Statistical nonparametric tests for group comparison of Diffusion Tensor Images

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Introduction:

Statistical analysis of scalar-valued images is a well-established component of contemporary science. However, the analysis of novel types of images, which are multimodal and nonlinear in nature is still under development [8].

Diffusion weighted (DW) imaging is becoming a standard technique in (structural) neuroimaging. A simple approach to process DW images consists in estimating a 3x3 positive definite diffusion tensor (DT) for each voxel [2].
Voxel-based statistical analysis of a population would therefore involve statistical tests among matrices rather than scalars. The simplest option is to convert the tensor information into a scalar information, such as fractional anisotropy. Nevertheless, both the intensity information and the orientation information potentially contain valuable information, calling for new methodological developments.

The challenge is methodological as well as computational because neuroimaging studies usually involve large populations and many voxels.

Methods:

If statistical analyses of scalar images are often performed through parametric methods [7], the fact that the distribution of multivariate data such as DT is seldom known is a motivation to use nonparametric methods to analyse those images.
Among these non parametric methods, permutation tests are often used because of their relative simplicity. Permutation methods provide statistical significance testing of difference between groups without having to assume a distribution of the data [10]. These methods have the ability to directly estimate the null distribution of the statistics describing the difference.

One of the most used statistic for permutation tests is the difference between the means of each group of subjects. However, for manifold-valued data such as DT, the computation of a mean of many subjects can be computationally expensive. Since this operation has to be repeated twice by permutation, and the number of permutations is usually very large, the total cost of this kind of tests is prohibitive for a real application.

We therefore propose to use dispersion statistics [9] for group comparison of DTI's. Using this statistic, we only need to build a similarity matrix between all data points.
This distance-based permutation test has the same statistical properties than the mean-based one, but a significant computational advantage is that the similarity matrix must be computed only once.
Many different similarity measures for DT exist, having different properties. Three similarity measures are considered: the Fractional Anisotropy [3], the Log-Euclidean distance [1] and the Spectral-Quaternion distance [5].

Results:

In this work, we compare the power of the dispersion test, using different measures. To do this, we simulate a few plausible differences between groups, as in [4].
For each simulation, the tests are computed 500 times. The power of the test is estimated as the ratio between the number of times a test is significant and 500.
We observe a 30 fold reduction of the computation duration when using the dispersion approach instead of the distance between means approach.

Figure 1*(a)* illustrates an example of results for increasing difference in mean diffusivity, from 0 till 1 (according to γ). Figure 1*(b)* illustrates the same situation but for increasing difference in tensor main direction. One can see that geometric measures can detect group differences in more situations than with a single scalar measure.

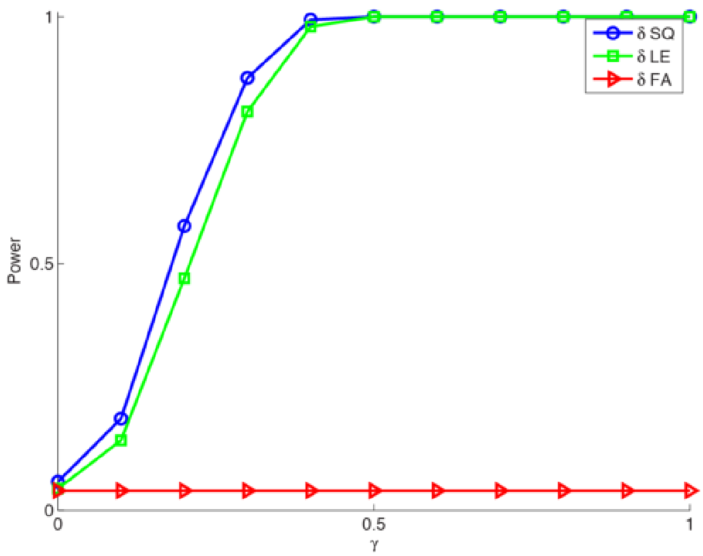

Figure 1*(a)* : Power of the statistical tests, for an increasing difference in mean diffusion between groups..
For γ=0, the groups are based on identical tensors. While γ increases, the distribution of one group of tensors is still based on this tensor, while for the other group, the reference tensor is characterized by a bigger mean diffusion. The spectral quaternion (SQ) and Log-Euclidean (LE) metrics enable to detect this difference, while the FA does not.

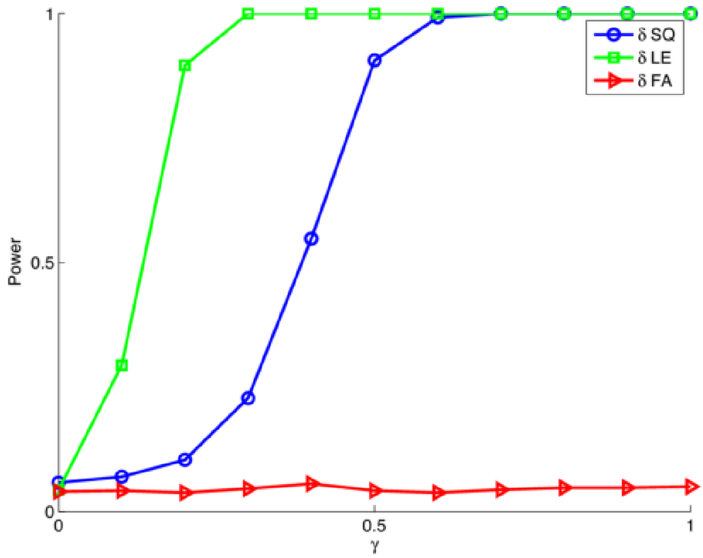

Figure 1*(b)* : Power of the statistical tests, for an increasing difference in the principal orientation of diffusion between groups.
For γ=0, the groups are based on tensors with the same orientation. While γ increases, the distribution of the two groups are based on differently oriented tensors. The angle between principal directions of diffusion is increased. The Log-Euclidean (LE) metric is very sensitive to this difference, while the Fractional Anisotropy does not detect this difference. The Spectral-Quaternion metric is also sensitive to the difference.

Conclusions:

This work shows that permutation tests could be advantageously used for the statistical analyses of DT Images [6]. These methods have several advantages, as they do not use any assumptions about the distribution of the data (which is seldom known). Moreover, the only specific tool needed for this group comparison is an appropriate similarity measure between the data. We also illustrate the computational advantage of basing the permutation test on dispersion rather than means.

Modeling and Analysis Methods:

Diffusion MRI Modeling and Analysis

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