Neurorobotics and Neurorehabilitation - Project 1: Analysis of EEG sleep spindles in COVID-19 survivors

Group AFV

Introduction

Sleep spindles occur during the stage 2 of NREM sleep and have spindle-shaped rhythmic waves (sigma rhythm), which gradually increase and then decrease in amplitude, and have slow (9–12 Hz) and fast (12–15 Hz) components. Sleep spindles are generated regularly every 3-6 seconds and propagate throughout the cortex. Sleep spindles are bursts of neural oscillatory activity that are generated by interplay of the thalamic reticular nucleus (TRN) and other thalamic nuclei. Sleep spindles transform and decrease the arousal capacity of sensory signals transmitted through the thalamus to the cortex and have been implicated in the processing of information acquired during the active period.

Work

The project consists of estimating the average of slow and fast spindles and locating them in inverse space. High-density EEG recording is acquired during the sleep phase on a patient discharged from an intensive care unit (ICU – 023) due to COVID-19 infection between March and May 2020 and a patient never infected by the virus (CTRL – 033). Coronavirus disease 2019 (COVID-19) is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which first appeared in Wuhan, China, in December 2019 and subsequently spread across the globe, being declared a pandemic disease by the World Health Organization.

Methods and Discussions

Initial part

To carry out the data analysis, we used Matlab software (R2023a), followed by the Brainstorm (v.2024) for the localization of the neural sources in inverse space. The data provided, CTRL033_nap.mat and ICU023_nap.mat, were loaded by setting the sampling frequency equal to 250 Hz. They were subsequently filtered in the respective frequency ranges [9-12] Hz and [12-16] Hz, in order to obtain two arrays for each patient regarding the slow and fast tracks.

In step 1, we have:

Matrix	$samples \times channels$
CTRL	996090×204
ICU	1167843×204

In step 2:

Matrix	$samples \times channels$
slow_tracks_033	996090×204
fast_tracks_033	996090×204
slow_tracks_023	1167843×204
fast_tracks_023	1167843×204

Using the time instants contained in spindles_timing_033.mat and spindles_timing_023.mat as starting points, we identify the spindles in the data, fixing the duration of each one to 500 milliseconds. Then, we computed the average for each spindle between all the EEG channels, respectively for the slow and fast tracks of each subject.

In step 3:

Matrix	$samp. \times chan. \times trials$
slow_tracks_033	$125 \times 204 \times 41$
fast_tracks_033	$125 \times 204 \times 59$
slow_tracks_023	$125 \times 204 \times 66$
fast_tracks_023	$125 \times 204 \times 45$

Then, in step 4:

Matrix	$samples \times trials$
avg_spindle_033_slow	125×41
avg_spindle_033_fast	125×59
avg_spindle_023_slow	125×66
avg_spindle_023_fast	125×45

The next step was to compute the spectrum of each signal obtained in step 4, using the pwelch.m function and plotting them.

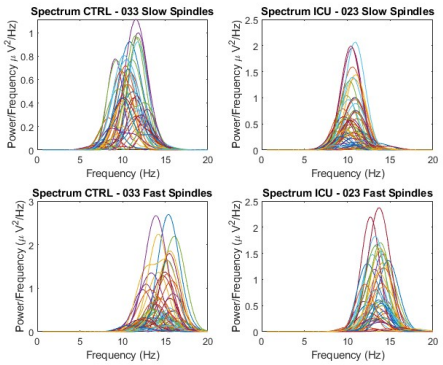

Figure 1: Power spectra of slow and fast signals in CTRL and ICU.

Once the spectra were defined, the spindles with the maximum peak frequency outside the range [9-12] Hz for the slow and [12-16] Hz for the fast were removed.

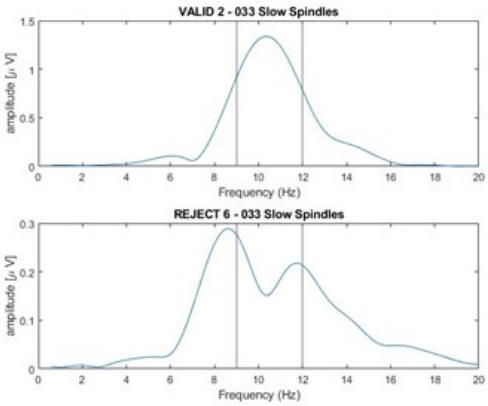

Figure 2: Valid and discarded spindles of slow CTRL.

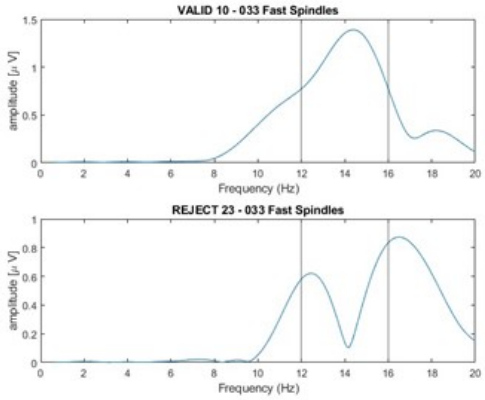

Figure 3: Valid and discarded spindles of fast CTRL.

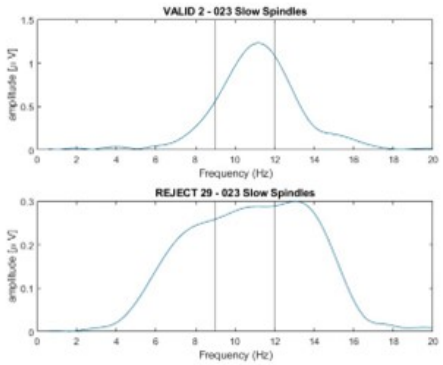

Figure 4: Valid and discarded spindles of slow ICU.

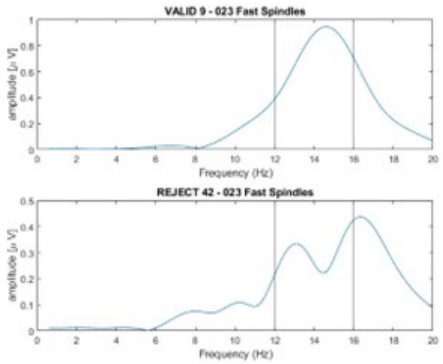

Figure 5: Valid and discarded spindles of fast ICU.

In the figures above we can observe some examples of valid and rejected spindles. Respectively we have: in 2 an example of a valid and a discarded spindle in the slow tracks of CTRL patient, in 3 an example of a valid and a discarded spindle in the fast tracks of CTRL patient, in 4 an example of a valid and a discarded spindle in the slow tracks of ICU patient and in 5 an example of a valid and a discarded spindle in the fast tracks of ICU patient.

In the next table we can see which spindles have been discarded.

Type	Discarded
slow_033	$1-6-7-16-18-21-29-30-39-40$
fast_033	$19-23-57$
slow_023	$12-21-22-29-59-65$
fast_023	$17-42$

After discarding the not valid trials, our matrices become like this:

Matrix	$samp. \times chan. \times trials$
valid_slow_tracks_033	$125 \times 204 \times 31$
valid_fast_tracks_033	$125 \times 204 \times 56$
valid_slow_tracks_023	$125 \times 204 \times 60$
valid_fast_tracks_023	$125 \times 204 \times 43$

Averaging the remaining trials considering all the channels we obtain a structure as:

Matrix	$samples \times channels$
avg_valid_slow_033	125×204
avg_valid_fast_033	125×204
avg_valid_slow_023	125×204
avg_valid_fast_023	125×204

Intermediate part

Once we have discarded the spindles with maximum peak frequency out of their respective range, we have computed their absolute values and averaged them over time, in order to plot the topographic maps as a 2-D circular view, looking down at the top of the head, using co-interpolation on a fine Cartesian grid.

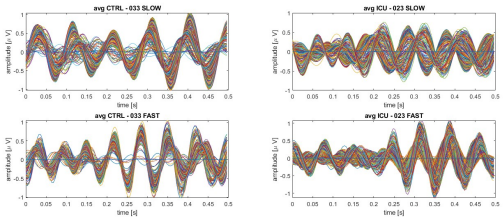

Figure 6: Averaged signals.

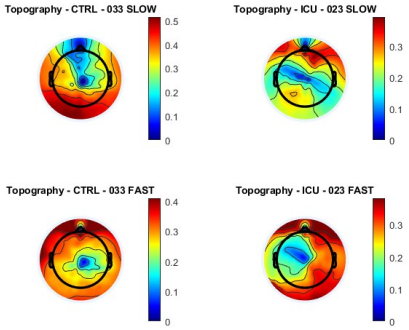

Figure 7: Topographic maps of slow and fast spindles in CTRL and ICU.

As we can observe, in CTRL, slow and fast spindles show different EEG topographical distributions: with the slow spindles more frontal and fast spindles more in the parietal lobe. In ICU, slow spindles shift to more posterior/temporal regions, while fast spindles becomes more anterior/temporal. We have observed significant differences in slow and fast EEG wave-forms spindle amplitude onset between CTRL and ICU subjects.

Final part

The data was loaded into the software separately together with the location channels GSN_204.sfp. The location was edited and then saved within the project. For each signal, the head model was computed using the 3-shell sphere method to obtain a functional 3D model in order to express an isotropic and homogeneous conductive volume. Finally, the noise covariance was calculated and the location of neural activity was plotted through sLORETA2018.

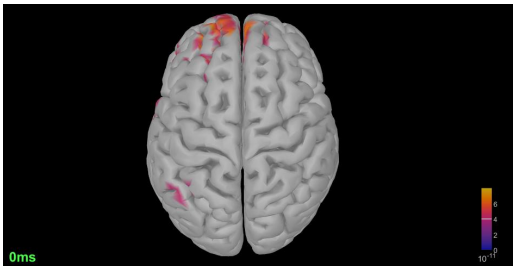

Figure 8: Slow CTRL

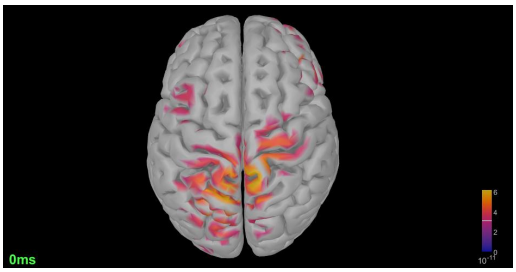

Figure 9: Fast CTRL

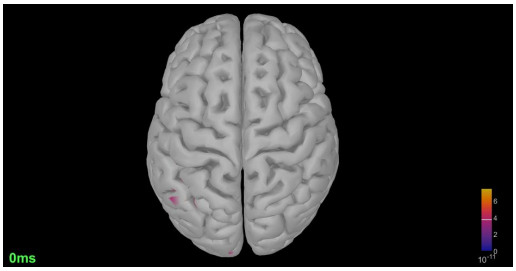

Figure 10: Slow ICU

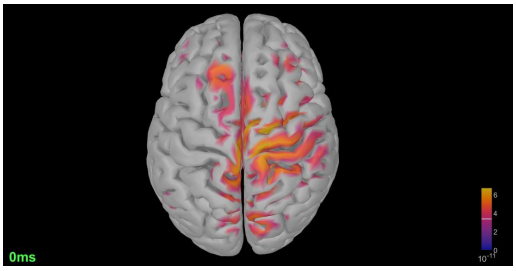

Figure 11: Fast ICU

All amplitude in slow and fast EEG source-waveforms spindle are reported in 8, 9, 10, 11. In CTRL, slow spindles are concentrated in the frontal cortices and fast spindles in the central brain regions. In ICU, fast spindles are generated in the temporal/parietal brain regions.