ScoreREM: A user-friendly Matlab-GUI for rapid eye movement (REM) sleep microstructure (Phasic/Tonic) annotation and quantification

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Abstract

Rapid eye movement (REM) sleep plays a crucial role in memory consolidation and learning and alterations in REM sleep structure and REM sleep behaviour disorder are considered early biomarkers of neurodegenerative disorders. Due to its clinical significance, accurate quantification of REM sleep and its microstructure is increasingly pursued. To address this growing need, we introduce ScoreREM, an open-source user-friendly MATLAB graphical user interface (GUI) designed for rapid annotation and quantification of REM sleep microstructure. Due to its intuitive functionalities and vast array of potential application areas, ScoreREM will serve as an indispensable tool for rapid and accurate REM microstructure quantification in clinical studies.

Keywords

Sleep Scoring; Automatic annotation; Graphical User Interface (GUI); Polysomnography (PSG); Rapid eye movement (REM); MATLAB

Metadata

Nr	Code metadata description	*Please fill in this column*
C1	Current code version	*v1.3*
C2	Permanent link to code/repository used for this code version	https://github.com/KiranKGR/ScoreREMGUI
C3	Permanent link to reproducible capsule	*NA*
C4	Legal code license	*GNU General Public License (GPL) v3.0*
C5	Code versioning system used	*Git*
C6	Software code languages, tools and services used	MATLAB and Python
C7	Compilation requirements, operating environments and dependencies	*Windows, Optimal display size - 24 in* *MATLAB 2023b, Signal processing toolbox and Python 3.11 (packages required: numpy, pandas, pytz, mne, yasa)*
C8	If available, link to developer documentation/manual	See Supplemental Materials and repository
C9	Support email for questions	k.guruswamyravindran@surrey.ac.uk

1. Motivation and significance

Sleep in humans consists of two different states, Rapid eye movement (REM) sleep, and Non-REM (NREM) sleep, which distinctly influence different cognitive and physiological processes. Sleep is characterised by unique changes in brain and peripheral physiological activity during these states and is monitored clinically using polysomnography which involves the collection of concurrent physiological signals. REM sleep state consists of rapid eye movements, low muscle tone and desynchronised electroencephalographic (EEG) resembling wakefulness. REM sleep has two distinct microstates called Phasic REM and Tonic REM. The Phasic REM state is characterized by signature short bursts of rapid eye movements of REM sleep, while Tonic REM state is the period of inactivity between two Phasic periods. REM sleep is thought to be involved in neuroplasticity, memory consolidation, learning and regulation of brain temperature [1], [2]. Further, parasomnia (abnormal behaviours during sleep) during REM sleep are of clinical significance due to their association with neurodegenerative disorders (Parkinson disease and Lewy body dementia)[3], [4].

To understand the role of REM sleep in memory consolidation and learning, and the underlying mechanisms of REM sleep parasomnias, the analysis of REM microstructures is necessary and is increasingly being pursued [5]–[7]. There is also a growing trend towards sleep monitoring using portable sleep tests to allow data collection longitudinally in naturalistic home settings, due to the time, effort and cost involved in laboratory polysomnographic studies [8], [9]. Currently, the quantification of REM microstructure is a laborious task that requires proprietary tools for annotation and analysis and trained human resources. These issues compounded by the nonstandard and diverse signal montages found in wearable sleep EEG devices, hinder the momentum in the progress of REM microstructure research. Although there are open-source general purpose annotation tools like EDFBrowser, they do neither allow automated annotation of REM microstructure nor allow the user to perform quantification of the scored microstructure. Furthermore, the user is required to have proficiency in programming languages to perform quantification and analysis of the annotated events.

To address this growing requirement, we need open source and user-friendly rapid quantification tools that can be easily used by clinical researchers. Other requirements of such a software tool include the capability to import multiple sleep recording types from diverse devices, channel selection options, automated tools for assisted annotation, and generation of summary measures. This work introduces a user-friendly graphical tool, ScoreREM, that fulfils the emerging need for rapid analysis of REM sleep and its microstructure, with extended capability to annotate other sleep stages. The prominent features of ScoreREM includes 1. Diverse data import options, 2. Import of clinical event markers, 3. Automated sleep staging and REM annotation, 4. Preprocessing and visualisation, 5. Manual annotation of REM microstructure, 6. Power spectral analysis, and 7. Export of REM microstructure summary and annotated labels.

2. Software description

ScoreREM is a user-friendly MATLAB graphical user interface (GUI) that provides an end-to-end tool to facilitate rapid annotation and analysis of rapid eye movement (REM) sleep microstructure (as Phasic/Tonic/Artefact). The GUI has a simple linear flow presenting the user with a selection of operations that are available at each step and a convenient keyboard-based interface for annotation, and exports scored labels, summary statistics, and EEG spectral analysis. The sleep recordings can range from full polysomnography recordings to partial recordings with a minimum of one electroencephalography (EEG), electrooculography (EOG) and electromyography (EMG) signals. Legacy cassette recordings and R&K hypnograms are also supported by the application [10], [11]. The user can also input a scored hypnogram and recording specific event markers for a more structured analysis. Additionally, the application can also be used as a general-purpose EOG micro event scoring tool in the imported EDF data[12].

2.1. Software architecture*:*

The schematic overview of the application pipeline is illustrated in Figure 1. The GUI of ScoreREM is built as a MATLAB application (.mlapp). The application requires MATLAB and the signal processing toolbox to perform its core operations and can be installed as an APP. ScoreREM pipeline is designed to be simple and easy to use and interacts with the user at every step of the application flow. All required information for decision making and application use is presented to the user at each checkpoint. The errors are captured and relayed to the user with available options in each case. All input files are checked for their compatibility, both in terms of the data and its structure. The optional automatic sleep staging and REM event detection functionality is facilitated through the Python language interpreter in MATLAB and requires the installation of a compatible Python distribution and supporting packages.

2.2. Software functionalities*:*

The ScoreREM front-end GUI is shown in Figure 2. The GUI is designed to display the full PSG data with two EOG channels: left outer canthus (LOC) and right outer canthus (ROC), followed by 6 EEG channels (standard channels: F4M1, C4M1, O2M1, F3M2, C3M2, and O1M2). The standard sleep data file will be in European data format (EDF). Once the user selects the EDF file to be used, the EEG channels are reassigned based on the channel labels in the EDF file.

Although the application navigation is predominantly keyboard-based, buttons are provided to perform data load, export and epoch-wise movement. The user can set the magnitude range in the GUI for viewing EOG, EEG, and EMG channels, change the scale of the signal magnitude, and reset any manually scaled plot object to the original signal magnitude. Information on the keyboard shortcuts for navigation and micro epoch scoring can be accessed by the user using the info icon in the application. The application displays the separating lines for micro epoch segments and the user-selected micro epoch is highlighted using red separated lines and is also displayed in the examination plot with both LOC and ROC plotted together. The labelled micro epochs are colour-coded to allow discrimination between the labels. The application displays a table with micro epoch-wise label to allow the user to verify the saved micro epoch labels.

2.2.1. Data import and preparation

The ScoreREM allows the user to import a wide variety of sleep data in EDF format with different channel configurations. This makes ScoreREM ideal for annotating full PSG as well as data from portable home sleep test devices. The ScoreREM requires only one EOG, EEG, and EMG channels to be present in the imported sleep recording to function, and the channels displayed are defined by the user. The user can also import prescored hypnograms from different file formats (EDF and .txt) and, in case of alternative hypnogram scoring formats, map them onto the standard American Academy of Sleep Medicine (AASM) format with five vigilance states (N1, N2, N3, REM and Wake)[13]. An additional marker file input option is provided to enable hypnogram scoring and label annotation from any user-defined start time within the recording period. This option allows the user to auto-generate hypnogram from rounded start times at 00 or 30-second intervals which is a preferred approach for the ease of analysis and scoring events in sleep research. The preprocessing involves the choice of the length of the scored micro epochs. The micro epoch length ranges between 1 to 3 seconds [14]. The user is then provided with an interface to select the filter settings for the different signals. The bandpass filtering of the signals and the power line interference removal is performed using a second order Butterworth filter via the 'filtfilt' function. A detailed description of the data import with three main data import scenarios, preprocessing and other user options are given in the application documentation in the supplemental materials using an example edf from a public PhysioNet repository.

2.2.2. Python interface for automated scoring

To allow seamless and rapid annotation of the imported sleep data file, ScoreREM exploits the Python language interface to invoke popular sleep data analysis Python tools, and allow the user to generate automated hypnograms and get assisted REM microstructure annotation via the automated REM detection. ScoreREM presents the user with the option to generate an automatic hypnogram when the EDF is imported, and *'SleepStaging'* function in the YASA package in Python is used to perform the automated sleep scoring[15]. The user is required to choose only one EEG and one EOG to perform this. The automatically generated hypnograms are exported in multiple formats and are compatible with external editors like EDFBrowser. Following the preprocessing, the user can opt to automatically score the REM microstructure facilitated through the *'rem_detect'* function in the YASA package[16], [17]. Since this requires two EOG channels, in case of single EOG channels, the inverted version is used as the second channel in '*rem_detect*'. The generated labels are rounded to the nearest second and used to match the micro epoch segment length chosen by the user. ScoreREM is designed with numerous support functions and error-catching mechanisms to make the interaction between MATLAB and Python smooth and robust.

2.2.3. Manual annotation of micro epochs and data export

The primary function of the ScoreREM GUI is to allow manual annotation of REM microstructure (Phasic/Tonic/Artefact). Once the user imports the data, completes the segmentation, preprocessing and assisted REM micro event annotation steps, ScoreREM provides a simple keyboard-based interface with several functionalities for quick and efficient annotation editing. ScoreREM allows the user to loop through REM epochs and edit or score the REM micro events as Phasic, Tonic, or Artefact using keyboard keys. The keyboard interface information can be easily accessed by the user through the info icon in the GUI (Figure 2). Complete details on keyboard interactions are provided in the supplemental materials. To avoid the loss of score events in case of any app malfunction due to operating system resource bottlenecks, all labels are saved when the auto-REM event scoring is initiated, when every epoch is scored and also when any movement between epochs is detected. The user can also score any epoch in the sleep recording, thus allowing more flexibility on the use cases of ScoreREM apart from REM annotation. Once the user completes annotation of the REM micro epochs and initiates data save, ScoreREM exports the summary measures, labels and the power spectrum of all EEG channels selected by the user. For each of the micro-epoch segment power spectral density (PSD) estimates, are computed via Fast Fourier Transform (FFT) with a Hanning window. Epoch-wise PSD are computed by averaging the PSD estimates of the micro-epochs. A detailed description of the exported data files and the definition of the summary measures is provided in the supplemental materials.

3. Illustrative examples

Here we provide an example of the steps involved in REM microstructure annotation on the sleep recording performed at home using the Somnomedics home sleep test (HST REM+) device. This portable sleep monitoring device is worn on the forehead of a participants and the sleep EDF contains two EOG channels, one EEG and EMG channel as depicted in Figure 3 A. After the EDF file is selected by the user, the channel selection option is set to the 4 available channels (See Figure 3 B). This provides an example of the ScoreREM's ability to handle reduced sleep montages from portable home sleep devices. An alternate example in the supplementary materials contains a higher number of EEG channels as is more commonly seen in laboratory polysomnography. In case of the HST recording, we choose 'EDF only' option and allow the ScoreREM to perform automatic sleep staging using the YASA package in Python through the Python language interface. We then choose the micro epoch length to be 2 seconds, accept default filtering options, and opt for automatic REM microstructure annotation to complete the import and view the data. At this stage, the loaded sleep recording has a hypnogram and automatically annotated REM Phasic/Tonic labels. The user now shifts through REM epochs using keyboard keys to find and edit mislabelled Phasic and Tonic micro epochs or identify artefacts. Once an epoch with an error is found as shown in Figure 3C, the user can then enable micro epoch editing and move to the specific epoch to view it in detail. In this example, the ROC EOG channel contains an artefact caused due to bad electrode contact and it appears as a spike in the ROC and in the EMG (circled in red in Figure 3 C). Since this happens predominantly in ROC during a Phasic event (Orange), the user edits the label of ROC micro epoch to Artefact (Red) as shown in Figure 3 D. It can be noted that the annotated label check table displays the corrected micro epoch label. Once the user completes and moves to the next epoch, the annotation the labels are automatically saved in a temporary file. After the completion of the annotation editing, the user can press the save icon to export the summary measures and labels, along with the PSD, and exit ScoreREM. A detailed description of all the different functions and data scenarios the ScoreREM can handle is provided in the supplemental materials with publicly available sleep recordings from PhysioNet.

4. Impact

Accurately analysing REM microstructure in laboratory polysomnographic recordings is a tedious task that requires proprietary annotation tools and experienced, well-trained personnel for scoring both REM and its phasic/tonic microstructure, including artifact removal and adhering to varying scoring rules[18], [19]. Due to the need for specialised tools and trained personnel, sleep staging and REM microstructure annotation becomes increasingly challenging and impractical for data collected longitudinally through home sleep testing devices. These bottlenecks hinder the longitudinal scaling of clinical studies in sleep and neuroscience research, in deployment of interventions targeting REM sleep and in a vast array of pharmacological and drug development studies.

ScoreREM addresses several of these bottlenecks by providing a simple user-friendly GUI that allows sleep and clinical researchers to conduct end-to-end analysis (importing, preprocessing, segmenting, annotating events, and exporting summary metrics) of sleep recordings to quantify REM and its microstructure, without requiring programming skills. Thus, ScoreREM has the potential to change the landscape of REM sleep research, improving its longitudinal scalability and analysis of large volumes of sleep data[20]. Furthermore, unlike proprietary sleep annotation software, ScoreREM allows the import of any EDF sleep recording with one EOG, EEG and EMG channels, enabling the analysis of sleep data collected using various home sleep testing devices (e.g., ZMax EEG headband, Somnomedics Home sleep test, etc.,) and other open source hardware. Because to these advantages and ease of use, an early version of the ScoreREM was employed for the manual annotation of REM Phasic/Tonic microstructure in sleep data collected in a closed-loop auditory stimulation (CLAS) study targeting REM sleep by Jaramillo et al, 2024[21].

5. Conclusions

In this paper, we introduce ScoreREM, a robust annotation tool with a simple, user-friendly GUI that facilitates rapid annotation and quantification of REM sleep and its microstructure. ScoreREM also utilises the Python language interface to assist the user with both sleep staging and scoring of REM Phasic/Tonic microstructure through state-of-the-art off-the-shelf machine learning tools. The diverse array of supported sleep recording and auxiliary file formats allows clinical researchers to apply the tool to a wide range of sleep recordings and export labels and processed output into spreadsheets for further analysis. Due to these novel features, we predict that the ScoreREM application will find numerous applications in the field of sleep and neuroscience research for better understanding REM sleep structure.

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CRediT authorship contribution statement

Kiran K G Ravindran: Conceptualization, Methodology, Software, Writing – original draft.

Derk-Jan Dijk: Writing – review & editing.

Declaration of Competing Interest

The authors declare no known competing financial or non-financial interests.

Appendix: Supplementary documentation

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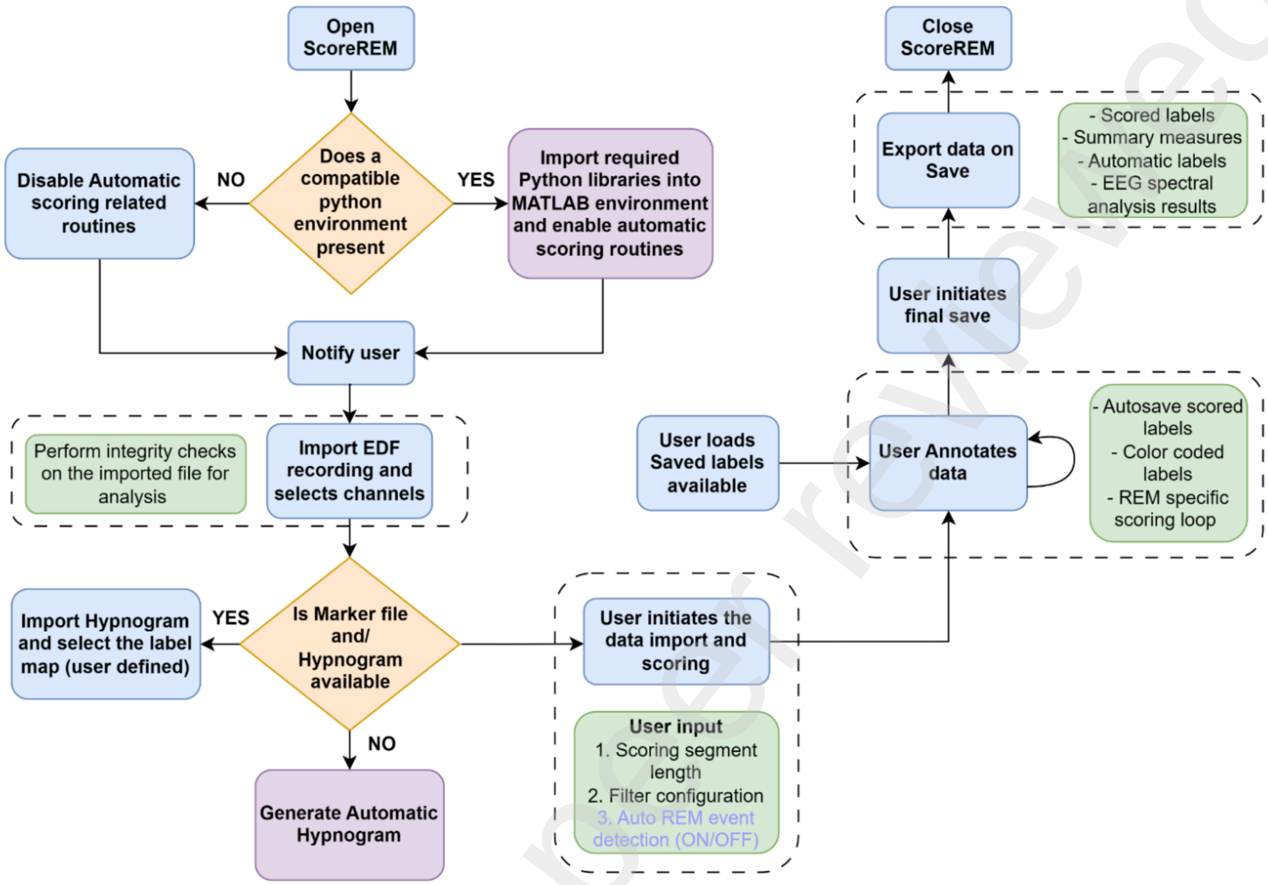

Figure 1. Schematic overview of the application flow and functionalities.

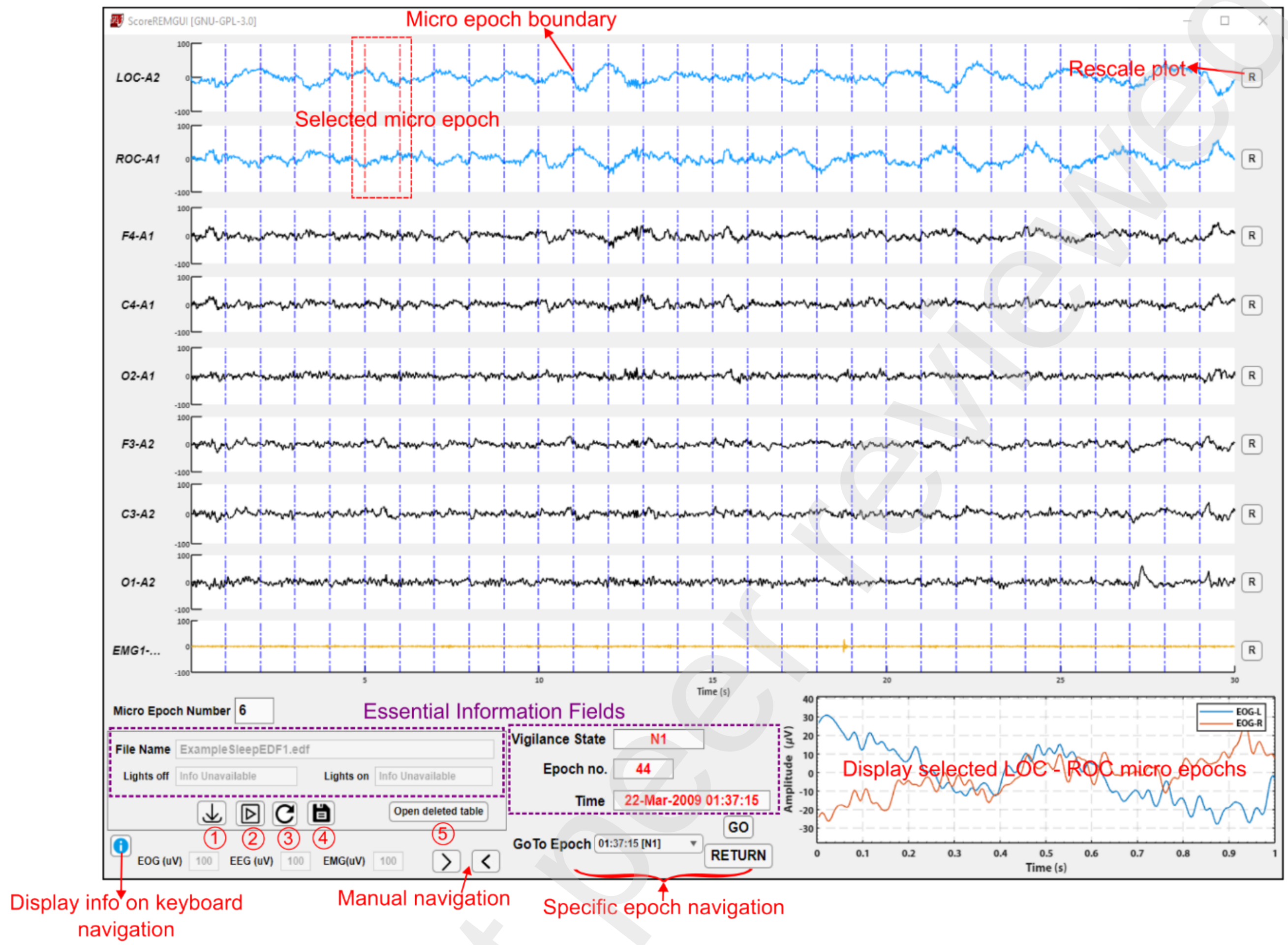

Figure 2. ScoreREM graphical user interface. The salient features are labelled, and the button descriptions are, 1. Load data button, 2. Import and preprocess data, 3. Reload a saved data file, 4. Save labels and 5. Reopen deleted label table. The rescale plot button allows for the plot range to be reset after manual magnification by the user.

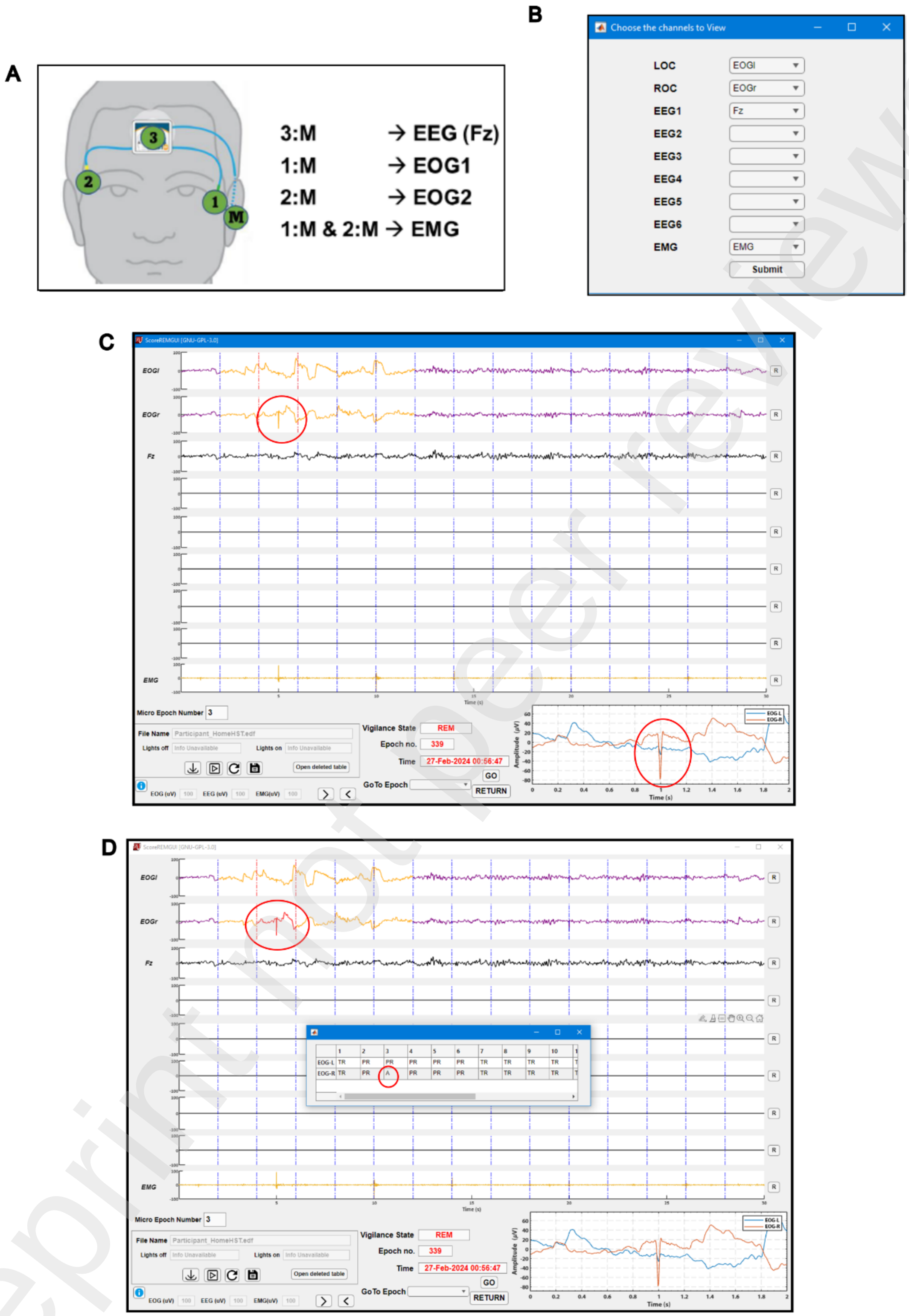

Figure 3. Example illustration of REM microstructure annotation using ScoreREM. The home sleep recording is collected using a Somnomedics Home sleep test device (HST REM+).