Characterization of the effects of task-correlated facial and head movements in fMRI

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Introduction. Subject motion is a primary limiting factor in virtually every fMRI experiment. In addition to reducing statistical power, movements can also cause type I errors (false positives), particularly if they are correlated with design tasks and/or stimuli (1). These effects can be lessened to an extent using physical restraints, prospective motion correction (2), retrospective registration/realignment (3), and inclusion of motion parameters as covariates in statistical analyses (4). Image resampling methods assume rigid (or at least 3D affine) motion of the head -- an assumption that does not hold for several common facial movements such as squinting, yawning, and smiling. Even in the case of rigid motion, type I errors can persist due to interpolation errors during realignment (5). The situation is further complicated by the sensitivity of the BOLD measurement to susceptibility-induced field distortions, particularly near the air-tissue interfaces of the sinuses, which are difficult to correct (6). Furthermore, including motion parameters as covariates during analysis may decrease sensitivity in block designs when task-correlated motion occurs (see (4)).

It is generally assumed that facial movements occur randomly throughout the fMRI scan, and are therefore not expected to cause type I errors, especially when data is compiled over a group of subjects. However, since humans use facial movements to express emotion, task-correlated movement cannot be ruled out, particularly if the cognitive processes being studied involve emotional states. For example, clenching of the jaw or frowning can be expected to occur more frequently during a stressful task (see (7) for an example of false detection of increased blood flow in the temporopolar cortex due to anxiety), whereas smiling or closing of eyes may also occur systematically at other points during the scan. If these movements cause systematic signal changes for voxels within the brain area (either by partial volume or susceptibility effects), then type I errors may occur at these locations.

The purpose of this study was to empirically characterize areas of the brain that are particularly sensitive to various kinds of head and face movements, in order to propose future improvements in the design of fMRI studies. Our focus is on real-time techniques where task-correlated motion is a particular concern. However, these results also have implications for the design of traditional single-scan and group fMRI analyses.

Methods. According to the instructions listed in Table 1, eight healthy volunteers were each instructed to move systematically during an fMRI examination (3 Tesla MRI scanner; Tim Trio; Siemens, Erlangen, Germany). For each of the twelve 36-second motion blocks, subjects were prompted (via both audial and visual cues) to alternate between two motion states, spending 6 seconds at a time in each state (3 repetitions per block). Blocks were separated by 10 second rest/instruction periods, and each of the twelve motion blocks were repeated during the examination for a total of ***6 repetitions of each motion type***. Total scan time was (46 seconds)x12x2 = 1104 seconds, or around 18 minutes. For example, each subject clenched his/her jaw and relaxed a total of 6 times during the procedure. Functional imaging was performed using 2D echo-planar imaging with the following parameters: TE = 31 ms, TR = 2 s, flip angle = 90°, resolution = (3.6 mm)^2, FOV = (230 mm)^2, 32 slices, slice thickness = 4.5 mm (image array size 64x64x32). Standard fMRI preprocessing and statistical analyses were then performed using FSL. Tests for signal differences between each pair of motion states were performed. Preprocessing included image alignment (motion correction) with 12 affine degrees of freedom.

1. Close/Open Eyes	**7. Open/Close Mouth**
2. Move Eyes Left/Right	**8. Clench/Relax Jaw**
3. Move Eyes Down/Up	**9. Raise/Lower Shoulders**
4. Blink/Relax Eyes	**10. Stretch/Relax Arms**
5. Squint/Relax Eyes	**11. Stretch/Relax Legs**
6. Smile/Frown	**12. Inhale/Exhale**

Table 1. Each pair of motion states was repeated a total of 6 times (12 seconds each repetition) during each motion characterization procedure.

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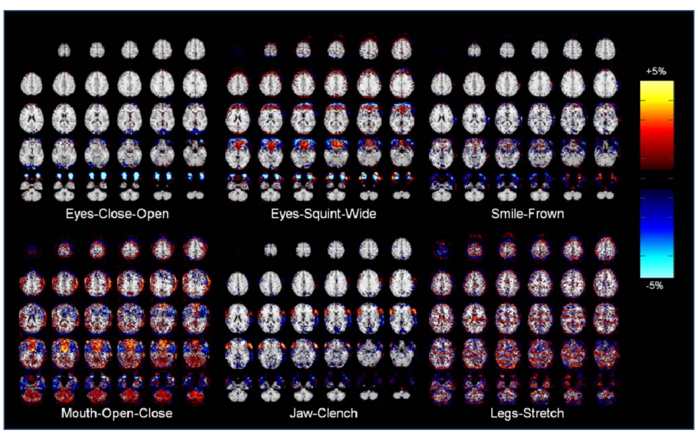

Fig. 1. Group percent difference maps for the six pairs of movement task.

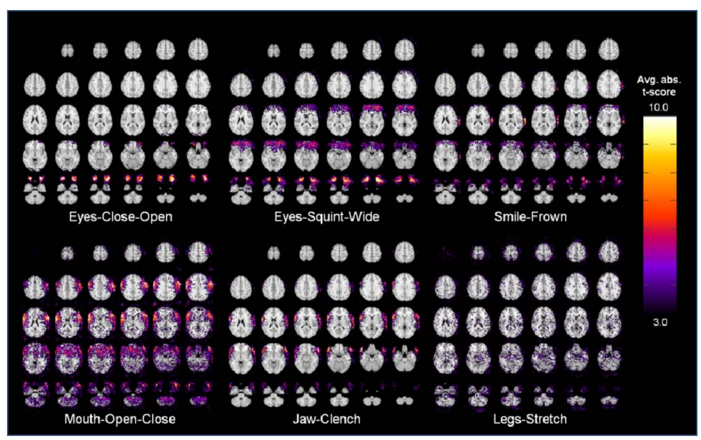

Fig. 2. Average absolute t-score maps for the six pairs of movement tasks.

Results. Fig. 1 shows difference maps, averaged over all subjects, for six of the twelve movement task pairs. The corresponding average absolute t-score maps are provided in Fig. 2. For the first four eye movement tasks, activations were primarily limited to the eye regions outside the brain. However, the next three task pairs (squint eyes, smile/frown, and open/close mouth) resulted in several brain regions having high statistical significance, even after motion correction and group averaging. Jaw clenching yielded the characteristic false activation in the region surrounding the temporal muscles. Slight movement of shoulders, arms, and legs as well as the breathing task resulted in significant, but non-localized false activations. These data may be used to characterize the potential confounding effects of systematic movements of the head, face, and body, and to aid in the design of fMRI experiments, particularly for real-time and single-subject analyses.