# Voluntary Head-Motion Suppression Using Simplified Head-Motion Feedback Information with Minimal Influence on FMRI Task Performance

S. Yang[1], T. J. Ross[1], Y. Zhang[1], E. A. Stein[1], Y. Yang[1]

[1]Neuroimaging Research Branch, National Institute on Drug Abuse, Baltimore, MD, United States

## Introduction

Subject head motion is a common problem in fMRI experiments. Although various physical restraints are routinely used at most facilities, the problem remains with a cost of lost data. The common methods for dealing with moderate head motion, "retrospective" motion correction using image registration in post-processing and "prospective" motion correction during ongoing scanning, are successful to varying degrees, but preventing motion during acquisition is still preferred. Therefore, we developed an alternate strategy - voluntary head-motion suppression by feeding back to subjects their own head motion information in real time. This work is an improvement of our previous report [1] where subjects watched six head motion parametric curves while performing an auditory verbal N-BACK task. In that study, while a reduction in head motion was observed, differences in brain activation were also seen. The design was revised, such that the feedback of head motion information was simplified to a visual cue shown within a visual N-BACK task. With this improved design, not only was significant head-motion suppression consistently observed in all subjects, the influence on task performance and brain activation was reduced to minimal levels.

## Methods

***Real-Time FMRI System and Data Flow.*** The real-time fMRI analysis system was developed on a Siemens 3T Magnetom Allegra scanner. The system hardware involves four computers that are interconnected on an internal network via Ethernet and serial ports. The hardware components form a closed loop in which the raw MR data were obtained from the subject in the scanner, the reconstructed image data were transferred, the head motion was estimated with AFNI (Analysis of Functional NeuroImages) package (2) and was finally fed back to the subject along with fMRI task in real-time.

***FMRI Task and MR Imaging Parameters.*** Twelve healthy right-handed male volunteers (mean age 26.9 years) participated in this experiment. The task is a modified version of a visual N-BACK task written in E-Prime (Psychology Software Tools Inc, Pittsburgh, PA). The task consists of six 4'12" runs in a pseudorandomized block design. Each run consisted of one block each of 1, 2 and 3-BACK conditions (15 stimuli/block), separated by blocks of 0-BACK (9 stimuli/block). The stimuli were letters, each presented for 500 ms with an inter-stimulus interval of 2500 ms. Motion information was conveyed to the subject via a group of arrows on the display along with the task (see below). Each subject repeated the N-BACK tasks under two scenarios with a counterbalanced design in one session, once with feedback of the head motion information (MotFB) and once without (No_MotFB). Whole-brain scanning was performed using a 2D EPI pulse sequence with 39 sagittal slices, TR/TE =3000/27 ms, matrix size = 64×64, FOV = 220 mm, slice thickness/gap = 4/0 mm, flip angle = 85º, bandwidth = 4112 Hz/pixel, number of measurements/run = 84.

***Feedback of the Head Motion Information.*** A four-way arrow group surrounded the screen center, where the task was presented as shown in Fig. 1. The arrow group sections, the inner (I), middle (II) and outer (III), were related to three empirically derived thresholds based on the composite online head motion index described below. When a subject's head motion index was below the 1st threshold, the three sections were all green (Fig. 1a). When the head motion index went beyond the 1st threshold but below the 2nd threshold, Section I turned red (Fig. 1b). Sections II and III turned red analogously when the 2nd and 3rd threshold were exceeded, respectively (Fig. 1c-d). The composite online head motion index is defined as $M(t)=w\cdot M(t-\Delta t)+\Delta MOT$, where $\Delta MOT$ = sqrt($[m_1(t)- m_1(t-\Delta t)]^2 + [m_2(t)- m_2(t-\Delta t)]^2 + [m_3(t)- m_3(t-\Delta t)]^2 + r_\theta^2\cdot[m_4(t)- m_4(t-\Delta t)]^2 + r_\varnothing^2\cdot [m_5(t)- m_5(t-\Delta t)]^2 + r_\varphi^2\cdot [m_6(t)- m_6(t-\Delta t)]^2$), "sqrt" stands for square root and $\Delta t$ = 1 TR. This is the total amount of head motion between two adjacent TRs, where $m_1(t)$, $m_2(t)$ and $m_3(t)$ are the three translational parameters, $m_4(t)$, $m_5(t)$ and $m_6(t)$ are the three rotational parameters estimated by AFNI, and $r_\theta$, $r_\varnothing$ and $r_\varphi$ are the semi-radii around the three axes. The definition is a typical recurrent expression, which gives a weight, $w$, of 1 to the motion that just happened, $\Delta MOT$, and a weight of less than 1 (0.35 used in the present experiments) to the previous motion, $M(t-\Delta t)$. Based upon analysis of historic data, the three empirical thresholds were set as 0.2, 0.4, 0.6 mm, respectively.

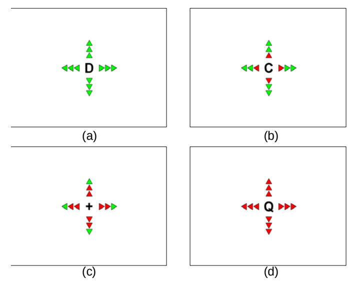


Fig. 1. The task with the four-way arrow group display

## Results and Discussions

FMRI image analysis was performed using AFNI. Data were preprocessed with retrospective motion correction. Motion curves from this step were analyzed two ways to determine the effectiveness of head motion suppression. Fig. 2 shows the mean number per session of greater than 0.2 mm head motion indices under the two scenarios. Head motion counts decreased significantly from a mean of 39.41 (No_MotFB) to a mean of 11.08 (MotFB) (Z=3.059, p=0.002). This head motion suppression was seen in every subject. Histogram analysis shows that task-related head motion was suppressed in the MotFB condition. No significant differences were found in the behavioral data between the MotFB and No_MotFB conditions. For accuracy, results of a 2 (feedback) X 4 (N-BACK task level) MANOVA were $F_{1,11}$=3.157, p=0.10 (n.s.) for a main effect of feedback and $F_{3,33}$=1.916, p=0.146(n.s.) for the feedback X task interaction. Similar analysis for reaction time yielded $F_{1,11}$=2.497, p=0.142(n.s.) for a main effect of feedback and $F_{3,33}$=2.046, p=0.126 (n.s.) for the feedback X task interaction. Results of the voxel-wise analysis of brain activation indicated no significant difference between the MotFB and No_MotFB conditions. More sensitive region of interest (ROI) analysis over 38 brain regions found no regions with a significant feedback X task interaction and <u>only 2</u> regions that had a significant main effect of feedback at p<0.05, *uncorrected.* Interestingly, the two significant regions, anterior cingulate ($F_{1,11}$=5.281, p=0.042) and right superior temporal gyrus ($F_{1,11}$=5.5, p=0.039) were both regions that were *deactivated* by the task. In both regions, there was less deactivation in the MotFB condition. There is evidence that deactivation is more related to internal processing during rest than being task driven. Fig. 3 shows activation in two regions, significant posterior cingulate (bottom) and a more typical nonsignificant region (top, superior parietal cortex).

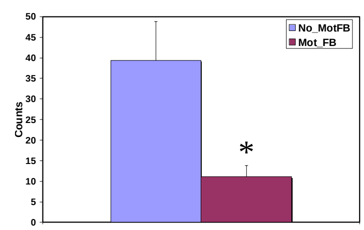


Fig. 2. Mean number of the head motion indices (> 0.2 mm) in one session

We demonstrated a new strategy to address head motion confounds. Significant reduction in mean head motion was observed, along with a reduction of task-correlated motion. The influence on task performance and brain activation was minimal. The current improved design indicates that a concise, clear, simple, non-overwhelming feedback of head motion information is the key to implementing this idea. It is proposed that under certain experimental conditions and subject populations, voluntary head motion suppression may feasibly be employed without significant compromise of fMRI data.

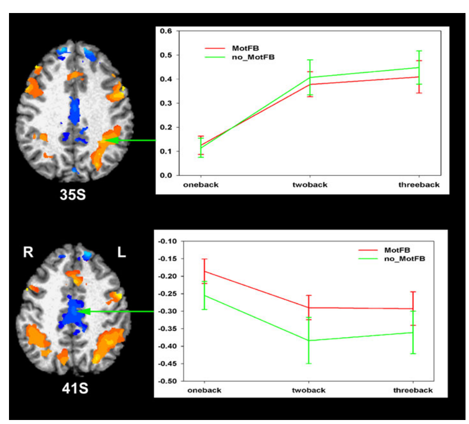


Fig. 3 ROI analysis results

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## References

[1] Yang S et al, ISMRM, p. 495 (2004). [2] Cox RW et al, *Comput. Biomed. Res.* 1996; 29: 162-173.