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Enhancing Hypnograms to Improve Sleep Disorder Diagnosis

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Enhancing Hypnograms to Improve Sleep Disorder Diagnosis

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Abstract

Human sleep goes through a number of stages. Disruptions in sleep stages can denote a sleep disorder in a patient. The sleep stages are visualized in hypnograms, which support the diagnosis of sleep disorders. In order to improve the quality and time it takes to diagnose a patient, several additional visualizations are proposed. The visualizations are displayed in a graphical user interface based on data uploaded by the user. The visualizations presented in this paper complement the current hypnograms. Therefore, it is suggested that they may improve the diagnosis of sleep disorders by better contextualizing the information that is displayed in the hypnogram.

Keywords: Sleep stages, sleep patterns, visualization, hypnogram, polysomnography (PSG), graphical user interface (GUI)

Introduction

Sleep is part of the daily routine of most people. As an article of the American Association of Sleep Medicine (AASM) showed, the recommendation for adults is to get seven or more hours of sleep per day [34], meaning that a healthy adult should spend at least 29% of their day sleeping.

Sleep helps people to stay healthy. During sleep, both the body and mind get the chance to recharge and recover from the stres of daily life [32]. Short-term effects of sleep deprivation or low-quality sleep lead to impaired attention and concentration, low productivity, and higher chances of accidents at work, home or on the road [3]. Research shows that a chronic lack of sleep or getting a poor-quality sleep, increases the risks of disorders, including high blood pressure and other cardiovascular diseases, obesity, memory impairment and depression [3, 23]. This makes it important that, to stay healthy, one has a healthy sleep rhythm.

A healthy sleep pattern includes several sleep stages that one naturally goes through. Sleep stages are usually scored in fragments of 30 seconds, called epochs [18]. Rechtstaffen and Kales (R&K) divided sleep into seven stages: wakefulness, stage 1 (S1), stage 2 (S2), stage 3 (S3), stage 4 (S4), stage REM (Rapid Eye Movement, also called the dreaming stage [6]), and movement time [11]. S1, S2, S3 and S4 are part of the Non-Rapid Eye Movement stage (NREM) [18]. Since its development, there has been a lot of criticism on the R&K scoring method. Main criticism points were that the method leaves too much room for interpretation which leads to great variability, and that the method was not very fitting for elderly people. Additionally, with R&K scoring, many sleep disorders, such as sleep walking or narcolepsy, are scored in the wrong stage, which leads to misdiagnoses [9, 18]. In 2007, the AASM modified the R&K guidelines and defined the sleep stages as follows: W, N1, N2, N3 and R, where W stands for wakefulness, N1 is S1 from R&K, N2 is S2 from R&K, N3 is S3 and S4 from R&K and R is the REM stage [10, 18]. The AASM has as main criticism points that it might be too simplistic. However, it is shown that AASM guidelines diagnose suspected sleep disorders correctly most of the time [8].

Sleep stages appear in cycles. A sleep cycle usually begins with Wakefulness, then a short period of stage N1, going to N2, N3 and finally to REM. Then, the REM stage is alternated with the three NREM stages [4]. According to Carskadon and Dement [2], the average length of the first NREM-REM cycle is 70 to 100 minutes, whereas the later cycles last longer – around 90 to 120 minutes. Additionally, in healthy adults, as the night progresses, the duration of the REM stage increases and stage N2 takes the time of the other NREM stages [4]. The NREM stages account for 75% to 80% of the entire sleep, whereas the REM stage is usually 20% to 25% of sleep [2].

Sleep stages can be influenced by many factors, such as age, prior sleep history, circadian rhythms, body temperature and medication. Also, sleep disorders have an impact on the structure and distribution of the sleep cycles and their stages [2]. The most common sleep stage anomalies associated with sleep disorders are:

– a suppression in the REM stage, associated with sleep apnea, a decrease in the airflow for at least ten seconds;

– a large proportion of the N1 stage during sleep, associated with periodic limb movements, repetitive movements of the legs and sometimes the arms during sleep;

– quick onset of the REM stage, associated with narcolepsy, tiredness and drowsiness during the day;

– disrupted sleep continuity, diminished amounts and different distributions of stage N3 and increased amounts of stage REM, associated with depression [2, 30, 35].

It is important to diagnose these disorders quickly and accurately, since sleeping healthily has an impact on the quality of life. As mentioned earlier, both short and long-term sleep deficiencies can lead to dangers for the patient and their surroundings [3, 23].

To diagnose such a disorder, one's sleep must be studied, which is done by polysomnography (PSG) [25]. During PSG, certain functions of the body, such as air flow in and out of the lungs, brain waves (electroencephalography (EEG)), eye movement (electrooculography (EOG)), heart rate (electrocardiography (ECG)), and muscle activity (electromyography (EMG)) are monitored [12, 19]. Sleep stages are determined based on these measurements; each of the stages has unique characteristics including variations in brain wave patterns, eye movements, and muscle tone [3, 4].

The sleep study outcomes will show the amount of time of the night spent in each sleep stage [30]. The visual representation of the sleep stages during the night is called a hypnogram. A hypnogram displays the different sleep stages and their duration throughout the sleep cycles. Since sleep disorders all have a different impact on the sleep cycles and stages, displaying them will show that the patient has had an abnormal night of sleep, following the criterion of the doctor.

In Figure 1, a hypnogram of a healthy person (A) is compared with a hypnogram of a depressed person (B). It can be seen that the patient suffering depression has more instances of the Wakefulness and REM stages and less instances of the N3 stage. This corresponds to the sleep stage disruptions associated with depression. In Figure 2, a hypnogram of a patient with obstructive sleep apnea (OSA) can be seen. OSA is the most occurring form of sleep apnea and is a huge factor for hypertension, strokes, myocardial infarctions (heart attacks) and diabetes [33]. Whereas hypnogram A in Figure 1 shows regular transitions between N2, N3 and REM stages, Figure 2 shows many transitions between N1 and N2 stages, and no occurrences of the N3 and REM stages. As mentioned earlier, sleep apnea suppresses the REM stage, which is clearly visible in Figure 2.

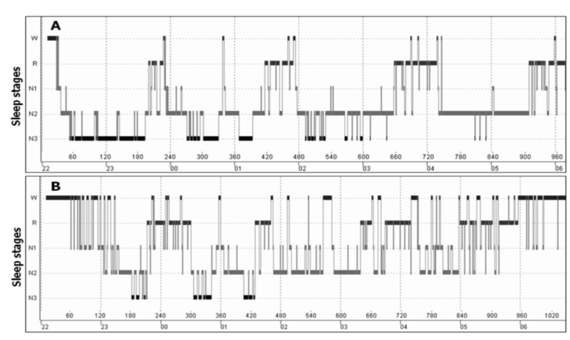

Figure 1: A hypnogram of a healthy person (A) and a hypnogram of a person suffering depression (B). [35]

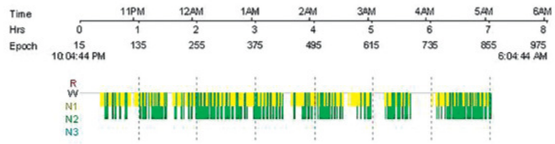

Figure 2: A hypnogram of a person with severe obstructive sleep apnea (OSA). [30]

The current hypnograms are sufficient for the somnologists in the way that it gives them the information that they need to diagnose a patient effectively and correctly. However, there are some improvements that could be made, such that more information can be obtained from the hypnogram. To give an example, hypnograms could be complemented with a visual representation of the number of transitions between the different sleep stages, so that it becomes clear for the somnologist which stages often follow each other. Additionally, the distribution of a certain sleep stage throughout the night can provide useful information, which otherwise could not be retrieved from the hypnogram. This could give more and quicker insights to the somnologists, saving valuable time. Therefore, this paper focuses on visually enhancing hypnograms.

Research question

The research question is defined as follows: *Can hypnograms be enhanced to better visualize sleep stages?*

The sub questions for this research question are:

1. How can sleep stages be visualised differently so that they add to current hypnograms?
2. What is the best implementation for these improvements to the hypnograms?

Background

Based on the measurements of, among others, the EEG, ECG, EMG and EOG of the patient, the scoring of sleep stages is done manually by highly trained technicians [31]. This is a very labour-intensive job because of the large data sets. Besides, human errors can happen, resulting in incorrect sleep scoring. Therefore, AI and machine learning have been used to detect the sleep stage based on the aforementioned measurements, so that time is saved and less mistakes are made. For example, Martin et al. [17] created a pattern recognition decision tree model that classifies the sleep stages. This study shows that human sleep scorers agree with each other approximately 89% of the time, and their agreement with the computerized recognition system was 7% less than the average agreement among the scorers. Malafeev et al. [16] were able to achieve a high accuracy in sleep staging by means of deep neural networks and could identify stage 1 and REM sleep as accurately as human experts. Shen et al. [31] created a State Space Model that classifies sleep stages based on the EEG data. The model reaches an average accuracy of 98.6% on the Sleep-EDF database of PhysioNet [26]. The convolutional neural network of Mousavi, Afghah, and Rajendra Acharya [21] reaches an overall accuracy of 84.26% on the same data.

Of course, automation of the classification of sleep stages is not enough. In order for somnologists to retrieve useful information from the stages, visualizations should be made to transfer that information in a clear and understandable way. Many insights with regard to sleep disorders or other physical or mental diseases can be obtained from the visualizations if made correctly. Several implementations have been made for this already. Combrisson et al. [5] created Sleep, an open-source Python module in the visbrain package that analyses and visualizes sleep data. They visualize, among others, the standard hypnogram and the electrophysical data including the EMG, EOG and EEG. Nikamalfard et al. [24] have created a system that detects sleep patterns and visualizes them for patients with early onset dementia. It gives visualizations for their caregivers to retrieve information about the sleep of the patients while at home. Another at home tool to make sense of the sleep stages is SleepExplorer by Liang et al. [15]. This helps people that track their sleep via smartphones and -watches make a connection between the sleep data and the contextual data, e.g. exercise, food, caffeine intake and stress. However, the visualization tools mentioned are not all meant for experts in the field, and do not give much additional information about sleep disorders that could not be obtained from existing visualizations yet. Also in these visualization methods, some improvements could be made.

Methodology

For this project, current hypnograms will be improved by including more valuable insights. This way, somnologists do not have to do this themselves, but have the total picture in just one glance and can diagnose patients more quickly. In order to do this, hypnograms will be created from scored sleep stages, and will be enhanced by adding other visualizations, such as the graph displaying the transitions between stages and the graph showing the distribution of a stage during the night as described earlier.

Data & pre-processing

For this project, the data from several subjects was used. This data was obtained in a study on the effects of age and gender on sleep [7, 13, 20]. This data includes 78 healthy data subjects, for which two nights were monitored. The data is in EDF format, which is the usual format for this kind of data [14]. For each subject, a PSG file and a hypnogram file are published. The PSG file includes all measurements from, among others, the EEG, EOG and the submental chin EMG [26]. The hypnogram file contains the scoring of the different sleep stages, which has been done manually by experts. This has been done according to the R&K guidelines of 1967 (W, R, 1, 2, 3, 4, Movement time and ? (not scored)). For this research, only the hypnogram files were used. Exploratory data analysis on the data can be found in Table 1.

Number of nights	153
Number of subjects	78
Number of males	37
Number of females	41
Minimum age	25
Average age	58.79
Maximum age	101
Earliest lightsoff	21:00h
Latest lightsoff	1:50h
Recorded between	1987 & 1991

Table 1: Exploratory data analysis on all subjects in the database.

Firstly, the data was loaded into the program Polyman, a tool used for plotting hypnograms from PSG and hypnogram data [1]. This gave more insights in what the data looked like. For this, two data sets from two different data subjects were used, to guarantee that the insights were general insights. The data was then loaded into Python with the use of the package PyEDFLib [22], and then preprocessed into a Pandas data frame with the following columns: the starting moment in seconds as integer, the sleep stage, and its duration in seconds as integer. The decision was made to develop the visualizations for AASM sleep stages. Since the data was not in this format, the sleep stages were converted to AASM stages, in which S1 becomes N1, S2 becomes N2, S3 and S4 become N3. Some cases with occurrences of the Movement time stage may remain.

The measurements of the data started very early – hours before the lights went off in the room according to the subjects file [26], and hours before the subject fell asleep, reaching the N1 stage. This resulted in odd visualizations, since there were hours of the data subject being awake in the data. Therefore, it was decided to replace the starting time of the data set to the timestamp at which the lights were switched off, which is retrieved from the subjects file that is included in the data from PhysioNet [26].

The data also showed a sudden occurrence of the Unknown stage at the middle of the second day. When looking at this occurrence in the data, this stage took place around 16:00h in the afternoon for the two data sets used. This leads to the assumption that this is an error in the measurements. The decision was made to remove this entry from the data if and only if:

1. this stage was the last stage recorded in the data set, and

2. the second-last entry has stage W.

If this is the case and the last entry of the data is deleted, then the duration of the second-last entry will be denoted by 15 minutes. If this is not the case, the Unknown stage will be kept in the data.

Another column was added to the data: next stage, denoting the upcoming sleep stage. This showed that data entries had the same sleep stage as their successor, that is, row i has the same sleep stage as row $i+1$ and possibly even row $i+2$ and further. After some discussion, the decision was made to not remove these duplicates, since these duplicates could also give useful insights to somnologists.

The remaining data set consists of five variables: the starting moment of the sleep stage in seconds as integer, the duration of the sleep stage as a timestamp of time (24 hours), the sleep stage itself according to the AASM guidelines, the upcoming sleep stage according to the AASM guidelines and the begin time of the sleep stage as a timestamp of date and time (24 hours).

From this Pandas dataframe, two other dataframes were created. One depicts the sleep stage for each second of the night. This is done to ensure that the visualization shows the data points for every second. The second one denotes the sleep stage per epoch (30 seconds) and is then counted per half hour. For each half hour in the data, the number of epochs per sleep stage is stated. This summarizes the behaviour of the sleep during the night.

Visual encoding of sleep stages

The three dataframes described earlier allow to make several visualizations of the sleep stages during the night. The choice was made to create all visualizations in Plotly, a Python module which easily allows for interacting with the visualizations [27]. Plotly also allows the user to deselect certain variables, to make it possible for the somnologist to focus solely on one or two sleep stages for example.

For testing the proposed visualizations, two subjects were used. The information about the subjects is mentioned in Table 2 and retrieved from the subjects Excel sheet from the PhysioNet database [26] and the EDF hypnogram files by using Polyman [1].

Subject number	00	01
Subject night	1	2
Age	33	33
Gender	Female	Female
Lights off time	00:38h	22:15h
Date	24-4-1989	30-3-1989

Table 2: Information on subject 00 night 1 and 01 night 2 of the database.

Firstly, the usual hypnogram is created from the dataframe of each second of the night. On the horizontal axis, the time is shown, on the vertical axis the sleep stages are displayed. This is the graph that somnologists are most familiar with and allows them to look at the duration of the sleep stages and derive conclusions from that. The hypnograms for the two subjects can be seen in Figures 3 and 4.

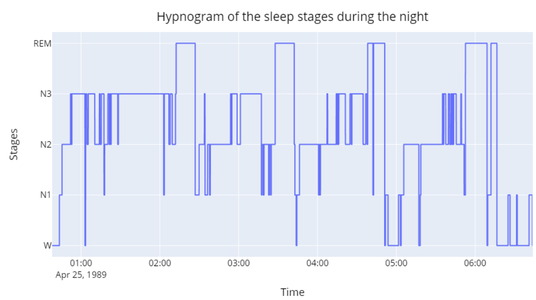

Figure 3: The hypnogram of subject 00 night 1. The time of the night is shown on the horizontal axis, the sleep stage is shown on the vertical axis.

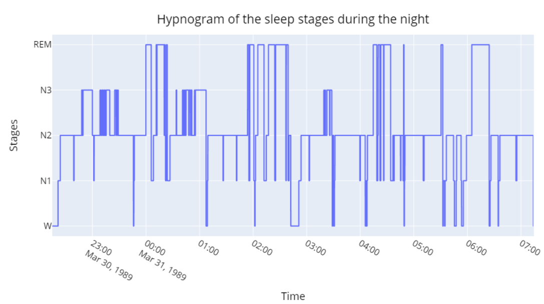

Figure 4: The hypnogram of subject 01 night 2. The time of the night is shown on the horizontal axis, the sleep stage is shown on the vertical axis.

The second visualization is a violin plot, to display the distribution of sleep stages over the night. For each sleep stage, a separate violin plot was created. On the horizontal axis, the stages are displayed, the time is shown on the vertical axis. The number of occurrences of this sleep stage at a point in time determines its width at that point. The line in the violin plot shows the mean of the occurrences of this sleep stage. The filling of the violin is a slightly lighter shade of the same colour as the border of the violin, its mean line and sometimes some data points, to clearly show those points and mean line. The colour of the border, mean line and data points for each sleep stage are the same colours used for each sleep stage in the other visualizations.

The violin plots are displayed in Figures 5 and 6.

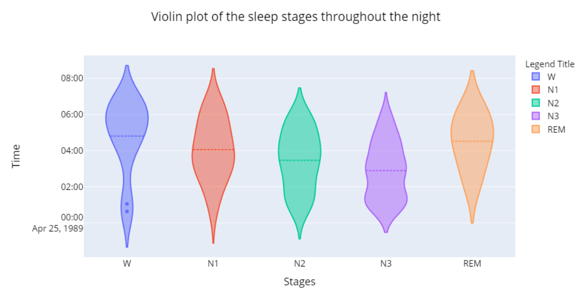

Figure 5: The violin plot of the sleep stages of subject 00 night 1. The horizontal axis shows the sleep stage, the vertical axis depicts the time of the night. The width shows the number of occurrences at that point in time. The mean line is shown.

Figure 6: The violin plot of the sleep stages of subject 01 night 2. The horizontal axis shows the sleep stage, the vertical axis depicts the time of the night. The width shows the number of occurrences at that point in time. The mean line is shown.

The third visualization is a strip plot, which displays the spread of each sleep stage during the night in more detail. The horizontal axis denotes the time of the night, the vertical axis shows the sleep stages. Again, each sleep stage is visualized separately with a different colour. This shows when each sleep stage starts and ends in the night of measurements and shows the occurrences per hour roughly. Clusters of sleep stages within a timeframe can be easily derived from this graph.

The strip plots of the two subjects can be seen in Figures 7 and 8.

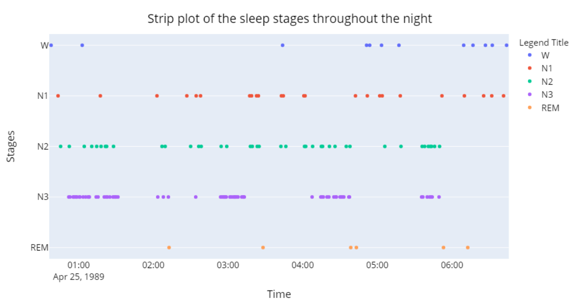

Figure 7: The strip plot of the sleep stages of subject 00 night 1. The horizontal axis shows the time of the night, the vertical axis depicts the sleep stage.

Figure 8: The strip plot of the sleep stages of subject 01 night 2. The horizontal axis shows the time of the night, the vertical axis depicts the sleep stage.

The fourth visualization created is a bar chart showing the number of epochs per sleep stage per half hour. Each bar depicts half an hour of the night as shown on the horizontal axis, the height of each bar section is the number of epochs in a certain sleep stage as shown on the vertical axis, its colour denotes the sleep stage. This shows the distribution of sleep stages per epoch.
Generally, each bar has a height of 60 epochs. It will often be the case that the first and the last bar, denoting the first and last half hour of the measurements, will not be the same height as the rest of the bars. This is because the measurements do not start exactly at the beginning of a certain half hour, and do not end exactly at the end of a certain half hour. For example, the measurements of subject 00 night 1 started at 00:38h, as can be derived from Table 2. This gives less measurements in the first half hour. The hypnogram, violin plot and strip plot (Figures 3, 5 and 7) show that the measurements end around 6:45h, also reducing the measurements for the last half hour. The same can be derived for subject 01 night 2.

The bar charts of the two subjects are displayed in Figures 9 and 10.

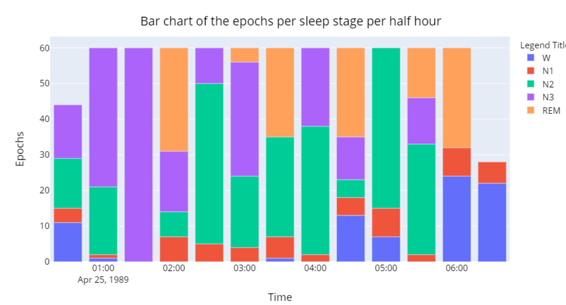

Figure 9: The bar chart of the sleep stages per epoch per half hour of subject 00 night 1. The horizontal axis shows each half hour of the night, the vertical axis denotes the sleep stage. The height of each bar section shows the number of epochs of a sleep stage during that half hour.

The fifth visualization is a histogram of the sleep stages throughout the entire night. The stages are shown on the horizontal axis, which each its own bar and

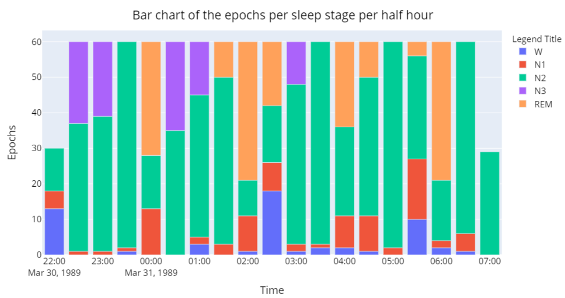

Figure 10: The bar chart of the sleep stages per epoch per half hour of subject 00 night 1. The horizontal axis shows each half hour of the night, the vertical axis denotes the sleep stage. The height of each bar section shows the number of epochs of a sleep stage during that half hour.

colour, the number of occurrences of the stages is shown on the vertical axis. This shows the total distribution of all sleep stages during the night.

The histograms of the two subjects used are displayed in Figures 11 and 12.

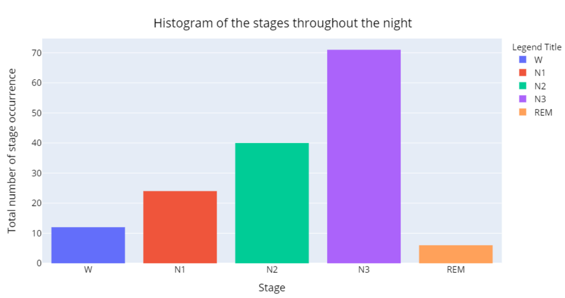

Figure 11: The histogram of the sleep stages of subject 00 night 1. The sleep stages are shown on the horizontal axis, the vertical axis shows the total occurrences of this stage during the entire night.

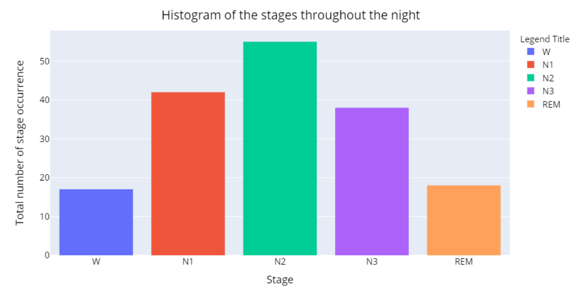

Figure 12: The histogram of the sleep stages of subject 01 night 2. The sleep stages are shown on the horizontal axis, the vertical axis shows the total occurrences of this stage during the entire night.

The sixth visualization is a heatmap showing the transitions between stages. The current sleep stage is shown on the horizontal axis, the next stage is shown on the vertical axis. The diagonal shows the transition between a stage and itself, so from N1 to N1 for example. For the colouring, a linear scale is used, going from the minimum number of transitions (very often this will be 0) to the maximum number of transitions between two stages. The scaling is shown in the legend on the right. This plot gives a clear image of the stages that follow from another stage, and experts hereby can have a quick overview of the transitions of a given subject. The heatmaps of subject 00 night 1 and subject 01 night 2 are shown in Figures 13 and 14.

Subquestion 1 was researched by means of the different visualizations for the sleep stages. The visualizations above are very easily created with the use of Python, but these alone would not be of use to somnologists. Therefore, for subquestion 2, a graphical user interface will be built so that a somnologist can load in an EDF hypnogram file, fill in the date and time that the visualizations should start, and the visualizations are created for them.

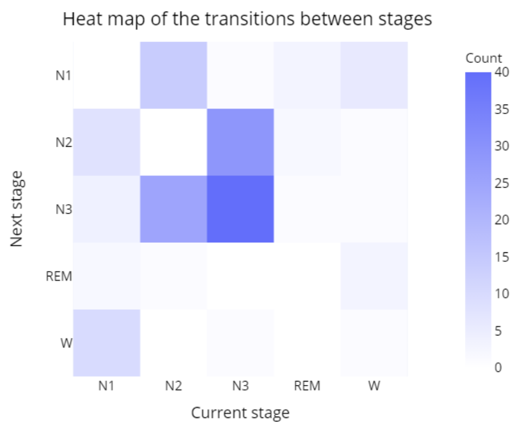

Figure 13: The heat map of the sleep stages of subject 00 night 1. The horizontal axis shows the current stage, the vertical axis shows the successive stage. A linear colourscale is used: the more transitions between stages, the darker the block.

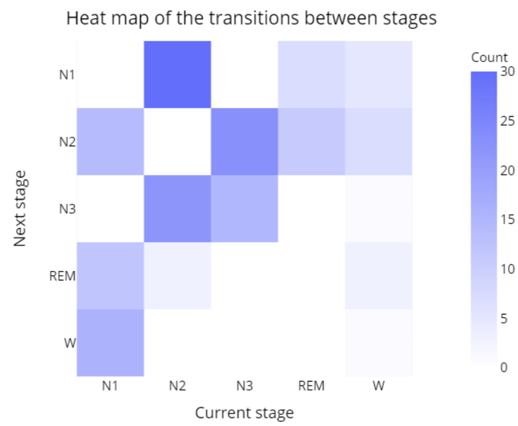

Figure 14: The heat map of the sleep stages of subject 01 night 2. The horizontal axis shows the current stage, the vertical axis shows the successive stage. A linear colourscale is used: the more transitions between stages, the darker the block.

Results

The first thing that can be noticed from the visualizations, is that the Unknown stage does not appear for both subjects. This is an indication that the data was pre-processed properly, but also that the scoring by the experts was well carried out. Having no missing values in the data makes that the visualizations are accurate and thereby trustworthy.

The visualizations can complement each other. For example, the number of occurrences of the Wakefulness stage for both subjects seems to be high based on the histograms (Figures 11 and 12) alone. Together with the violin plots (Figures 5 and 6), strip plots (Figures 7 and 8) and bar charts (Figures 9 and 10), it becomes clear that the Wakefulness stage most often occurs in the last hours of the night of sleep. The heatmaps (Figures 13 and 14) show that stage W is most often followed by stage N1 and the other way around. This gives a clear explanation for the number of occurrences for the Wakefulness stage.

What can also be seen in the visualizations is that subject 01 night 2 has overall more occurrences of each sleep stage than subject 00 night 1, except for stage N3. The higher number of overall sleep stages can be explained by the fact that the night of subject 00 night 1 was shorter than the night of subject 01 night 2, which can easily be derived by comparing the plots. What then follows from the violin plot (Figure 6), strip plot (Figure 8) and bar chart (Figure 10) of subject 01 night 2, is that stage N3 is not recorded after 3:30h, whereas the stages N1, N2 and REM keep occurring. Since there are still transitions between the other stages and REM, meaning that the hypnogram line crosses stage N3, this would not easily have been derived from their hypnogram (Figure 4). For subject 00 night 1, it is not the case that N3 ends significantly earlier than the other stages. Comparing the violin plots (Figures 5 and 6) of these two subjects really makes this difference in sleep stages clear. These complementary visualizations give a lot of new insights into the data that would not have been made from solely the data and that would have been harder to make if just the hypnogram was available.

After the visualizations have been created and analyzed, it will now be possible to incorporate them into a graphical user interface (GUI). Initially, the plan was to make a user interface using PySimpleGUI. PySimpleGUI is based on Tkinter, easy to make and use and very customizable, making it a good option for this research [29]. Another option that came up for the interface was Dash. Dash is a part of Plotly and gives a web output with the visualizations, which makes sharing the interface easy and accessible to users with any device [28]. Therefore, the switch was made to Dash for the user interface. The graphs shown before were created with Plotly and are very easy to include in the Dash interface.

Switching to Dash posed another problem: loading the EDF file into the Dash dashboard did not work the way it was supposed to. This led to several alternatives:

1. making the interface with PySimpleGUI alone, meaning that the graphs would have to be recreated with Matplotlib, making interaction with the graphs harder;

2. not allowing the user to load in a data file, resulting in the tool to be less accessible in the real world;

3. only allowing the user to work with the tool via a Python script, which would not be optimal and would cost time;

4. using PySimpleGUI for processing the data into a csv, which can be loaded into Dash for the visualizations.

Eventually, it was decided to work with both PySimpleGUI and Dash, the first for loading the data and filling in the starting moment for the visualizations, the latter for loading in the csv created by the PySimpleGUI tool and making the graphs.

Firstly, the user loads in the EDF file with the scored sleep stages into a program. They enter the date that the patient came in and the time that the lights were turned off, so that these can be used in the data pre-processing. This information was formerly retrieved from the subjects file on the data set, but this will not be available for a patient that is not included in the PhysioNet database. Figure A.1 shows what this looks like in the interface. The data is then pre-processed in the way explained earlier. In a second window, the user selects the folder in which they want to save the processed data and the file name, and the data is saved as csv file in the chosen folder under the chosen name. Figure A.2 shows what this looks like in the interface.

The saved csv file can then be loaded into the second interface made with Dash. This generates the data frame of sleep stages per second and the data frame of the total number of occurrences per sleep stage per half hour. Finally, all visualizations are created and shown in the dashboard. In Figures B.1–B.4, the output of the dashboard after loading the data is shown.

As mentioned earlier, Plotly visualizations come with many options, such as the ability to interact with the plot by means of hovering, saving the picture directly or zooming in and out. This is marked in Figure B.1 on the hypnogram of subject 00 night 1 of the data set.

To test the usability of the interfaces and the manner the data is handled when loaded, another data set will be retrieved from the PhysioNet database and will be loaded into the interfaces. Randomly elected is subject 29, night 2. The information about this subject is shown in Table 3. Their data is loaded into the first interface and the csv file is created. This is then loaded into the Dash dashboard. The visualizations are shown in Figures 15–20.

Subject number	29
Subject night	2
Age	51
Gender	Female
Lights off time	23:04h
Date	17-9-1991

Table 3: Information on subject 29 night 2 of the database.

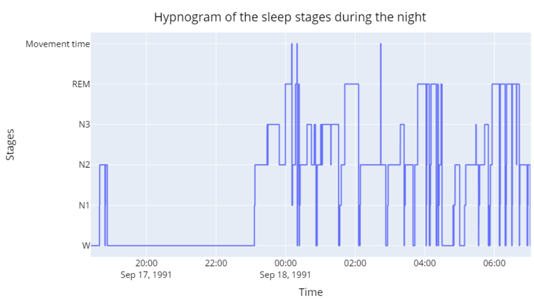

Figure 15: The hypnogram of subject 29 night 2. The time of the night is shown on the horizontal axis, the sleep stage is shown on the vertical axis.

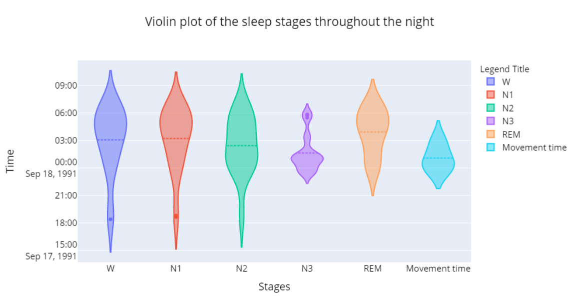

Figure 16: The violin plot of the sleep stages of subject 29 night 2. The horizontal axis shows the sleep stage, the vertical axis depicts the time of the night. The mean line is shown.

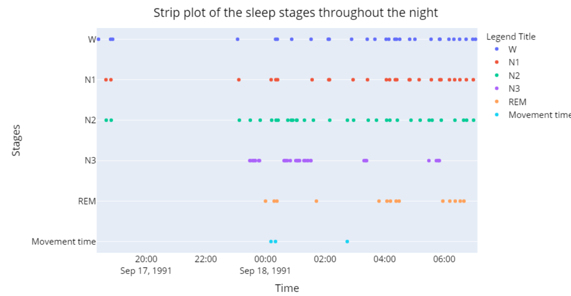

Figure 17: The strip plot of the sleep stages of subject 29 night 2. The horizontal axis shows the time of the night, the vertical axis depicts the sleep stage.

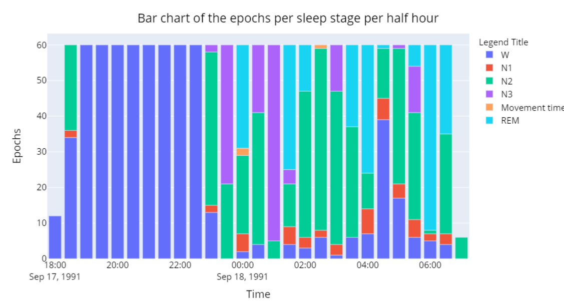

Figure 18: The bar chart of the sleep stages per epoch per half hour of subject 29 night 2. The horizontal axis shows each half hour of the night, the vertical axis denotes the sleep stage. The height of each bar section is determined by the number of epochs of a sleep stage during that half hour.

Subject 29 night 2 turns out to be one of the cases in which Movement time is still present as a sleep stage. Fortunately, this is visualized properly in the graphs. What can also be noticed is that the patient took a nap of approximately 15 minutes around 18:30h, which has not come forward in the data of the other two subjects. Since this was not expected initially, a part of code to handle naps was added to the pre-processing function. When this is used, the nap is still nicely visualized in the graphs. Other than that, there are no anomalies to be seen in the visualizations of subject 29 night 2.

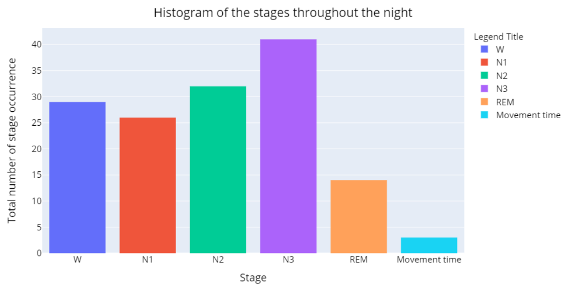

Figure 19: The histogram of the sleep stages of subject 29 night 2. The sleep stages are shown on the horizontal axis, the vertical axis shows the total occurrences of this stage during the entire night.

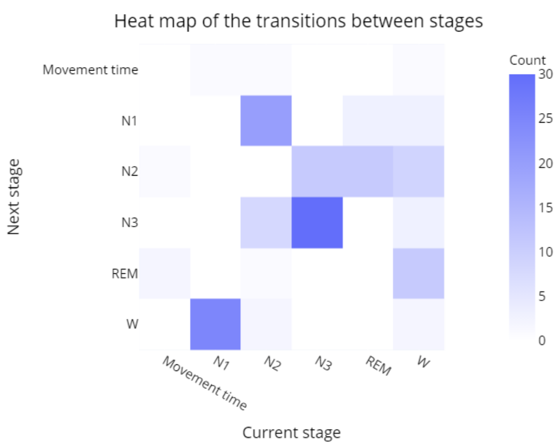

Figure 20: The heat map of the sleep stages of subject 29 night 2. The horizontal axis shows the current stage, the vertical axis shows the successive stage. A linear colourscale is used: the more transitions between stages, the darker the block.

Discussion

In this section, the limitations of the research will be elaborated upon. Additionally, it will be explained what can be studied on the topic of hypnogram visualization in the future.

Limitations

The pre-processing was initially done on two files from the dataset: subject 00 night 1 and subject 01 night 2. It was then modified to fit other data files as well as possible, so that not only files from the PhysioNet database could be loaded in, but also the hypnogram data that somnologists have available. This was then tested on another subject's data, subject 29, which worked almost perfectly: their nap was unexpected and led to an addition to the pre-processing. Also, the Movement time stage was not considered in the beginning and had to be added to the possible sleep stages. Hopefully, such unexpected sleep cycles and sleep stages will not occur in other patient's data. However, if this would be the case, the visualizations will still be made, they will show some anomalies compared to others, and their processed data may look off, making its direct exploration harder. Overall, the code should have been more generalized from the start, since this would have saved effort and time.

Another generalization that should have been made relates to the Dash interface. The tool runs on hard-coded column names in the data, which are created with the pre-processing in the PySimpleGUI and saved into the csv file. However, if a user would load in a csv file that was created in a different manner, the column names would not correspond, leading to an error output. This could be solved by letting the interface firstly read the loaded csv file, followed by letting the user select the columns that depict the start, duration, date and stage. Then, in case of missing columns, the tool further pre-processes the data. Finally, the new dataframes and visualizations can be created.

As mentioned, the research makes use of two interfaces. The reason for this choice was that PySimpleGUI is very fitting to process the data into a working Pandas dataframe, but the visualizations are better with Dash and Plotly. However, this is far from optimal since the user will have to use both to get to the desired results.

Several attempts were made to create an .exe file from the PySimpleGUI tool, but this gave running time errors in the console. This means that the first interface will have to be loaded via Python, which then opens another Python window with the tool. Dash currently is also launched via the Python console and creates a localhost link to view and work with the dashboard. Attempts were made to create a publicly accessible link for the dashboard, but this seems only feasible with the paid version of Dash. This, unfortunately, means that both tools will have to be launched via a Python script. As a result of all this together, the user will have to use two Python scripts to get their results.

The goal of the research was to improve current hypnograms, so that more information about the patient's sleep stages can be gained in a quick glance of the somnologist. An important visualization for this would be regarding the transitions between sleep stages, which is done by means of the heatmap (Figures 13, 14 and 20). It would however have been nice if the literature suggested more possible improvements that could have been made, since the visualizations now seem intuitive and simple to create. Literature on the topic has been searched for thoroughly, but most prior research is regarding sleep stages in the medical field, or regarding automating the sleep stage scoring, which was outside of the scope of this research. Therefore, it is suggested that much more can still be done to improve the visualization of sleep stages.

Future work

Discussing the proposed visualizations with experts, applying their feedback and creating additional visualizations that they request would have been beneficial to this research. This is something that would be very valuable for the development of the visualization of sleep stages.

The limitations of this research described above can make up for a large part of the future work. This can be done by using other tools that allow for data preprocessing and clear visualizations, but also by finding a way to make the current tools publicly accessible, for example, by getting the paid version of Dash and finding a way around the running time error for compiling the .exe file for the PySimpleGUI tool.

Additionally, modifying the code so that it will match almost every EDF file entry would add much to the usability of the system.

Conclusion

It has been shown why the visualization of sleep stages is of great importance. Somnologists use these visualizations to diagnose patients with suspected sleep disorders, but also other issues such as depression. Not diagnosing these disorders or diagnosing them incorrectly has severe consequences, since sleep disorders can be very dangerous to the patient and their surroundings when undiagnosed.

Since hypnograms are an essential visualization to diagnose sleep disorders, it is of great importance that the hypnograms are interpretable and accurate. Therefore, research has been done to review the current hypnograms and enhance them smaller visualizations that give detailed information and answers to certain questions. The visualizations are shown in a dashboard that can be easily used by somnologists.

There are still possibilities to improve the visualizations made and the way that they are shown, as described in the Discussion section. However, the belief is that the visualizations are already of good use for somnologists. Thus, it can be concluded that hypnograms can be enhanced such that sleep stages are better visualized and sleep disorder diagnosis is improved.

It is of importance that research in sleep disorders stays ongoing, also in the medical field, so that visualization techniques stay up to date and their results are valid to the users and their patients.

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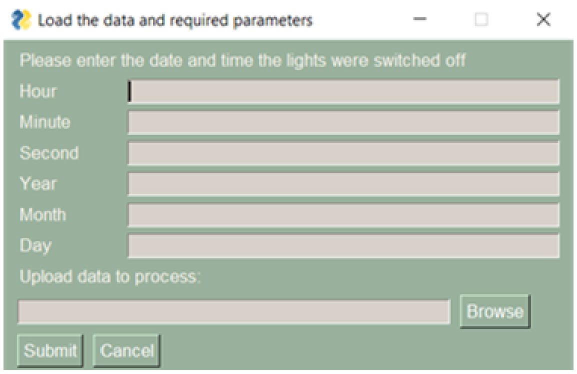
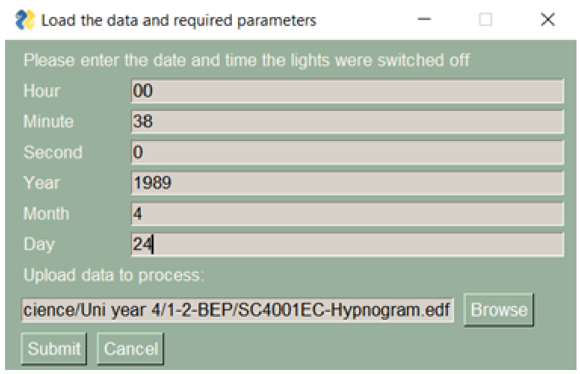
Appendices

Appendix A: PySimpleGUI interface

Figures A.1 and A.2 show the layout of the PySimpleGUI interface.

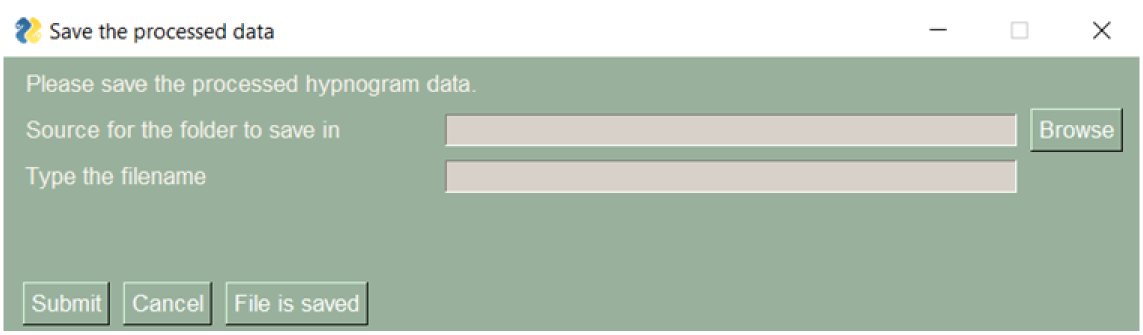


a. The first window in which the user fills in the time and date and loads in the .edf file

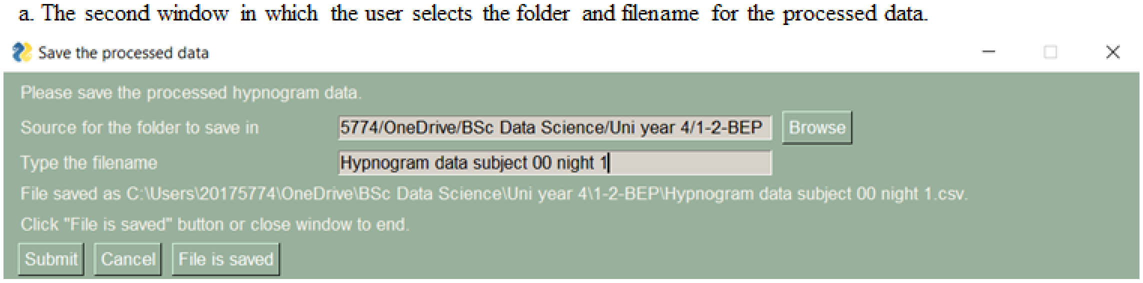


b. The filled in GUI for subject 00, night 1 from the dataset.

Figure A.1: The first window of the data loading interface.



a. The second window in which the user selects the folder and filename for the processed data.



b. The second window filled in, submit has been clicked. "File is saved" will close the window.

Figure A.2: The second window of the data loading interface.

Appendix B: Dash interface

Figures B.1–B.4 show the layout of the Dash interface.

Figure B.1: The layout of the Dash interface and the hypnogram. In the top of the screen, the user can upload the data. When the data is processed, the interface shows the filename and the date and time the file was created, the date and time the file was uploaded and the time it took for the data to be processed. Marked with the red frame are the options available with Dash and Plotly: hovering and setting its options, zooming in and out, panning, selecting a frame, and saving the graph as png.

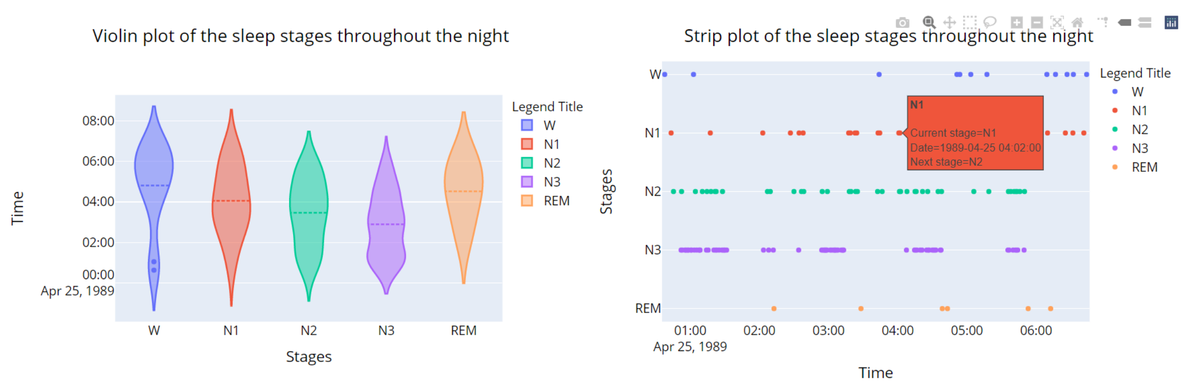


Figure B.2: The violin plot and strip plot of the stages over time in the Dash interface.

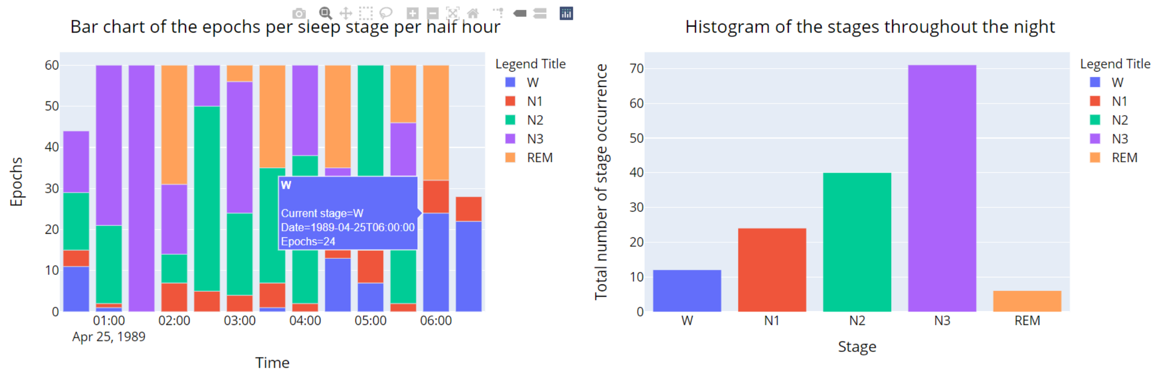


Figure B.3: The bar chart of the epochs and the histogram of all sleep stages in the Dash interface.

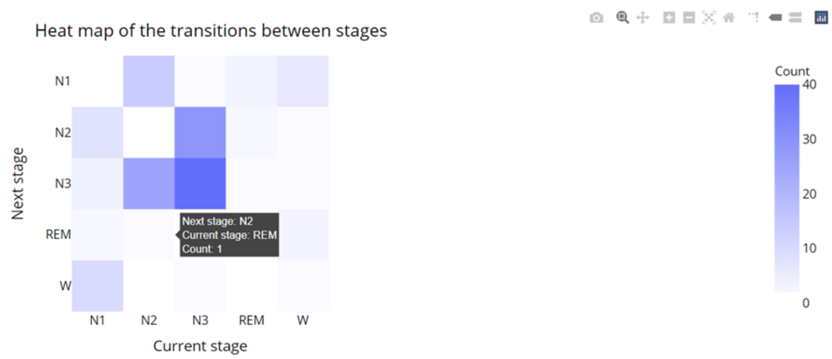


Figure B.4: The heatmap of the transitions in the Dash interface.