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

Bolger Deirdre, Mestre Daniel, Pergandi Jean-Marie, Zappa Ana and Frenck-Mestre Cheryl

Institute of Language, Communication and the Brain (ILCB), Centre de Réalité Virtuelle de la Méditerranée (CRVM), Laboratoire de Parole et Langage (LPL)



## 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 pre-motor activity and characterising these features may assist the study of pre-motor 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  $\implies$  quantify trajectory complexity at the single trial level to refine analysis of pre-motor activity.
- ▶ If kinematic features are planned prior to action  $\implies$  characterise the **General Movement Features** (Li et al, 2014) of the trajectory.
- ▶ if a less complex action is less prone to variation  $\implies$  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.

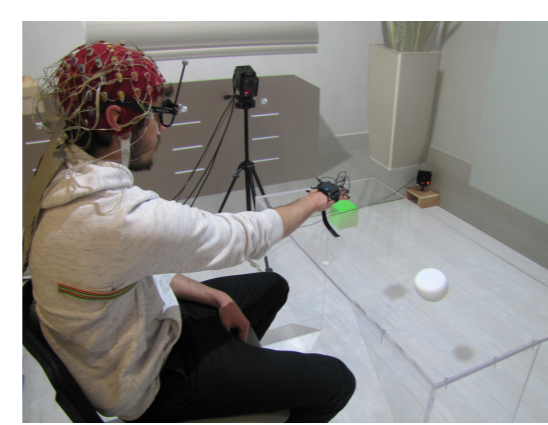


Figure 1: Participant with finger-tracking device manipulating virtual object.

## 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.

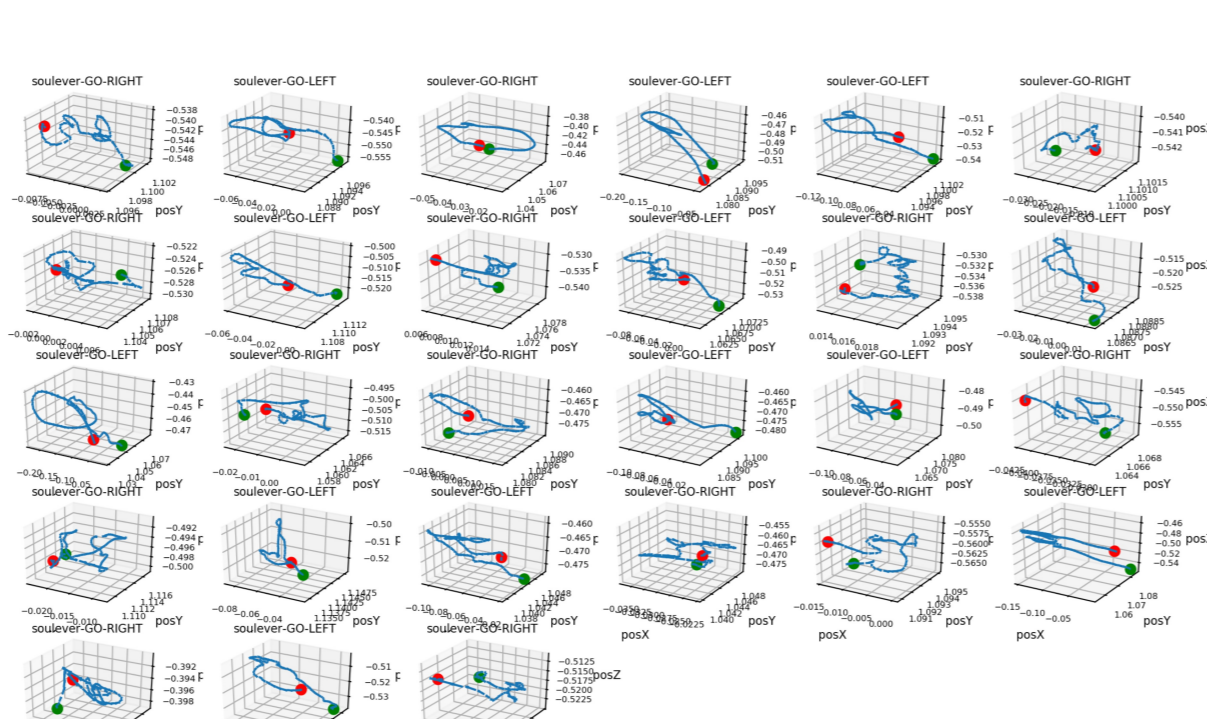
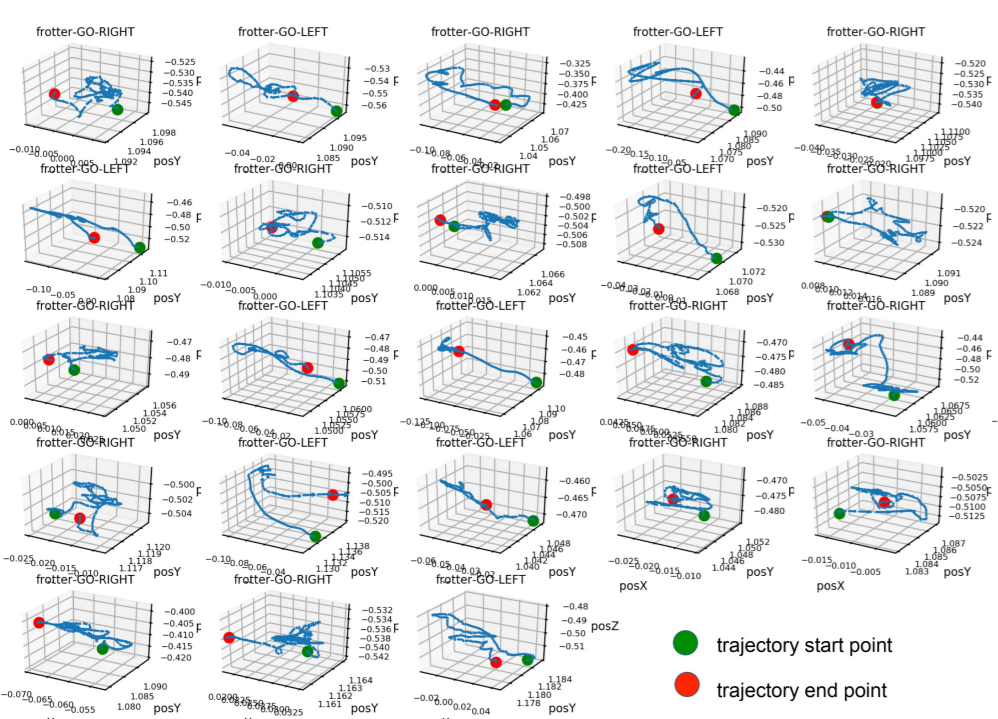


Figure 2: Quiver plot of X, Y, Z hand trajectory of action **frotter**

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.

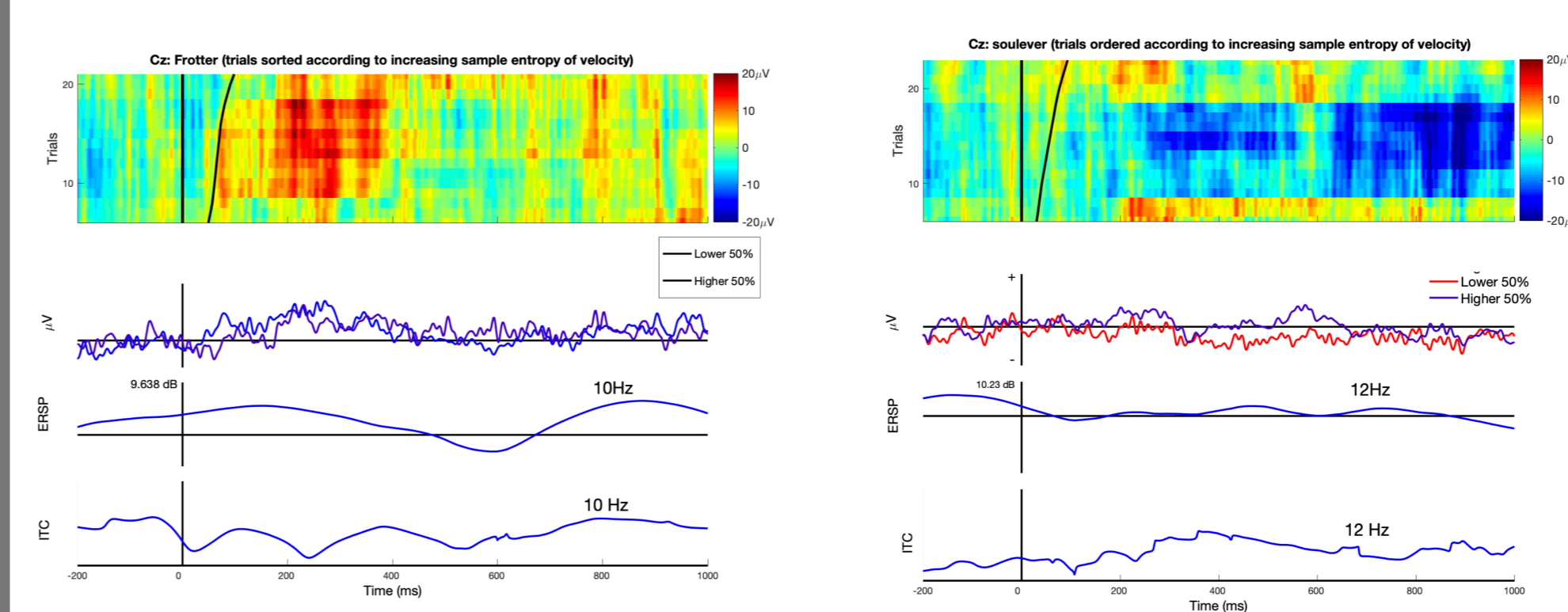
$$Straightness_{p_i, t_i} = \frac{distance(p_i - 1, p_i) + distance(p_i, p_{i+1})}{distance(p_{i-1}, p_{i+1})}$$

Where  $p_i$  is the sampling point at time  $i$ .

## Complexity Measure

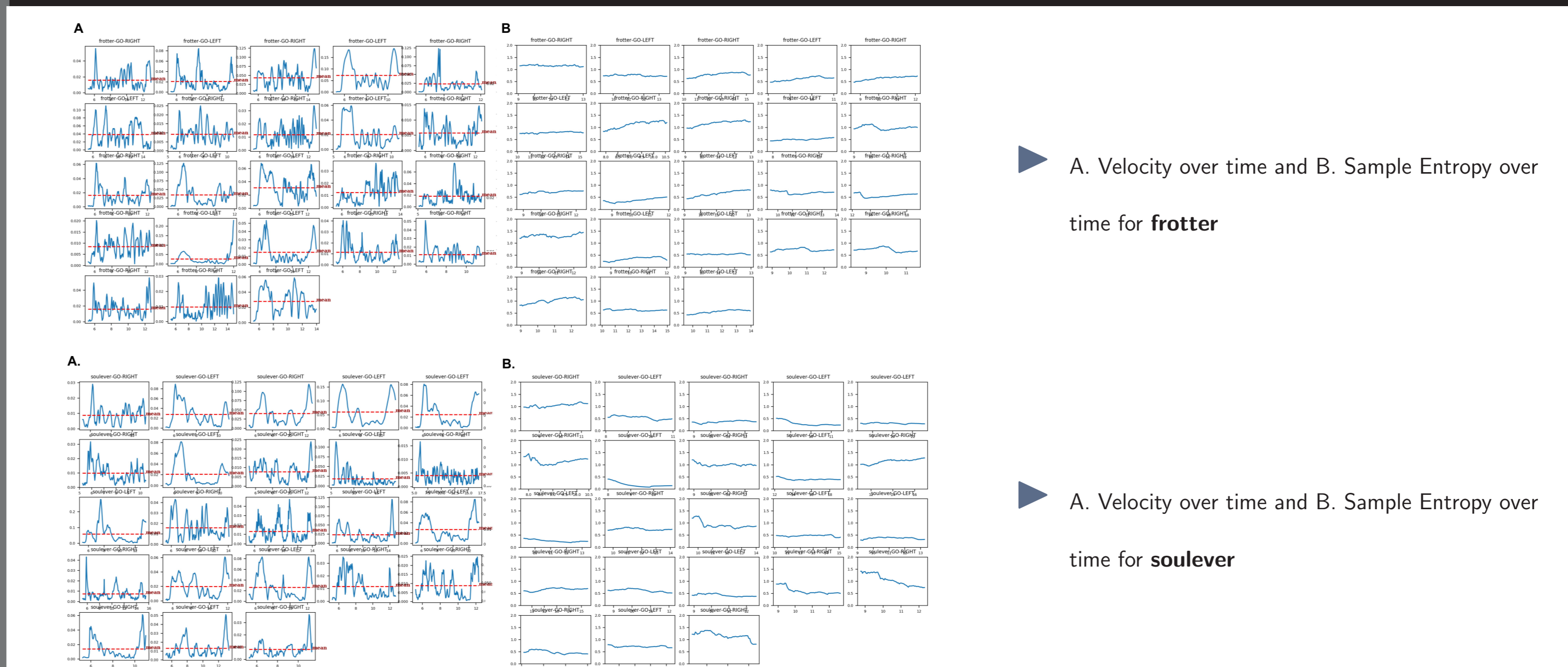
- ▶ **Sample Entropy** is the negative natural logarithm of the conditional probability that two sequences similar for  $m$  points will remain so at the next point.
- ▶ A lower sample entropy of a given time-series implies greater self-similarity.
- ▶ It is relatively stable as a function of time-series 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



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

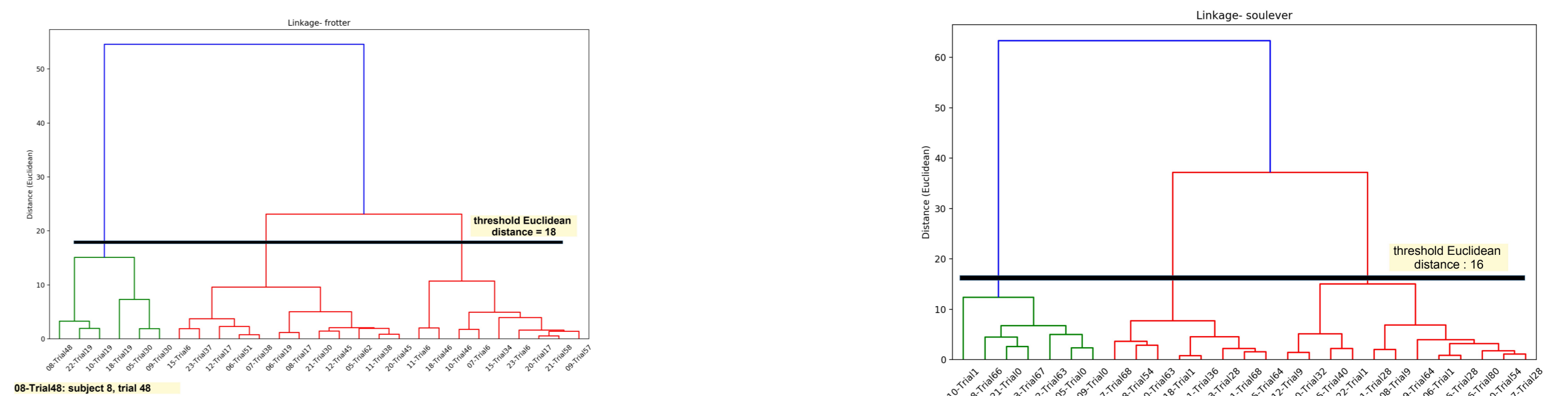
## General Movement Features and Sample Entropy



- ▶ 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 dendrogram 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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