DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

SLEEP STAGE ANALYSIS

by
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İZMİR

SLEEP STAGE ANALYSIS

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **“SLEEP STAGE ANALYSIS”** completed by **SERKAN DEMİR** under supervision of **ASST.PROF.DR. METEHAN MAKİNACI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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SLEEP STAGE ANALYSIS

ABSTRACT

In this project, methods for extraction features and classification for sleep stage using EEG (Electroencephalogram) are presented. The algorithm consists of basically two modules, feature extraction and classification. Firstly, features used in the classification step are extracted. In the beginning of feature extraction, segmentation is applied for breaking down the signal into fixed sections to match with the labels. Then the parameters are extracted from these fixed sections. The extracted features are the parameters of Hjorth, harmonic parameters, the relative band energy ratios and the parameters that are obtained by applying wavelet packet transformation (WPT). Then all these extracted features are used in the classifiers which are constructed by using k-nearest neighbor, multilayer neural network and linear discriminant analysis.

Keywords: EEG analysis, sleep stage, parameters of Hjorth, wavelet packet transformation, neural network, k-nearest neighbor, linear discriminant analysis.

UYKU EVRELERİ ANALİZİ

ÖZ

Bu projede EEG sinyalindeki uyku evrelerinin sınıflandırılması için gereken öznitelik çıkarma metotları ve sınıflandırıcılar konu alınmıştır. Algoritma, öznitelik çıkarma ve sınıflandırma olmak üzere 2 ana aşamadan oluşmaktadır. İlk olarak sınıflandırma aşamasında kullanılacak olan öznitelikler çıkartılmıştır. Öznitelik çıkarma aşamasının ilk adımı olarak sinyal, uyku evrelerinin etiket değerleriyle eşleşebilecek şekilde eşit aralıklara ayrılmaktadır. 2. adım ise öznitelikleri bu eşit aralıklı sinyal aralıklarından çıkarma metotlarını kapsamaktadır. Çıkarılan öznitelikler, Hjorth parametreleri, armonik parametreler, bant enerji oranları ve dalgacık paket dönüşümü metoduyla elde edilen özniteliklerdir. Bütün bu öznitelikler en yakın k komşu, çok katmanlı sinir ağları ve doğrusal ayırma analizi metotları kullanılarak oluşturulan sınıflandırıcılarda kullanılmıştır.

Anahtar sözcükler: EEG analizi, uyku aşamaları, Hjorth parametreleri, dalgacık paket dönüşümü, sinir ağları, k en yakın komşu, doğrusal ayırma analizi

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CHAPTER ONE
INTRODUCTION

1.1 Sleep

Sleep is a period which denotes unconsciousness of the individual. In this state, the brain is relatively more reactive to internal stimuli than external stimuli. Sleep and coma have distinctions that sleep can be reversed by external stimuli; coma can not be reversed by stimulation. Sleep is necessary for a healthy human body. It is a complicated physiological phenomenon that scientists do not completely explain.

In the past, sleep was considered as a passive state. On the contrary, sleep is now known as a dynamic process, and brain functions are active throughout sleep. Sleep has influences on our physical and mental health. Also it is necessary for all systems of our body. The effect of sleep on the immune system affects one’s ability to fight disease.

There are some different activating and inhibiting forces that generated in the brain and they adjust brain activity during the sleep and wakefulness. Neurotransmitters which are chemicals involved in nerve signaling can determine whether one is asleep or awake through acting on nerve cells in the brain.

In people, the metabolic activity of the brain shows decreasing significantly after 24 hours of sustained wakefulness. Sleep deficiency causes a decrease in body temperature, a decrease in immune system function and a decrease in human growth release. Increased heart rate variability can also be a result of sleep deficiency.

Sleep is needed for healthy nervous system. A person feels tiredness and lacks attention to concentrate while having sleep deficiency. It also has detrimental effects on memory and physical performance. Hallucinations and mood swings may develop if sleep deficiency continues.

1.2 Electroencephalogram (EEG)

EEG is an electrical activity produced by brain. It is recorded by attaching two electrodes to the surface of human scalp and connecting to an amplifier. The EEG is the summation of many cortical neurons firing independently. The amplitude of the normal EEG can vary between approximately -100 and +100 μV, and its frequency ranges up to about 40 Hz.

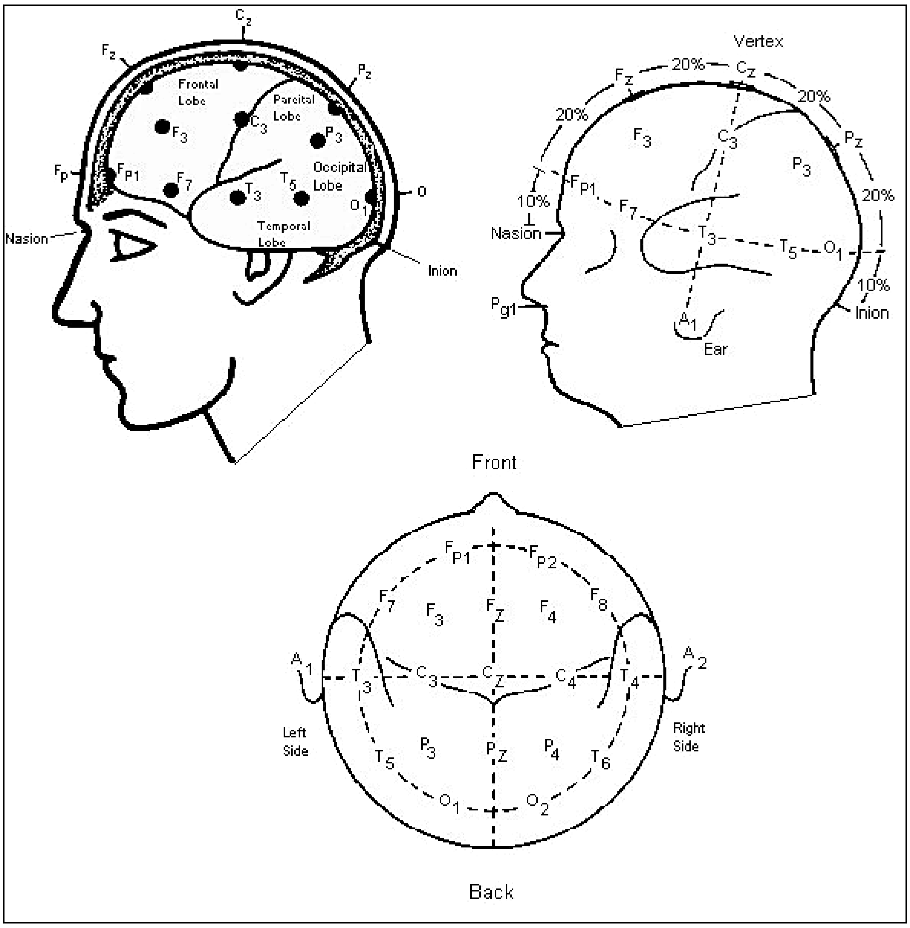

Figure 1.1 Position of the electrodes on the skull. (Paulo, Andre, Sandra, & Agostinho, 2000)

1.3 Sleep Stages

Sleep consists of several stages that cycle throughout the night. At waking stage, body prepares for sleep. During falling asleep, muscles start to relax and eye movement slows to a roll.

Stage 1 is considered as first in the sequence where waking is not included. In this stage, the eyes are closed. Stage 1 may last for 5 to 10 minutes.

Stage 2 is light sleep during which peaks of brain waves become higher and higher. These waves show spontaneous periods of muscles.

Stages 3 and 4 are also called slow-wave sleep or deep sleep, and it is very difficult to wake someone from them. When stage 3 begins, the brain produces very slow brain waves, called delta waves. At stage 4, electromyogram records slow waves of high amplitude, showing a figure of deep sleep.

The NREM is composed of Stages 1-4 and lasts from 90 to 120 minutes, each stage lasting from 5 to 15 minutes. In a surprising manner, Stages 2 and 3 repeat backwards before REM sleep is attained. Thus, a normal sleep cycle is defined as waking, stage 1, 2, 3, 4, 3, 2, REM. Normally, REM sleep begins 90 minutes after sleep onset.

REM sleep is different from NREM sleep that in the REM period, heart rate increases, breathing becomes more rapid and eyes jerk rapidly. During REM sleep, most vivid dreaming occurs as a result of heightened cerebral activity and, if awoken during REM sleep, a person can remember the dreams.

1.3.1 Sleep Cycle

Sleep is a cycle period comprising repetition of five stages. The first cycle lasts about 100 minutes which ends after the completion of the first REM stage. Following cycle lasts longer and five cycles occur in a typical night sleep.

The distribution and amount of sleep stages as a function of time give important diagnostic information. Hypnograms provide a simple way to display this information. The chart in figure 1.2 is an example for a hypnogram.

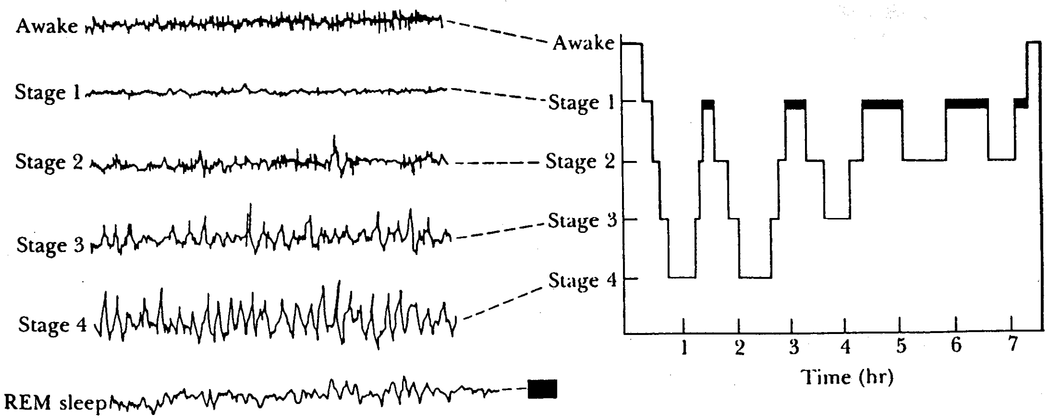

Figure 1.2 Example of a hypnogram (Anonymous, 2009)

1.4 Outline

In the first chapter an introduction for sleep, EEG and sleep stages are given. This chapter ends with an outline of this report. In chapter 2, a background theory that is relevant to understand the remaining part of the report is summarized. Classification methods k-nearest neighbor, neural networks and linear discriminant analysis are explained briefly. Chapter 3 presents the methods that are used in feature extraction and feature selection. In the fourth chapter classification methods are explained. In chapter 5, classification results are presented in details. A summary of the entire work is explained in the last chapter.

CHAPTER TWO
THEORETICAL BACKGROUND

In this chapter theoretical background information is given for the classification applications, K nearest neighbor, multilayer neural networks and linear discriminant functions that are used in the project. This chapter is based on the book Duda, R. O., Hart, P. E., Stork, D. G., (2001). *Pattern classification* (2nd ed.). Canada: Wiley.

2.1 K Nearest Neighbor Rule

The rule of k-Nearest Neighbor is an easy and useful estimation of non parametric techniques. In this method a new sample is classified by being assigned into a label of the group whose samples are commonly located within the k nearest ones.

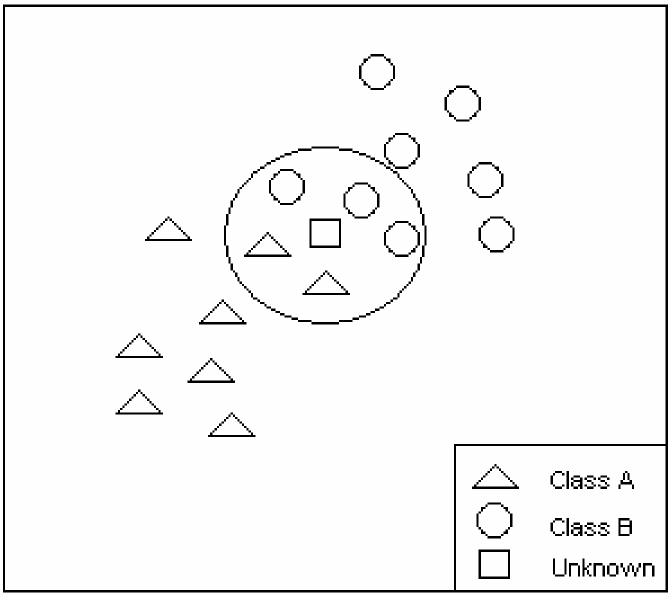

Figure 2.1 An example of k-NN classification

In figure 2.1 an example of k-NN classification is represented for two class case. The classification operation starts with the point where the sample with unknown class is located. Then the point is expanded with a shape of circle and it grows up until the number of k nearest samples is reached. As in figure 2.1, if k equals 5, the sample with unknown label is classified with the label of class B.

For two class cases it must be avoided to have even k values, because there is a possibility having equal number of nearest sample or samples for each class.

All the k nearest neighbor are supposed to be random variables assuming the values w_i with the probabilities $P(w_i \mid x), i = 1,2$. If $P(w_m \mid x)$ is defined with a highest probability, Bayes decision rules always select that one. As a rule, the value of k makes a decision to select w_m. The more the value of k the higher possibility w_m will be selected.

The error rate for two class case is limited above by the function $C_k(P^*)$, where $C_k(P^*)$ is the smallest concave function of P^* that is greater than $\sum_{i=0}^{(k-1)/2} \binom{k}{i} \left[(P^*)^{i+1}(1-P^*)^{k-i} + (P^*)^{k-i}(1-P^*)^{i+1} \right]$. The first term in the brackets represents the probability of error due to *i* points coming from the category that have the minimum probability and $k-i > i$ points from the other one. The second term in the brackets represents the probability of error due to $k-i$ points coming from the category that have the minimum probability and $i+1 < k-i$ points from the higher one. To find the full error these two terms must be added.

2.2 Multilayer Neural Networks

Feed forward networks are widely used parts of neural networks.

2.2.1 An Artificial Neuron

An artificial neuron is a simple processing unit which is fixed with n inputs and these inputs are connected to a neuron with a weighted link w_i. Finally the neuron sums the inputs and an activation function, usually a threshold function or a continuous non linear function, is used to calculate the output.

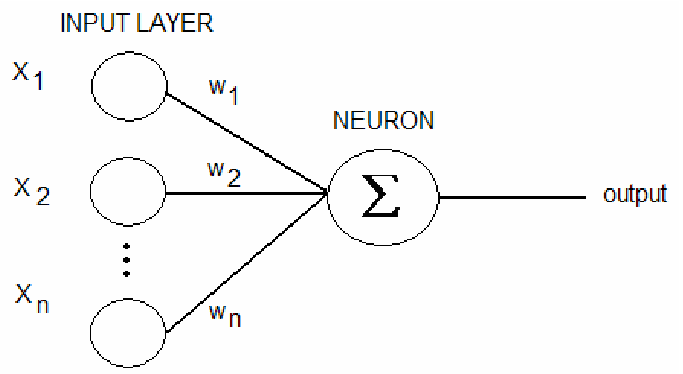

Figure 2.2 An artificial neuron

2.2.2 A Single Layer Network

These kind of networks are very simple and include m neurons each has n inputs. These networks are not qualified to classify non linear separable dataset. Multilayer networks are used to overcome this problem. A learning algorithm which is also the same for a single neuron can be used.

2.2.3 Multilayer Neural Network

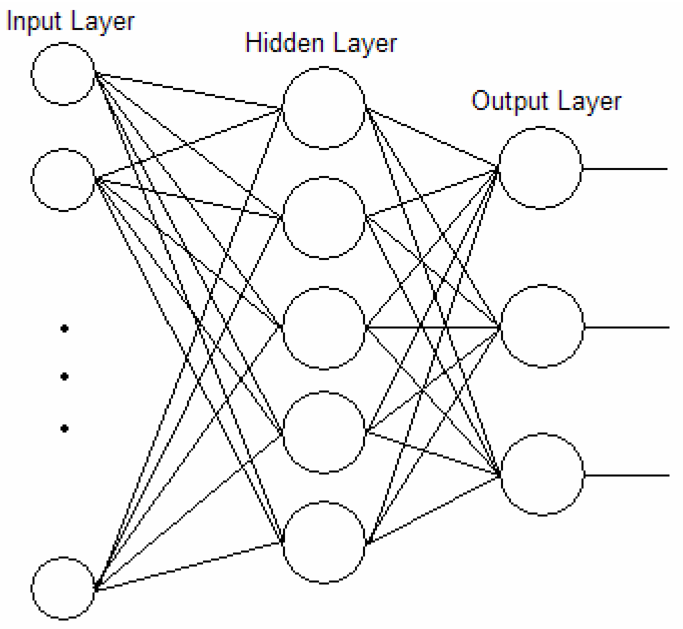

Figure 2.3 An example of 2 layer network

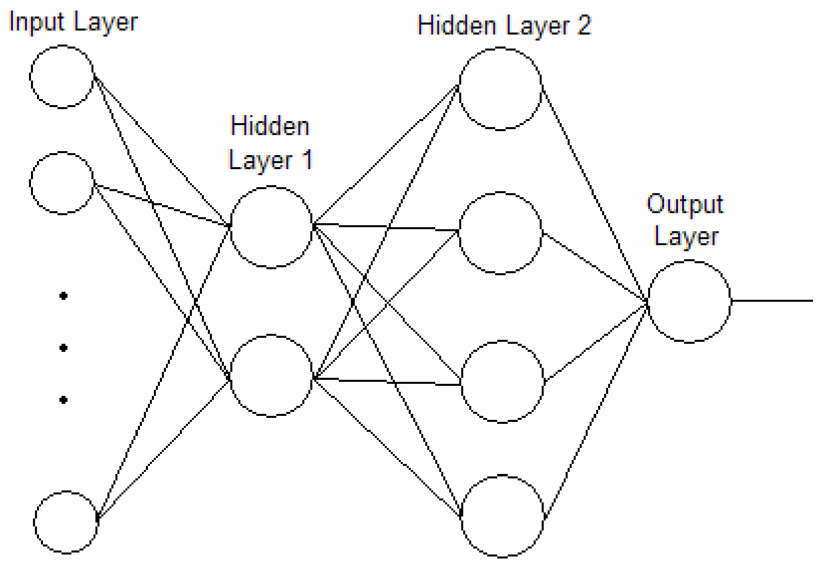

Figure 2.4 An example of 3 layer network

The error in the output layer is back-propagated to the hidden layers to find the weight changes. This method is implemented on each sample in the training set.

The starting points in the error landscape are selected by defining the initial weights. These starting points check out if the learning process finalized in a local minimum or the global minimum. Also defining small initial weights will cause small changes which result a very small learning process.

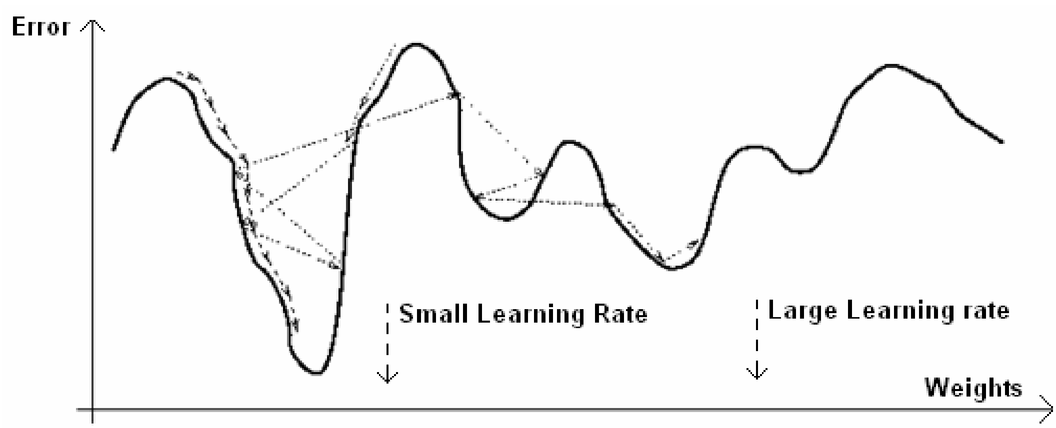

Figure 2.5 Effect of learning weights on the weight changes (Schmidt, 2000)

2.3 Linear Discriminant Functions

2.3.1 The Two Category Case

A discriminant function can be expressed as $g(x) = w^t x + w_0$, where w is the weight vector and w_0 is the bias or threshold weight. The rule for classification is deciding w_1 if $g(x) > 0$ and w_2 if $g(x) < 0$. If $g(x) = 0$ x can be classified either into w_1 or w_2.

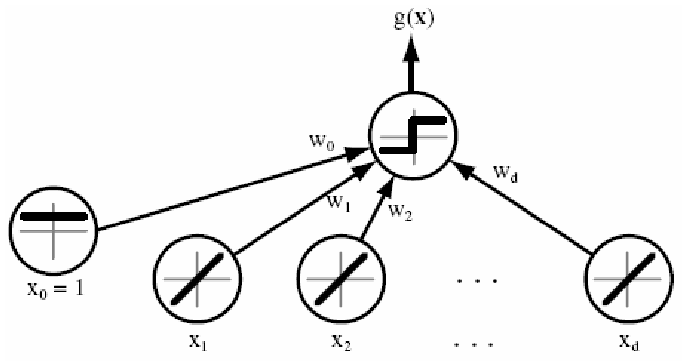

Figure 2.5 A simple linear classifier with d inputs. Each input multiply with its weight. The output is the sum of all. (Duda, Hart & Stork, 2001)

$g(x) = 0$ is a decision region which separates the categories w_1 and w_2. If $g(x)$ is defined as a linear function then the decision region will be a hyperplane.

2.3.2 The Multi Category Case

Linear discriminant functions are defined as $g_i(x) = w^t x_i + w_{i0}$, i = 1,…,c. The rule decides w_i if $g_i(x) > g_j(x)$ for all $i \neq j$ and in the case of a tie the classification will be left undefined. If R_i and R_i are contiguous, the region between them is a portion of hyperplane H_{ij} which is defined by $g_i(x) = g_j(x)$.

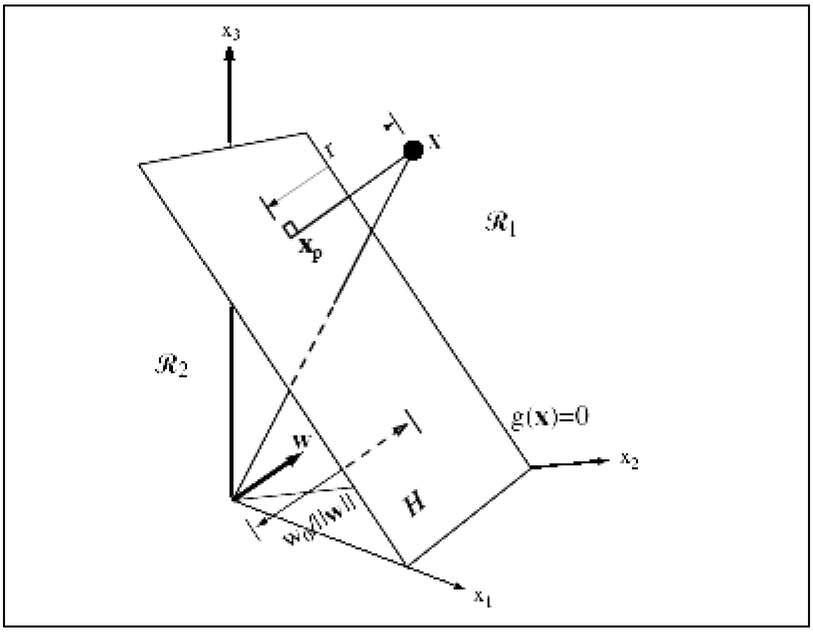

Figure 2.6 Linear decision region H , which seperates the feature space into two half-spaces R_1 and R_2 .(Duda, & friends, 2001)

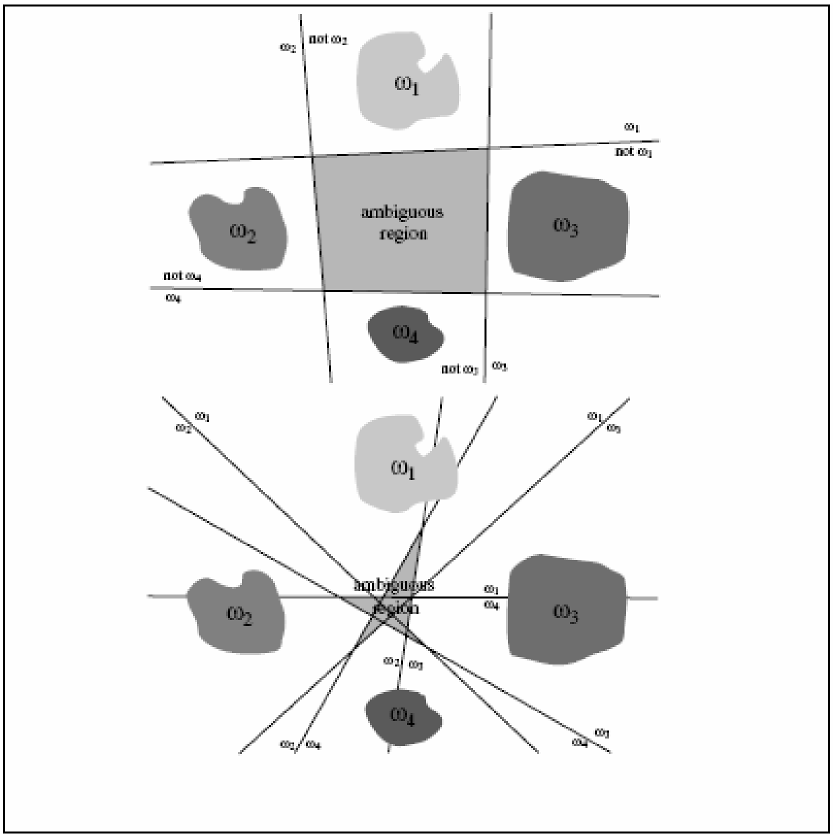

Figure 2.7 Linear decision regions for four-class problem (Duda, & friends, 2001)

CHAPTER THREE
FEATURE EXTRACTION AND SELECTION

In this chapter, short information for the data sets used in this project and the sources of these data sets are given. Then the feature extraction methods applied on these two data sets are explained in details. This chapter ends with ttest method which is used for selecting the features according to their significance.

3.1 Data Acquisition

In this project, two EEG recordings whose sets of polysomnographic signals were stored in EDF data format are used. Then an EDF to ASCII data converter to extract the required channel data from 17 different channels including the hypnogram, which is manually scored by an expert, is also used. The lengths of the used sleep EEG recordings are 20 minutes and 7 hours. 20 minutes sleep recording data is taken from http://www.edfplus.info (Kemp & Roessen, 2008) and 7 hours sleep recording data is taken from http://www.physionet.org/ (Kemp, 2008). The first ten seconds of 20 minutes recording is given in figure 3.1.

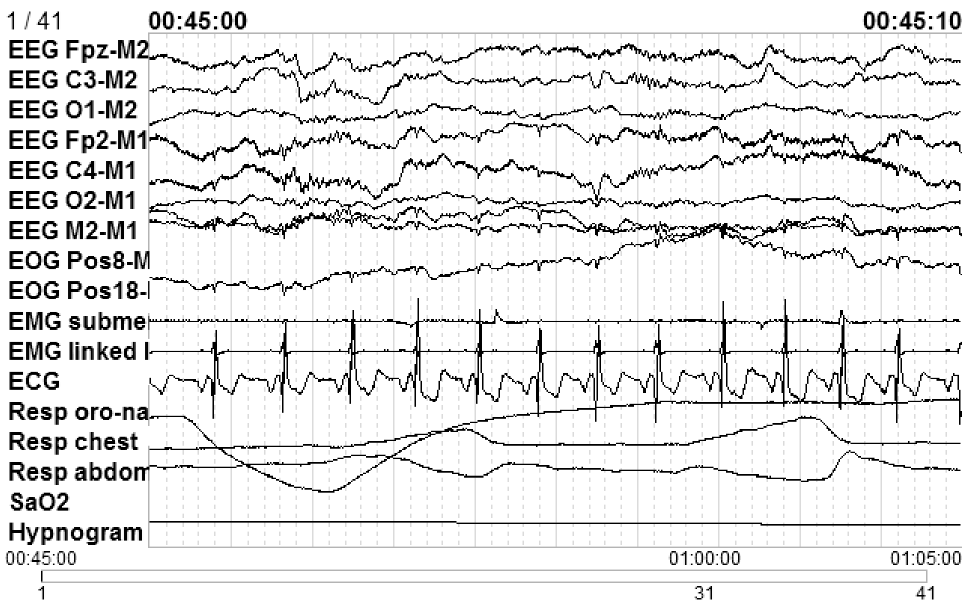

Figure 3.1 Polysomnographic recording showing a 10-second part of a 20-minute sleep recording.

3.2 Feature Extraction

In this part the sleep recording data sets are divided into segments and from each segment the features are extracted. These features are the parameters of Hjorth, harmonic parameters, the relative band energy ratios and the parameters that are obtained by applying wavelet packet transformation (WPT) on each segment.

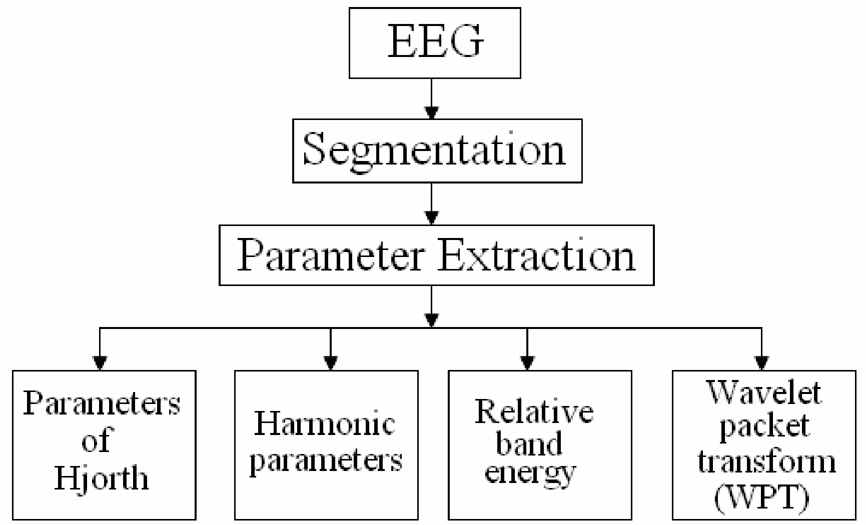

Figure 3.2 Schematic overview of the feature extraction algorithm

3.2.1 Segmentation

In this step, both EEG signals are divided into groups with same lengths which are also can be called segments. The equal length of each segment is chosen as 10 seconds and 30 seconds because the sleep recordings are manually scored in steps of 10 seconds and 30 seconds. Finally 120 segments for 20 minutes sleep recording and 849 segments for 7 hours sleep recording are calculated.

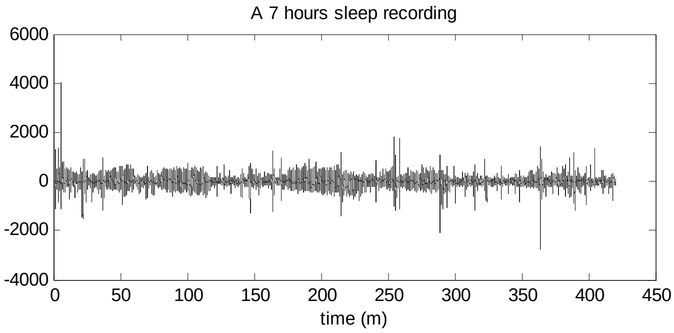

Figure 3.3 Seven hours sleep recording

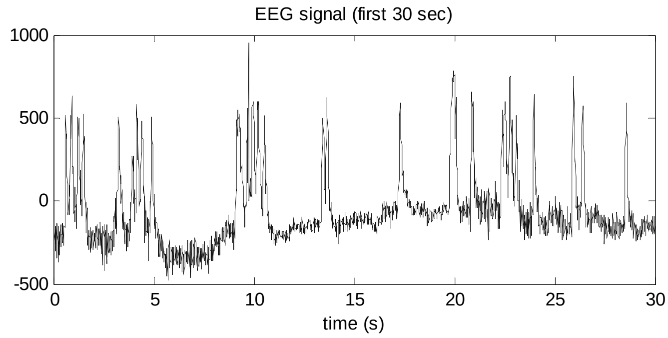

Figure 3.4 First 30 seconds of 7 hours sleep recording

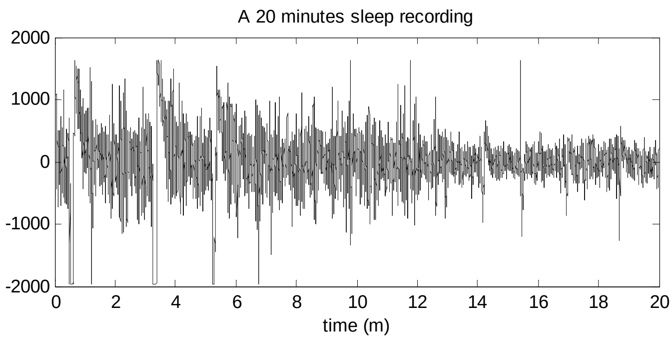

Figure 3.5 20 minutes sleep recording

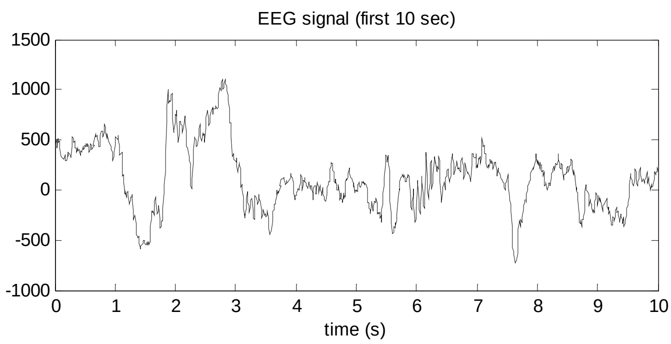

Figure 3.6 First 10 seconds of 20 minutes sleep recording

3.2.2 Parameter Extraction

3.2.2.1 Parameters of Hjorth

These parameters can be related with the variance of the signal and its first and second derivatives in a segment. If σ_0 is called the variance of the original signal, then the variance of the $i-th$ derivative can be defined as σ_i. Calculated Hjorth parameters are shown in table 3.1.

Table 3.1 Parameters of Hjorth (Hese, Philips, Koninck, Walle, & Lemahieu, 2001)

Feature	1	2	3
Feature Name	Activity	Mobility	Complexity
Formula	$A = \sigma_0^{\ 2}$	$M = \sigma_1 / \sigma_0$	$C = \sqrt{(\sigma_2 / \sigma_1)^2 - (\sigma_1 / \sigma_0)^2}$

These parameters can also be associated with the moments of the spectral density function, denoting that mobility is a kind of measure for the center frequency and complexity is a kind of measure for the bandwidth of the signal.

3.2.2.2 Relative Band Energy

The relative band energy ratios can be calculated through making a ratio between the energy in band of the segment to the total energy of that segment. The starting and finishing frequencies of the used 7 bands are detailed in table 3.2

Table 3.2 Predefined frequency bands for relative band energy ratios (Hese, & friends, 2001).

Feature	4	5	6	7	8	9	10
Band	Delta1	Delta2	Theta1	Theta2	Alpha	Beta1	Beta2
Range (Hz)	0.5 – 2.5	2.5 – 4	4 – 6	6 – 8	8 – 12	12 – 20	20 – 45

3.2.2.3 Harmonic Parameters

To calculate these parameters an estimate (method of Welch) of power spectral density function is used.

3.2.2.3.1 PSD with using method of Welch. The method of Welch begins with dividing the time domain data into smaller parts and then forming a periodogram for all parts. Then the periodogram is calculated for each part which creates a series of power & frequency measurements. Afterward a window function is applied to time domain data, discrete Fourier transform is calculated and finally squared magnitude of the results are computed.

3.2.2.3.2 1/f Parameter Estimation. The harmonic parameters are also introduced in the power spectrum. Their effects on the power spectrum and fractal dimension can be discarded by using some useful controlling operations.

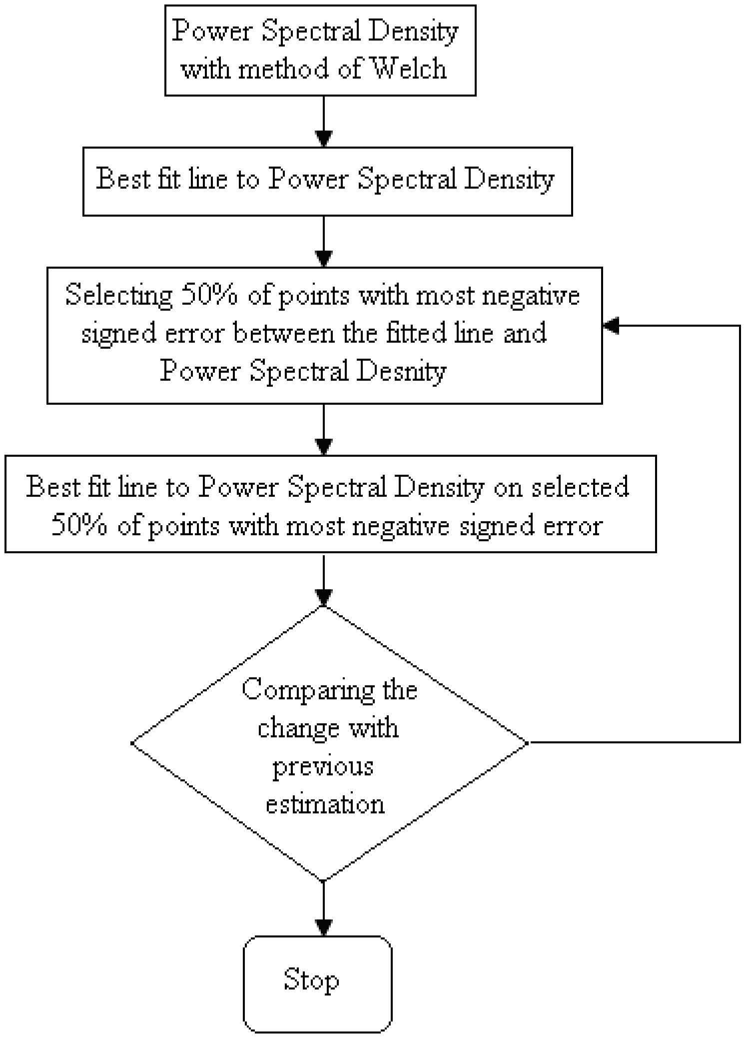

Figure 3.7 1/f parameter estimation algorithm (Hese, & friends, 2001).

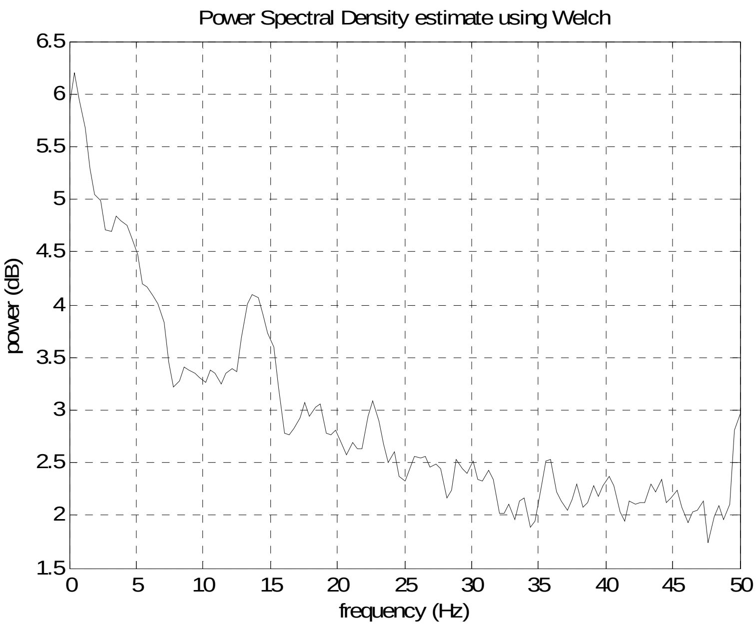

Figure 3.8 Power Spectral Density estimate using Welch for the first 10 seconds of the sleep recording data with the length of 20 minutes.

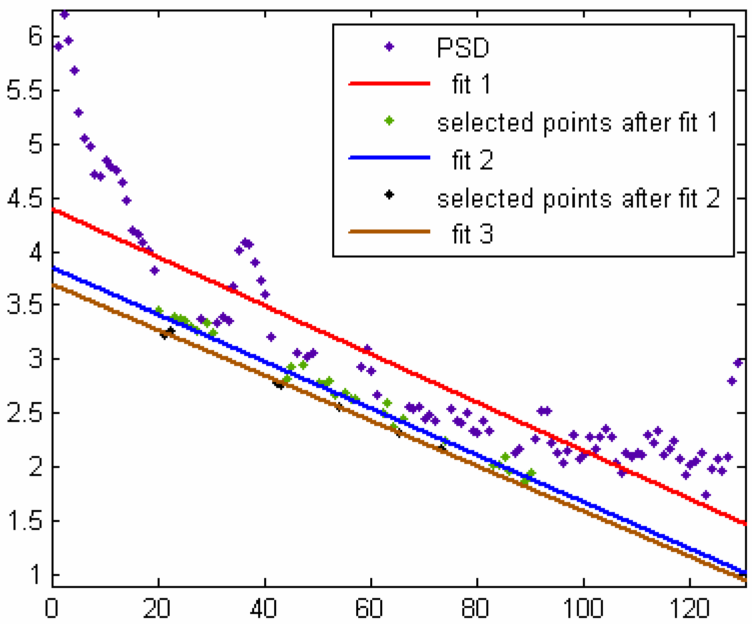

Figure 3.9 All fitted lines using 1/f parameter estimation algorithm for the first ten seconds of the sleep recording data with the length of 20 minutes.

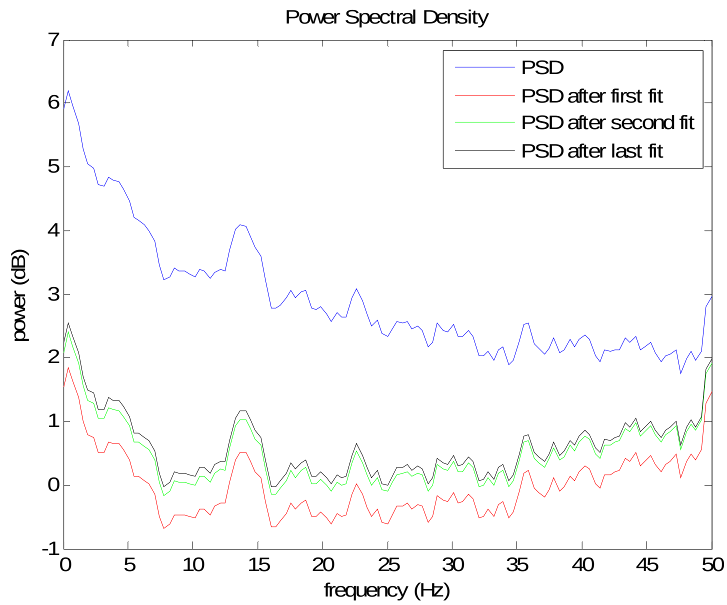

Figure 3.10 Power Spectral Density after each fitting operation for the first ten seconds of the sleep recording data with the length of 20 minutes.

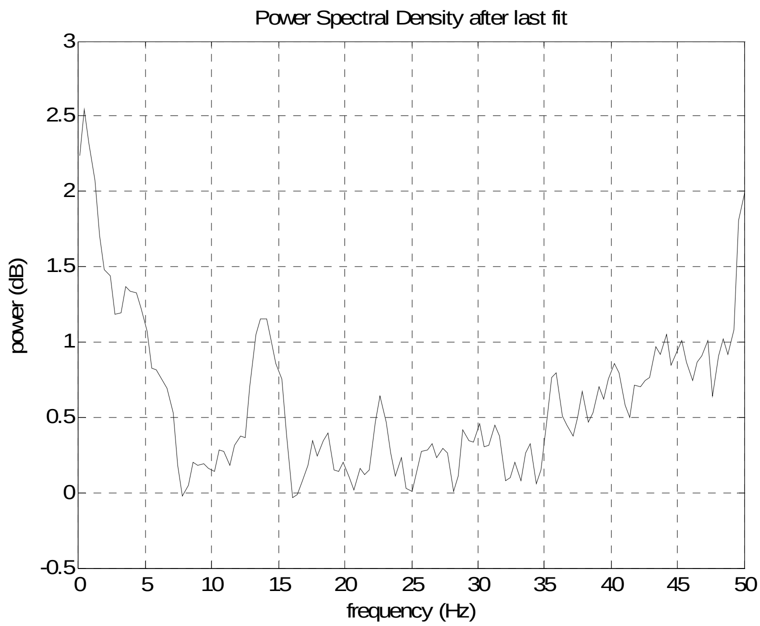

Figure 3.11 Power Spectral Density estimate after last fit operation for the first ten seconds of the sleep recording data with the length of 20 minutes.

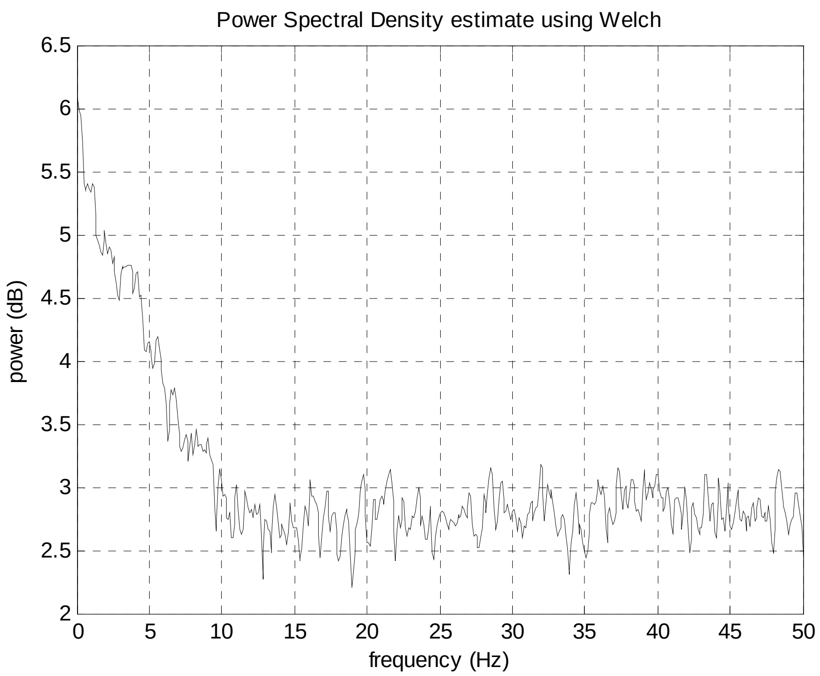

Figure 3.12 Power Spectral Density estimate using Welch method for the first 30 seconds of the sleep recording data with the length of 7 hours.

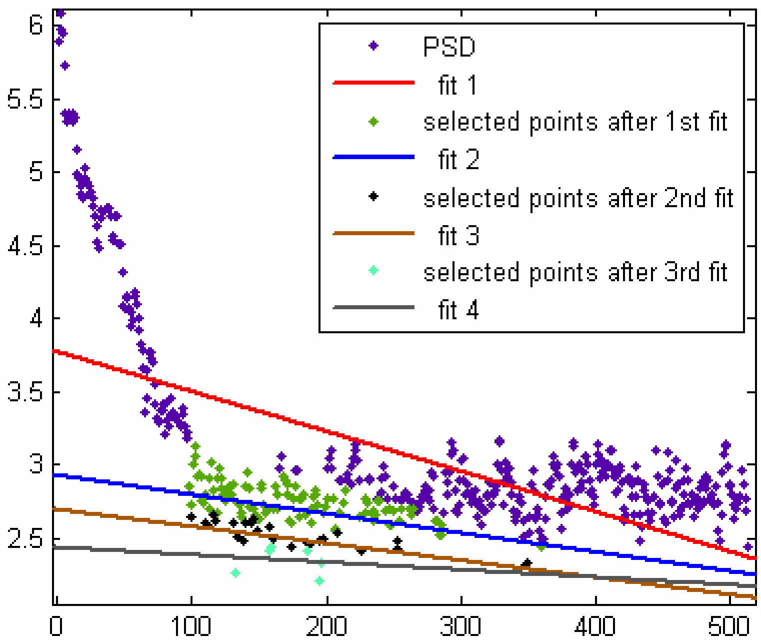

Figure 3.13 All fitted lines using 1/f parameter estimation algorithm for the first thirty seconds of the sleep recording data with the length of 7 hours.

Figure 3.14 Power Spectral Density after each fitting operation for the first thirty seconds of the sleep recording data with the length of 7 hours.

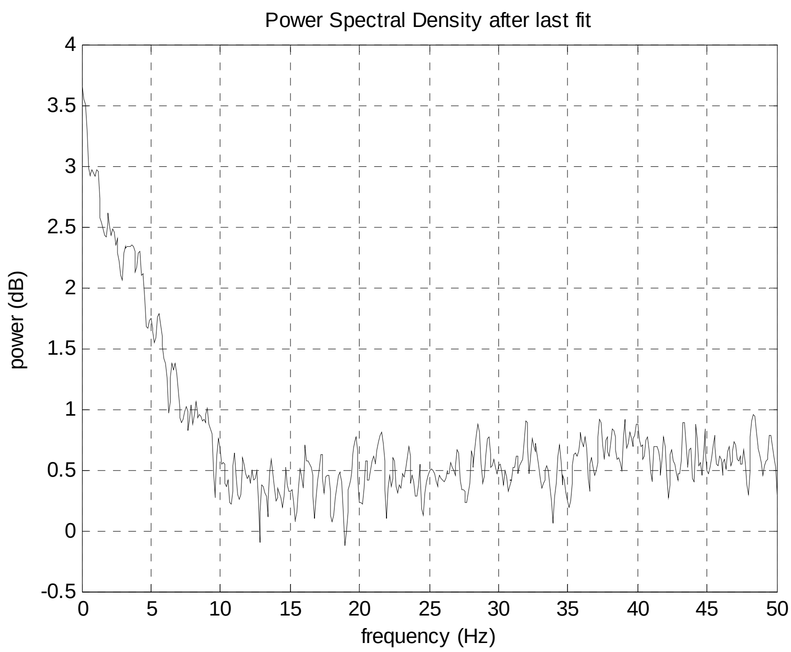

Figure 3.15 Power Spectral Density estimate after last fit operation for the first thirty seconds of the sleep recording data with the length of 7 hours.

3.2.2.3.3 Calculated Harmonic Parameters. After spectral density function estimation with method of Welch harmonic parameters are calculated and the frequency ranges in table 3.3 are defined for inspecting specific bands in power spectrum instead of inspecting the whole frequency band in power spectrum.

Table 3.3 Predefined bands for harmonic parameters (Hese, & friends, 2001).

Band	**Range (Hz)** ($f_L - f_H$)
Delta	0.5 – 4
Theta	4 – 8
Alpha	8 – 12
Beta	12 – 30
Gamma	>30

Table 3.4 Calculated harmonic parameters (Hese, & friends, 2001).

Center Frequency	**Bandwidth**	**Value at Center Frequency**
$f_c = \dfrac{\int_{f_L}^{f_H} f.S_x(f)df}{\int_{f_L}^{f_H} S_x(f)df}$	$f_\sigma = \sqrt{\dfrac{\int_{f_L}^{f_H} (f-f_c)^2 S_x(f)df}{\int_{f_L}^{f_H} S_x(f)df}}$	$S_{f_c} = S_x(f_c)$

Using 5 predefined bands in table 3.3 and 3 harmonic parameters given in table 3.4. Finally 15 features are extracted from each sleep recordings.

Table 3.5 All calculated harmonic parameters

Features	Calculated Harmonic Parameter
11, 12 ,13	f_c Delta, f_σ Delta, S_{f_c} Delta
14, 15, 16	f_c Theta, f_σ Theta, S_{f_c} Theta
17, 18, 19	f_c Alpha, f_σ Alpha, S_{f_c} Alpha
20, 21, 22	f_c Beta, f_σ Beta, S_{f_c} Beta
23, 24, 25	f_c Gamma, f_σ Gamma, S_{f_c} Gamma

3.2.2.4 Wavelet packet transformation

A WPT (Wavelet Packet Tree) with a depth of 8 was designed. As in calculating the harmonic parameters some specific bands are predefined for also wavelet coefficients. These bands are detailed in table 3.6.

Table 3.6 Predefined frequency bands for wavelet coefficients (Oropesa, Cycon, Jobert, 1999)

Feature	Range	Band
26	0.4 – 1.55 Hz	K-complexes + Delta
27	1.55 – 3.2 Hz	Delta
28	3.2 – 8.6 Hz	Theta
29	8.6 – 11.0 Hz	Alpha
30	11.0 – 15.6 Hz	Spindle
31	15.6 – 22.0 Hz	Beta 1
32	22.0 – 37.5 Hz	Beta 2

Using the above frequency informations, 7 subbands given in figure 3.16 are selected.

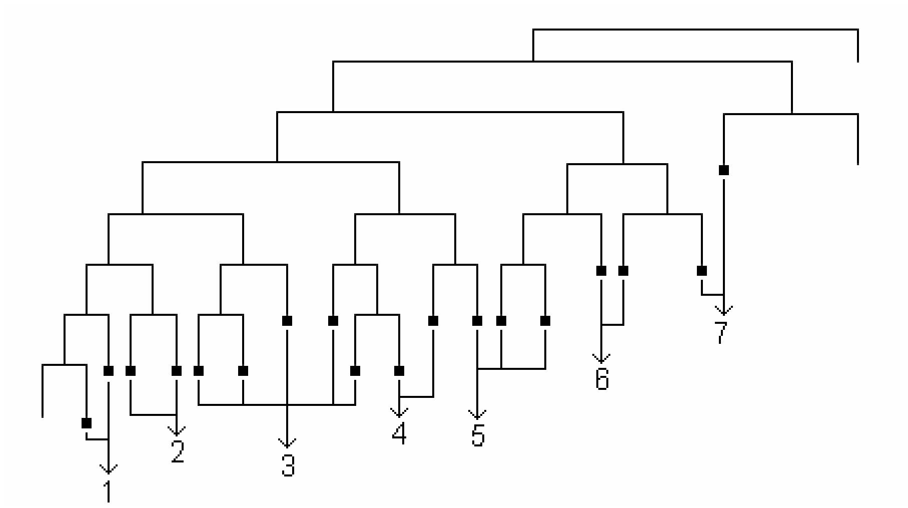

Figure 3.16 WPT, selected subbands (Oropesa, & friends, 1999)

In each branch of the above tree the time resolution changes according to the band in logarithmic scales. The top subband in the below figure contains the original signal with Nyquist frequency Fn.

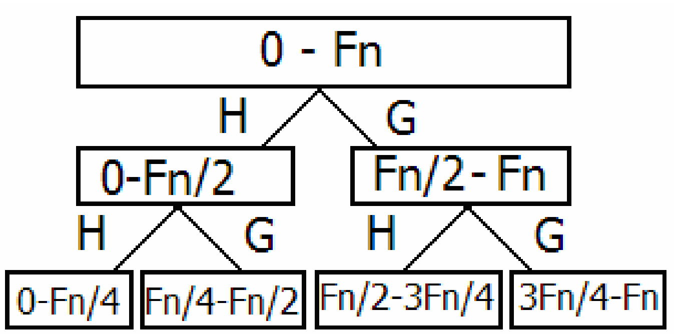

Figure 3.17 Wavelet packet tree (WPT), (Oropesa, & friends, 1999)

For every 10 and 30 seconds epochs taken from each EEG, the Energy "E" of the WP coefficients for each of the 7 bands in table 3.6 are calculated. For each epoch these calculated 7 energy values are used as the features. Also 6 more features are calculated based on the energy values of the 7 band in an epoch and their combinations with each other and the total energy of that epoch.

Table 3.7 Features based on total energy and ratio of the different energy values (Oropesa, & friends, 1999).

Feature	Value	Explanation
33	$E8 = \sum_{i=1}^{7} E_i$	Total Energy of the 7 bands
34	(E1 + E2) / E8	Delta Activity (%)
35	E4 / E8	Alpha Activity (%)
36	(E1 + E5) / E8	K-Komplex and Spindle (%)
37	E4 / E3	Alpha / Theta
38	(E1 + E2) / E3	Delta / Theta

3.3 Feature Selection

Finally 38 features are extracted from each sleep recording data. The number of the extracted features is more than the length of the sleep recording data set. Especially for the 20 minutes sleep recording, so the size of the feature matrix is expected be decreased and the most significant features shall be used in the classification step. To do that elimination, an independent evaluation criterion ‘ttest’ method is used.

CHAPTER FOUR
CLASSIFICATION APPLICATIONS

After all features are extracted and selected according to their significance, they are used as the inputs of the classifiers. “K-Nearest Neighbor”, “Multilayer Neural Network” and “Linear Discriminant” methods are used as classification methods.

The 20 minutes sleep recording data includes three classes with labels 2, 3 and 5 that correspond to sleep stages 2, 3 and REM. The 7 hours sleep recording data includes six classes with labels 0, 1, 2, 3, 4 and 5 that correspond to sleep stages. W, 1, 2, 3, 4 and REM. To make an efficient comparison between the results of these two sleep recordings, only sleep stages 2, 3 and REM are tested and classified.

Table 4.1 Number of samples in each class for 20 minutes sleep recording

Class	**Number of samples**
2	42
3	36
5	42

Table 4.2 Number of samples in each class for 7 hours sleep recording

Class	**Number of samples**
0	59
1	89
2	382
3	83
4	20
5	216

The class 3 in the 7 hours sleep recording has 83 samples which shall be the common number for also class 2 and class 5 that have 382 and 216 samples respectively.

4.1 K-Nearest Neighbor Classification

The main idea in k-NN is classifying an unlabeled example based on the similarities with the examples in the training group. For a given unlabeled example, k closest labeled examples in the training data set are found and then the unlabeled example is assigned to the class that appears most frequently within the k-subset.

4.1.1 Training the data

In the training part of k-NN classification to select the train and the test groups "leave one out" method is used. For each classification step, one observation with the selected features is used as the test data and the remaining parts are used for training process. The network is trained and tested 120 times for 20 minutes sleep recording and 249 times for 7 hours sleep recording.

Table 4.1 K-NN training method for 7 hours sleep recording

Classes			**Number of samples**
2	3	5	
Tested in each step			1
Trained in each step			248

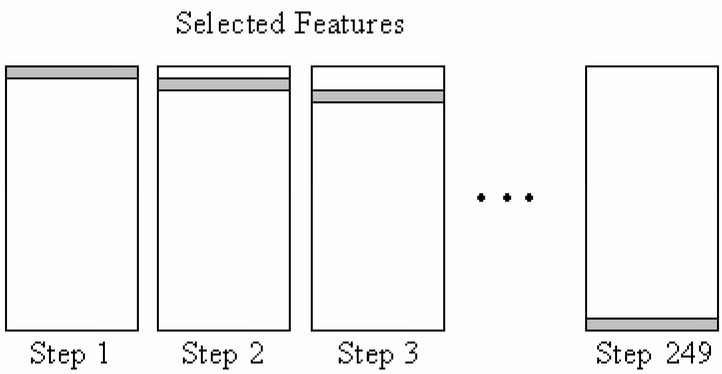

Figure 4.1 K-NN training method for 7 hours sleep recording. Grey parts show the tested features and white parts show the trained features. One sample is tested and the test sample is shifted one below in each step

Table 4.2 K-NN training method for 20 minutes sleep recording

Classes			Number of samples
2	3	5	
Tested in each step			1
Trained in each step			119

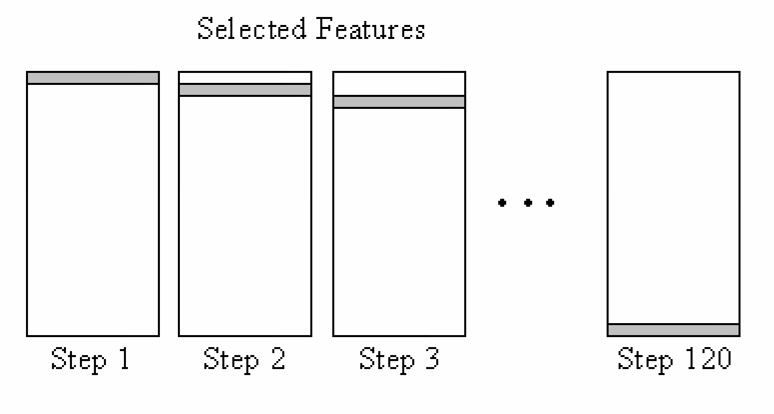

Figure 4.2 K-NN training method for 20 minutes sleep recording. Grey parts show the tested features and white parts show the trained features. One sample is tested and the test sample is shifted one below in each step.

4.1.2 K values

The k value is used for deciding the closest number of neighbors to look for when assigning an unlabeled example into a class. In this project classification is made with k values 1, 3, 5, 7, 9, 11, 13 and 15 for each sleep recording.

4.2 Multilayer Neural Network

Neural networks are usually stands for representing a circuit or network by using of biological neurons. Also they can be called as artificial neural networks in the literature. These constructions are based on neurons or nodes. In this project a Feed Forward Backpropagation Network is used. The number of input neurons of this network is based on the number selected features.

4.2.1 Training the data

In the training part of multilayer neural network classifier two methods are used as validation and cross-validation.

4.2.1.1 Validation method

In the training part of 7 hours sleep recording two different number of training samples 53 and 63 are used.

Table 4.3 Training method 1 for 7 hours sleep recording

Classes			**Number of samples**
2	3	5	
Tested in each step			30
Trained in each step			53

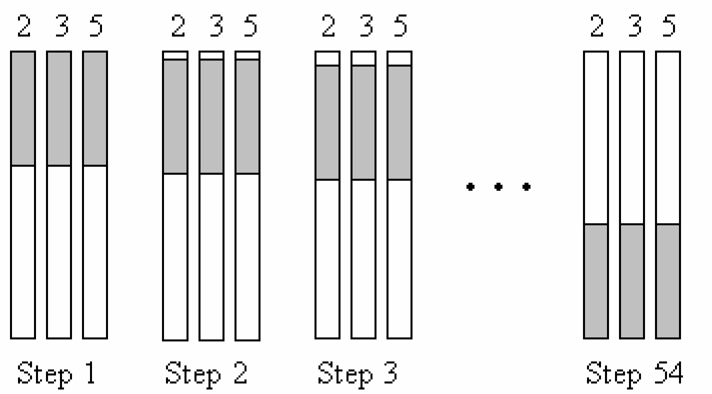

Figure 4.3 ANN training method for 7 hours sleep recording. Grey parts show the tested features and white parts show the trained features. 30 samples are tested and the test samples are shifted one below in each step.

Table 4.4 Training method 2 for 7 hours sleep recording

Classes			Number of samples
2	3	5	
Tested in each step			20
Trained in each step			63

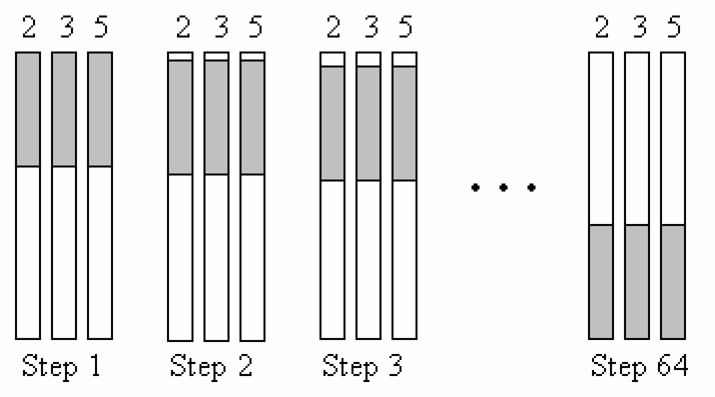

Figure 4.4 ANN training method for 7 hours sleep recording. Grey parts show the tested features and white parts show the trained features. 20 samples are tested and the test samples are shifted one below in each step.

The above tables and figures (table 4.3, table 4.4, figure 4.3 and figure 4.4) show the number of trained and tested samples for 7 hours sleep recording. If the test groups are shifted 1 sample below for each classification step, finally there will be 54 cycles for method 1 and 64 cycles for method 2. For each cycle the algorithm is run for 30 times. Then the averages of these results are calculated.

In the training part of 20 minutes sleep recording 30 samples from each class are used and all samples are trained in two step classification.

Table 4.5 Training method for 20 minutes sleep recording

Classes		Number of samples	Classes	Number of samples
3	5		2	
Trained		30	Trained	30
Tested		12	Tested	6

Table 4.5 shows the number of trained and tested samples for 20 minutes sleep recording. If the trained groups are shifted 1 sample below for 13 classification step, finally there will be used 13 different training and test groups for class 2 and 5 because of the unequal number of samples in class 3. For each step the algorithm is run for 30 times. Then the averages of these results are calculated.

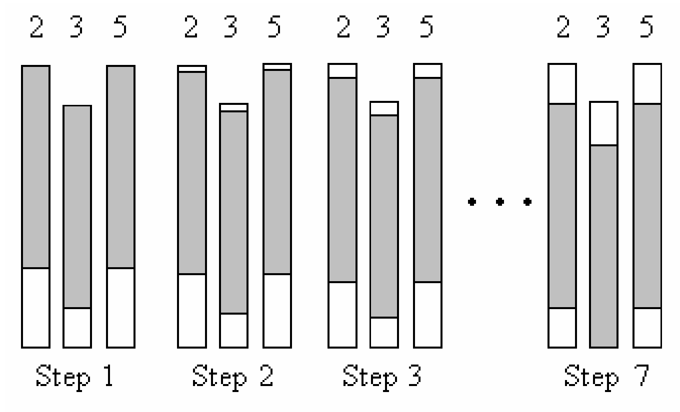

Figure 4.5 First part of ANN training method for 20 minutes sleep recording. Grey parts show the trained features and white parts show the tested features. 30 samples are trained and the trained samples are shifted one below in each step until the last samples are trained for class 3.

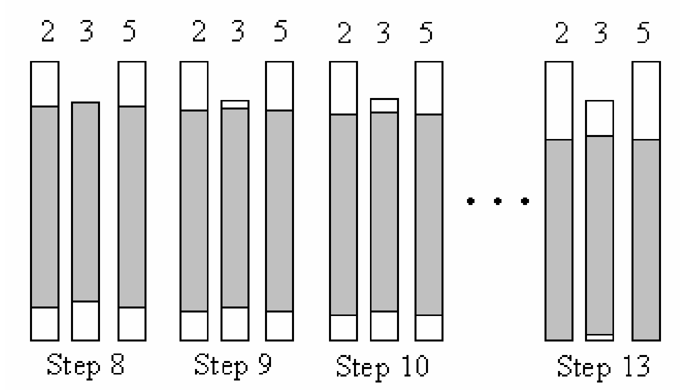

Figure 4.6 Second part of ANN training method for 20 minutes sleep recording. Grey parts show the trained features and white parts show the tested features. 30 samples are trained and the trained samples are shifted one below in each step until the last samples are trained for classes 2 and 5.

4.2.1.2 Cross-Validation method

In the training part with cross-validation method, randomly 90 test samples are selected for 7 hours sleep recording and 90 training samples are selected for 20 minutes sleep recording. For each training set, the algorithm is run 30 times as in validation method. This method is repeated for 30 steps, which produces 30 randomly selected test and train sets.

4.2.2 Number of neurons in hidden layer

When designing the multilayer neural network it is possible to define the number of neurons in the hidden layer as a changeable variable. In this project different numbers of neurons in the hidden layer are used and their effects on the classification process are observed. 2, 4, 6, 8, 10, 12 and 14 neurons are used in the hidden layer respectively.

4.2.3 Training epochs

Another changeable variable when designing a multilayer neural network is the number of training epochs. In this project different number of training epochs is used.

4.3 Linear Discriminant Analysis

As a last technique to classify a group of samples into predefined classes, linear discriminant analysis is used with SPSS. The main idea is using predictors or input variables to make a decision for the class of a sample. This technique can be constructed on the samples whose classes are given. By using the training set, this method can built a group of linear functions of the predictors or inputs. These linear functions can be called as discriminant functions. Then the new samples with unknown classes are classified by using discriminant functions.

In this project stepwise selection method is used. This method consists of two steps. First step is forward selection and the second step is the backward elimination. In the first step, firstly the independent variable with negative or positive highest correlation and the dependent variable are selected. Then the next variable is examined by F test if it has a zero coefficient or not. If the obtained F value is equal or less than the default F, the forward selection continues. If the value is bigger then the selection will stop. In the second step, all independent variables are selected which is different than the forward selection. The variable which has the lowest correlation coefficient is examined first. The variables which have bigger F values than the default F are eliminated.

CHAPTER FIVE
RESULTS

In this part the all the classification result are listed and these classifications are performed with some of the feature combinations explained in table 5.1.

Table 5.1 Feature combinations used in classification

Feature Combination	Content of the feature
1	All wavelet features (Features 26 to 38)
2	Hjorth parameters + Relative band energy ratios +Harmonic parameters (Features 1 to 25)
3	Feature Combination 1 + Feature Combination 2
4	Features 27, 28, 29, 33 detailed in table 3.6 and 3.7.
5	Features 28, 29, 30, 32, 34 detailed in table 3.6 and 3.7.

Feature combinations 4 and 5 are determined based on the result of feature selection method ttest. The results of the ttest method disclosed the most significance features in a row for each class separately. But when these selected features are used together in classification step, they could show different effects. It is also observed that the wavelet features are more effective when they are used together with the features in feature combination 2.

5.1 K-NN Classification

In table 5.2, all K-NN classification results with different K values for 20 minutes sleep recording are listed. The highest classification value is observed by using feature combination 4 explained in table 5.1 with K equals 7.

Table 5.2 K-NN classification result with different K values for 20 minutes sleep recording

Feature Combination	K values							
	1	**3**	**5**	**7**	**9**	**11**	**13**	**15**
1	64.2	65.8	67.5	59.2	61.7	67.5	61.7	64.2
2	51.7	53.3	52.5	58.3	58.3	57.5	59.2	59.2
3	51.7	53.3	52.5	58.3	58.3	57.5	59.2	59.2
4	64.2	65	64.2	70.8	70	68.3	67.5	65

In tables 5.3, 5.4, 5.5 and 5.6 details of each classification in counts and percents are listed for each class.

Table 5.3 Classification details for feature combination 1 with K=5 in table 5.2

Class		Predicted Group Membership			Total
		2	**3**	**5**	
Count	**2**	18	22	2	42
	3	12	24	0	36
	5	2	1	39	42
%	**2**	42.86	52.38	4.76	100
	3	33.33	66.67	0	100
	5	4.76	2.38	92.86	100

In table 5.3 classification details by using feature combination 1 with K equals 5 for each class are listed. Class 5 can be separated from other classes 2 and 3 with a percent of 92.86 but class 2 and class 3 mixed together.

Table 5.4 Classification details for feature combinations 2 and 3 with K=13 in table 5.2

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	12	25	5	42
	3	12	24	0	36
	5	3	4	35	42
%	**2**	28.57	59.52	11.91	100
	3	33.33	66.67	0	100
	5	7.14	9.52	83.34	100

In table 5.4 classification details by using feature combinations 2 and 3 with K equals 13 for each class are listed. Class 5 can be separated from other classes 2 and 3 with a percent of 83.34. However the classification results are less than the ones observed in the classification results using feature combination 1.Class 2 and class 3 mixed together again.

Table 5.5 Classification details for feature combination 2 and 3 with K=15 in table 5.2

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	14	23	5	42
	3	14	22	0	36
	5	3	4	35	42
%	**2**	33.33	54.76	11.91	100
	3	38.88	61.12	0	100
	5	7.14	9.52	83.34	100

In table 5.5 classification details by using feature combinations 2 and 3 with K equals 15 for each class are listed. The average result is the same as in table 5.4. The only difference is a small increase for classification of class 2 and a small decrease for classification of class 3.

Table 5.6 Classification details for feature combination 4 with K=7 in table 5.2

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	18	20	4	42
	3	7	29	0	36
	5	3	1	38	42
%	**2**	42.86	47.62	9.52	100
	3	19.44	80.5	0	100
	5	7.14	2.38	90.48	100

In table 5.6 the details of the highest k-NN classification results for 20 minutes sleep recording are listed. It can be observed that class 2 and class 3 are mixed together less than the other results.

In table 5.7, all K-NN classification results with different K values for 7 hours sleep recording are listed. The highest classification value is observed by using feature combination 5 explained in table 5.1 with K equals 5.

Table 5.7 K-NN classification result with different K values for 7 hours sleep recording

Feature Combination	**K values**							
	1	**3**	**5**	**7**	**9**	**11**	**13**	**15**
1	88	87.2	88	87.6	87.2	87.6	86.8	86.8
2	69.1	69.5	73.5	74.7	75.9	76.3	77.5	75.5
3	69.1	69.5	73.5	74.7	75.9	76.3	77.5	75.5
5	90.4	90.8	92	91.6	91.6	91.2	90.8	90

In tables 5.8, 5.9, 5.10 and 5.11 details of each classification in counts and percents are listed for each class.

Table 5.8 Classification details for feature combination 1 with K=1 in table 5.7

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	70	9	4	83
	3	8	75	0	83
	5	8	1	74	83
%	**2**	84.34	10.84	4.82	100
	3	9.64	90.36	0	100
	5	9.64	1.2	89.16	100

In table 5.8 classification details by using feature combination 1 with K equals 1 for each class are listed. It can be seen that by using the 7 hours sleep recording class 2 and class 3 can be separated much more than using 20 minutes sleep recording.

Table 5.9 Classification details for feature combination 1 with K=5 in table 5.7

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	72	10	1	83
	3	4	79	0	83
	5	14	1	68	83
%	**2**	86.75	12.05	1.2	100
	3	4.82	95.2	0	100
	5	16.87	1.2	81.93	100

In table 5.9 classification details by using feature combination 1 with K equals 5 for each class are listed. The average result is the same as in table 5.8. The only difference is a small increase for classification of classes 2 and 3 and a small decrease for classification of class 5.

Table 5.10 Classification details for feature combination 2 and 3 with K=13 in table 5.7

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	62	11	10	83
	3	4	79	0	83
	5	23	8	52	83
%	**2**	74.70	13.25	12.05	100
	3	4.82	95.2	0	100
	5	27.71	9.64	62.65	100

In table 5.10 classification details by using feature combinations 2 and 3 with K equals 13 for each class are listed. The result is the same for classification of class 3 with the previous one but there are decreases in the classification results of classes 2 and 5.

Table 5.11 Classification details for feature combination 4 with K=5 in table 5.7

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	72	8	3	83
	3	4	79	0	83
	5	5	0	78	83
%	**2**	86.75	9.64	3.61	100
	3	4.82	95.2	0	100
	5	6.02	0	93.88	100

In table 5.11 the details of the highest k-NN classification results for 7 hours sleep recording are listed. It can be observed that class 3 and class 5 are separated from each other totally.

5.2 Multilayer Neural Network Classification

In multilayer neural network classification part, feature combination 5 explained in table 5.1 is used. Classification is performed with validation and cross-validation methods.

5.2.1 Classification results with validation method

Number of the test samples is selected as 20 and 30 for 7 hours sleep recording. In table 5.12 and 5.13 average classification results of all steps for different number of neurons in the hidden layer are listed.

Table 5.12 Average of the all steps with 30 test samples and validation method for 7 hours sleep recording

Feature Combination	Number of neurons in the hidden layer					
	4	6	8	10	12	14
5	88.6	88.7	88.8	88.7	88.6	88.0

Table 5.13 Average of the all steps with 20 test samples and validation method for 7 hours sleep recording

Feature Combination	Number of neurons in the hidden layer					
	4	6	8	10	12	14
5	82.5	82.4	82.2	82.0	81.5	80.1

As the algorithm runs 30 times in each step, row Max. refers to the highest classification result for that step, and row Min. refers to the minimum classification result. AVG is the average of the 30 results of the classifier for each step.

Table 5.14 Classification results (%) with 30 test samples, 4 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 54											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	83.3	85.6	86.7	83.3	86.7	85.6	85.6	86.7	87.8	87.8	90.0
Min.	73.3	76.7	78.9	74.4	75.6	77.8	76.7	78.9	77.8	77.8	82.2
AVG	80.7	81.9	82.8	79.7	82.1	82.6	82.1	82.4	83.5	85.4	86.0
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	91.1	90.0	92.2	91.1	91.1	90.0	91.1	92.2	92.2	92.2	93.3
Min.	81.1	84.4	84.4	81.1	84.4	84.4	67.8	84.4	77.8	82.2	86.7
AVG	86.6	86.9	87.5	88.2	87.6	88.0	87.8	88.9	88.7	88.6	90.7
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	93.3	94.4	94.4	93.3	94.4	93.3	91.1	92.2	92.2	91.1	94.4
Min.	85.6	86.7	84.4	86.7	83.3	86.7	83.3	87.8	87.8	77.8	90.0
AVG	90.6	90.7	90.1	89.8	90.3	90.9	89.2	89.1	90.1	89.0	92.1
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	95.6	95.6	95.6	95.6	94.4	95.6	94.4	95.6	94.4	94.4	95.6
Min.	62.2	82.2	90.0	63.3	85.6	91.1	88.9	88.9	86.7	88.9	91.1
AVG	93.1	92.6	92.9	92.0	92.6	93.3	92.5	93.1	92.1	91.9	93.0
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	
Max.	93.3	93.3	93.3	93.3	91.1	94.4	94.4	93.3	91.1	92.2	
Min.	88.9	87.8	63.3	84.4	86.7	87.8	85.6	86.7	86.7	85.6	
AVG	90.9	90.8	88.3	90.0	89.4	90.1	88.3	88.8	88.5	88.1	

The total average of 54 classification steps with 30 test samples and 4 neurons in the hidden layer for 7 hours sleep recording is 88.6%. The highest average result of 30 classifications is observed at step 39 with 93.3%.

Table 5.15 Classification results (%) with 30 test samples, 6 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 54											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	84.4	84.4	87.8	83.3	85.6	86.7	85.6	85.6	87.8	90.0	88.9
Min.	75.6	78.9	78.9	74.4	78.9	80.0	77.8	80.0	73.3	82.2	80.0
AVG	80.9	82.1	82.4	79.3	82.6	82.6	82.1	82.7	83.0	85.4	85.6
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	91.1	90.0	92.2	91.1	92.2	91.1	92.2	92.2	92.2	93.3
Min.	85.6	82.2	84.4	85.6	83.3	83.3	85.6	86.7	86.7	84.4	86.7
AVG	87.6	86.7	87.7	88.1	87.5	88.4	88.3	89.2	89.4	88.5	89.9
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	94.4	93.3	94.4	92.2	93.3	93.3	92.2	91.1	92.2	91.1	94.4
Min.	87.8	85.6	85.6	84.4	86.7	85.6	84.4	86.7	86.7	87.8	88.9
AVG	90.7	90.6	91.1	89.2	90.5	90.6	88.9	88.9	90.0	89.6	92.2
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	95.6	94.4	94.4	95.6	95.6	95.6	95.6	95.6	95.6	94.4	95.6
Min.	91.1	90.0	90.0	90.0	88.9	91.1	86.7	90.0	88.9	88.9	88.9
AVG	94.1	92.4	92.9	92.9	93.4	93.4	92.6	93.1	92.3	92.3	92.8
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	
Max.	94.4	92.2	93.3	92.2	92.2	93.3	92.2	91.1	91.1	92.2	
Min.	88.9	87.8	86.7	85.6	86.7	86.7	85.6	86.7	85.6	85.6	
AVG	91.6	90.7	90.0	89.5	89.4	90.0	87.8	88.8	88.4	88.4	

The total average of 54 classification steps with 30 test samples and 6 neurons in the hidden layer for 7 hours sleep recording is 88.7%. The highest average result of 30 classifications is observed at step 34 with 94.1%.

Table 5.16 Classification results (%) with 30 test sample, 8 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 54											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	84.4	85.6	84.4	83.3	84.4	84.4	85.6	85.6	86.7	88.9	88.9
Min.	77.8	77.8	76.7	75.6	78.9	78.9	77.8	80.0	78.9	82.2	81.1
AVG	81.7	81.7	81.6	79.5	81.6	82.3	81.9	82.4	83.3	85.7	85.6
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	90.0	90.0	91.1	90.0	91.1	91.1	93.3	92.2	93.3	93.3
Min.	83.3	84.4	84.4	84.4	84.4	83.3	85.6	83.3	86.7	85.6	84.4
AVG	87.3	86.8	87.5	88.2	87.7	88.4	89.2	89.7	89.5	89.6	90.4
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	94.4	93.3	93.3	91.1	93.3	93.3	91.1	91.1	91.1	91.1	93.3
Min.	86.7	87.8	87.8	86.7	86.7	86.7	86.7	84.4	84.4	86.7	87.8
AVG	90.7	90.5	90.3	89.3	90.1	91.3	89.1	88.7	89.4	89.5	91.5
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	95.6	95.6	95.6	95.6	94.4	95.6	94.4	95.6	94.4	94.4	94.4
Min.	88.9	90.0	90.0	90.0	90.0	88.9	90.0	88.9	88.9	88.9	88.9
AVG	93.9	93.1	93.3	93.2	93.1	93.1	93.0	93.1	92.1	92.4	92.4
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	
Max.	96.7	93.3	91.1	92.2	92.2	94.4	92.2	92.2	93.3	92.2	
Min.	87.8	88.9	87.8	86.7	86.7	85.6	86.7	85.6	85.6	85.6	
AVG	91.4	91.2	90.0	89.9	89.7	89.8	89.0	89.1	89.0	89.2	

The total average of 54 classification steps with 30 test samples and 8 neurons in the hidden layer for 7 hours sleep recording is 88.8%. The highest average result of 30 classifications is observed at step 34 with 93.9%.

Table 5.17 Classification results (%) with 30 test sample, 10 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 54											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	85.6	84.4	86.7	83.3	86.7	85.6	84.4	86.7	86.7	88.9	90.0
Min.	76.7	78.9	76.7	76.7	77.8	77.8	80.0	78.9	80.0	81.1	83.3
AVG	81.5	81.6	81.3	80.1	82.2	81.6	82.6	82.9	83.5	85.5	86.3
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	90.0	92.2	90.0	90.0	91.1	91.1	92.2	93.3	92.2	93.3
Min.	84.4	83.3	84.4	83.3	83.3	86.7	85.6	85.6	85.6	86.7	86.7
AVG	87.5	86.9	87.9	87.6	87.2	88.4	88.7	89.1	88.9	88.9	89.7
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	92.2	93.3	94.4	92.2	92.2	93.3	93.3	91.1	91.1	92.2	95.6
Min.	86.7	87.8	87.8	84.4	85.6	86.7	86.7	86.7	86.7	86.7	87.8
AVG	90.2	90.3	90.6	88.9	90.3	90.8	89.7	88.7	89.6	89.3	92.1
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	96.7	95.6	95.6	94.4	94.4	94.4	94.4	94.4	94.4	94.4	94.4
Min.	91.1	90.0	91.1	91.1	88.9	90.0	90.0	88.9	87.8	90.0	88.9
AVG	93.7	93.4	92.8	93.3	92.4	92.4	92.9	92.8	91.9	92.0	92.2
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	
Max.	93.3	93.3	92.2	92.2	92.2	92.2	92.2	92.2	91.1	92.2	
Min.	90.0	88.9	88.9	87.8	85.6	85.6	86.7	85.6	86.7	84.4	
AVG	91.4	90.9	90.0	89.7	89.9	89.4	89.1	89.4	88.4	88.8	

The total average of 54 classification steps with 30 test samples and 10 neurons in the hidden layer for 7 hours sleep recording is 88.7%. The highest average result of 30 classifications is observed at step 34 with 93.7%.

Table 5.18 Classification results (%) with 30 test sample, 12 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 54											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	85.6	84.4	84.4	83.3	86.7	84.4	84.4	84.4	86.7	88.9	90.0
Min.	78.9	77.8	77.8	75.6	76.7	80.0	78.9	75.6	80.0	83.3	82.2
AVG	81.8	82.3	81.1	79.3	81.4	82.4	81.7	82.0	83.6	85.8	85.6
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	90.0	91.1	91.1	91.1	93.3	91.1	93.3	93.3	92.2	92.2
Min.	83.3	80.0	84.4	83.3	84.4	84.4	82.2	85.6	84.4	85.6	86.7
AVG	87.3	86.3	87.3	87.7	87.0	88.4	88.6	89.4	89.4	89.4	89.9
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	92.2	92.2	93.3	92.2	92.2	92.2	92.2	91.1	92.2	92.2	94.4
Min.	86.7	86.7	86.7	85.6	87.8	85.6	83.3	86.7	86.7	85.6	87.8
AVG	90.2	90.0	90.5	89.0	90.3	90.0	89.1	89.0	89.3	89.3	91.5
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	96.7	95.6	94.4	94.4	94.4	94.4	95.6	95.6	94.4	94.4	95.6
Min.	90.0	88.9	90.0	90.0	90.0	88.9	88.9	90.0	86.7	90.0	88.9
AVG	93.3	93.3	92.7	93.1	92.5	92.7	92.8	92.5	92.1	92.1	92.4
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	
Max.	93.3	93.3	92.2	93.3	92.2	92.2	91.1	93.3	92.2	92.2	
Min.	88.9	90.0	87.8	85.6	85.6	85.6	85.6	85.6	86.7	85.6	
AVG	91.5	91.4	89.6	89.4	89.6	89.9	89.0	88.6	89.5	89.2	

The total average of 54 classification steps with 30 test samples and 12 neurons in the hidden layer for 7 hours sleep recording is 88.6%. The highest average result of 30 classifications is observed at steps 34 and 35 with 93.3%.

Table 5.19 Classification results (%) with 30 test sample, 14 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 54											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	85.6	85.6	86.7	82.2	85.6	86.7	84.4	85.6	86.7	87.8	90.0
Min.	67.8	70.0	73.3	76.7	76.7	52.2	36.7	68.9	73.3	71.1	61.1
AVG	80.7	81.6	80.9	79.4	81.3	80.3	79.4	81.2	82.2	83.9	84.3
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	88.9	91.1	91.1	90.0	91.1	91.1	92.2	92.2	92.2	91.1
Min.	44.4	57.8	61.1	84.4	71.1	85.6	81.1	66.7	76.7	67.8	86.7
AVG	84.6	84.6	86.0	87.5	86.5	88.6	88.0	87.9	88.8	87.8	89.7
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	93.3	93.3	92.2	92.2	93.3	94.4	92.2	91.1	92.2	92.2	94.4
Min.	72.2	52.2	86.7	85.6	52.2	86.7	85.6	85.6	87.8	86.7	82.2
AVG	88.9	89.2	89.5	89.0	88.8	90.2	89.0	88.8	89.6	89.4	91.0
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	95.6	95.6	95.6	94.4	94.4	95.6	96.7	95.6	95.6	94.4	94.4
Min.	57.8	91.1	84.4	85.6	86.7	86.7	90.0	88.9	87.8	88.9	86.7
AVG	91.4	93.1	93.2	92.6	92.5	92.8	92.9	92.8	92.1	92.2	91.6
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	
Max.	94.4	93.3	93.3	92.2	93.3	93.3	92.2	92.2	93.3	91.1	
Min.	86.7	87.8	58.9	84.4	86.7	85.6	86.7	66.7	68.9	83.3	
AVG	91.3	91.1	89.0	89.6	90.4	89.6	88.6	88.3	88.3	88.3	

The total average of 54 classification steps with 30 test samples and 14 neurons in the hidden layer for 7 hours sleep recording is 88.0%. The highest average result of 30 classifications is observed at step 36 with 93.2%

Table 5.20 Classification results (%) with 20 test samples, 4 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 64											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	81.7	81.7	83.3	81.7	80.0	80.0	81.7	80.0	78.3	80.0	81.7
Min.	68.3	66.7	68.3	68.3	70.0	70.0	73.3	73.3	71.7	65.0	71.7
AVG	73.1	74.2	74.1	74.3	74.7	75.2	76.7	75.7	75.6	76.4	76.9
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	81.7	85.0	85.0	83.3	83.3	86.7	83.3	85.0	90.0	88.3	86.7
Min.	71.7	70.0	70.0	73.3	70.0	73.3	68.3	71.7	71.7	63.3	75.0
AVG	76.1	75.1	76.4	78.6	78.6	81.2	78.3	80.9	81.3	82.9	82.4
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	86.7	85.0	86.7	88.3	88.3	90.0	86.7	86.7	85.0	88.3	88.3
Min.	76.7	61.7	76.7	78.3	61.7	80.0	80.0	58.3	75.0	78.3	78.3
AVG	82.3	79.8	81.9	82.9	83.2	83.9	83.3	81.8	81.0	84.1	84.9
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	90.0	91.7	91.7	90.0	93.3	90.0	88.3	88.3	88.3	90.0	90.0
Min.	80.0	80.0	81.7	63.3	80.0	80.0	76.7	78.3	75.0	80.0	73.3
AVG	86.5	85.4	86.3	85.9	86.8	84.2	83.4	83.7	83.7	84.8	85.8
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
Max.	90.0	91.7	90.0	90.0	91.7	93.3	93.3	93.3	93.3	93.3	91.7
Min.	81.7	81.7	76.7	80.0	83.3	86.7	61.7	85.0	60.0	85.0	83.3
AVG	87.4	87.3	86.5	86.6	88.7	91.1	90.9	89.3	87.3	89.0	87.1
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**		
Max.	91.7	90.0	91.7	90.0	93.3	91.7	91.7	91.7	91.7		
Min.	81.7	80.0	75.0	73.3	76.7	78.3	60.0	76.7	80.0		
AVG	87.2	86.1	83.8	83.1	84.8	84.2	83.3	84.6	85.8		

The total average of 64 classification steps with 20 test samples and 4 neurons in the hidden layer for 7 hours sleep recording is 82.5%. The highest average result of 30 classifications is observed at step 50 with 91.1%.

Table 5.21 Classification results (%) with 20 test samples, 6 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 64											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	78.3	81.7	81.7	81.7	83.3	80.0	80.0	78.3	78.3	80.0	81.7
Min.	63.3	63.3	68.3	68.3	70.0	70.0	73.3	70.0	71.7	73.3	66.7
AVG	70.8	73.9	74.0	74.1	75.0	73.9	75.7	75.2	75.1	76.9	76.1
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	83.3	83.3	85.0	81.7	83.3	85.0	83.3	85.0	85.0	88.3	88.3
Min.	71.7	66.7	71.7	70.0	73.3	75.0	68.3	71.7	71.7	78.3	78.3
AVG	76.2	75.5	77.5	76.6	79.4	80.2	77.3	79.7	80.3	82.6	83.1
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	86.7	86.7	86.7	86.7	90.0	90.0	90.0	86.7	88.3	88.3	88.3
Min.	76.7	73.3	76.7	76.7	75.0	80.0	75.0	76.7	76.7	78.3	81.7
AVG	80.6	80.3	82.6	82.6	83.1	84.8	83.5	81.7	82.2	83.3	84.8
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	91.7	90.0	90.0	90.0	90.0	88.3	88.3	90.0	88.3	90.0	90.0
Min.	76.7	80.0	63.3	83.3	83.3	78.3	76.7	78.3	78.3	81.7	80.0
AVG	85.9	85.2	84.8	86.9	86.5	85.3	82.4	83.3	84.1	86.0	86.4
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
Max.	90.0	91.7	91.7	91.7	91.7	95.0	93.3	93.3	93.3	93.3	91.7
Min.	81.7	81.7	81.7	83.3	85.0	83.3	83.3	80.0	76.7	83.3	78.3
AVG	86.9	88.3	87.4	86.7	88.6	90.1	90.8	90.2	88.1	88.9	87.3
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**		
Max.	91.7	91.7	90.0	90.0	90.0	91.7	90.0	90.0	90.0		
Min.	81.7	83.3	80.0	76.7	81.7	78.3	76.7	78.3	78.3		
AVG	87.3	86.7	84.7	83.1	85.8	84.3	84.2	85.2	84.3		

The total average of 64 classification steps with 20 test samples and 6 neurons in the hidden layer for 7 hours sleep recording is 82.4%. The highest average result of 30 classifications is observed at step 51 with 90.8%.

Table 5.22 Classification results (%) with 20 test samples, 8 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 64											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	80.0	81.7	83.3	80.0	80.0	81.7	81.7	80.0	80.0	80.0	81.7
Min.	60.0	66.7	65.0	71.7	71.7	70.0	71.7	71.7	71.7	71.7	70.0
AVG	71.6	72.1	72.7	74.4	74.8	75.1	76.4	75.1	75.0	76.2	76.1
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	80.0	83.3	80.0	81.7	83.3	88.3	83.3	86.7	86.7	86.7	88.3
Min.	71.7	68.3	71.7	71.7	73.3	73.3	70.0	73.3	71.7	76.7	80.0
AVG	75.7	75.7	75.7	77.5	78.8	80.6	79.7	80.3	80.3	82.1	83.6
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	88.3	85.0	86.7	88.3	88.3	88.3	88.3	86.7	85.0	86.7	88.3
Min.	76.7	76.7	73.3	76.7	78.3	76.7	78.3	76.7	75.0	78.3	78.3
AVG	81.8	80.7	82.0	82.1	82.7	83.2	83.2	81.6	80.1	83.1	85.2
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	90.0	88.3	90.0	91.7	91.7	91.7	88.3	90.0	88.3	88.3	90.0
Min.	76.7	81.7	81.7	81.7	81.7	81.7	75.0	78.3	80.0	80.0	80.0
AVG	85.2	85.9	85.6	86.5	86.9	86.4	83.3	83.3	84.6	84.6	86.7
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
Max.	90.0	91.7	90.0	91.7	91.7	95.0	93.3	95.0	93.3	93.3	93.3
Min.	76.7	80.0	81.7	78.3	80.0	85.0	85.0	85.0	78.3	78.3	80.0
AVG	85.7	87.5	87.3	86.2	87.9	90.4	91.0	89.6	87.1	88.8	86.8
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**		
Max.	91.7	90.0	90.0	90.0	91.7	88.3	91.7	88.3	91.7		
Min.	83.3	78.3	73.3	78.3	76.7	78.3	78.3	78.3	76.7		
AVG	86.7	85.8	82.9	83.1	85.4	83.9	83.9	84.2	84.8		

The total average of 64 classification steps with 20 test samples and 8 neurons in the hidden layer for 7 hours sleep recording is 82.2%. The highest average result of 30 classifications is observed at step 51 with 91.0%.

Table 5.23 Classification results (%) with 20 test samples, 10 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 64											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	80.0	81.7	76.7	81.7	80.0	78.3	81.7	78.3	80.0	80.0	83.3
Min.	61.7	68.3	68.3	68.3	70.0	68.3	71.7	71.7	70.0	71.7	70.0
AVG	71.4	72.7	72.1	73.3	74.7	73.6	76.2	75.7	75.9	76.2	76.2
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	80.0	78.3	81.7	80.0	83.3	85.0	85.0	88.3	86.7	88.3	88.3
Min.	70.0	70.0	71.7	71.7	71.7	71.7	73.3	75.0	71.7	75.0	76.7
AVG	75.9	74.3	77.1	76.8	77.8	79.6	78.4	80.7	79.7	82.6	82.4
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	86.7	85.0	86.7	88.3	86.7	88.3	90.0	85.0	85.0	90.0	90.0
Min.	76.7	75.0	76.7	73.3	75.0	75.0	76.7	75.0	71.7	78.3	76.7
AVG	82.2	80.4	81.7	82.3	81.7	83.5	83.3	80.4	80.6	82.9	85.5
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	90.0	91.7	90.0	90.0	91.7	88.3	88.3	88.3	88.3	90.0	91.7
Min.	80.0	78.3	81.7	81.7	81.7	80.0	76.7	80.0	80.0	80.0	80.0
AVG	86.4	84.9	84.5	86.2	86.2	84.4	83.4	83.1	84.2	84.4	86.4
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
Max.	91.7	91.7	91.7	90.0	93.3	93.3	93.3	93.3	93.3	93.3	90.0
Min.	81.7	78.3	83.3	81.7	78.3	85.0	83.3	83.3	78.3	81.7	75.0
AVG	86.1	87.2	87.3	86.2	88.5	89.9	91.0	89.9	87.7	87.9	85.3
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**		
Max.	90.0	90.0	88.3	91.7	91.7	91.7	90.0	90.0	90.0		
Min.	80.0	80.0	76.7	76.7	76.7	78.3	78.3	75.0	81.7		
AVG	86.2	86.3	82.8	82.6	84.8	84.8	84.7	83.3	85.1		

The total average of 64 classification steps with 20 test samples and 10 neurons in the hidden layer for 7 hours sleep recording is 82.0%. The highest average result of 30 classifications is observed at step 51 with 91.0%.

Table 5.24 Classification results (%) with 20 test samples, 12 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 64											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	78.3	81.7	80.0	80.0	80.0	78.3	80.0	76.7	80.0	80.0	81.7
Min.	61.7	66.7	68.3	68.3	66.7	70.0	70.0	71.7	71.7	70.0	70.0
AVG	70.1	71.9	71.9	73.4	73.4	73.6	75.4	74.9	75.2	75.6	76.2
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	81.7	83.3	81.7	80.0	83.3	86.7	83.3	85.0	85.0	86.7	88.3
Min.	70.0	70.0	68.3	68.3	71.7	73.3	70.0	73.3	73.3	75.0	76.7
AVG	75.3	75.4	75.2	75.8	78.0	80.6	77.1	79.4	79.3	81.6	81.9
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	86.7	83.3	85.0	88.3	88.3	88.3	88.3	86.7	85.0	88.3	91.7
Min.	75.0	76.7	75.0	78.3	75.0	78.3	75.0	73.3	71.7	76.7	78.3
AVG	80.6	79.8	81.2	82.7	81.4	83.3	82.3	80.8	79.9	82.9	84.7
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	90.0	88.3	90.0	90.0	90.0	88.3	86.7	86.7	86.7	90.0	90.0
Min.	81.7	81.7	81.7	83.3	80.0	78.3	76.7	78.3	80.0	80.0	81.7
AVG	85.8	85.1	85.3	85.7	85.8	84.2	82.9	82.3	83.4	85.0	85.9
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
Max.	90.0	90.0	93.3	91.7	91.7	93.3	95.0	93.3	93.3	91.7	91.7
Min.	80.0	83.3	81.7	75.0	83.3	81.7	83.3	83.3	81.7	75.0	75.0
AVG	86.3	87.1	86.3	85.1	88.0	88.8	90.0	89.1	86.6	87.0	85.9
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**		
Max.	91.7	91.7	90.0	88.3	91.7	90.0	90.0	88.3	88.3		
Min.	76.7	80.0	75.0	76.7	78.3	80.0	76.7	76.7	80.0		
AVG	84.9	85.3	82.8	83.3	85.1	83.9	84.1	82.8	84.4		

The total average of 64 classification steps with 20 test samples and 12 neurons in the hidden layer for 7 hours sleep recording is 81.5%. The highest average result of 30 classifications is observed at step 51 with 90.0%.

Table 5.25 Classification results (%) with 20 test samples, 14 neurons in the hidden layer with validation method for 7 hours sleep recording

Classification results for each step, 1 to 64											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	76.7	76.7	76.7	80.0	76.7	78.3	80.0	80.0	80.0	80.0	81.7
Min.	60.0	65.0	53.3	68.3	68.3	65.0	68.3	70.0	70.0	38.3	71.7
AVG	69.9	71.2	71.2	73.8	73.0	72.6	75.1	74.8	75.5	74.3	76.6
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	80.0	78.3	83.3	83.3	81.7	85.0	86.7	85.0	85.0	88.3	90.0
Min.	70.0	68.3	61.7	36.7	70.0	61.7	46.7	65.0	71.7	75.0	71.7
AVG	75.4	74.0	75.2	75.7	77.7	78.8	75.0	79.2	79.7	81.6	82.4
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Max.	83.3	85.0	88.3	86.7	86.7	86.7	88.3	85.0	85.0	90.0	88.3
Min.	73.3	66.7	76.7	68.3	41.7	70.0	53.3	33.3	70.0	33.3	33.3
AVG	80.3	79.7	81.4	80.6	79.7	81.5	81.2	77.3	80.3	80.4	82.0
	34	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Max.	90.0	88.3	88.3	90.0	88.3	88.3	86.7	86.7	86.7	90.0	91.7
Min.	75.0	76.7	76.7	71.7	83.3	60.0	70.0	76.7	78.3	78.3	80.0
AVG	84.1	84.2	82.9	84.5	85.6	83.3	81.6	82.3	82.3	85.1	85.6
	45	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
Max.	90.0	90.0	93.3	90.0	91.7	95.0	95.0	93.3	95.0	93.3	91.7
Min.	78.3	71.7	78.3	61.7	40.0	38.3	81.7	61.7	41.7	78.3	58.3
AVG	85.6	85.4	86.6	84.9	85.1	87.6	90.1	87.0	86.1	86.3	84.6
	56	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**		
Max.	91.7	91.7	90.0	90.0	93.3	88.3	91.7	88.3	90.0		
Min.	35.0	43.3	40.0	73.3	76.7	80.0	53.3	76.7	81.7		
AVG	83.7	84.6	81.1	82.0	85.0	83.9	82.1	84.0	85.3		

The total average of 64 classification steps with 20 test samples and 14 neurons in the hidden layer for 7 hours sleep recording is 80.1%. The highest average result of 30 classifications is observed at step 51 with 90.1%.

Number of the trained samples is selected as 30 for each class when 20 minutes sleep recording is used. Remaining samples are used for testing the classifier. 12 test samples are used for class 2 and class 5 and 6 test samples are used for class 3. In table 5.26 average classification results of all steps for different number of neurons in the hidden layer are listed.

Table 5.26 Average of the all steps with 30 trained samples and validation method for 20 minutes sleep recording

Feature Combination	Number of neurons in the hidden layer					
	4	6	8	10	12	14
1	73.3	72.2	71.8	71.2	71.7	71.1

Table 5.27 Classification results (%) with 30 trained samples, 4 neurons in the hidden layer with validation method for 20 minutes sleep recording

Classification results for each step. 1 to 13							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Max.	76.7	76.7	76.7	76.7	76.7	76.7	76.7
Min.	63.3	60.0	70.0	66.7	56.7	66.7	63.3
AVG	72.6	73.0	73.3	72.9	71.4	72.3	72.6
	8	**9**	**10**	**11**	**12**	**13**	
Max.	76.7	80.0	80.0	76.7	76.7	73.3	
Min.	63.3	66.7	70.0	70.0	73.3	70.0	
AVG	73.7	73.3	74.1	75.2	75.2	72.9	

The total average of 13 classification steps with 30 trained samples and 4 neurons in the hidden layer for 20 minutes sleep recording is 73.3%. The highest average result of 30 classifications is observed at steps 11 and 12 with 75.2%.

Table 5.28 Classification results (%) with 30 trained samples, 6 neurons in the hidden layer with validation method for 20 minutes sleep recording

Classification results for each step. 1 to 13							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Max.	76.7	76.7	76.7	76.7	76.7	76.7	76.7
Min.	66.7	66.7	70.0	63.3	60.0	63.3	60.0
AVG	72.4	73.3	73.9	71.7	71.2	71.9	71.0
	8	**9**	**10**	**11**	**12**	**13**	
Max.	76.7	80.0	80.0	76.7	76.7	73.3	
Min.	73.3	70.0	66.7	70.0	73.3	73.3	
AVG	74.1	74.2	73.6	74.1	75.2	73.3	

The total average of 13 classification steps with 30 trained samples and 6 neurons in the hidden layer for 20 minutes sleep recording is 72.2%. The highest average result of 30 classifications is observed at step 12 with 75.2%.

Table 5.29 Classification results (%) with 30 trained samples, 8 neurons in the hidden layer with validation method for 20 minutes sleep recording

Classification results for each step. 1 to 13							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Max.	76.7	76.7	76.7	76.7	76.7	76.7	76.7
Min.	63.3	66.7	66.7	63.3	60.0	63.3	63.3
AVG	71.4	71.9	73.4	71.7	70.7	71.8	71.9
	8	**9**	**10**	**11**	**12**	**13**	
Max.	76.7	80.0	76.7	76.7	76.7	73.3	
Min.	70.0	63.3	66.7	70.0	70.0	70.0	
AVG	74.2	72.2	74.2	74.1	75.4	73.1	

The total average of 13 classification steps with 30 trained samples and 8 neurons in the hidden layer for 20 minutes sleep recording is 71.8%. The highest average result of 30 classifications is observed at step 12 with 75.4%.

Table 5.30 Classification results (%) with 30 trained samples, 10 neurons in the hidden layer with validation method for 20 minutes sleep recording

Classification results for each step. 1 to 13							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Max.	76.7	76.7	76.7	76.7	76.7	76.7	76.7
Min.	66.7	66.7	70.0	66.7	60.0	66.7	60.0
AVG	72.0	71.8	72.7	71.8	68.3	71.3	70.8
	8	**9**	**10**	**11**	**12**	**13**	
Max.	76.7	80.0	80.0	80.0	76.7	76.7	
Min.	73.3	66.7	66.7	70.0	70.0	70.0	
AVG	74.4	74.1	73.8	74.1	75.4	73.2	

The total average of 13 classification steps with 30 trained samples and 10 neurons in the hidden layer for 20 minutes sleep recording is 71.2%. The highest average result of 30 classifications is observed at step 12 with 75.4%.

Table 5.31 Classification results (%) with 30 trained samples, 12 neurons in the hidden layer with validation method for 20 minutes sleep recording

Classification results for each step. 1 to 13							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Max.	76.7	76.7	76.7	76.7	76.7	76.7	76.7
Min.	56.7	63.3	66.7	66.7	63.3	63.3	63.3
AVG	71.2	72.8	72.7	72.0	71.1	71.7	70.7
	8	**9**	**10**	**11**	**12**	**13**	
Max.	76.7	76.7	76.7	76.7	76.7	73.3	
Min.	70.0	66.7	70.0	70.0	70.0	73.3	
AVG	74.3	73.2	74.3	73.9	74.7	73.3	

The total average of 13 classification steps with 30 trained samples and 12 neurons in the hidden layer for 20 minutes sleep recording is 71.7%. The highest average result of 30 classifications is observed at step 12 with 74.7%.

Table 5.32 Classification results (%) with 30 trained samples, 14 neurons in the hidden layer with validation method for 20 minutes sleep recording

Classification results for each step. 1 to 13							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Max.	76.7	76.7	76.7	76.7	76.7	76.7	76.7
Min.	63.3	66.7	63.3	60.0	60.0	66.7	66.7
AVG	70.9	72.4	72.2	69.9	69.3	71.7	71.0
	8	**9**	**10**	**11**	**12**	**13**	
Max.	80.0	76.7	76.7	76.7	76.7	76.7	
Min.	70.0	70.0	66.7	70.0	70.0	66.7	
AVG	75.0	73.3	73.9	74.8	74.8	72.6	

The total average of 13 classification steps with 30 trained samples and 14 neurons in the hidden layer for 20 minutes sleep recording is 71.1%. The highest average result of 30 classifications is observed at step 12 with 74.8%.

5.2.2 Classification results with cross-validation method

Number of the test samples which are randomly defined is selected as 30 for 7 hours sleep recording. In table 5.33, average classification results of all steps for different number of neurons in the hidden layer are listed.

Table 5.33 Average of all 30 steps with 30 test samples and cross-validation method for 7 hours sleep recording

Feature Combination	Number of neurons in the hidden layer					
	4	**6**	**8**	**10**	**12**	**14**
5	85.5	87.3	86.6	86.4	87.5	87.1

Table 5.34 Classification results (%) with 30 test sample, 4 neurons in the hidden layer with cross-validation method for 7 hours sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	92.2	88.9	93.3	91.1	86.7	90.0	88.9	88.9	87.8	90.0	81.1
Min.	85.6	35.6	85.6	78.9	61.1	82.2	58.9	36.7	63.3	46.7	71.1
AVG	90.0	83.0	90.2	85.7	83.1	86.8	84.4	85.1	84.0	85.3	79.2
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	91.1	95.6	91.1	86.7	87.8	93.3	93.3	93.3	92.2	93.3	87.8
Min.	82.2	80.0	66.7	37.8	46.7	58.9	82.2	58.9	63.3	82.2	57.8
AVG	86.3	91.1	87.7	80.9	81.5	88.1	89.2	88.0	87.4	89.0	83.5
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	90.0	87.8	90.0	92.2	86.7	90.0	91.1	86.7			
Min.	63.3	55.6	57.8	86.7	57.8	55.6	85.6	76.7			
AVG	85.2	82.5	82.4	89.5	82.8	83.9	87.9	82.7			

Table 5.35 Classification results (%) with 30 test sample, 6 neurons in the hidden layer with cross-validation method for 7 hours sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	87.8	87.8	88.9	92.2	94.4	91.1	92.2	90.0	94.4	88.9	91.1
Min.	81.1	78.9	81.1	86.7	84.4	78.9	66.7	83.3	85.6	81.1	82.2
AVG	84.6	83.3	84.8	89.4	90.5	84.8	87.5	85.9	91.0	85.9	86.8
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	94.4	90.0	91.1	94.4	92.2	88.9	90.0	90.0	92.2	90.0
Min.	72.2	84.4	81.1	81.1	87.8	82.2	73.3	84.4	83.3	84.4	73.3
AVG	85.5	88.6	86.9	86.7	91.7	86.7	85.0	87.3	86.4	88.2	83.3
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	94.4	90.0	93.3	93.3	91.1	90.0	92.2	95.6			
Min.	84.4	81.1	88.9	86.7	81.1	81.1	78.9	83.3			
AVG	90.5	85.8	91.4	90.6	86.6	85.4	86.0	91.4			

Table 5.36 Classification results (%) with 30 test sample, 8 neurons in the hidden layer with cross-validation method for 7 hours sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	86.7	92.2	92.2	93.3	90.0	85.6	87.8	96.7	91.1	93.3	92.2
Min.	78.9	84.4	80.0	87.8	81.1	74.4	82.2	85.6	84.4	86.7	84.4
AVG	83.1	88.3	86.6	90.6	85.8	78.1	85.4	89.9	88.5	89.9	90.0
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	92.2	92.2	93.3	88.9	88.9	92.2	88.9	88.9	92.2	93.3	90.0
Min.	80.0	84.4	83.3	83.3	80.0	84.4	81.1	75.6	82.2	80.0	81.1
AVG	88.0	89.8	89.9	86.0	83.3	88.3	84.7	84.7	87.0	85.9	85.4
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	91.1	90.0	93.3	85.6	93.3	85.6	90.0	93.3			
Min.	82.2	82.2	83.3	78.9	82.2	75.6	74.4	87.8			
AVG	87.4	86.4	88.9	82.3	87.8	80.7	83.7	90.8			

Table 5.37 Classification results (%) with 30 test sample, 10 neurons in the hidden layer with cross-validation method for 7 hours sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	91.1	85.6	91.1	91.1	87.8	90.0	92.2	96.7	90.0	91.1	91.1
Min.	80.0	77.8	84.4	83.3	80.0	81.1	82.2	86.7	83.3	75.6	84.4
AVG	85.1	81.6	87.7	88.1	84.1	84.7	86.5	92.0	87.6	85.6	87.3
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	92.2	88.9	87.8	88.9	91.1	88.9	87.8	95.6	92.2	92.2	88.9
Min.	81.1	78.9	72.2	78.9	76.7	81.1	82.2	88.9	84.4	83.3	73.3
AVG	86.7	85.1	83.9	83.4	87.7	84.5	85.8	92.0	87.6	87.7	84.1
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	88.9	91.1	94.4	87.8	88.9	91.1	91.1	91.1			
Min.	77.8	83.3	86.7	74.4	82.2	83.3	82.2	83.3			
AVG	84.7	87.5	91.0	82.6	86.7	87.1	87.4	87.3			

Table 5.38 Classification results (%) with 30 test sample, 12 neurons in the hidden layer with cross-validation method for 7 hours sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	91.1	88.9	92.2	85.6	91.1	90.0	90.0	94.4	84.4	92.2	90.0
Min.	76.7	83.3	84.4	78.9	83.3	83.3	82.2	85.6	76.7	81.1	82.2
AVG	87.3	86.7	89.4	82.1	86.4	87.9	87.6	91.6	81.6	88.3	86.4
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	91.1	88.9	93.3	95.6	91.1	91.1	91.1	96.7	88.9	92.2	90.0
Min.	82.2	78.9	86.7	80.0	83.3	84.4	78.9	90.0	77.8	81.1	80.0
AVG	88.7	84.5	89.7	91.3	87.9	87.6	88.4	93.4	85.4	88.1	85.5
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	92.2	92.2	91.1	92.2	90.0	90.0	90.0	92.2			
Min.	82.2	85.6	85.6	86.7	82.2	84.4	81.1	84.4			
AVG	87.3	88.2	88.4	89.8	85.3	86.9	86.1	88.6			

Table 5.39 Classification results (%) with 30 test sample, 14 neurons in the hidden layer with cross-validation method for 7 hours sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	88.9	90.0	90.0	88.9	86.7	90.0	90.0	90.0	91.1	93.3	91.1
Min.	78.9	82.2	83.3	78.9	77.8	82.2	77.8	82.2	83.3	84.4	81.1
AVG	83.7	86.4	87.4	84.5	84.0	86.3	85.4	87.1	86.7	90.5	85.6
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	90.0	93.3	95.6	90.0	88.9	91.1	93.3	91.1	94.4	91.1	88.9
Min.	84.4	86.7	87.8	82.2	82.2	77.8	85.6	84.4	86.7	83.3	84.4
AVG	87.2	90.5	92.7	86.9	85.3	85.0	90.4	87.2	90.3	86.6	86.2
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	92.2	91.1	92.2	90.0	87.8	88.9	90.0	94.4			
Min.	77.8	81.1	82.2	81.1	80.0	80.0	75.6	84.4			
AVG	87.3	87.6	89.1	85.3	84.1	85.6	86.1	90.8			

The maximum average result of 30 classification steps with 30 randomly selected test samples is observed with 12 neurons in the hidden layer for 7 hours sleep recording as 87.5%. The highest average result of 30 classification steps is observed with 93.4%.

Number of the test samples which are randomly defined is selected as 30 for 20 minutes sleep recording. In table 5.40, average classification results of all steps for different number of neurons in the hidden layer are listed.

Table 5.40 Average of all 30 steps with 30 test samples and cross-validation method for 20 minutes sleep recording

Feature Combination	Number of neurons in the hidden layer					
	4	6	8	10	12	14
1	65.5	65.6	64.7	65.9	65.7	64.1

Table 5.41 Classification results (%) with 30 test sample, 4 neurons in the hidden layer with cross-validation method for 20 minutes sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	80.0	83.3	76.7	76.7	70.0	73.3	80.0	80.0	73.3	73.3	70.0
Min.	60.0	56.7	50.0	50.0	53.3	56.7	53.3	60.0	53.3	53.3	46.7
AVG	69.7	67.8	66.3	63.3	61.2	65.7	68.0	70.0	63.8	62.6	59.0
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	76.7	73.3	76.7	70.0	73.3	76.7	70.0	80.0	80.0	76.7	73.3
Min.	46.7	53.3	53.3	43.3	60.0	53.3	43.3	63.3	50.0	53.3	53.3
AVG	63.3	64.1	62.2	59.2	67.6	65.4	63.6	68.1	65.7	63.2	62.2
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	83.3	76.7	73.3	83.3	83.3	83.3	73.3	83.3			
Min.	63.3	56.7	50.0	60.0	56.7	50.0	53.3	63.3			
AVG	71.9	66.2	65.1	69.1	69.4	67.0	62.9	71.8			

Table 5.42 Classification results (%) with 30 test sample, 6 neurons in the hidden layer with cross-validation method for 20 minutes sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	83.3	80.0	86.7	76.7	83.3	80.0	76.7	76.7	76.7	76.7	63.3
Min.	50.0	50.0	53.3	53.3	56.7	60.0	56.7	56.7	50.0	53.3	40.0
AVG	68.3	67.2	68.0	65.8	68.8	70.1	65.2	68.0	65.4	63.6	53.0
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	83.3	76.7	83.3	73.3	63.3	70.0	86.7	76.7	80.0	73.3	80.0
Min.	56.7	50.0	50.0	50.0	50.0	53.3	50.0	53.3	60.0	56.7	53.3
AVG	66.3	68.3	63.7	59.9	55.8	63.6	68.2	67.4	71.7	64.9	66.3
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	76.7	83.3	80.0	73.3	66.7	80.0	86.7	73.3			
Min.	50.0	63.3	50.0	53.3	50.0	56.7	53.3	50.0			
AVG	65.2	72.9	66.2	66.0	56.8	69.1	66.9	66.4			

Table 5.43 Classification results (%) with 30 test sample, 8 neurons in the hidden layer with cross-validation method for 20 minutes sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	66.7	70.0	66.7	76.7	80.0	80.0	83.3	76.7	83.3	70.0	76.7
Min.	53.3	46.7	36.7	46.7	56.7	50.0	56.7	56.7	56.7	43.3	60.0
AVG	61.7	60.8	53.0	62.8	67.9	68.2	73.3	65.9	70.2	57.9	65.4
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	70.0	86.7	80.0	80.0	66.7	70.0	83.3	66.7	76.7	70.0	70.0
Min.	53.3	63.3	53.3	53.3	50.0	50.0	66.7	46.7	60.0	56.7	50.0
AVG	62.1	76.6	64.6	68.6	57.0	60.9	75.0	59.8	68.3	63.8	58.8
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	90.0	80.0	73.3	80.0	66.7	86.7	70.0	73.3			
Min.	60.0	56.7	50.0	53.3	53.3	56.7	43.3	43.3			
AVG	76.7	67.2	61.2	68.7	60.1	69.7	55.6	59.4			

Table 5.44 Classification results (%) with 30 test sample, 10 neurons in the hidden layer with cross-validation method for 20 minutes sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	86.7	80.0	76.7	80.0	73.3	83.3	83.3	76.7	83.3	80.0	76.7
Min.	66.7	56.7	60.0	60.0	50.0	56.7	46.7	53.3	63.3	56.7	53.3
AVG	73.2	69.4	69.0	68.1	61.2	68.9	62.3	68.1	71.7	69.1	64.4
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	70.0	70.0	83.3	73.3	73.3	83.3	80.0	73.3	76.7	76.7	76.7
Min.	43.3	53.3	56.7	46.7	50.0	53.3	56.7	46.7	46.7	56.7	60.0
AVG	58.2	63.0	69.9	63.0	60.8	69.9	66.3	60.9	63.3	66.8	67.9
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	73.3	80.0	70.0	70.0	80.0	76.7	73.3	83.3			
Min.	46.7	60.0	46.7	50.0	56.7	53.3	46.7	56.7			
AVG	61.8	69.1	59.7	64.0	70.7	65.2	60.0	70.6			

Table 5.45 Classification results (%) with 30 test sample, 12 neurons in the hidden layer with cross-validation method for 20 minutes sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	73.3	83.3	76.7	73.3	66.7	70.0	80.0	80.0	80.0	76.7	76.7
Min.	60.0	50.0	60.0	53.3	40.0	53.3	56.7	53.3	50.0	50.0	60.0
AVG	65.6	65.0	68.4	66.0	56.7	61.3	63.8	66.6	65.7	59.9	68.2
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	70.0	83.3	76.7	83.3	70.0	73.3	80.0	76.7	76.7	80.0	86.7
Min.	50.0	60.0	60.0	56.7	50.0	53.3	53.3	43.3	60.0	53.3	53.3
AVG	59.8	74.0	68.7	68.2	61.8	63.2	67.4	61.8	66.9	66.2	71.1
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	76.7	76.7	73.3	83.3	73.3	83.3	80.0	76.7			
Min.	46.7	53.3	50.0	60.0	56.7	60.0	56.7	53.3			
AVG	62.6	65.9	62.9	73.4	67.2	73.1	66.3	63.9			

Table 5.46 Classification results (%) with 30 test sample, 14 neurons in the hidden layer with cross-validation method for 20 minutes sleep recording

Classification results for each step, 1 to 30											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Max.	70.0	83.3	80.0	80.0	66.7	76.7	83.3	66.7	66.7	73.3	70.0
Min.	50.0	60.0	46.7	56.7	46.7	53.3	60.0	46.7	50.0	50.0	53.3
AVG	64.1	70.6	60.9	67.4	61.0	66.2	70.2	58.8	58.1	60.7	63.9
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Max.	80.0	73.3	70.0	80.0	90.0	80.0	70.0	83.3	73.3	70.0	83.3
Min.	60.0	46.7	50.0	60.0	63.3	53.3	50.0	56.7	50.0	50.0	50.0
AVG	69.2	57.7	61.2	69.3	72.6	64.7	57.8	72.2	63.0	59.4	62.6
	23	**24**	**25**	**26**	**27**	**28**	**29**	**30**			
Max.	80.0	73.3	80.0	83.3	80.0	66.7	73.3	76.7			
Min.	53.3	46.7	46.7	56.7	56.7	46.7	53.3	53.3			
AVG	67.1	61.8	65.2	69.6	67.8	53.7	63.6	63.1			

The maximum average result of 30 classification steps with 30 randomly selected test samples is observed with 10 neurons in the hidden layer for 20 minutes sleep recording as 65.9%. The highest average result of 30 classification steps is observed with 86.7%.

5.3 Linear Discriminant Analysis

In table 5.47, all discriminant analysis results with different feature combinations for 7 hours sleep recording are listed. The highest classification value 96.4% is observed by using feature combination 3 explained in table 5.1. For both 20 minutes and 7 hours sleep recordings F to enter and F to remove parameters are selected as 3.84 and 2.71 respectively.

Table 5.47 Discriminant analysis with different feature combinations for 7 hours sleep recording

Feature Combination	1	2	3	5
Classification Result	82.7	93.6	96.4	78.7

According to significance values of the features, F to enter and F to remove parameters some features are not used in classification.

Table 5.48 Discriminant analysis using feature combination 1 for 7 hours sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	69	4	10	83
	3	14	69	0	83
	5	15	0	68	83
%	**2**	83.1	4.8	12.0	100
	3	16.9	83.1	0	100
	5	18.1	0	81.9	100

In table 5.48 details of discriminant analysis results using feature combination 1 for 7 hours sleep recording are listed. Wavelet features 29, 35, 38, 34, 37, 27, 30 and 36 are used in classification.

Table 5.49 Discriminant analysis using feature combination 2 for 7 hours sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	75	8	0	83
	3	6	75	2	83
	5	0	0	83	83
%	**2**	90.4	9.6	0	100
	3	7.2	90.4	2.4	100
	5	0	0	100.0	100

In table 5.49 details of discriminant analysis results using feature combination 2 for 7 hours sleep recording are listed. Features 17, 13, 9, 3, 25, 1, 20, 21, 18, 24, 11, 12, 7, 5, 10 are used in classification. All class 5 samples are classified correctly.

Table 5.50 Discriminant analysis using feature combination 3 for 7 hours sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	80	3	0	83
	3	5	77	1	83
	5	0	0	83	83
%	**2**	96.4	3.6	0	100
	3	6.0	92.8	1.2	100
	5	0	0	100.0	100

In table 5.50 details of discriminant analysis results using feature combination 3 for 7 hours sleep recording are listed. Features 17, 29, 3, 35, 34, 20, 21, 13, 1, 32, 25, 24 and 18 are used in classification. All class 5 samples are classified correctly again. Also the highest result for discriminant analysis is observed in this part with a percent of 96.4.

Table 5.51 Discriminant analysis using feature combination 5 for 7 hours sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	65	3	15	83
	3	17	65	1	83
	5	17	0	66	83
%	**2**	78.3	3.6	18.1	100
	3	20.5	78.3	1.2	100
	5	20.5	0	79.5	100

In table 5.51 details of discriminant analysis results using feature combination 5 for 7 hours sleep recording are listed. Features 29, 34, 28, 32 and 30 are used in classification. Class 3 and class 5 can be separated from each other but they mix with class 2. Also the minimum result for discriminant analysis is observed in this part with a percent of 78.7.

In table 5.52, all discriminant analysis results with different feature combinations for 20 minutes sleep recording are listed. The highest classification value 70.8% is observed by using feature combination 3 explained in table 5.1.

Table 5.52 Discriminant analysis with different feature combinations for 20 minutes sleep recording

Feature Combination	1	2	3	4
Classification Result	67.5	58.3	70.8	68.3

Table 5.53 Discriminant analysis using feature combination 1 for 20 minutes recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	19	13	10	42
	3	14	22	0	36
	5	1	1	40	42
%	**2**	45.2	31.0	23.8	100
	3	38.9	61.1	0	100
	5	2.4	2.4	95.2	100

In table 5.53 details of discriminant analysis results using feature combination 1 for 20 minutes sleep recording are listed. Wavelet features 33, 29 and 35 are used in classification.

Table 5.54 Discriminant analysis using feature combination 2 for 20 minutes sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	12	25	5	42
	3	16	18	2	36
	5	2	0	40	42
%	**2**	28.6	59.5	11.9	100
	3	44.4	50.0	5.6	100
	5	4.8	0	95.2	100

In table 5.54 details of discriminant analysis results using feature combination 2 for 20 minutes sleep recording are listed. Wavelet features 13, 7, 20, 21, 8 and 1 are used in classification.

Table 5.55 Discriminant analysis using feature combination 3 for 20 minutes sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	25	13	4	42
	3	16	19	1	36
	5	0	1	41	42
%	**2**	59.5	31.0	9.5	100
	3	44.4	52.8	2.8	100
	5	0	2.4	97.6	100

In table 5.55 details of discriminant analysis results using feature combination 3 for 20 minutes sleep recording are listed. Features 33, 20, 21, 8, 13, 1 and 31 are used in classification.

Table 5.56 Discriminant analysis using feature combination 4 for 20 minutes sleep recording

Class		**Predicted Group Membership**			**Total**
		2	**3**	**5**	
Count	**2**	19	12	11	42
	3	14	22	0	36
	5	0	1	41	42
%	**2**	45.2	28.6	26.2	100
	3	38.9	61.1	.0	100
	5	0	2.4	97.6	100

In table 5.56 details of discriminant analysis results using feature combination 4 for 20 minutes sleep recording are listed. Features 33 and 29 are used in classification.

CHAPTER SIX
CONCLUSION

The investigated parameters, the parameters of Hjorth, the harmonic parameters, the relative band energy ratios and parameters extracted by applying wavelet packet transformation are capable of getting information from the EEG. It can be easily said that these features have discrimination power for sleep stage classification.

After feature extraction, these parameters are analyzed to decrease the size of the feature vector. As it can be observed that, the number of parameters is not proportional to the amount of the data of 20 minutes sleep recording. So it becomes very difficult to classify the sleep stages. Thus the useful parameters are expected to be selected from feature vector. Then these parameters can be used as the inputs of the sleep stage classifiers.

After a successful feature selection step, all features, selected features and their combinations with each other are used in classification section, and different classifiers are utilized.

The highest correct classification result for k-nn method, where k equals five, is observed with 92% for the 7 hours sleep recording data which is 30% more than the highest classification result obtained with 20 minutes sleep recording. The main reason for this difference in classification results is based on the dimensionality. Because the number of the samples in 7 hours sleep recording is approximately six times more than the samples in 20 minutes sleep recording.

In multilayer neural networks classification there are test and train groups which are shifted during the classification one by one for validation method. Two different number of test samples are used for seven hour sleep recording. The number of neurons in the hidden layer is increased which has a little effect on the classification results. Also increasing the number of training epochs can cause a small increase in the classification results. But it must be avoided overtraining when increasing the training epochs. The maximum result for 7 hours sleep recording with 30 test samples for each class is 88.8%, where there are 8 neurons in the hidden layer, and 82.5% with 20 test samples for each class, where there are 4 neurons in the hidden layer. Also the maximum result for 20 minutes sleep recording with 30 trained samples for each class is 73.3%, where there are 4 neurons in the hidden layer. It can again be observed that the results for 7 hours sleep recording are 20 percent more than the results calculated with 20 minutes sleep recording. Because of randomly selected initial weight values multilayer classification is performed 30 times in each step and the average result is recorded.

In multilayer neural networks classification for cross-validation method, test and train groups are selected randomly. The maximum result for 7 hours sleep recording is 87.5%, where there are 12 neurons in the hidden layer. Also the maximum result for 20 minutes sleep recording with 30 trained samples for each class is 65.9%, where there are 10 neurons in the hidden layer. It can again be observed that the results for 7 hours sleep recording are 32.8 percent more than the results calculated with 20 minutes sleep recording.

In discriminant function analysis results, the same success rate is observed for 7 hours sleep recording against 20 minutes one. But in this method, the highest results are observed using all the features different than K-NN and multilayer neural network classifications. All features entered but F to enter and F to remove parameters select the features which can be used in classification. The result for 7 hour sleep recording is satisfactory with a percent of 96.4. Again the highest result is 36 percent more than the highest classification result obtained with 20 minutes sleep recording.

In literature there are different applications on automatic sleep stage classification. By using a neural network and wavelet packet transform 93% and 77.6% correct classification results are observed in two studies. There is also a success with 93.2% by using multi channel EEG signal modeling. A neuro-fuzzy approach is applied for sleep stage classification and 88.2% performance is obtained. In the same study multi layer neural network is used and 87.3% success is achieved.

When compared with the previous applications, the results in this work show a noteworthy performance. Especially the classification result obtained with linear discriminant analysis (96.4%) is successful. In multilayer neural network classification, overall results 88.8% (with validation) and 87.5% (with cross-validation) denote an average performance against the previous results in literature which are between 75 and 95 percents. Also the performance of the k-NN classifier which is an easy and useful estimation is quite high with an overall success rate over 90 percent (92%) when compared with the other classifiers.

The methods and the results show that the automatic sleep stage detection is possible. The results also show that different feature extraction methods and different classifiers can be a reason for observing various successes in sleep stage classification. For the feature work, different feature extraction methods can be investigated through different classifiers.

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