# Introduction

## **Sleep stages**

Graphical user interface

Description automatically generatedMany events occur in the body during this state: blood pressure falls, heartbeat slows down, muscles relax, and the body’s metabolic rate decreases. According to Rechtschaffen and Kales (RK) sleep scoring standard [1], sleep states consist of two general stages: rapid eye movement (REM) and non-rapid eye movement (NREM). NREM is in turn subdivided into four stages: 1, 2, 3, and 4.

**Stage 1** is a transition stage between wakefulness and sleep. It usually lasts between 1 to 5 minutes. This stage consists of a low-voltage EEG tracing with well-defined alpha and theta activity, occasional vertex spikes, and slow rolling eye movements (SEMs).

**Stage 2** is the “baseline” of sleep and it is characterized by the occurrence of **sleep spindles** and K-complexes and a relatively low-voltage, mixed frequency EEG background. Sleep spindles are episodic bursts of activity in the **12 to 14 Hz** range that last for a minimum of 0.5 sec.

**Stage 3** is referred to a period during which **at least 20%** and **not more than 50%** of the sleep consists of EEG signals with frequencies of **2 Hz** or smaller and amplitudes of more than 75 μV (delta waves).

**Stage 4** is quite similar to Stage 3, except that **delta waves** **cover 50% or** **more** of the record. Sleep Stage 4 usually represents 12-15% of the total sleep time. Stages 3 and 4 together are also known as “deep sleep” or slow wave sleep (SWS) and this is the most restorative part of sleep.

**REM** is well-known by the incidence of rapid eye movements under closed eyelids, motor atonia and low voltage EEG patterns. It was found that SEMs are waves in the frequency range of **0.1 Hz to 0.45 Hz** [4].

# Graphical user interface Description automatically generatedMethods

## **Frequency range**

The frequency ranges of the EEG signal were broken down into Delta (below 3.5 Hz, about 300 μV), Theta (4-7 Hz), Alpha (8-13 Hz), and Beta (14-30 Hz, around 5 μV) bands [12]. In the sleep EEG, because of presence of sleep spindles, there is another frequency band, that is, spindle frequency band.

## **Preprocessing**

The complete EEG vector was processed using a sixth order **Butterworth bandpass filter** with cutoff (corner) frequencies of **0.5 - 50 Hz**. A zero-phase digital filter was realized by filtering the EEG signals in both forward and reverse directions resulting in its filtering by a 12th order filter. (Estrada, E., et al. 2004.)

### **ICA**

## **Feature extraction**

### Power spectral density (Estrada, E., et al. 2004.)

### Entropy (<https://raphaelvallat.com/entropy/build/html/index.html>)

### Wavelet (Ebrahimi, Farideh, et al. IEEE, 2008)

A wavelet packet tree (WPT) of depth 7 (7 levels) was designed for this purpose. Daubechies order 2 (db2) wavelet transform was applied to 30-second epochs of EEG signal. Out of the family of sub-bands, those containing frequency information of the following 6 bands were manually selected (Fig. 2). The following statistical features were used to represent the time–frequency distribution of the EEG signals:

1. Mean quadratic value or Energy (E1, E2, ..., E6) of wavelet packet (WP) coefficients for each of the 6 bands,

2. Total Energy (E7),

3. Ratio of different Energy values (E8, E9, E10),

4. Mean of the absolute values of the coefficients in each sub-band, and

5. Standard deviation of the coefficients in each sub-band.

Diagram

Description automatically generatedEnergy (E7) is the sum of energy in the above- mentioned 6 frequency bands. E8 is the ratio of energy in the Alpha band and the combined power in Delta and Theta bands, E9 is the ratio of energy in the Delta band and the combined power in Alpha and Theta bands and E10 is the ratio of energy in Theta band and the combined power in Delta and Alpha bands. These feature vectors, calculated for the frequency bands 1-6, were used for classification of the EEG signals.

# Results

Table 1 TOTAL NUMBER OF 30-s EEG EPOCHS FOR TRAINING AND TESTING

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | epochs | N1 | N2 | N3 | REM | AWAKE |
| Training |  |  |  |  |  |  |
| Testing |  |  |  |  |  |  |

Confusion matrix