Validating an anatomical brain atlas for analyzing NIRS measurements of brain activation

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Abstract: We are validating the use of a brain atlas for analyzing NIRS data of brain activation to guide anatomical interpretation of the NIRS results when the subject's true head anatomy is not available.

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1. Introduction

NIRS systems have been developed with a relatively large number of sources and detectors that use tomographic methods to reconstruct 3D images of brain activation [1-3]. This tomographic approach uses short and long distance measurements to provide depth resolution and enables separation of superficial scalp signals from deeper brain signals. To further improve images of brain activity, subject-specific spatial priors of the head anatomy can be exploited to inform the optical tomography problem [4]. However, it is not always feasible to obtain subject-specific head anatomy to guide the optical tomography problem. We thus proposed a method to image the hemodynamic response to brain activation using an atlas head model to guide the optical tomography problem and anatomical interpretation of the resultant images [5]. This MRI-free approach to obtaining optical images is based on registering a selected head template (atlas) to the subject head surface and solving the photon migration forward problem on the registered atlas; optical measurements are acquired on the physical subject; and then a map of the cortical absorption coefficient changes is calculated.

This approach can introduce errors that arise from differences in head anatomy between the subject and the atlas. We are quantifying the errors that can arise from these anatomical differences by analyzing images reconstructed for a group of 32 subjects using their true head anatomy versus using the atlas.

2. Materials and methods

Our procedure for registering the atlas to the subject is based on the standard 10/20 locations on the scalp and is described in detail in [5]. Basically we perform an affine transformation to register the 10/20 locations of the atlas to those same 10/20 locations on the subject in the subject space. The atlas we use is the well-documented MNI single subject atlas [6]. This atlas has defined the scalp, skull, gray, and white matter of the head. For the subjects we obtained MRI anatomical volumetric images of 32 subjects and using the FreeSurfer software package segmented these volumes into gray and white matter and extra-cerebral tissues [7].

In order to explore the image errors that can arise when using an atlas instead of the subjects true anatomy, we designed a probe that covered a large surface of the scalp to report error metrics for as much of the cortex as possible. This probe consisted of 29 sources and 100 detectors. The optodes where arranged in a hexagonal pattern with nearest neighbor source-detector separations of 2 cm and next nearest neighbor separations of 3.4 cm. This geometry allows us to get overlapping measurements with NIRS imaging systems to improve image resolution. The probe layout on the atlas head is shown in figure 1. Between subjects, we keep the physical dimensions of the probe constant. To investigate the spatial variation in the probe positions across subjects we calculated the mean distance and variation from each optode location to the nearest 10-20 coordinate across subjects.

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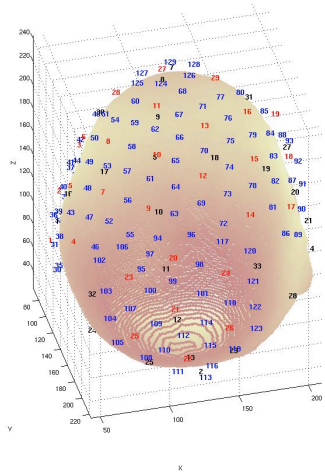

Fig. 1 - Hexagonal symmetry probe projected on a head volume, sources in red and detectors in blue.

Given the optode positions on the subjects and on the atlas that has been registered to each of the subjects, we then run the photon migration forward problem using a GPU based Monte Carlo program [8]. From this, we construct the forward matrix operator for calculating the optical measurements given a spatial variation of the absorption changes confined to the cortex of the subject. We then can reconstruct images of the absorption changes using the subject's own anatomy or the registered atlas anatomy. The image reconstruction details are described in [5].

We simulate brain activation for individual ~1 cm diameter blobs for hundreds of unique positions over the surface of the brain. For each activation location, we calculate error metrics including: 1) difference in centroid position of the image reconstructed in the subject with respect to the true image; and 2) difference in the centroid position of the image reconstructed in the registered atlas with respect to the true image. If the centroid of the reconstructed image is near the centroid of the true image but on a different gyrus of the brain, this error metric will report a small distance error but there will in fact be a large anatomical error. We thus also calculated an error metric based on the distance along the cortical surface using a Hausdorff and geodesic distance rather than the distance in Euclidean space.

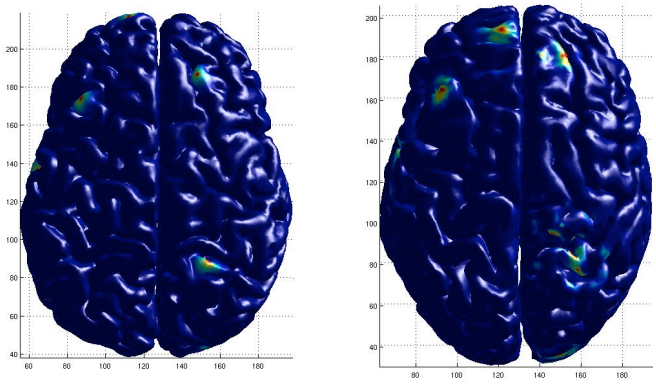

Fig. 2 - Simulated activations in real subject space (left) and reconstructed activations in registered atlas space (right).

3. Results

An example image reconstructed on the subject and the registered atlas is shown in figure 2. The Euclidean distance between the original activation and the reconstructed activation in the registered atlas space gives a first estimation of the localization errors that can arise when using an atlas geometry instead of the subjects

true anatomy. Preliminary results have given us errors of 2 ± 2 *cm* in activation localization. The geodesic distance error metric contains information about the gyrus localization of the activation itself: a reconstructed activation could be close to the original one but lay on a different gyrus. Preliminary results for this metric appear similar to the Euclidean distance.

4. Discussion

The results of this study will quantify the error that can arise when using an atlas to analyze NIRS data rather than the subject's true anatomy. This error will vary across brain regions. By studying this spatial variation across brain regions and across subjects, it will provide important guidance to the design of future studies. Specifically, researchers will be able assess their ability to anatomically interpret their NIRS results and distinguish activations from different brain regions before running their study.

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