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Less head motion during MRI under task than resting-state conditions

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ABSTRACT

Head motion reduces data quality of neuroimaging data. In three functional magnetic resonance imaging (MRI) experiments we demonstrate that people make less head movements under task than resting-state conditions. In Experiment 1, we observed less head motion during a memory encoding task than during the resting-state condition. In Experiment 2, using publicly shared data from the UCLA Consortium for Neuropsychiatric Phenomics LA5c Study, we again found less head motion during several active task conditions than during a resting-state condition, although some task conditions also showed comparable motion. In the healthy controls, we found more head motion in men than in women and more motion with increasing age. When comparing clinical groups, we found that patients with a clinical diagnosis of bipolar disorder, or schizophrenia, move more compared to healthy controls or patients with ADHD. Both these experiments had a fixed acquisition order across participants, and we could not rule out that a first or last scan during a session might be particularly prone to more head motion. Therefore, we conducted Experiment 3, in which we collected several task and resting-state fMRI runs with an acquisition order counter-balanced. The results of Experiment 3 show again less head motion during several task conditions than during rest. Together these experiments demonstrate that small head motions occur during MRI even with careful instruction to remain still and fixation with foam pillows, but that head motion is lower when participants are engaged in a cognitive task. These finding may inform the choice of functional runs when studying difficult-to-scan populations, such as children or certain patient populations. Our findings also indicate that differences in head motion complicate direct comparisons of measures of functional neuronal networks between task and resting-state fMRI because of potential differences in data quality. In practice, a task to reduce head motion might be especially useful when acquiring structural MRI data such as T1/T2-weighted and diffusion MRI in research and clinical settings.

Introduction

Head motion is a principal confound when acquiring brain magnetic resonance imaging (MRI) data. Head motion induces artifacts in brain images, may render data useless, and can bias group results (e.g. Alexander-Bloch et al., 2016; Fellner et al., 2016; Glover and Lee, 1995; Pardoe et al., 2016; Power et al., 2012; Reuter et al., 2015; Satterthwaite et al., 2012; Van Dijk et al., 2012; Yan et al., 2013; Zaitsev et al., 2015). Although methods for motion correction have been improving over the past years, these corrections remain imperfect and come at a cost (e.g. Ferrazzi et al., 2014; Goto et al., 2015; Griffanti et al., 2014; Power et al., 2015; Tisdall et al., 2015; Yan et al., 2013; Zaitsev et al., 2016). Prospective motion correction during MRI, with reacquisition strategies, increases the total scan time. Retrospective corrections, for example in functional MRI (fMRI), typically remove corrupted scans and effectively reduce the number of observation in a time series. Thus, strategies that help reduce head motion during MRI can improve data quality for both scientific research and diagnostic purposes in the clinic.

In a clinical setting, it is common to play music or movies to increase compliance, especially in children or patients. Inspired by clinical MRI, Vanderwal et al. (2015) demonstrated that a movie could reduce head motion compared to an eyes-open fixation resting-state condition. The authors argued that cognitive engagement that comes with watching a movie reduces head motion (Vanderwal et al., 2015). Extending this argument, we hypothesize that an engaging cognitive task can also reduce head motion during MRI.

In a series of three experiments, we investigated head motion

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during resting-state conditions and several cognitive task conditions typically used in functional MRI experiments (e.g. Barch et al., 2013; Krienen et al., 2014; Poldrack and Gorgolewski, 2015; 2014; Wager et al., 2007). Our aim was not to examine the direct influence of the cognitive tasks on the *blood-oxygen-level dependent (BOLD) signal n*or to attempt to segregate task-evoked (extrinsic) and spontaneous (intrinsic) fMRI activity (e.g Cole et al., 2014; Fransson, 2006; Geerligs et al., 2015; Huijbers et al., 2013; Krienen et al., 2014; Northoff et al., 2010; Smith et al., 2009). Instead, we used the fMRI time-series to estimate head motion. In three experiments, with a total of 369 participants, we explored different task conditions as a strategy to reduce head motion and potentially improve the quality of neuroimaging data.

Materials and methods

Overview

In Experiment 1, we examined head motion in a passive memory encoding task and under resting-state conditions. In Experiment 2, using functional MRI data from the University of California Los Angeles (UCLA) Neuropsychiatric Phenomics Study, we examined head motion under several cognitive tasks and resting-state conditions. Both Experiment 1 and 2 had a fixed order of conditions across participants, so we could not rule out whether, for instance, the first or last scan in a session might be particularly prone to head motion. Therefore, we conducted Experiment 3 in which we collected fMRI data during several cognitive tasks, a movie, and during resting-state with an acquisition order counter-balanced across participants.

Experiment 1: head motion in resting-state and a passive task condition

We recruited 56 participants (age range 20–46, M=25, SD=4.74, 32 female) from the Bonn community in the context of our pre-studies for the Rhineland Study, a novel prospective cohort study. All participants provided written informed consent. The study was approved by the medical ethics committee of the Medical Faculty of the University of Bonn.

Functional Magnetic Resonance Imaging (fMRI) data were acquired using a 3 T Siemens MAGNETOM Prisma system (Siemens Medical Systems, Erlangen, Germany). The scanner was equipped with a 64-channel phased-array head/neck coil. Auditory stimuli were presented via S14 Insert Earphones (Sensimetric, Malden, USA). Visual stimuli were presented via a monitor located at the head of the magnet bore and seen via a mirror mounted on the head coil. The visual and auditory stimuli were presented using PsychoPy software v1.82 (Peirce, 2007), running on a Windows PC. Using inflatable air pads head movement was minimized and participants were instructed to lie still while the scanner was running.

We acquired four fMRI time-series of 140 volumes using echo-planar imaging (EPI). Each volume consisted of 32 axial slices of 3mm thickness with a 0.75mm skip. The repetition time (TR) was 2000 ms, echo time (TE) 30 ms, flip angle (FA) 84°, readout bandwidth 2300 Hz/pixel, and field of view (FOV) was 192×192 mm resulting in an effective voxel size of 3.0×3.0×3.75 mm. After a first resting-state fMRI run (REST1) and two fMRI runs using a memory encoding task (ENC1 and ENC2), we collected T1-weighted, T2-weighted, and diffusion MRI data, (which are not included in this manuscript), followed by a second resting-state fMRI run (REST2). The total acquisition time was approximately 48 min and the time between the end of ENC2 and the beginning of REST2 was approximately 18 min. During REST1 and REST2, a white fixation cross was presented at the center of a black screen. During the task runs we presented visual images of faces or scenes and auditory sounds of vocal or non-vocal sounds, together or separate, using a mixed-event/block design (Visscher et al., 2003). The task did not require any motor responses using a button-box (or otherwise). Participants were instructed to pay attention and were told that their memory for the visual images and for the sounds would be tested after the scanning session.

The fMRI data were pre-processed using MATLAB (Mathworks, Natick, MA, USA), the Statistical Parametric Mapping Toolbox (SPM8, UCL, London, UK) and GLM_Flex (MGH, http://mrtools.mgh.harvard.edu/index.php/GLM_Flex, MA, USA). We dropped the first 4 volumes and realigned the time-series to the first volume. From the realignment, we obtained the motion parameters for translation and rotation. To calculate mean translational motion, we first took the relative difference in translations between two consecutive volumes. Next, we combined the mean translation in x, y and z direction into a single number using the root mean square (RMS) (Van Dijk et al., 2012). To calculate mean rotation, we took the Euler angle of the rotation parameters (x, y and z) and combined the Euler angles by averaging the absolute difference between two volumes. The Euler range is expressed in radians and was multiplied by 1000 to obtain a value with a similar scale to the mean translational motion metric (Van Dijk et al., 2012). To calculate the framewise displacement, we first transformed rotation from degrees to millimeters by calculating displacement on the surface of a sphere with a radius 50 mm, which is approximately the mean distance from the cerebral cortex to the center of the head (Jenkinson et al., 2002; Power et al., 2012). Next, we combined root mean squares of the volume-to-volume translation and volume-to-volume rotation and calculated the mean framewise displacement over the total number of volumes in a series. We also estimated the number of motion spikes by counting number of volumes where the volume-to-volume framewise displacement exceeded 0. 20 mm. The absolute number of motion spikes was divided by the total number of volumes in a series, to correct for the series duration, and defined as percentile motion spikes. For all statistical analyses, we log-transformed the percentile motion spikes after substituting the zero values with the half of the minimal observed value. We used Pearson's product moment correlations for associations between variables. For post-hoc comparisons between two conditions we used paired-t-tests (two-sided) and for comparisons between groups we used two-sample t-tests (two-sided). The figures were generated using ggplot2 (Hadley, 2009).

Experiment 2: head motion in the UCLA Consortium for Neuropsychiatric Phenomics LA5c Study

We downloaded data from 290 participants (age range 22–50, M=33, SD=9.25, 124 female) who participated in the UCLA Consortium for Neuropsychiatric Phenomics LA5c Study. The data was obtained via the public database openfMRI (Poldrack et al., 2013; Poldrack and Gorgolewski, 2015) and approved by the UCLA Institutional Review Board The LA5c dataset includes 138 healthy controls, 58 individuals diagnosed with schizophrenia, 49 with bipolar disorder and 45 with attention deficit hyperactivity disorder (ADHD). These participants were recruited from the LA2k study, see also for more details (Bilder et al., 2009; Jalbrzikowski et al., 2012). The fMRI data were acquired using a 3 T Siemens MAGNETOM TrioTim system (Siemens Medical Systems, Erlangen, Germany) on two different days in a counterbalanced design. Day A included fMRI data of a balloon analog risk task (BART) (Helfinstein et al., 2014; Lejuez et al., 2002; Schonberg, 2012) and the encoding (ENC) plus retrieval (RET) phase of a paired associates memory task. Day B included fMRI data of resting-state run (REST), a stop-signal task (STOP) (Congdon et al., 2014), a spatial working memory capacity task (WM) (Montojo et al., 2013)and a task-switching paradigm (SWITCH).The resting-state and task conditions were acquired using the same EPI sequence. Each volume consisted of 34 axial slices of 4mm thickness. The TR was 2000 ms, TE 30 ms, FA 90°, and FOV was 192×192 resulting in an effective voxel size of 3.0×3.0×4.00 mm. The BART consisted of 267