Statistical analysis of neuronal connectivity in patients with Gilles de la Tourette syndrome

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Purpose of the Project

Study differences concerning *shape* and *organization* between cerebral anatomical configurations of 27 controls and 47 patients subject to *Gilles de la Tourette syndrome* in order to test the hypothesis presented in Worbe et al.

**Gilles de la Tourette syndrome:**

- Multiple motor tics and at least one vocal tic.
- Tics occur many times everyday for at least one year.
- Onset before 18 years old.
- No drugs or any other general medical condition.
Worbe’s hypothesis: “Gilles de la Tourette syndrome is associated with dysfunctions of the cortico-striato-thalamo-cortical circuits.”

Multiple inputs from several functionally related cortical areas (A,B,C) are "funneled“ back through the basal ganglia and thalamus to a particular area of the cortical surface.
Purpose of the Project

(a) Motor circuit
(b) Associative circuit
(c) Limbic circuit

TRENDS in Neurosciences
Gilles de la Tourette syndrome

Sub-cortical Structures

Cortical Surface

Fiber bundles

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Atlas Construction

\[ X_s = \phi_s(T) + \epsilon_s \]
Atlas Construction

\[ E(T, \{\phi_s\}) = \sum_{s=1}^{N} \frac{1}{2\sigma^2} D(\phi_s(T), X_s) + \text{Reg}(\phi_s) \]

- Template
- Deformations
- Dissimilarity measure
Dissimilarity measure

\[ X_s = \phi_s(T) + \epsilon_s \]
Dissimilarity measure

**Currents**

1. For both surfaces and curves
2. No need of point or fiber correspondences
3. Robust to different sampling
4. Global geometrical differences

\[ X_1 \]

\[ \phi_1(T) \]

Dissimilarity measure

The framework of **Currents** can represent both curves and surfaces and it doesn’t need point or fiber correspondence.

Characterize an object via its response to probing vector field

\[
T_1(w) = \int_{T_1} w(t)^T \alpha(t) dt \sim \sum_i w(x_i)^T \alpha_i
\]

\[
w(x_i) = \sum_k K^w(x_i, y_j) \beta_j
\]

\[
\langle T_1, T_2 \rangle_{W^*} = \sum_i \sum_j \beta_j^T K^w(y_j, x_i) \alpha_i
\]
Template Initialization

$$E(T, \{\phi_s\}) = \sum_{s=1}^{N} \frac{1}{2\sigma^2} D(\phi_s(T), X_s) + \text{Reg}(\phi_s)$$
Template Initialization

\[ X_1 \]

\[ X_2 \]

\[ X_4 \]

\[ X_3 \]

Template Initialization

$T$

$I_1$  $I_2$  $I_3$  $I_4$ ...

Template Initialization

\[ I^* = \arg\min_{I_k} \| T - I_k \|_{W_*}^2 \]
Template Initialization

\[ I^* = \arg\min_{I_k} \| T - I_k \|_{W_*}^2 \]
Deformations

\[ E(T, \{ \phi_s \}) = \sum_{s=1}^{N} \frac{1}{2\sigma^2} D(\phi_s(T), X_s) + \text{Reg}(\phi_s) \]
Deformations

- Enables a global description of the whole brain preserving the underlying organization of structures
  
  One single diffeomorphism for the whole 3D space

- Captures local non-linear variations
  
  Framework of diffeomorphism

- Low dimension parameterization
  
  New control point formulation

Deformations

The whole 3D space is deformed by a single diffeomorphism

\[ \phi_t(x) = x + \int_0^t v_s(\phi_s(x)) ds \]

differential equation

\[ v_t(x(t)) = \sum_{p=1}^{c_p} K(x(t), c_p(t)) \alpha_p^i(t) \]

deformation parameters

\{ \alpha_i^j(0) \} \rightarrow \text{Deformation parameters} \rightarrow \text{Linear Statistics}

Position of point \( x \) at time \( t \)

Control point

Momenta

time-varying vector field

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Deformations
Deformations

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PCA – first mode

- $2\sigma$

Updated template

+ $2\sigma$

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First mode

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Conclusions

- New multi-object atlas construction method based on *currents* for shape complexes
- Joint analysis of white matter tracts and gray matter surfaces preserving spatial organization of the structures
- Fiber bundles template with anatomically correct topology
- Limited number of deformation parameters well suited for linear statistical analysis
Perspectives

• Include the cortical surface into our analysis

• Decrease the computational time of the process using a GPU-CUDA code

• Find a suitable statistical test to highlight few important differences between the two populations
Deformetrica

- Software for the statistical analysis of 2D and 3D shape data: curves, surfaces, images, point clouds
- Multi-object registration and atlas construction
- Different kinds of deformation: rigid, affine, diffeomorphism
- Longitudinal analysis
- GPU implementation (under construction, Alexandre Routier)
- Bayesian Framework (under construction, Pietro Gori)
- Multi-scale analysis (under construction, Barbara Gris)
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Thank You for your attention!