NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 25 (2005) 328–331

Technical Note

A full-size MRI-compatible keyboard response system

George Andrew James,[a,b,*] Guojun He,[b] and Yijun Liu[a,b]

[a]*Department of Neuroscience, University of Florida, 100 S. Newell Drive L4-100, PO Box 100256, Gainesville, FL 32610-0256, USA*
[b]*Department of Psychiatry, University of Florida, Gainesville, FL 32610-0256, USA*

Received 8 June 2004; revised 7 November 2004; accepted 10 November 2004
Available online 20 January 2005

Two commercially available plastic keyboards were contrasted in the degree to which they interfered with echo planar imaging. One keyboard (GrandTec USA's "Virtually Indestructible Keyboard") caused significantly less temporally variant and invariant signal loss and was integrated into a MRI interface system for recording participants' manual motor responses. The response recording system is safe, accurately records reaction time behavioral data, and does not interfere with functional data collection. Implementing this MRI-compatible keyboard allows the collection of motor responses from complex manual behaviors (i.e., typing) and thus represents a valuable tool for functional MRI (fMRI) studies.

Keywords: fMRI; Keyboard; Response; Signal

Introduction

Functional MRI's (fMRI) strong magnetic field severely limits how participant behavioral data are recorded. Input devices containing paramagnetic components may (at best) interfere with data acquisition or (at worst) pose a serious hazard to participants. Although some systems overcome this limitation with fiber optics, they typically are expensive (approximately US$2000–4000 in 2004), require specialized software, or are limited to four buttons.

A full-size keyboard would be an ideal recording device, especially for studying complex motor responses (Fig. 1). Keyboards were previously adapted for fMRI use by removing all nonessential ferromagnetic components (Gordon et al., 1998), but the influence of remaining ferromagnetic components upon the MRI signal was not assessed. The presence of such components could disrupt magnetic field homogeneity and thus diminish overall signal to noise ratio (SNR). Differing keyboard brands or cannibalization techniques could variably diminish the SNR, leading to inconsistent findings across research groups.

The ideal recording device would be an inherently MRI-compatible keyboard—one requiring no modification for fMRI use. Two commercially available keyboards composed of plastics appeared to meet these criteria and were compared for MRI compatibility.

Materials and methods

Response recording system

Two plastic keyboards (GrandTec USA "The Virtually Indestructible Keyboard", model #FLX-1000; the Adesso "Foldable Keyboard", model #FOLD-2000) were separately connected with 20 ft of keyboard cable by wall panel (using a pi-filter DB15 connector) from the scanner room to a laptop computer (Dell Latitude C810 model PP01X) in the control booth. Participant behavioral output was recorded with in-house Matlab programs (The MathWorks Inc., 2002). An MRI-compatible auditory system (Resonance Technology Inc.) with stereo earphones and a microphone permitted verbal communication between participant and operator.

Scanning parameters

Scanning occurred in a 3.0-T Siemens MRI head-dedicated scanner (Siemens) with a dome-shaped head coil (MRI Devices, Inc.; Fitzsimmons et al., 1997). Functional images were collected with echo-planar (EPI) scanning of 36 axial slices covering the whole brain (TR = 3.0 s, TE = 25 ms, flip angle = 90°, FOV = 240 mm, matrix size = 64 × 64, and slice thickness = 3.8 mm without gaps). Anatomical MRIs were acquired with a 3D fast SPGR pulse sequence (flip angle = 25°, FOV = 220 mm, matrix size = 256 × 256, slice thickness = 1.4 mm).

Phantom scans

A glass phantom head underwent echo-planar imaging (EPI) (see above) to determine if introducing each keyboard to the scanning environment interfered with the MRI signal. The phantom was scanned under three conditions for each keyboard: without keyboard, with keyboard without key presses, and with

* Corresponding author. Department of Neuroscience University of Florida, 100 S. Newell Drive L4-100, PO Box 100256, Gainesville, FL 32610-0256, USA. Fax: +1 352 392 2579.
E-mail address: ajames@psychiatry.ufl.edu (G.A. James).
Available online on ScienceDirect (www.sciencedirect.com).

1053-8119/$ - see front matter
doi:10.1016/j.neuroimage.2004.11.016

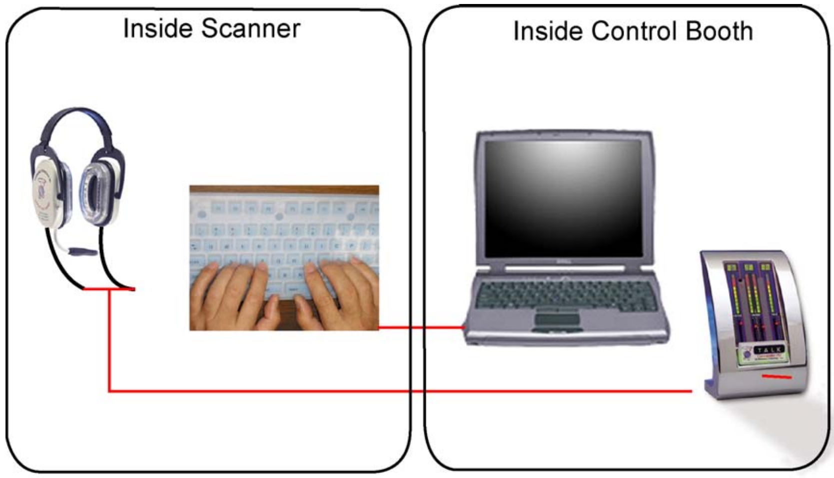

Fig. 1. Keyboard apparatus. The full-length keyboard was placed in the MRI scanner (approximately 20 in. from head coil, where a participants' abdomen would be) and attached by filter connection (see Materials and methods) to a laptop in the scanner control room. The arrangements of the keyboard and other equipment are described in the text.

keyboard with one button continuously depressed with a glass rod. When present, the keyboard was placed in the same location approximately 20 in. from the phantom's base (i.e., where a participant's abdomen would be). Each EPI scan lasted 5 min.

Signal analysis

Signal distortions can be time invariant (manifesting as image warping, blurring, or signal loss) or time variant (affecting the temporal signal to noise ratio, TSNR). To assess time-invariant distortions, we constructed a "mean phantom image" (MPI) for each condition, where each phantom voxel has the intensity giving the minimum sum of squares for that voxel's residuals across time. Time-variant distortions were assessed by constructing TSNR maps for each condition and keyboard; for a TSNR map, each voxel's intensity is the reciprocal of *Fn*, a measure of that voxel's signal deviation with time (Weisskoff, 1996). Comparing MPIs and TSNR maps for the phantom across keyboards and conditions (no

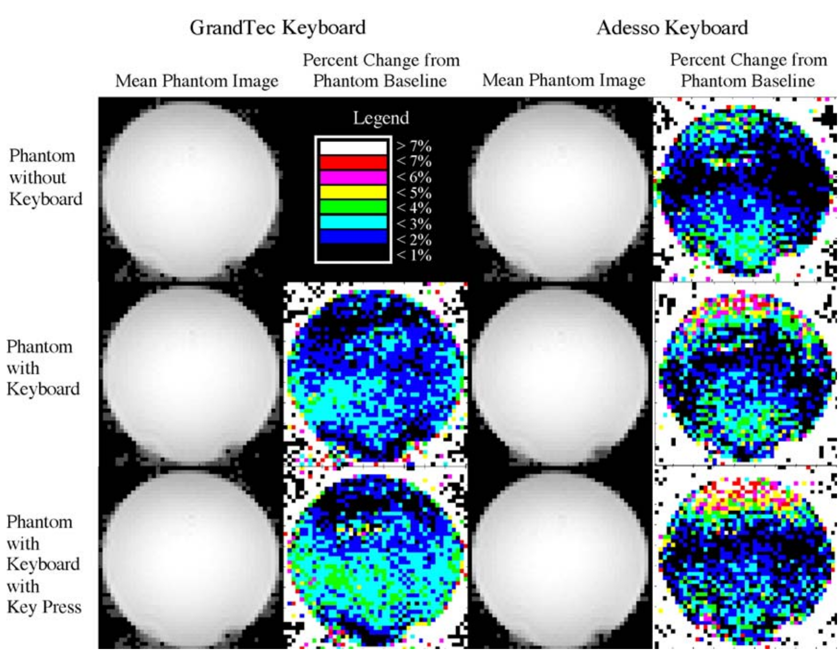

Fig. 2. Assessing temporally invariant signal changes with mean phantom images (MPI). Phantom images were created by calculating the intensity for each voxel such that the squares of the sum of that voxel's residuals (for each EPI image) were minimized. MPIs are presented for each condition (without keyboard, with keyboard, and with keyboard with key press) and each keyboard (Adesso and GrandTec USA). Each MPI's change from baseline (the phantom MPI without keyboard for the corresponding keyboard) was assessed by dividing the absolute value between MPI and baseline by baseline; that is, ($|MPI_{phantom\ with\ keyboard} - MPI_{phantom\ alone}|$)/$MPI_{phantom\ alone}$. Percent signal changes across repeat scans of the phantom without keyboard are also shown. For all comparisons, percent changes were color coded as per the figure key.

Table 1
Temporal signal to noise ratio by keyboard and condition

Conditon	GrandTec USA TSNR		Adesso	TSNR
	Slice 13	Slice 30	Slice 13	Slice 30
Phantom (no keyboard)	178	143	178	144
Phantom + keyboard				
without key press	163	135	93	87
with key press	172	141	95	89

The temporal signal to noise ratio (TSNR; Weisskoff, 1996) was calculated for every voxel of two arbitrarily selected phantom slices. The phantom was scanned six times across three conditions (without keyboard, with keyboard, and with keyboard with continuous key press) and both keyboards. Values represent the maximum TSNR for all voxels of each slice. The phantom was scanned twice without either keyboard to measure phantom TSNR stability at different time points.

keyboard, keyboard without key press, keyboard with key press) will reveal temporally invariant and variant signal distortions, respectively.

Response time

Three right-handed male human participants (mean age = 27.3 (2.1) years) performed the serial reaction time task (SRTT; Nissen and Bullemer, 1987) inside and outside of a full-body 3-T GE MRI scanner to determine if the scanner affected the keyboard's capacity for recording reaction times. (Note: unrelated technical difficulties following a hardware upgrade prevented proper echo-planar imaging with the GE scanner. These behavioral findings are presented since they should be independent of scanner choice.) Participants made a key press response with one of four fingers whenever a stimulus (a bold X) appeared in one of four corresponding locations in their visual field. Participants were instructed to make responses as quickly and accurately as possible, and stimulus location was random for each trial. Our power analysis (Marks, 1999) indicated that three participants performing a repeated measures, 200-trial task would be sufficient to discern reaction time differences due to being in the scanner (estimated σ = 80 ms, estimated meaningful difference = 30 ms, α (two-tail) = 0.01, β = 0.01, n = 171 trials per participant).

Results and discussion

Temporally invariant signal distortions due to the keyboard will manifest as patterns of voxels with large differences in MPI intensity. Fig. 2 depicts changes in an arbitrarily selected phantom slice due to introducing each keyboard into the scanner. Introduc-

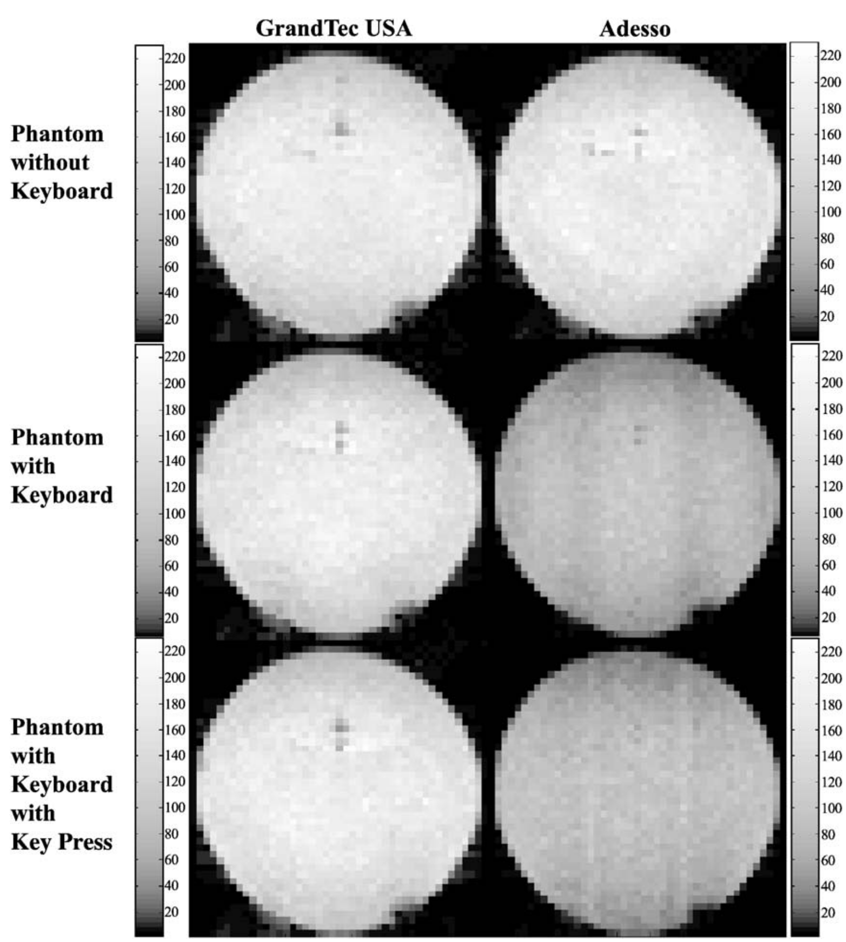

Fig. 3. Assessing temporally varying signal changes with temporal signal to noise ratio (TSNR) maps. Maps were constructed such that each voxel's intensity reflects the phantom's TSNR for that scan. TSNR maps were constructed for each condition (without keyboard, with keyboard, and with keyboard with key press) and each keyboard (Adesso and GrandTec USA). Figure keys were scaled so all would include 225 as a maximum value; this scaling allows comparison across TSNR maps and with literature values.

ing the GrandTec USA keyboard caused signal changes exceeding 4% in only 2–6% of phantom voxels (without and with key presses, respectively). These percentages may not be meaningful, since 8% of phantom voxels differed by the same magnitude on repeated scans of the phantom without keyboard. In contrast, 7–15% of phantom voxels demonstrated a 4% or greater signal change from the Adesso keyboard (without and with key presses, respectively). Signal changes tended to be of greater magnitude and localized more toward the phantom's superior edge with the Adesso keyboard. Although the GrandTec USA keyboard causes less temporally invariant signal loss than the Adesso keyboard, loss of signal from physiological sources has been estimated as high as 30% (Krüger and Glover, 2001) and may overshadow interference from either keyboard.

Analysis of temporal signal variance also supports the GrandTech USA keyboard as the superior keyboard. TSNR, a ratio of phantom signal to background noise across time, was measured for two arbitrarily selected slices; slices 13 (mid-superior) and 30 (inferior) of the 36 EPI slices. TSNR differed across slices but remained constant across repeated scans of the phantom. TSNR decreased by no more than 10% with addition of the GrandTech USA keyboard; in contrast, the Adesso keyboard decreased TSNR by as much as 48%!

Table 1 provides only the maximum TSNR for all voxels in each slice. The difference between keyboards becomes more apparent with TSNR maps, where each voxel's intensity represents its TSNR. Fig. 3 provides TSNR maps for an arbitrarily selected phantom slice across keyboards and conditions. TSNRs vary by scanner and coil but are typically around 210 for a head dedicated coil (Weisskoff, 1996). Fig. 3's legends were scaled to have 225 as a maximum TSNR value. TSNR does not differ across repeat scans of the phantom alone or scans including the GrandTec USA keyboard, but decreases by nearly 40% with addition of the Adesso keyboard. This loss of temporal SNR stability makes the Adesso keyboard a poor choice for use in an MRI scanner.

As previously noted, these EPI scans were performed in a head-dedicated scanner due to unrelated technical difficulties using a whole-body scanner. Each keyboard, placed where a participant's abdomen would be (i.e., 20 cm from the coil base), lied outside the magnet bore. The keyboard may introduce magnetic field inhomogeneity when placed in a MRI scanner's magnet bore; the influence of this potential inhomogeneity should be assessed prior to scanning with a full-body scanner.

A recording system incorporating the GrandTec USA keyboard also reliably collects behavioral data from participants during functional scanning. Response times did not significantly differ (two-tailed t test, $P = 0.39$) for subjects performing the SRTT inside the scanner (281 ms) or outside the scanner (276 ms). Given the low probability for false negatives ($\beta = 1\%$), we can conclude with 99% confidence that no difference exists between subject response time data collected during functional scanning and data collected outside of the scanner. Both tests were performed with 20 ft of keyboard cable connecting the keyboard to the laptop. The additional cable length should not introduce a significant delay in recording response time data since the time required for a current to travel this distance is negligible compared to other factors affecting response times, including intra-subject variation. Thus, the magnetic environment of the MRI scanner does not interfere with behavioral data collection.

Above all other considerations, a response recording system must be safe. The keyboard component of this system has minimal metallic content. The greatest danger from the keyboard is the extension cable connecting it to the control booth laptop; the cable could encircle a participant's limb and generate a harmful current. As long as experimenters prevent the keyboard cable from moving during the experiment (for example, by securing the cable to the scanner bed with tape), we believe that this recording system poses no hazard at scanner field strengths of 3 T or less.

In order to be suitable for use in functional MRI experiments, a response recording system must meet a number of requirements; it must not interfere with functional data acquisition, it must be able to accurately and reliably record the participant's behavioral responses, and it must not pose a risk of physical harm to the participant and experimenters. Of the two keyboards examined, GrandTec USA's Virtually Indestructible Keyboard caused considerably less (and arguably negligible) signal loss. In addition to meeting the above criteria of safety and accuracy, the VIK is a considerably versatile MRI-friendly recording device. The keyboard requires no special driver software and attaches to a computer by PS-2 or USB port (depending upon model). This ease of integration allows a broad range of software to be used for behavioral data collection. The keyboard is also relatively inexpensive (approximately US$50). These qualities prime the VIK to become a standard response recording device in the functional imaging community, either as a stand-alone device or Integrated with other peripherals.

Acknowledgments

We thank Dr. David Peterson and Paul Wright for their technical assistance and Dr. Keith White for his assistance in locating the keyboard. The Evelyn F. McKnight Brain Research Grant supported this research. No funding has been sought nor will be accepted from GrandTec USA, Adesso Inc., or their distributors.

References

Adesso Inc. Additional information available at www.adesso.com.

Fitzsimmons, J.R., Scott, J.D., Peterson, D.M., Wolverton, B.L., Webster, C.S., Lang, P.J., 1997. Integrated RF coil with stabilization for fMRI human cortex. Magn. Reson. Med. 38 (1), 15–18.

Gordon, A.M., Lee, J.H., Flament, D., Ugurbil, K., Ebner, T.J., 1998. Functional magnetic resonance imaging of motor, sensory, and posterior parietal cortical areas during performance of sequential typing movements. Exp. Brain Res. 121, 153–166.

GrandTec USA. Additional information available at www.grandtec.com.

Krüger, G., Glover, G.H., 2001. Physiological noise in oxygenation-sensitive magnetic resonance imaging. Magn. Reson. Med. 46 (4), 631–637.

Marks, R.G., 1999. Designing a Research Project: The Art of Doing Science. Renaissance Printing, Gainesville, FL.

Nissen, M.J., Bullemer, P., 1987. Attentional requirements of learning: evidence from performance measures. Cogn. Psychol. 19, 1–32.

Weisskoff, R.M., 1996. Simple measurement of scanner stability for functional NMR imaging of activation in the brain. Magn. Reson. Med. 36 (4), 643–645.