FSTP-1

Sub-project PEPATO

(PErformance indicators of spatiotemporal PATterns of the spinal muscle coordination Output during walking with an exoskeleton)

General description

PEPATO sub-project consists of three main tasks:

- The first two tasks develop software for automatic generation of two main groups of outcome indicators for evaluating muscle coordination during walking in the exoskeleton (muscle synergies [**TASK 1**] and spinal maps [**TASK 2**]).

- The third task [**TASK 3**] provides the reference database and reference performance indicators for normal walking of neurologically intact individuals. The reference datasets are provided for young adults (n=10) for all speeds (2, 4 and 5 km/h) and for elderly (n=10) for 2 and 4 km/h.

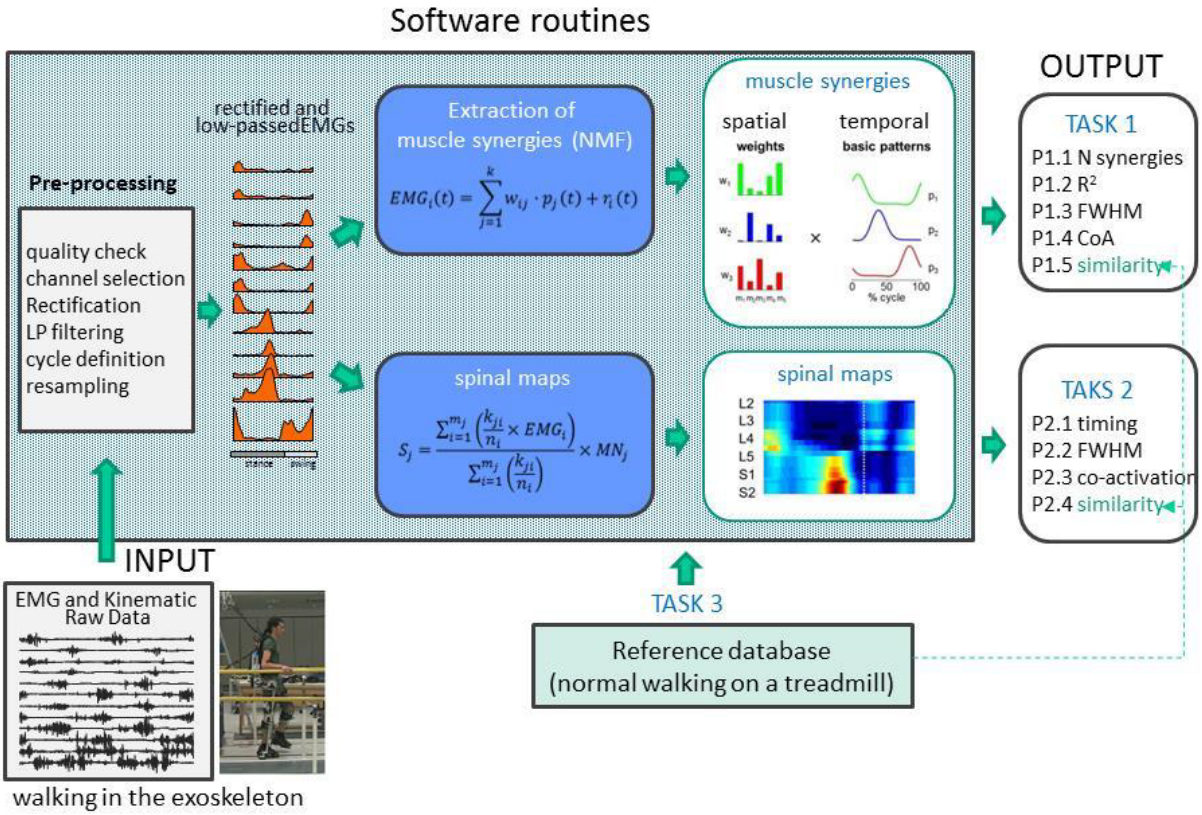


Fig. 1 General scheme: input, output and main elements of the data processing chain.

Description of the scenario/protocol

The protocol consists in walking on a treadmill at a constant speed: 2, 4 and 6 km/h. At least 10 consecutive strides should be recorded for each speed condition. PEPATO software also allows to characterize only one or two speed conditions in case the participant cannot perform all speed conditions (e.g., some exoskeletons allow only slow walking).

Input and output data for the PEPATO software are compliant with the **EUROBENCH Data Format** and are listed below. The names of the files, performance indicators and their format are described in the attached excel sheet including protocol/PI/PI Algo description.

INPUT

- EMGs of the lower limb. The current version of PEPATO processes 8 EMGs that are most accessible for recordings during walking in most exoskeletons: soleus (Sol), gastrocnemius medialis (GaMe), tibialis anterior (TiAn), rectus femoris (ReFe), vastus lateralis (VaLa), vastus medialis (VaMe), semitendinosus (SeTe), biceps femoris (long head, BiFe). PEPATO also allows data reference updating to include more muscles, subjects and conditions. Raw EMG data are collected in .csv file.

- Gait events. Processed gait events should only specify the timing of touchdown events of the recorded strides and are saved in a .yml file.

OUTPUT:

The following 2 main groups (TASK 1 and TASK 2) of performance indicators of the spinal muscle coordination output are generated using the above-mentioned input.

TASK 1 (muscle synergies) evaluates spatial (muscle weightings) and temporal (basic patterns) components of muscle modules (EMGs are normalized to its maximum value across speed conditions):

muscle_synergy_number - the number of muscle synergies best describing the EMG data (for each speed)

emg_reconstruction_quality - reconstruction quality (R2) of EMG patterns from muscle synergies

pattern_fwhm - FWHM (full width at half maximum), duration estimate of basic patterns

pattern_coa - centre-of-activity (CoA) of basic patterns

patterns_similarity - the degree of similarity of temporal components with the reference group (4 muscle module clusters for each speed) = the correlation between temporal components and reference temporal components of the module cluster centers.

synergies_similarity - the degree of similarity of muscle synergies with the reference group (4 muscle module clusters for each speed) = the scalar product of muscle weightings to the reference muscle weightings of the module cluster centers.

TASK 2 (spinal maps):

motor_pool_max_activation_timing - timing of the main loci of MN activity: timing of maximum activation of sacral (S1+S2) and upper lumbar (L3+L4) motor pools (for each speed)

motor_pool_fwhm - FWHM of activation of sacral and upper lumbar spinal motor pools

motor_pool_coactivation - co-activation index of sacral and upper lumbar motor pools

motor_pool_similarity - the degree of similarity (correlation) of activation of sacral and lumbar motor pools with respect to the reference group

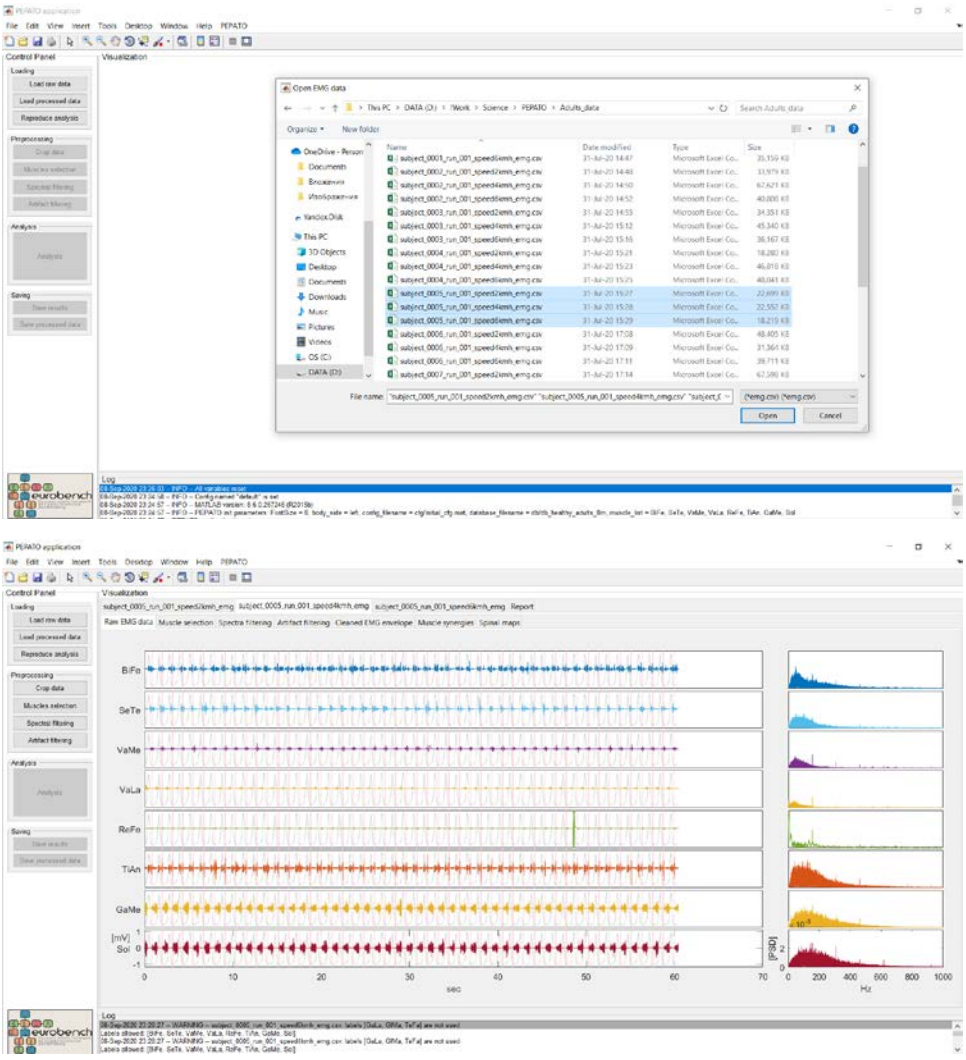
The above-mentioned parameters were also described in the previous publications and characterize the functional and structural changes at the spinal cord level induced by exoskeleton assisted walking that can be evaluated by characterizing muscle synergies and spinal maps of MN activity, as a means to look backward from the periphery to the central motor programming (Ivanenko et al. J Neurophysiol 2006, 95:602–618; Lacquaniti et al. J Physiol 2012, 590:2189–2199; Martino et al. Clin Neurophysiol 2018, 129:516–525). For instance, widening of spinal segmental output represents important physiological marker of pathological gait and/or unstable walking conditions (Martino et al. J Neurophysiol 2015, 114(5):2867-82; Martino et al. Clin Neurophysiol 2018, 129:516–525), while an abnormal spatiotemporal integration of activity in specific spinal segments may result in a risk for failure or abnormalities in gait recovery (Ivanenko et al. Front Comput Neurosci 2013, 7:123).

The attached video PEPATO_demo_xvid.avi illustrates all steps of the PEPATO software and in the Appendix (see below) the main steps are summarized.

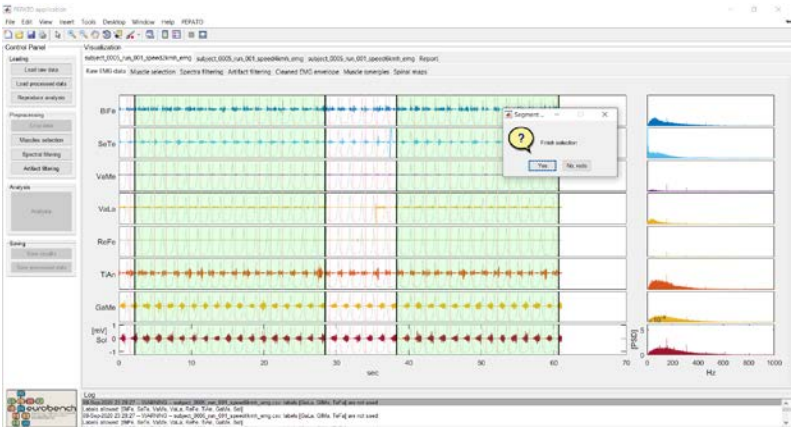
Appendix

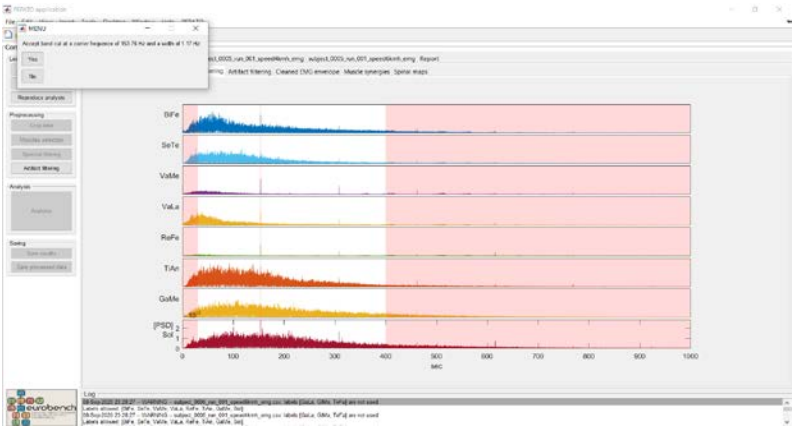
Below the main steps of the data processing chain are illustrated.

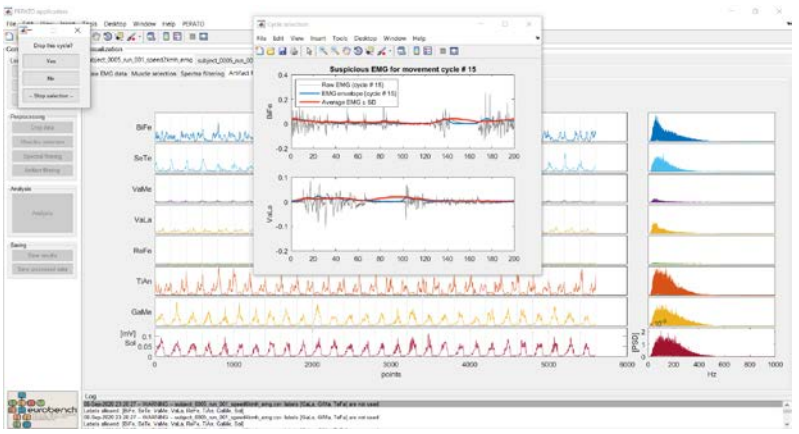
1. Data loading



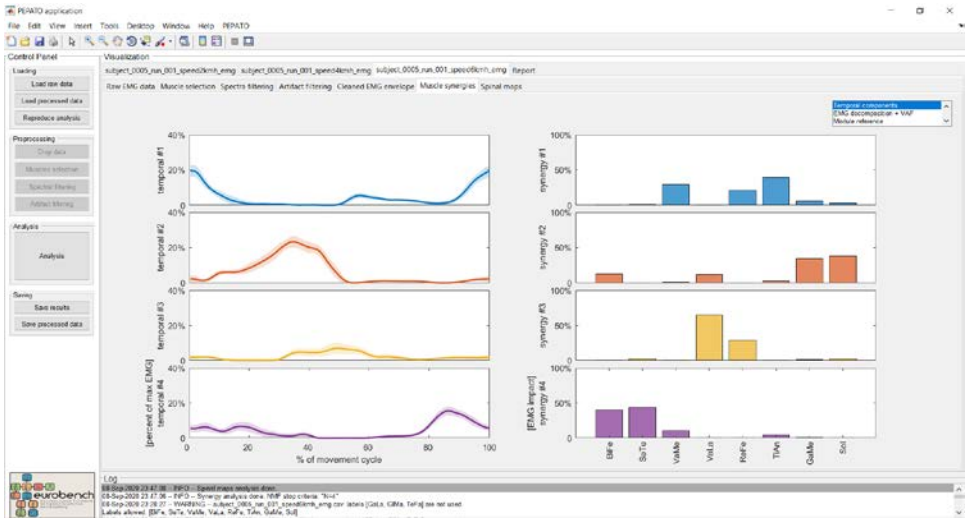
2. Data processing

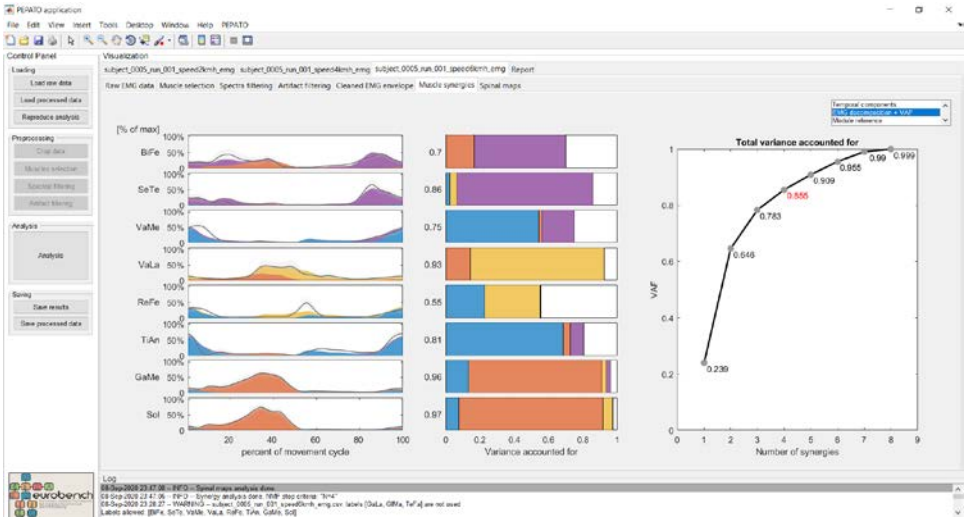


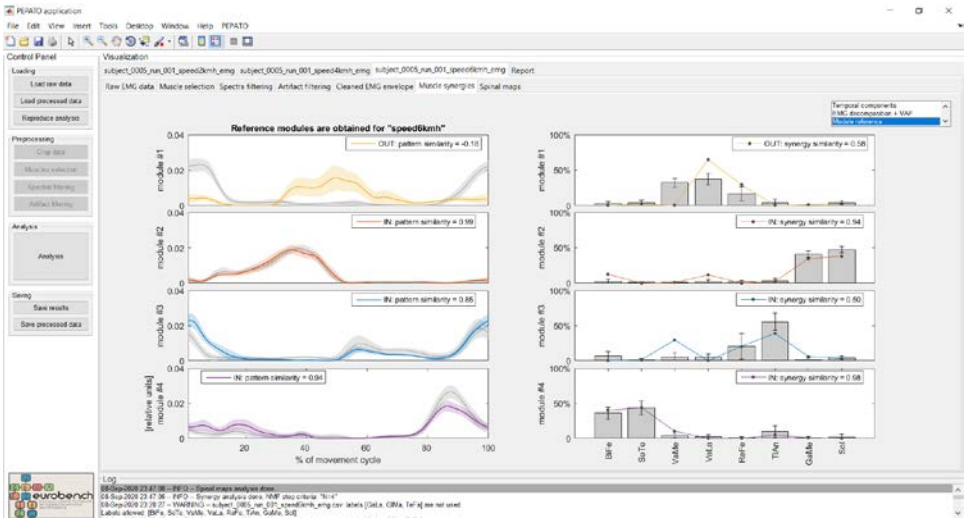




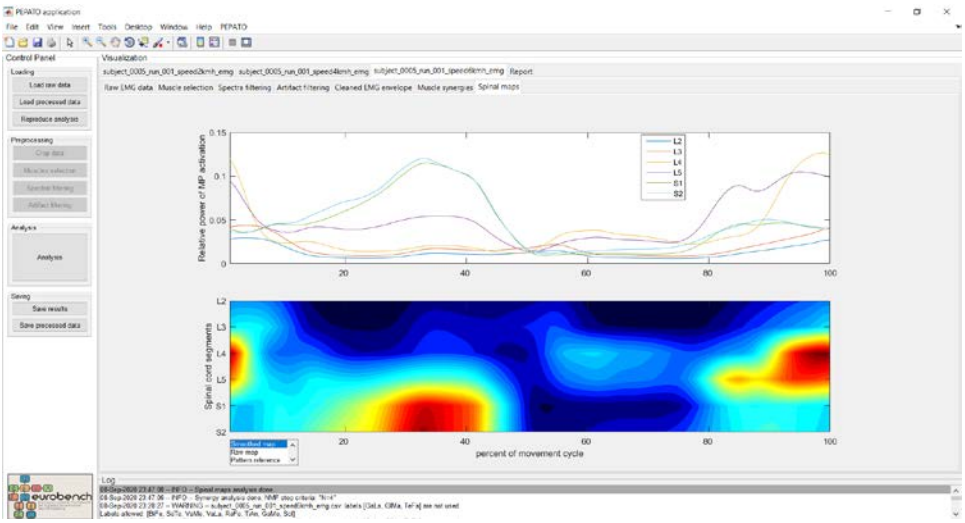
3. Muscle synergy analysis

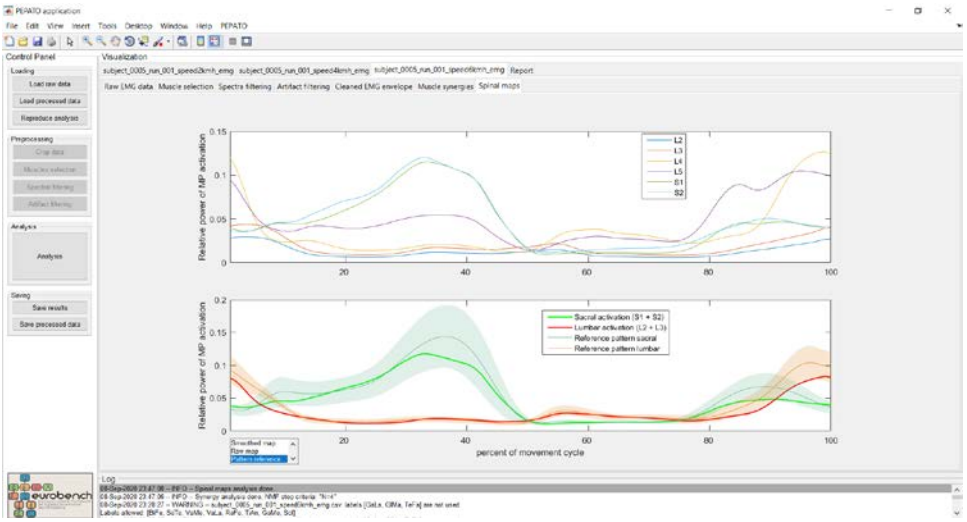


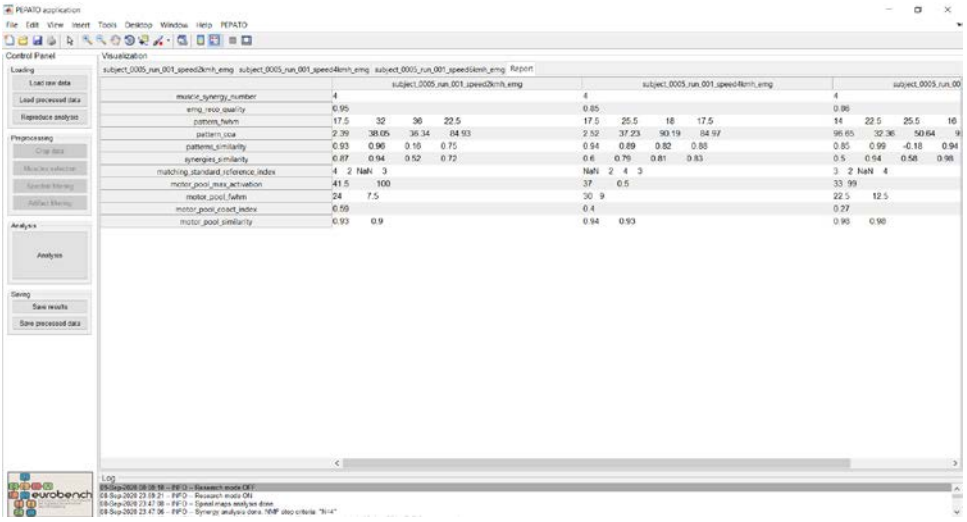




4. Spinal maps analysis

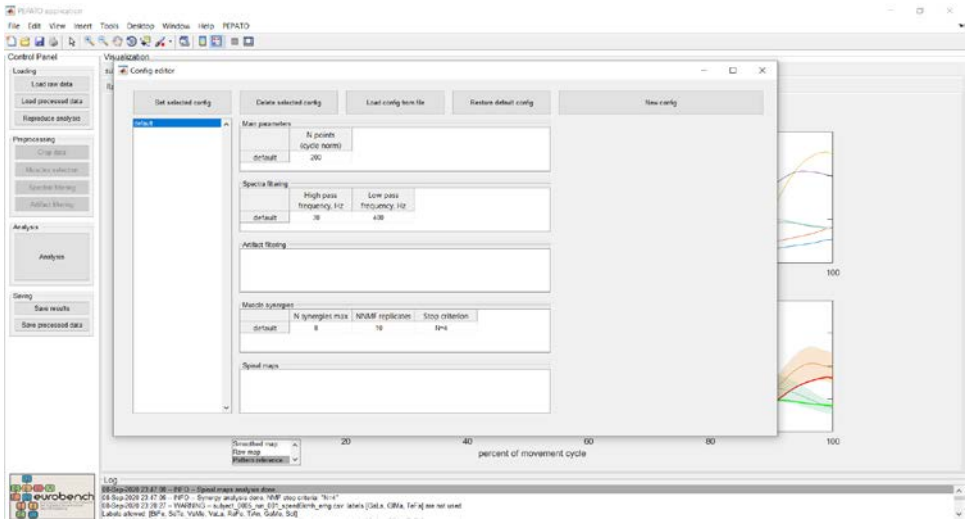






5. Additional options

Configuration customization



Database creation and updating