Hand Trajectory Analysis in the Study of Premotor Activity: An Exploration

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Introduction

- Here we present a first step in the exploration of the use of movement trajectory data in single-trial EEG analysis, based on the hypothesis that certain features of the actual movement to be executed may be reflected in premotor activity and characterising these features may assist the study of premotor activity at a single-trial basis.
- Research has posited that a **trajectory-path representation** may be used to plan reaching and grasping gestures (Wong et al, 2016).
- Activity in dorsal pre-motor and motor cortices and the SMA has been linked to planning high level kinematic parameters such as **movement direction**,**amplitude** and **speed** in reaching and grasping actions(Pearse and Moran, 2012, Torres et al, 2013).

Hypotheses

- The relative **complexity** of a planned movement trajectory may be reflected in pre-motor activity $\Longrightarrow$ quantify trajectory complexity at the single trial level to refine analysis of pre-motor activity.
- If kinematic features are planned prior to action $\Longrightarrow$ characterise the **General Movement Features** (Li et al, 2014) of the trajectory.
- if a less complex action is less prone to variation $\Longrightarrow$ calculate the distance between different instances of the same movement.
- Use complexity measure (**sample entropy**) as regressor in single trial analysis.
- Group single trials based on analysis of *distance* between the complexity, over time, of different instances of an action.

Data Acquisition

- **Hand movement data** was acquired via a wireless finger-tracking device (ART: Advanced Realtime Tracking) that tracks, in real time, the orientation and position of the hand and fingers during a GO-NOGO protocol in a fully immersive VR environment.

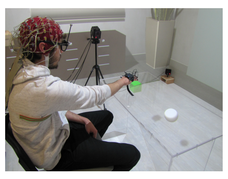


Figure 1: Participant with finger-tracking device manipulating virtual object.

Trajectory Representation

- Trajectory: the path of a moving object composed of quasi-linear segments at which points are attributed spatial and temporal information e.g.$\{X_t, Y_t, Z_t\}$.
- The trajectories, below, are based on a subset of single GO trials over 14 participants.

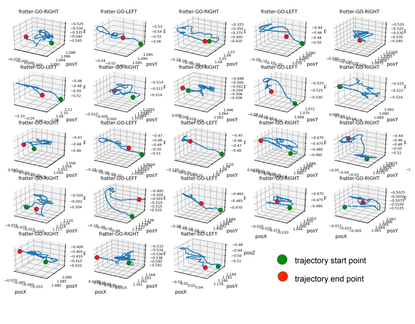


Figure 2: Quiver plot of X, Y, Z hand trajectory of action **frotter**

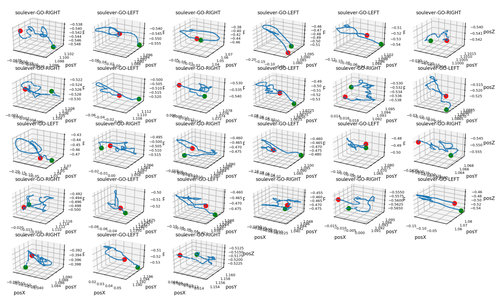


Figure 3: Quiver plot of trajectory of action **soulever**.

General Movement Trajectory Features

- **Velocity:** Rate of location change from the previous time point to the next.

$$Velocity_{p_i,t_i} = \frac{distance(p_{i+1})}{\Delta_{t_i}}$$

- **Acceleration:** Rate of velocity change from the previous time step.

$$Acceleration_{p_i,t_i} = \frac{Velocity(p_{i+1}, p_i)}{\Delta_{t_i}}$$

- **Straightness Index:** The ratio of the length of two consecutive trajectory segments and the displacement from the start of the first segment to the end of the second.

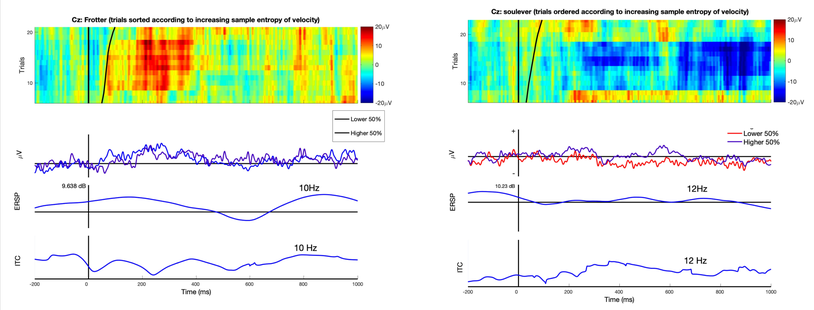
$$Straightness_{p_i,t_i} = \frac{distance(pi-1, p_i) + distance(p_i, p_{i+1})}{distance(p_{i-1}, p_{i+1})}$$

Where p_i is the sampling point at time i.

Complexity Measure

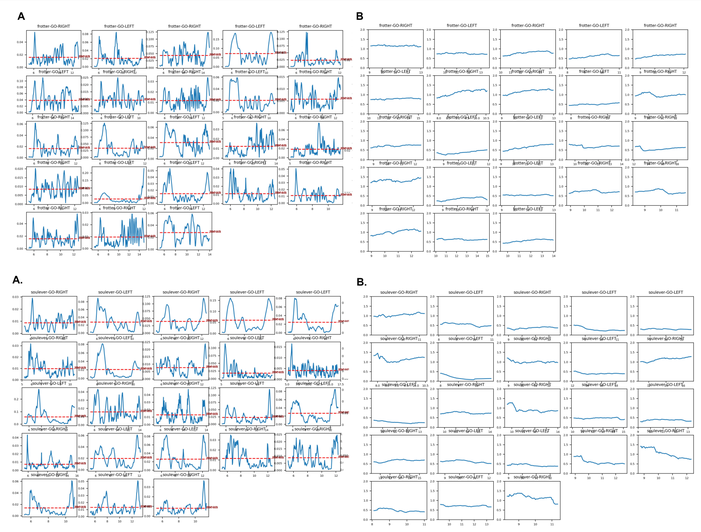
- **Sample Entropy** is the negative natural logarithm of the conditional probability that two sequences similar for m points will remain so at the next point.
- A lower sample entropy of a given time-series implies greater self-similarity.
- It is relatively stable as a function of time-series length.
- Calculation of time-dependent sample entropy of *velocity, acceleration* and *straightness* from 0.5 of time-series duration (Li et al, 2014).

Total Sample Entropy in Single-trial Analysis



- ERPimages of single trials ordered according to increasing **sample entropy** (black line) for (left) **frotter** and (right) **soulever**.

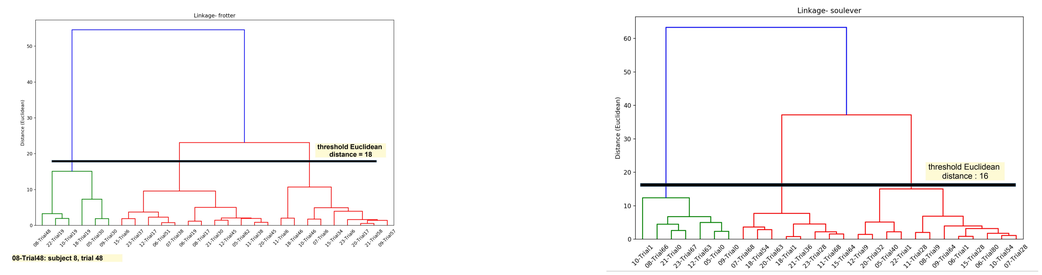
General Movement Features and Sample Entropy



- A. Velocity over time and B. Sample Entropy over time for **frotter**
- A. Velocity over time and B. Sample Entropy over time for **soulever**

Velocity Dis/Similarity Calculation

- With the aim of grouping trials based on the complexity of the movement features, we applied Hierarchical Clustering on the sample entropy of the velocity. **Dynamic Time Warping** was applied to compute the cross-similarity matrix ; the distance metric applied is the Euclidean distance.



- The result of the hierarchical clustering can indicate the number of clusters and a minimum inter-cluster distance for subsequent clustering algorithms, such as Kmeans clustering.
- The dendogram for **frotter** (left) suggests 3 clusters and an inter-cluster distance of 18.

To be continued...

Here we present a very first step in this work. Some of the issues that need to be tackled include:

- Test other movement features and means of characterising the trajectory data to determine those descriptors that best capture pre-motor activity variation across trials.
- Calculate **sample entropy** of other movement features and of the trajectory.
- Test clustering methods (Kmeans, Self-organising maps) to group hand trajectories according to different features that may refine single-trial analysis.

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