hydrogen concentrations, which results in excellent resolution of anatomical structures. For fMRI, the same scanner is tuned to be sensitive to oxygen use, which results in excellent resolution of areas with oxygen, such as the blood.

Most new scanners have built-in software that allows the user to choose the type of scan they want, so knowledge of MR sequences is not always necessary. However, it always will be valuable to have an experienced collaborator or MRI technician to recommend optimal settings for the scanner and for the experimental protocol. But, without those collaborators, one still will be able to collect good data, even if it is not optimal data. For optimal data, it is ideal to be in a situation where an MR physicist is available, or to be in an environment where optimized protocols already exist. Furthermore, every publication should have detailed information on scanning parameters, so simply reading a paper which used desired scanning techniques often will be sufficient for obtaining the correct scanning parameters.

If you are at a place where no functional brain imaging is being performed, but yet they have an MRI machine, the best bet is to meet with the Director of the MR center and ask about performing functional imaging. A large majority of places are performing functional imaging, even if their scanning is not of the brain (e.g. cardiac or prostrate are common ones). By expressing your interests to the Directors at such a center, they may be willing to move into brain imaging as well. It is not overly difficult to move from one type of imaging to brain imaging, but the support of the Director and a MR technician will be necessary for it.

3. HARDWARE

The major hardware constraint during fMRI experiments revolves around the fact that the MRI machine is an extremely powerful magnet. A 3T MRI scanner is 60,000 times stronger than the earth's magnetic field, so iron materials must be avoided during MRI scanning. The majority of over-the-counter gaming / VR hardware almost always contains some iron, whether it is screws, springs, or motors, and any device with iron can be drawn to the magnet with incredible power and speed which could damage the scanner and create a deadly accident for the participant.

The solution for these problems can be relatively simple. To detect whether a piece of hardware has iron, the simplest way is to run a small hand magnet over the hardware to detect where the iron is located. If the iron is a screw or spring, these typically can be replaced with plastic substitutes that can be bought easily either online or at a local hardware store. For larger iron pieces, such as a force-feedback motor, the options are much less apparent, and the experimenters should ask themselves whether that hardware feature is absolutely necessary for the experimenter.

Alternatively, there are a number of companies that now sell MRI-compatible interfaces such as joysticks, trackballs, and keypads. These products often utilize fiber optic technology and work well. The downside is that these often are quite expensive, about $1500 USD for a joystick, and are fragile.

In our lab, it has proven most effective and cost- and time-efficient to cannibalize an over-the-counter product to work in an MRI environment. When we were designing steering wheels and gas/brake pedals for the scanner, we sought quotes from a few companies, and each quote was well over $10,000. Eventually, we settled on buying a $40 Logitech racing wheel and replaced the metal screws and springs with plastic ones, for an additional cost of about $100. Another steering wheel system using the same Logitech wheel has been made MR-compatible by replacing the springs with thick rubber bands, collectively costing us about $200. Hence, there are numerous alternatives to spending thousands of dollars on MRI-compatible hardware.

Lastly, whereas iron is problematic and dangerous in an MR environment, this is not the case with all metals. Aluminum and copper (and other metals) can often be used where metal is absolutely necessary. The two main issues with a substitute metal are that certain metals can heat up from the radio frequency signal during scanning. The 2nd problem is that the metal may create artifact in the brain imaging signal, so that the brain imaging data are unusable. Both of these can be tested out without a participant being in the scanner to assess whether these problems arise.

4. VISUAL DISPLAY

For all VR scenarios, it is critical to have a good visual display. However, the visual display issue during fMRI is not as complicated as one might think. Because the participants cannot move their head during a brain scan, most advantages of the standard HMD are no longer relevant. For example, head tracking is a moot point when the participant cannot move their head, so the display typically can be reduced down to having a projection screen and an LCD projector. In this case, there is a projection screen either below or above the participant's body, and the image is displayed on the screen from an LCD projector; the participant views the screen with 45 degree mirror glasses. An alternative is to purchase fiber optic goggles that can be used. However, fiber optic goggles can be quite expensive, possess lower resolution that an LCD projector, and are difficult to fit in the MRI scanner, depending on the size of the scanner opening and the head coil. Nonetheless, if one is interested in presenting different visual images to each eye, fiber optic goggles are the one of the only solutions.

5. SOFTWARE

The major issues in software design revolve around providing relevant information for analysis. Often during the analysis stage, it is valuable to the experimenter to have a software marker that would link critical events in the VR scenario to the brain imaging data. For example, if a rare event occurs in the VR scenario, such as a car accident, it might be of interest to examine the brain-related changes linked to this event. Given that such events occur unpredictably (it would depend on how fast the participant is driving, where they are in the environment, etc), there is no *a priori* way to know how to link the behavior with the brain imaging data. Stated another way, there would be no way to know which brain images, within a large stream of brain images, are the images of interest. To address this, software simply needs to put out markers to a data file of when important events occur, so that this later can be linked to the brain imaging files, and the appropriate analysis can be conducted. This is a simple thing to do for groups that have access to the source code for their software, but would prove difficult when using over-the-counter software that is not easily modified.

6. FEASIBILITY

Even with the proper software and hardware, it may prove difficult to conduct a reasonable fMRI experiment. Most institutes charge a hefty fee for scanning, typically about $500/scan, so that a simple study with 20 participants costs $10,000, without considering software, hardware, analysis, and participant reimbursement costs. There are, however, a few ways to negotiate these expenses. Aside from getting grants, numerous institutes have "Pilot Study" grants, where 10-20 free scans are given to a researcher in order to collect enough pilot data to submit a grant with funding for a larger imaging study. Such "pilot study" mechanisms are rarely detailed at an institute's website, but they are quite common.

Alternatively, another way of acquiring free scans is to meet with the director of the center and express your interest in obtaining some pilot data for your dissertation, future grant, etc. Most people are sympathetic to newcomers in the field and will allow some free scanning. Note that your chances of obtaining free scans will be dramatically improved if you present a well thought out plan on how these data will be used to acquire funds for future scans. Because of the huge cost of a scanner, imaging centers are typically always watching their budgets, and they are pleased when researchers are able to bring in funds specifically ear-marked for scanning.

For graduate students, an excellent way for free scans is to ask the director (or similar higher-level researcher) of the imaging center to be on your dissertation committee. Another productive method is to ask a researcher who is scanning if you can add a short task onto their scanning protocol. Effectively, that researcher is paying for the scans, and you are using 10-15% of their scan time as your own. Of course, you'll want to engage in some sort of barter system with this researcher; for example, discussing co-authorship on your publications, or perhaps sharing software or programming with their lab. In my experience, if some or all of these techniques are attempted, almost anyone can start some scanning without any funding.

7. ANALYSIS

Collecting good data is only the tip of the iceberg. The analysis portion can be simple or very complex depending on design and theoretical constraints. For somebody with grant support, imaging centers often have people who will analyze the data for you, and who will summarize it nicely for you with figures and written text. These people are a wonderful asset to any project, but they can be costly, and you will forever be dependent on such individuals unless you know how to analyze data by yourself. An alternative way is to meet with somebody knowledgeable about analysis that will show you how to analyze the data. This will be more time-consuming and frustrating in the beginning, but you will quickly become more independent and learn analysis techniques with this method.

Critically, there often are divisions on how best to analyze data and which software to use to analyze it etc. Avoid these traps! It is easy to spend years debating such issues which really are not relevant to your experiment. Find some published papers that you admire, examine their analysis techniques, and try to adopt something similar. For many of the popular analysis software (SPM, AFNI, Brain Voyager), there are wonderful websites, blogs, and help options available where users can post questions and receive reasonable answers.

8. DESIGN

Lastly in any research project, there never is a substitute for good experimental design. A large amount of time should be spent on the design of the experiment, including having a very specific idea on how the data will be analyzed. This can be daunting (particularly the analysis part), and the best way to address this is to consult with experts in your field via email or in person about how best to design the study. Brain imaging has many projects designed with questions such as "What activates in the brain when somebody does X?"

Such approaches devoid of theory and *a priori* hypotheses almost inevitably result in poor design, poor analysis, and worse interpretation. As in any study, the design should be constrained and shaped by related studies, even if they are not VR- or brain imaging based.

9. SUMMARY

In summary, VR can be used during brain imaging if some appropriate steps are taken. As in all scientific endeavors, probably the best way to learn and implement any new technique is find a knowledgeable and respected researcher and seek their advice for your specific interests. Without such a person, a motivated individual still can integrate brain imaging into their experiments using some of the advice detailed above, but it will take a bit more legwork and perseverance. Nonetheless, integrating VR and brain imaging can be a valuable tool for understanding the neural basis of realistic behaviors.

10. SAMPLE ARTICLES INTEGRATING VR AND FMRI

Translational article combining fear conditioning in VR environments with fMRI.

R P Alvarez, A Biggs, G Chen, D S Pine and C Grillon (2008), Contextual fear conditioning in humans: cortical-hippocampal and amygdala contributions, J. Neurosci., 2008 Jun 11;28(24):6211-9.

Technically difficult experiment with steering wheel, pedals, and VR during fMRI.

K N Carvalho, G D Pearlson, R S Astur and V D Calhoun (2006), Simulated driving and brain imaging: combining behavior, brain activity, and virtual reality, CNS Spectr., 2006 Jan;11(1):52-62.

Excellent use of custom VR goggles for fMRI use and stereoscopic visual presentations.

H G Hoffman, T L Richards, J Magula, E J Seibel, C Hayes, M Mathis, S R Sharar and K Maravilla (2003), A magnet-friendly virtual reality fiberoptic image delivery system, Cyberpsychol. Behav., 2003 Dec;6(6):645-8.

Standard spatial memory assessment during fMRI using VR and joystick.

S L Shipman and R S Astur (2008), Factors affecting the hippocampal BOLD response during spatial memory, Behav. Brain Res., 2008 Mar 5;187(2):433-41.