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Cortico-muscular Synchronization in novelty management with the dominant and non-dominant hemi body: new measures used, new phenomena discovered

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Outline

- Background
- EEG study
- Results
- Discussion

Cortico-muscular synchronization

The typical assessment of the cortex-muscles synchronization during a motor task is the spectral coherence known as **cortico-muscular coherence** (CMC) - between the **EEG/MEG** signals from the contralateral sensorimotor cortex and the electromyography (**EMG**) from the prime mover muscle recorded simultaneously

CMC is a valuable tool for understanding the neural mechanisms underlying movement control, and it provides insights into brain activity related to motor function

CMC helps to understand specific physiological conditions such as fatigue

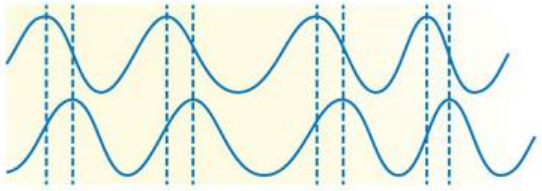
Cortico-muscular Coherence estimation

Linear correlation between x(t) and y(t) as a function of frequency

$$Coh(\mathrm{x},\mathrm{y},f) = \frac{|Cs\ (\mathrm{x},\mathrm{y},f)|^2}{P(\mathrm{x},\mathrm{x},f)\ P(\mathrm{y},\mathrm{y},f)}$$

x(t) Brain source activity

y(t) EMG signal



Nature Reviews | Neuroscience

Cs : cross-spectral density matrix
f : frequency bin
P: spectral power

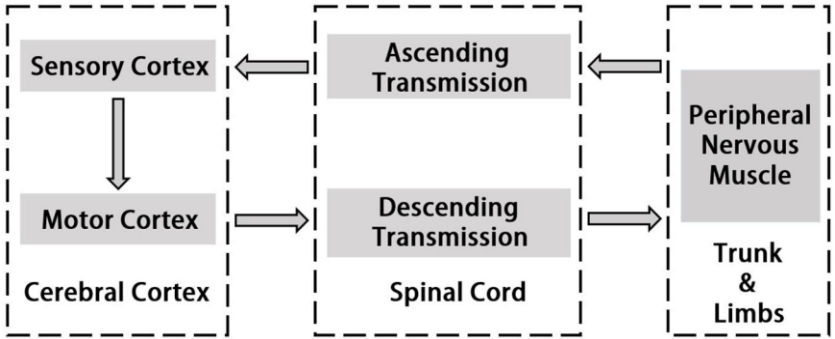
As recently reviewed by (Liu et al., 2019), CMC is maximal in the **beta band** (14–30 Hz) when studied movements involve a static force, while CMC prevails in **gamma band** (above 30 Hz) during movements changing in time. Furthermore, stronger forces correspond to smaller CMC amplitudes

Figure: Siegel at al, 2012

CMC limitations?

Though CMC is considered a well-established index of cortex-muscle information flow both in healthy and pathological conditions clear limitations emerged (Yang et al., 2018)

- the synchronization in the sensorimotor system originates from ascending somatosensory feedback and descending motor commands (Kilner et al., 2004) but CMC cannot separate this **bidirectional** contribution in cortico-muscular interaction
- the sensorimotor system appears to be **non-linear**, showing cross-frequency coupling, paving the way to non-linear measures able to complement linear ones



Liu et al., 2019

Aim of the study (Pascarella et al., 2022)

Can we use a new methodology to study the similarity between EEG and EMG signals to highlight new features ?

To detect differences in how the brain represents or organizes information about the right hand compared to the left hand using the Normalized Compression Distance (NCD) measure.

Main Hypothesis:

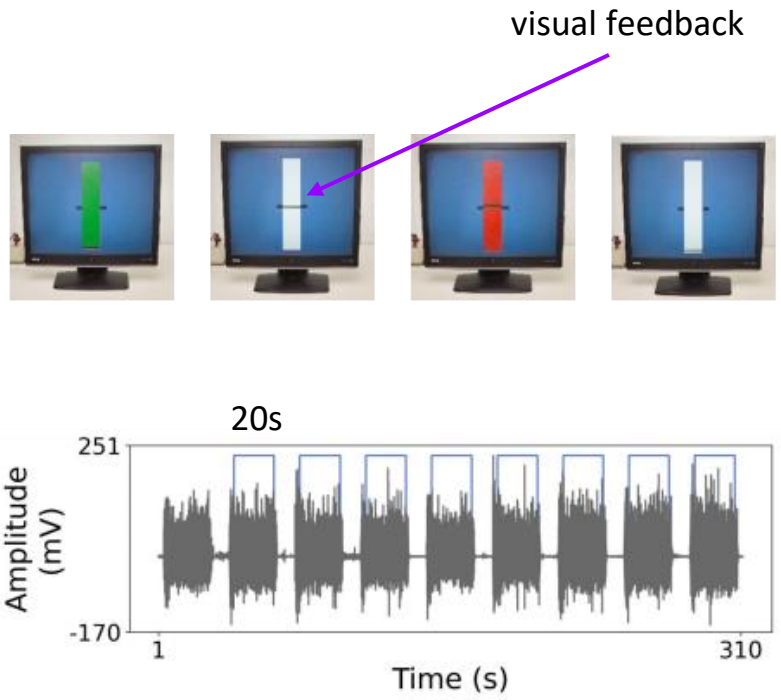
- Cortico-muscular NCD (CMncd) will show dependence on hand executing the task and the level of visual feedback

Experiment

Participants
18 right-handed subjects

EEG data
64-channel acti-CHamp System

EMG data
right and left opponents pollicis muscle were recorded with a belly tendon montage



Data acquired at S. Giovanni Calibita Hospital, Rome

Pascarella et al., 2022
L'Abbate et al., 2022

TASK: handgrip, either with left or the right hand, separately, against the resistance of a semi-compliant air-bulb connected to a digital board recording the exerted pressure while giving the subject a visual feedback (InPresS; Tomasevic et al, 2013)

Experiment

- Each succession of contraction and rest sequences lasted about 5 min
- The target level was set to 5% maximum voluntary contraction (MVC), to minimize weariness related to the task

- The task was executed in presence of visual feedback and, thereafter, in absence of it, with an identical setting but with the horizontal bar fixed in the central position

- The four handgrips (about 5 min each) were executed in the same order in all subjects:
  - first with the dominant hand with visual feedback (**DxYes**)
  - then without (**DxNo**)
  - thereafter with the non-dominant hand with visual feedback (**SnYes**)
  - and without visual feedback (**SnNo**).

The EEG-EMG session lasted about 30 min overall.

CMC estimate

AIM -> to assess whether CMC is sensitive to manual dominance and visual sensory feedback within the internal dynamics underlying continuous motor control

EEG data pre-processing

EEG data filtered 1-250 Hz

fastICA to remove biological and non-biological artifacts

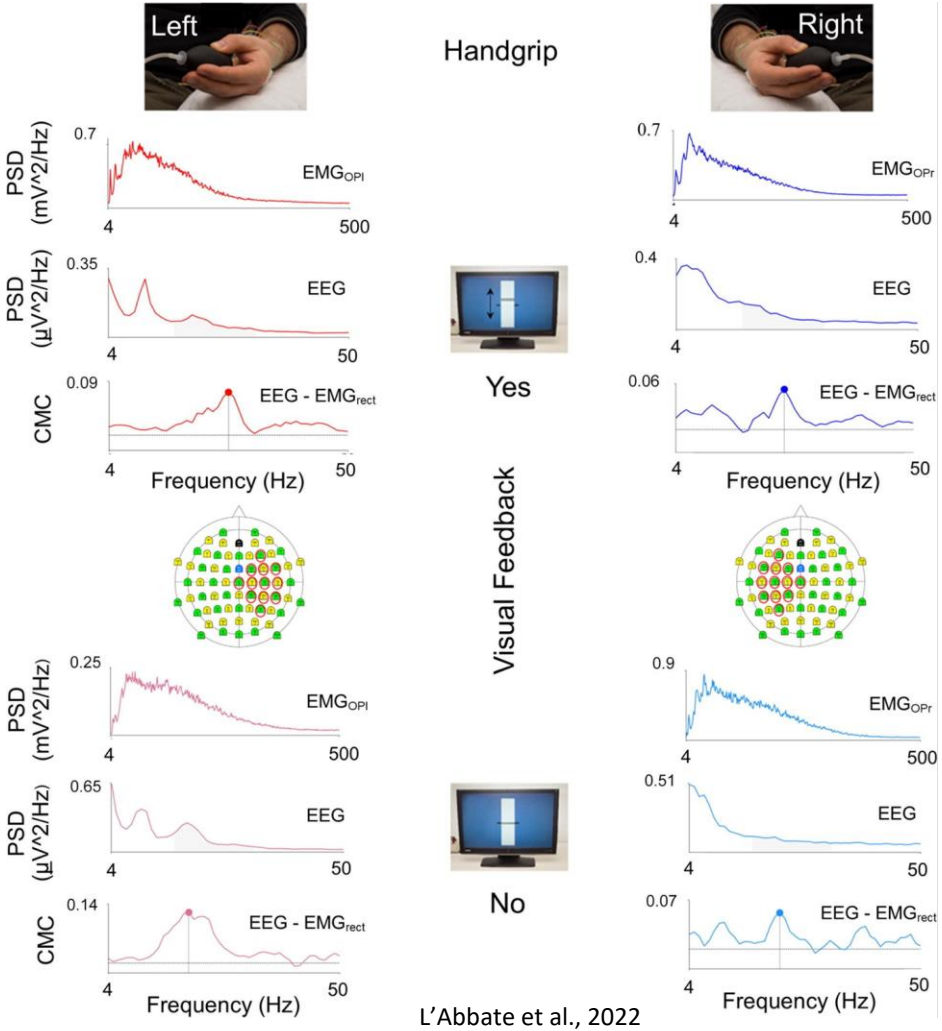
For each sbj, 180s of artifact-free signal

CMC estimate

CMC between the EMG and a single representative bipolar EEG derivation

CMC was scored by the amplitude and the frequency of the maximum amplitude peak

The CMC peak was investigated in the **beta band**, between 15 to 33 Hz



L'Abbate et al., 2022

CMC results (L'Abbate et al., 2022)

The absence of visual feedback

- ❖ decreased the CMC peak frequency from 27 Hz to 23 Hz
- ❖ increased the CMC peak amplitude from 0.05 to 0.07
- ❖ increased the electroencephalographic beta band power

Online visual monitoring of exerted pressure modifies the cortico-muscular synchronizations controlling the motor execution

Table 1. Demographic and CMC peak features

			Cortico-muscular coherence (CMC) peak							
			Right hand				Left hand			
			With Vf		Without Vf		With Vf		Without Vf	
Sex		Age	Freq (Hz)	Amp	Freq (Hz)	Amp	Freq (Hz)	Amp	Freq (Hz)	Amp
10 F 8 M	**Mean**	29	26.9	0.05	23.1	0.07	27.6	0.06	22.0	0.08
	SD	6	3.8	0.04	3.2	0.04	3.9	0.05	4.2	0.05

M = male, F = female; Mean and standard deviations (SD) of cortico-muscular coherence peak frequency (Freq, Hz) and amplitude (Amp, dimensionless) in the experimental conditions of interest. For amplitudes the value is the exponential transformation of the mean of logarithmic transformed values. For frequency the square root of the averages of the squared values.

None of these measures changed in dependence on the performing hand, indicating that CMC is not sensitive to manual dominance

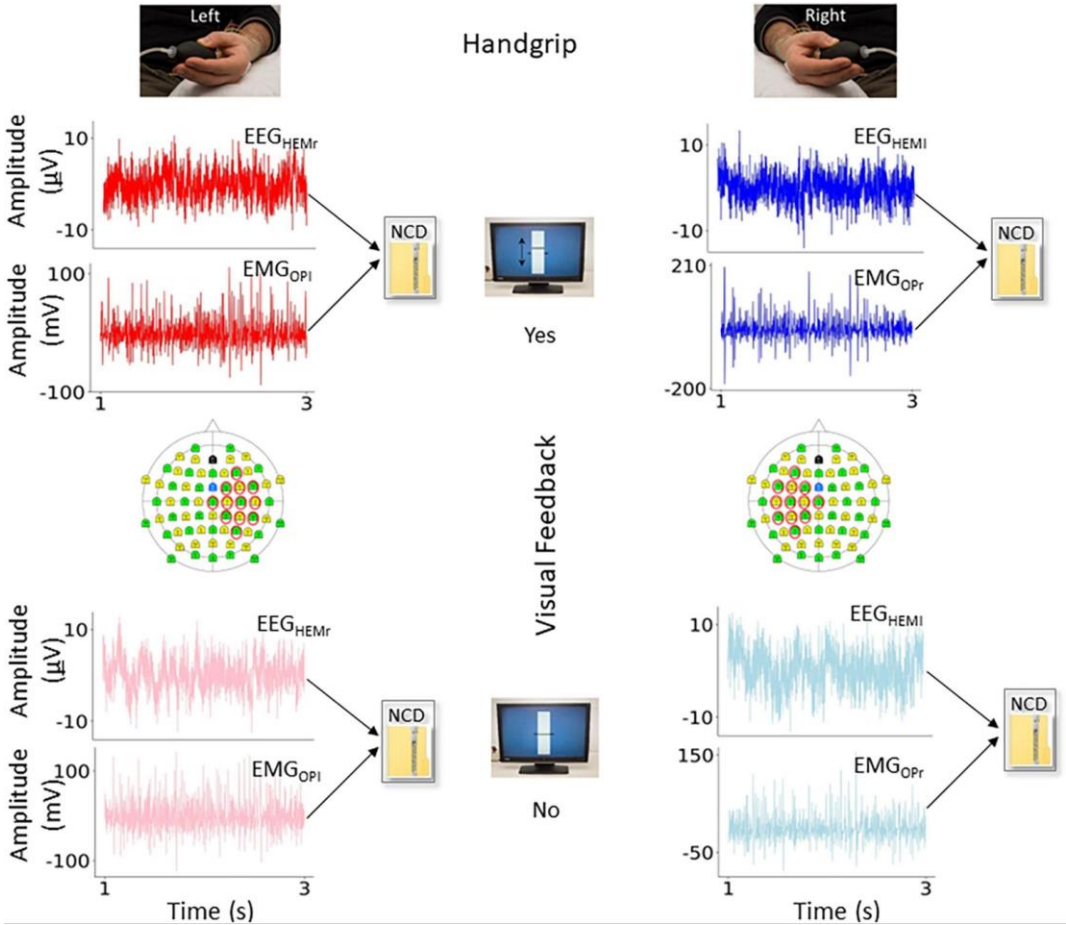
CMncd

We studied with the **NCD** the synchronization between cortex and muscle (CMncd) while executing the same weak isometric handgrip task, with either the right or left hand, with or without visual feedback of their exerted pressure

EEG data filtered 1-250 Hz
fastICA to remove biological and non-biological artifacts

For each sbj 180s of artifact free signal

Bipolar derivations selected based on maximal peak amplitude of CMC in beta band in each of the four condition



Pascarella et al., 2022

Normalized Compression Distance (NCD)

- NCD (Cilibrasi and Vitanvy, 2005) is a **parameter free, quasi-universal metric** defined to detect similarities between signals
- NCD is based on the concept that two signals are similar if we can significantly “compress” one using the information of the other

- Since it's based on compression algorithms like the Lempel-Ziv algorithm or other universal compressors (like gzip), it doesn't rely on the nature or content of the data but rather on its structural complexity

- The NCD computed between two signals x and y is defined as

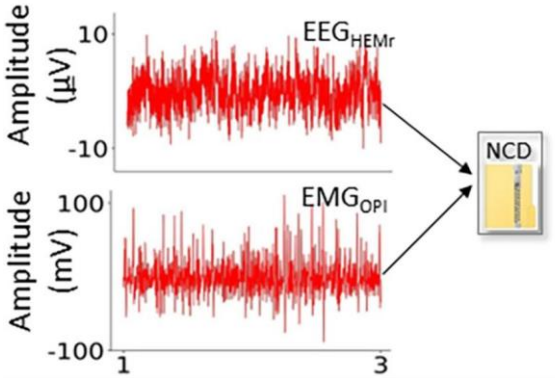
$$\mathrm{NCD}(x, y) = \frac{C(xy) - \min(C(x),\ C(y))}{\max(C(x),\ C(y))},$$

where C(x, y) denotes the compressed size of the concatenation of x and y, C(x) the compressed size of x and C(y) the ones of y

- NCD assumes values between 0 and 1 where 0 indicates maximum similarity and 1 the opposite

CMncd

- We studied with the NCD the synchronization between cortex and muscle (CMncd) while executing a simple movement typical of everyday activity
- Higher CMncd corresponds to lower synchronization
- To test the robustness of NCD to the compressor we used two different type of compressor

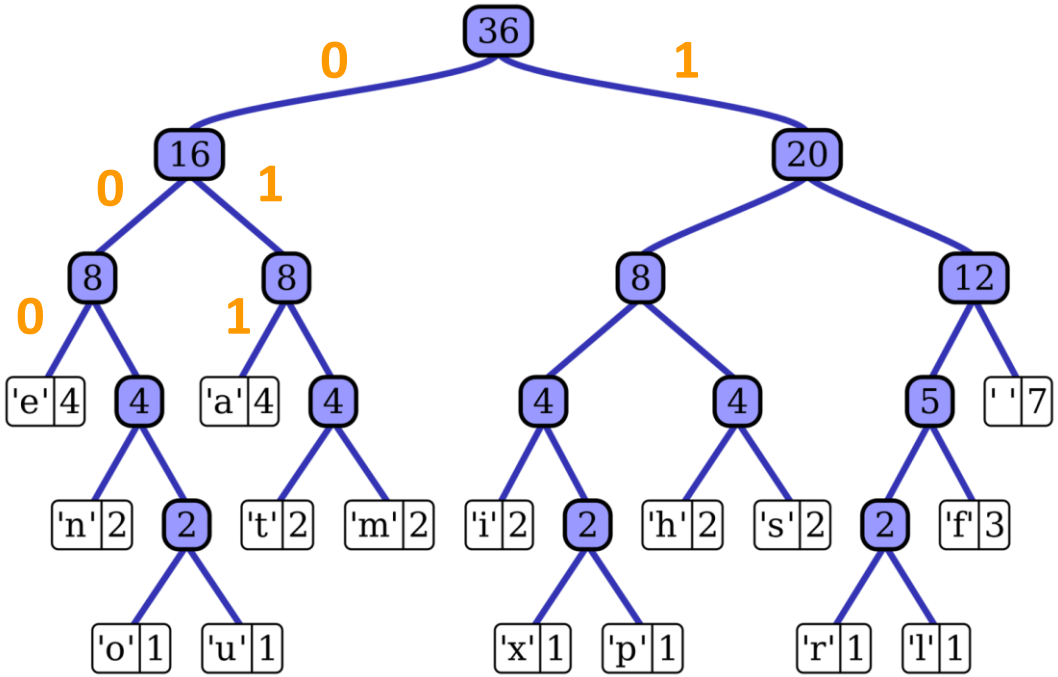


Huffman coding

Lossless compressor

Assign variable length codes to different character based on their frequency

The more frequent characters are given shorter codes, reducing the overall space required to store the data



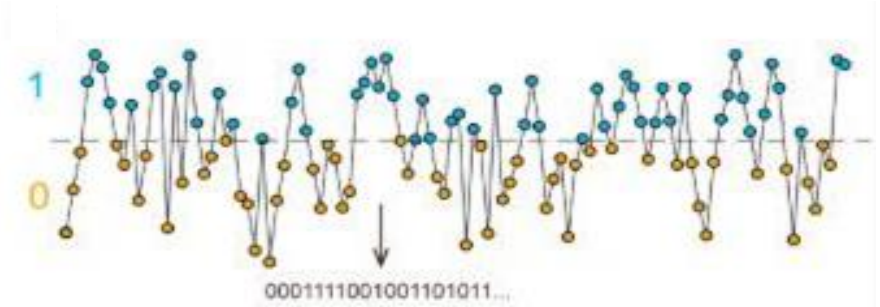
Example: this is an example of a Huffman tree (Wikipedia)

Lempel-Ziv complexity (Lziv)

Lziv complexity provides a measure of entropy by “counting the number of distinct patterns of activity in the data. It can be thought of as being proportional to the size of a computer file containing the data, after applying a compression algorithm” (Schartner et al., 2015).

- Complexity measure designed for binary sequences and text
- It counts the number of unique sub-strings in a sequence measuring how repetitive a signal is
- **O’Byrne and Jerbi, 2022**

Normalized version of Lziv which scales Lziv by $\log_b(n)/n$, where n is signal length and b the number of unique characters in the signal



Lu and Rodriguez-Larios, 2018

Results

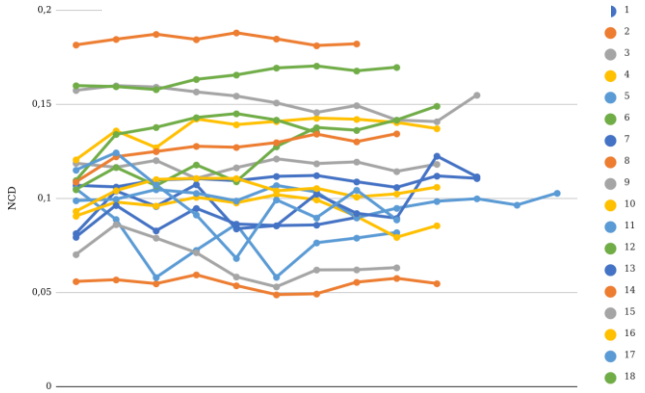
For each subject and condition, we computed the CMncd between the cleaned EEG and EMG signals

- EEG is the selected bipolar channel
- for 10 segments lasting 18 s (a minimum of 6–10 s intervals were included in all subjects)

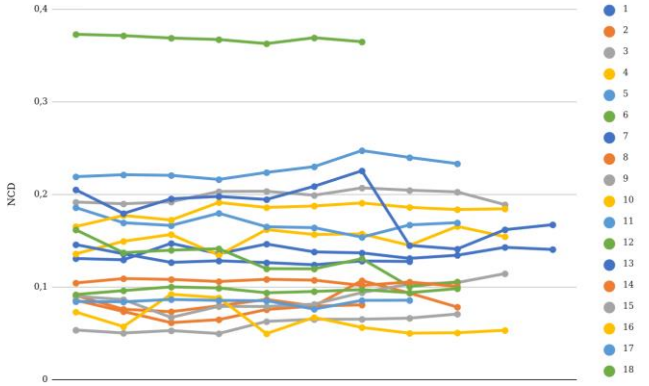
Non parametric statistical test to identify CMncd differences between

- presence and absence of visual feedback when using the same hand
- dominant and non-dominant hand representations within the same feedback condition (absence or presence)

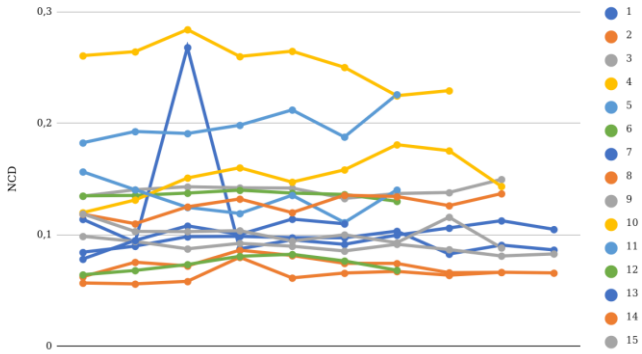
DxYes



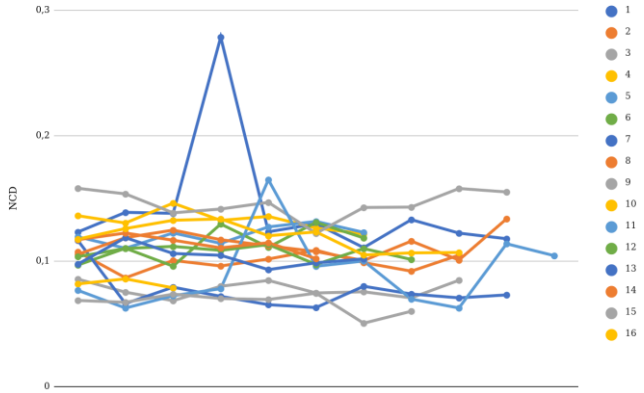
SxYes



DxNo



SxNo



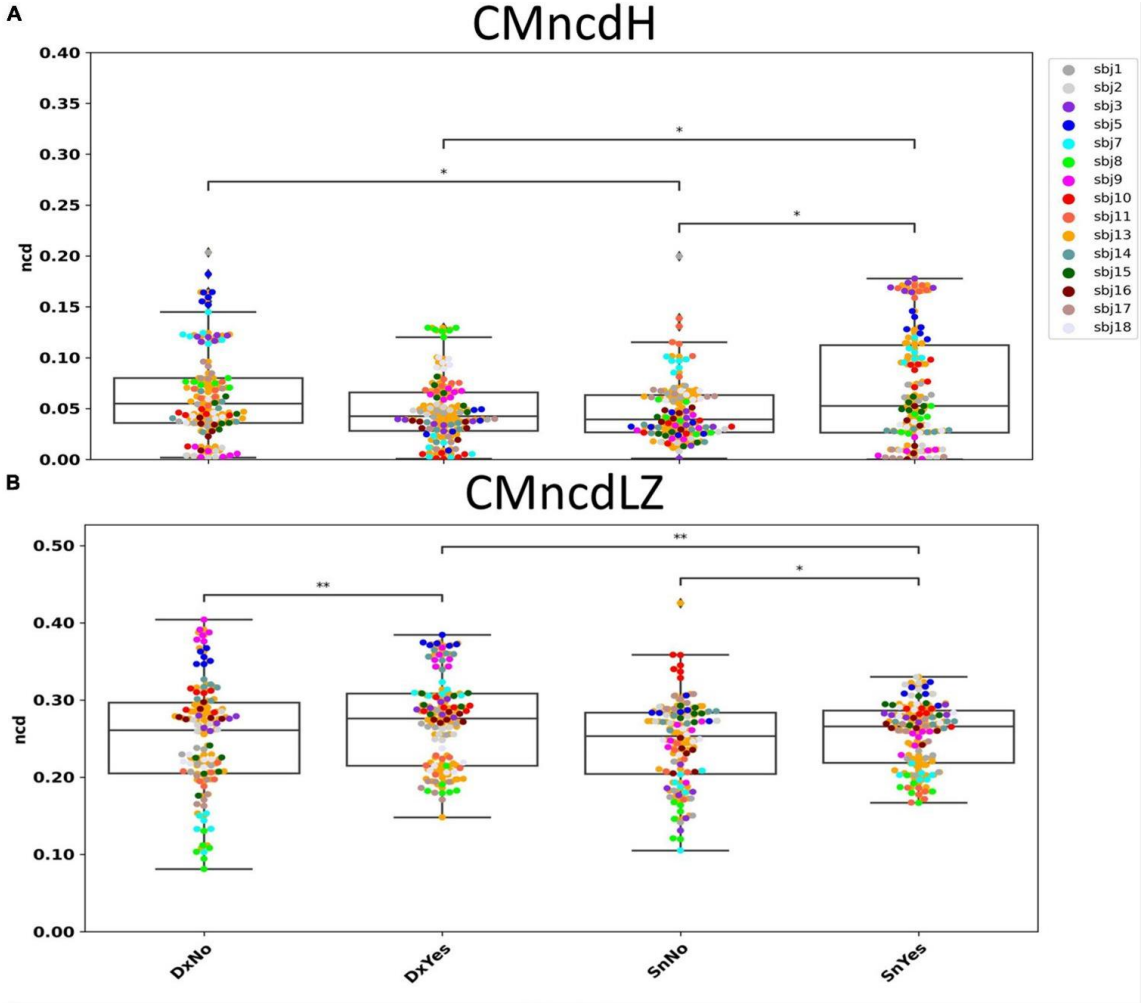
Significant difference

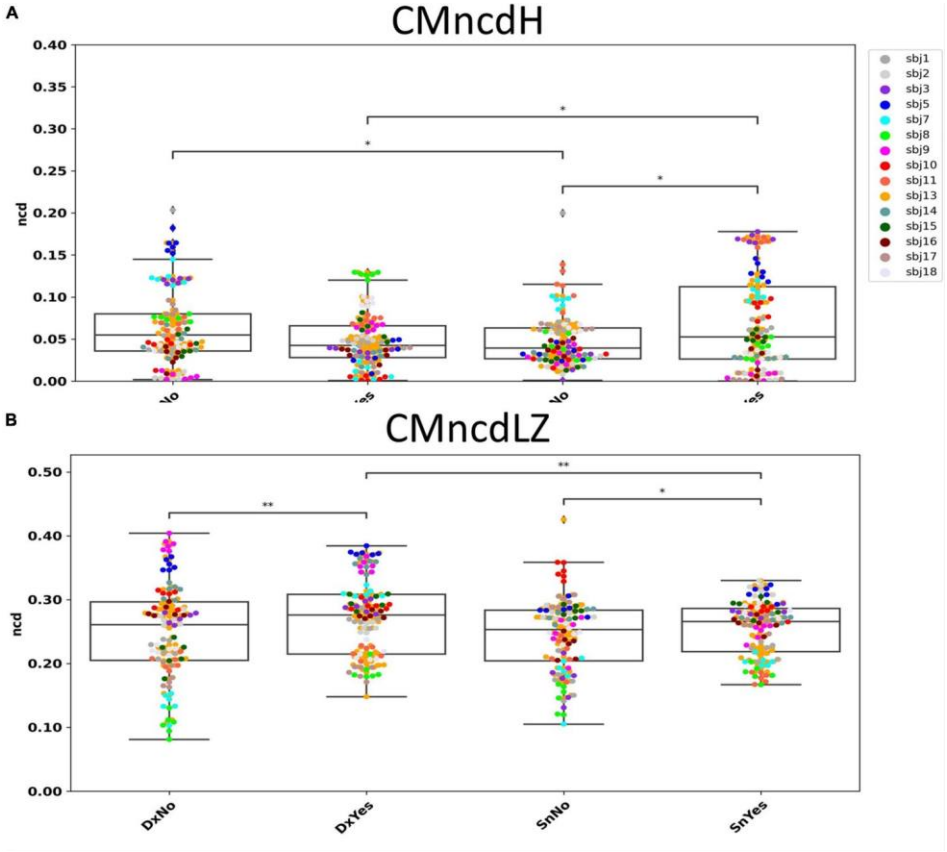
Huffman

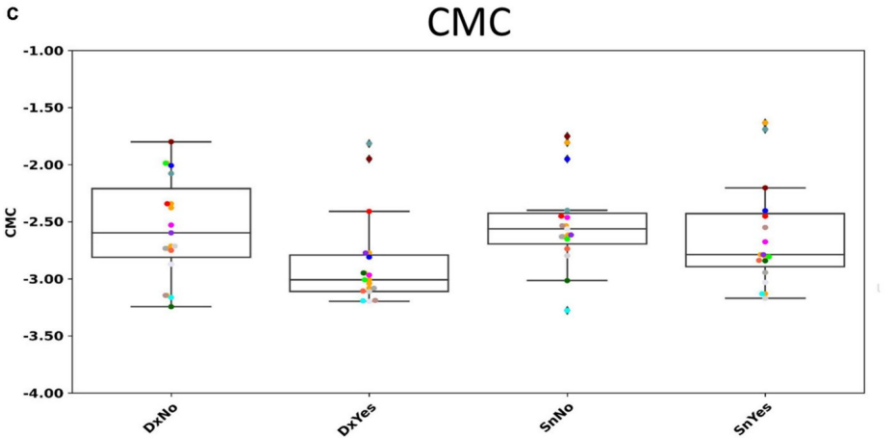
DxYes vs SnYes (p=0.011)
DxNo vs SnNo (p=0.016)
SnNo vs SnYes (p=0.012)

LZiv

DxYes vs SnYes (p=0.007)
DnNo vs DnYes (p=0.0016)
SxNo vs SnYes (p=0.024)




A
CMncdH
ncd
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
*
*
*
sbj1
sbj2
sbj3
sbj5
sbj7
sbj8
sbj9
sbj10
sbj11
sbj13
sbj14
sbj15
sbj16
sbj17
sbj18
B
CMncdLZ
ncd
0.50
0.40
0.30
0.20
0.10
0.00
**
**
*
DxNo
DxYes
SnNo
SnYes


C
CMC
CMC
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
DxNo
DxYes
SnNo
SnYes

Results

- Both CMncdH and CMncdLZ display higher values in presence wrt absence of visual feedback when executing the **left handgrip** (**SxNo vs SxYes**)
  - minor synchronization btw cortex and muscles when the task requires the integration of transposed visual feedback
  - similarly to CMC, CMncd shows sensitivity to visual feedback
  - the unfamiliar task integrating unusual information and focusing attention reflected in a minor cortico-muscular synchronization
- In presence of **visual feedback** CMncd appears sensitive to **laterality of movement**: higher values for the left than for the right handgrip (**DxYes vs SxYes)**
  - CMncd is sensitive to motor control dexterity, differentiating the dominant vs non-dominant sides and revealing the difficulty of the non-dominant side to integrate unusual information during an unfamiliar task
  - CMncd reveals better synchronizations for the dominant hand not emerging in CMC

Results

- CMncdH evidenced the dependence on hemibody dominance also in everyday activities (**DxNo vs. SnNo**)
- CMncdLZ evidenced the dependence on visual feedback also when moving the dominant hand (**DxNo vs DxYes**)

Further investigations are required to deep understanding how different compressors detect physiological properties via NCD

Take home message

- NCD measures the **similarity** of signals by comparing their compression lengths
- NCD does not require any features or background knowledge about the data and does **not** require a **synchronous recording**
  - this could be very useful when comparing the activities of a specific area at different times along the lifetime or as effect of a disease in longitudinal studies
- NCD is also suitable for the comparison of **signals with different lengths**
  - for example, in the case of activities where artifacts occur in different periods and lead to incongruent epoch rejections
- NCD is sensitive to the dominant-non dominant asymmetry when novelty management is required

NCD can represent a relevant enrichment tool to assess synchronization phenomena between two nodes

Collaborations

Franca Tecchio

Eugenia Giani
Matteo Abbondanza
Karolina Armonaite
Francesca Pitolli
Massimo Bertoli
Teresa L'Abbate
Joy Grifoni
Domenico Vitulano
Vittoria Bruni
Livio Conti
Luca Paulon

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thank you!

La sottoscritta Annalisa Pascarella dichiara di non avere conflitti di interessi e rapporti con aziende farmaceutiche

Sviluppi futuri

1) La NCD può mettere in evidenza la dominanza della mano di un soggetto, questa ipotesi dovrà essere avvalorata da ulteriori studi.

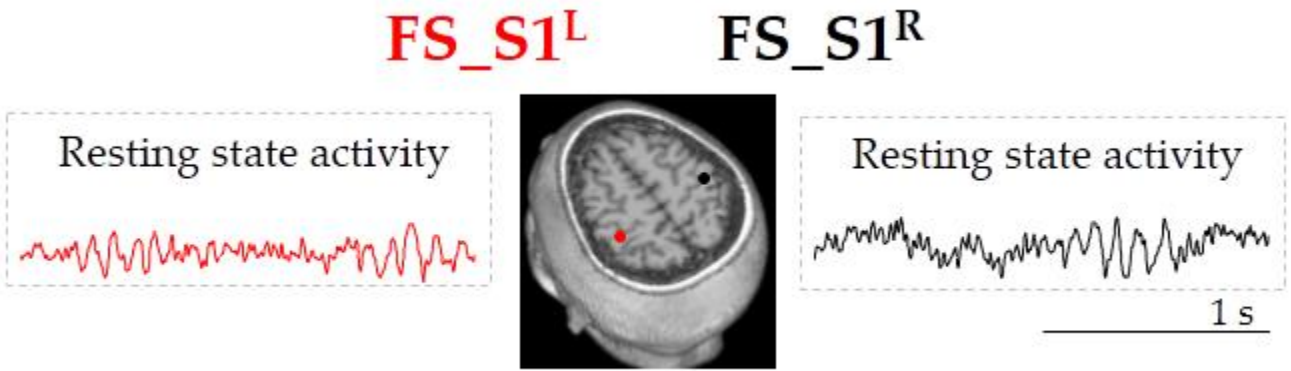
2) L'ipotesi che la NCD sia una caratteristica soggettiva potrebbe portare in un futuro al suo utilizzo fissando delle soglie al di sopra delle quali può essere diagnosticata una patologia neurologica o muscolare.

3) Si può ipotizzare che malattie degenerative neurali o muscolari possano aumentare i valori della NCD, ciò vuol dire una minore somiglianza tra i segnali EEG ed EMG, e quindi si potrebbe utilizzare per studiare la velocità con la quale si sviluppa la degenerazione ; inoltre, potrebbe essere utilizzata per quantificare lo stato degenerativo di una patologia.

mancini
pazienti

MEG study

We used NCD to assess that the similarity between the left and right homologous areas in single subject is greater than across the entire group[of intra-individual inter-hemispheric homolog areas' neurodynamics is higher than comparing the neurodynamics of different people]

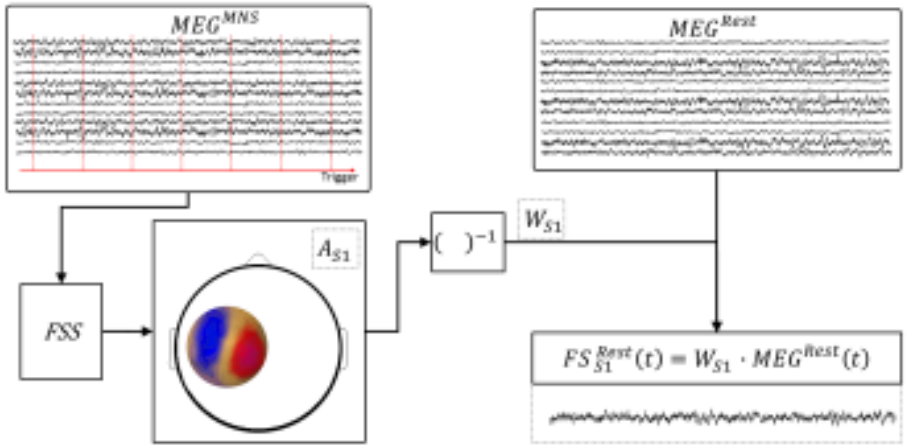


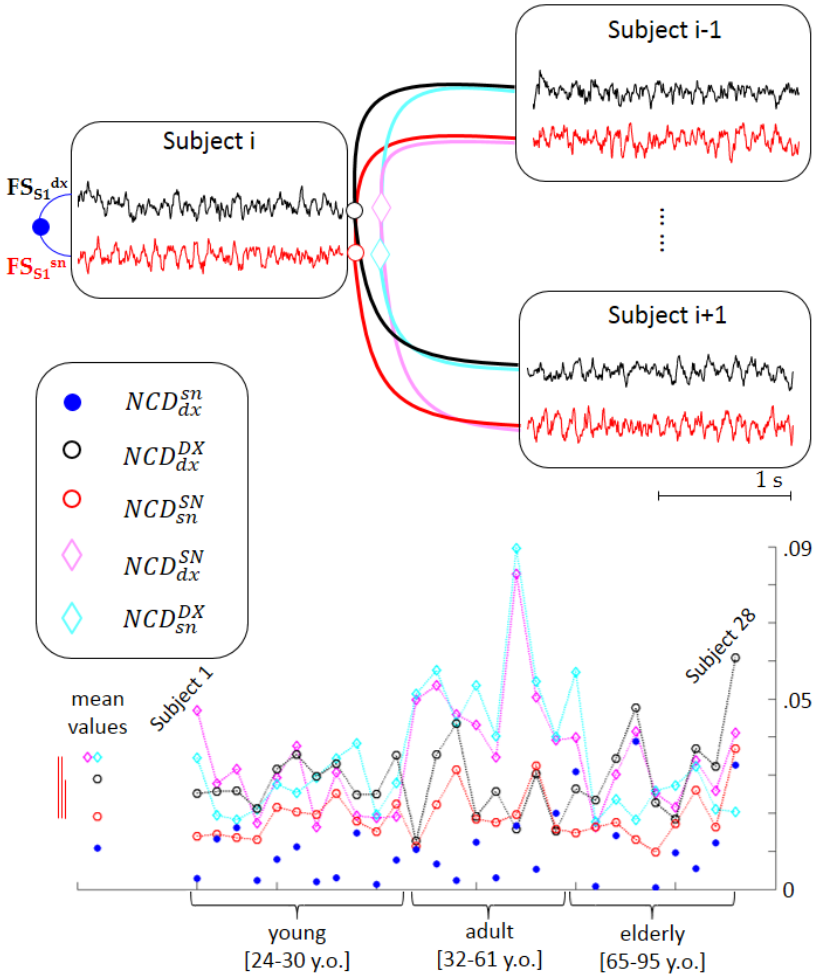
We considered the functionally homologous areas devoted to hand perception with primary somatosensory cortex (S1) in both hemispheres, which we expect to display masimally similar neuronal activity at rest

FSS takes in input the MEG data recorded during median nerve stimulation wirst and provides the S1 Functional Source's magnetic field distribution A_S1 as output

Then the weight vector W_S1 (pseudo-inverse of A_S1) is applied to MEG data recorded during rest producing the S1 Functional Source at rest

FSS identifies S1 as the cortex that processes nerve stimulation





	NCD_{dx}^{DX}	NCD_{sn}^{SN}	NCD_{dx}^{SN}	NCD_{sn}^{DX}
NCD_{dx}^{sn}	$5.41 \cdot 10^{-9}$	$9.23 \cdot 10^{-4}$	$6.03 \cdot 10^{-9}$	$4.25 \cdot 10^{-7}$
NCD_{sn}^{SN}	$3.14 \cdot 10^{-7}$		$2.57 \cdot 10^{-6}$	
NCD_{dx}^{DX}			0.09	

- NCD catches the neurodynamics similarity between hemispheric homologs (left and right S1 neurodynamics)
- The similarity between the activities of the right and left functionally homologous S1 areas at rest was greater when comparing those of within a single sbj with those in the four conditions across subjects
- The similarity btw left FS_S1 and the left source activities of all other sbjs was greater than the other 3 conditions
- We also found that NCD on resting neurodynamics catches signs of hemispheric dominance and variability as a function of age

Measuring the similarity between resting neurodynamics can provide a measure of the balance between hemispheric homologs.