Independent component analysis and artifact removal in human calf muscle functional MRI

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Introduction: Alterations in tissue perfusion occur in a variety of disorders such as cardiovascular disease [1]. Tissue reperfusion after ischemia involves two mechanisms: a strong increase in tissue perfusion and a change in oxygenation levels, both of which contribute to the contrast in blood oxygenation level-dependent functional magnetic resonance imaging (fMRI) [2]. Echo planar imaging (EPI) can be used to acquire fMRI of muscle, but it is sensitive to artifacts, particularly those from motion [2]. Artifacts are exaggerated by the fact that the ischemia-reperfusion experiment takes a relatively long time and is therefore susceptible to effects like thermal drifts. Independent component analysis (ICA) is used successfully in electroencephalography and brain fMRI to separate data into components and determine artifacts. The goal of our study was to use temporal ICA to identify fMRI time-course artifacts in calf muscle with simulated ischemia and also to separate and investigate the data's temporal components. Unlike spatial ICA, which is suitable for identifying cooperating networks, temporal ICA is more suitable for differentiating independent signal patterns, and is thus better suited to separating physiological effects and artifacts.

Methods: *MR Experiments*: Eleven healthy male volunteers were scanned after a routine physical examination, laboratory tests and electrocardiography, and no clinical significant abnormalities were found. MR images were acquired using a Siemens Tim Trio scanner using a flexible coil wrapped around the subjects' calf and an inflatable cuff wrapped around their thigh. The subjects were supine with their right leg fixed in an ergometer to perform plantar flexion [3]. Fat-suppressed EPI images were continuously acquired for 45 min (90° flip angle, 128x102 acquisition matrix, FOV=18 x 18 cm, GRAPPA 2, T_E=44 ms, T_R=0.5 s, 5 axial slices of 5 mm thickness; see Fig. 1). Two minutes after EPI acquisition began, the cuff was inflated to suppress femoral blood flow, thereby simulating ischemia. 18 min thereafter, the subjects were instructed to perform a plantar flexion every 4 s until exhausted. After 5 minutes of stenosis (30 mmHg below cystolic pressure), the cuff was fully deflated.

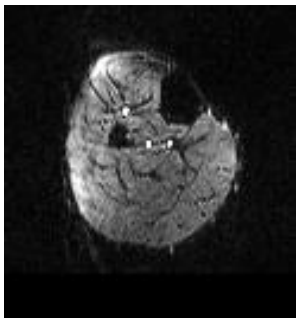

Fig 1: Axial EPI of human calf muscle in one volunteer.

Data Analysis: Post-processing consisted of first resampling and registering the EPI images [4]. Further analysis was done using Matlab (Matlab R2007a, The Mathworks, Inc.) and ICA toolboxes written for the Matlab environment. Data was thresholded to 1% of its maximum in order to remove noise from outside of the muscle area. The temporal section of data during exercise was removed due to excess motion artifacts, which could interfere during separation of components using ICA. Principal component analysis (PCA) was performed using Matlab to reduce data size before using Fast ICA (temporal ICA; Matlab ICA toolbox ICALAB for signal processing, http://www.bsp.brain.riken.jp/ICALAB/) to separate the data into components that exhibit an independent temporal evolution. Visual inspection of the ICA components identified elements that originated from artifacts which were then reconstructed into artifact-only original data. The reconstructed artifacts were removed from the original data to obtain the final image with most artifacts removed.

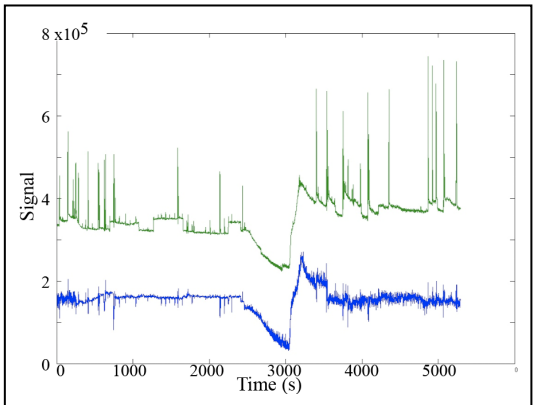

Fig. 2: Comparison of a time-course before (top) and after (bottom) artifact removal using temporal ICA.

Results: Using temporal ICA, it was possible to separate components representing expected physiological effects from artifacts arising primarily due to motion, therefore making it possible to remove the artifact components from the time-courses. After artifact removal, the time-courses followed the expected pattern with fewer jumps and spike artifacts as demonstrated in Fig. 2 for the worst data set, where the upper time-course includes artifacts while the lower time-course shows the same data with many major artifacts removed. In this data set, the artifact reduction was an estimated 46% for the number of spikes and 78% for the number of jumps due to motion. Prior to removal of artifacts, the data set was unusable; following artifact removal, further analysis could be performed.

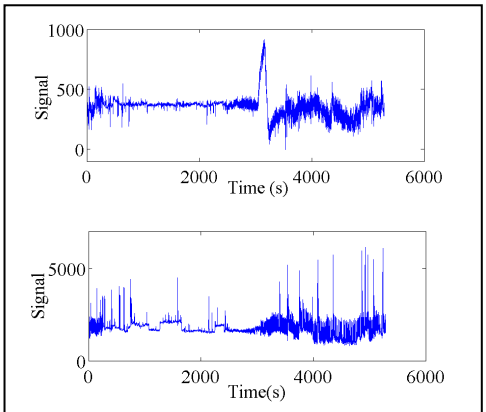

Fig. 3: Examples of components found using temporal ICA. The upper component is most likely part of the reperfusion time-course, while the bottom one is most likely artifact.

Discussion: The use of temporal ICA for artifact removal and temporal component separation is a novel method to process muscle fMRI data and has proven successful thus far. As ICA is capable of identifying artifacts, it is not interfering with physiologically stimulated signals. Some individual components could be attributed to different features of the experiment, such as large vessels or the hyperemic peaks (Fig. 3). Motion is an issue with long experiments, and correction procedures in muscle do not work as well as they do in the brain, which has a rigid boundary. Separation of the data into components allows for more accurate analysis and helps the identification and separation of different features in skeletal muscle fMRI time-courses.

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