Investigating the Relationship between Nocturnal Facial Expressions and Mood

Bachelor's Thesis in Medical Engineering

submitted
by

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Chapter 1

Introduction

Sleep quality is known to affect people's physical and mental health [Fol04]. Sleep disorders have been linked to medical conditions such as cardiovascular disease [Gan06] or diabetes [Cap10]. On the other hand, nightmares have been linked to a huge impact on mental illnesses, including suicide attempts [Sjö09], post-traumatic stress disorder [Rot01], anxiety disorders [Gre12] and insomnia [Sch09]. In addition, insufficient sleep has been associated with dampened positive affect [Fra08], greater physiological reactivity to negative or stressful stimuli [Yoo07] and self-reported negative emotions [Min12]. Sleep quality also has a major impact on depression [Nak14], which is a major problem in society as it is one of the top ten global diseases [Mat06]. As mood disorders are often associated with depression [Bag11], they may also be directly related to sleep disorders [Tri19]. There is no consistent system for quantifying sleep quality, but researchers tend to focus on facial muscle activity [RIV11] [Riv19] and facial expressions [Clé19] [Mar21] at night.

As Charles Darwin explored, facial expressions are a form of non-verbal emotional communication between people [Dar79]. In the late 20th century, Paul Ekman studied the cross-cultural perception of emotion and the measurement of facial expressions [Ekm64] [Ekm65] [Ekm87] [Ekm93]. Several facial coding systems have been invented to describe human emotion, for example *Monadic Phases Coding System (MP)* [Tro80], *Maximally Discriminative Facial Movement Coding System (MAX)* [Lew90] or *Facial Animation Parameters (FAP)* [Wei04]. The best known is the *Facial Action Coding System (FACS)*, which was originally invented by Ekman in 1978 [Ekm78] and updated in 2002 [Ekm02]. While in the beginning at least two independent but well-trained experts were needed to evaluate one of these coding systems, today the trend is towards automated facial detection and expression recognition.

Automatic detection of facial action units has found numerous applications over the last few decades. For example, real-time detection of driver fatigue to avoid accidents [Ji06], automatic pain detection in the clinical environment [Luc10], or different facial reactions in response to basic tastes [Wen11]. It is also important for robots to analyse and respond directly to human emotions [DeV14], and the entertainment industry benefits from analysing players' facial expressions during games [Blo14]. FACS can also be used to predict negative emotions such as depression, anxiety and stress [Gav19]. What all these examples have in common is that the facial expressions were calculated from awake people.

A concrete correlation between emotions and sleep architecture has already been shown, for example after watching a stressful film [Tal13] or after a stressful day [Bla17]. Lack of sleep, on the other hand, leads to stronger negative emotions during the day [Dan10] [Sco06]. However, there is still a lack of adequate methods to measure emotional behaviour during the night. Current methods used are based on self-report [Tri19], video polysomnography (PSG) including electromyography (EMG) [RIV11] [Clé19] [Mar21] or experimental awakening combined with questionnaires [Riv19] [Oka20]. However, studies that extract the facial expressions of sleeping people and examine the relationship between emotional states during the night and the mood the next day cannot be found in the literature so far.

The goal of this bachelor's thesis is therefore to implement a pipeline that covers the extraction of facial action units and the computation of facial emotions. For this purpose, a dataset of 27 nights containing full-night videos from three infrared cameras with respect to different spatial perspectives was recorded and post-processed with *OpenDBM* for automated extraction of facial movements. Each night was preceded by questionnaires assessing the subjective mood of the participant at three different times during the day. By analysing this dataset, the correlation between facial expressions during the night and the mood of the following day, based on patient questionnaires, will be investigated.

Chapter 2

Related Work

2.1 Sleep and Emotion Regulation

Sleep is known to play an important role in the processing of emotions during the night. Therefore, biochemical processes related to emotional dynamics take place at night. It has already been shown that processing of emotional memories occurs during the rapid eye movement (REM) phase [Pal17], as the activity of anxiety-promoting neurotransmitters such as norepinephrine and serotonin is inhibited [Hob02]. In addition, increased release of the stress hormone cortisol in the hippocampus may be related to the consolidation of memories in the amygdala regions during REM sleep [Bor04]. Furthermore, higher amygdala activation was observed during REM sleep, which is directly related to emotional stimuli [Cor16]. More generally, REM sleep deprivation could have an impact on the emotional processing areas, as their activity increases [Ros12]. Therefore, sleep behaviour and in particular REM sleep quality could be examined as a measure in the diagnosis of depression [Pal13].

Sleep disorders are associated with higher levels of anger [Shi05] and lower levels of control and drive [Ott11]. In addition, a bidirectional relationship has been observed between sleep disturbance and anxiety or depression [Alv13]. Although sleep has an influence on the social context and the development of emotional regulation. Family-related stress and negative social emotions [Tav16] as well as daily positive experiences on the other hand [Sin17] also have a bidirectional relationship with sleep duration. Therefore, sleep deprivation impairs accurate facial emotion judgments [Van10] and leads to increased anxiety and general distress [Bab10]. Sleep loss is also a problem in young adolescents because it significantly reduces their empathy [Gua16] and increases their risk of unhealthy substance use, such as drug and alcohol use [Owe17]. In addition to the negative effects, sleep quality also shows positive effects on emotion regulation

[Lat19], improved self-control and prevention of mood swings [Liu20].

There is also a known direct link between sleep quality and mental health. One study showed that sleep loss leads to a decrease in positive moods, such as happiness, and an increase in depression, anger and fatigue [Pat11]. Sleep and dreaming have therefore been described as an important compensator for psychological allostatic overload in humans [Agn11]. On the other hand, chronic sleep deprivation has been found to impair performance in assessing basic facial emotions [Crö16]. Insomnia symptoms also negatively affect behaviour towards anxiety stressors and, over time, increase the risk of anxiety disorders [Sho18]. In addition, poor sleep quality has also been linked to post-traumatic stress disorder, while sleep disturbance leads to difficulties in emotion regulation [Pic16]. On the other hand, studies have shown that good sleep quality supports the treatment of anxiety disorders [Wal17].

2.2 Measure of Sleep Quality

Patient questionnaires completed after a night's sleep have often been used to investigate the relationship between sleep patterns and emotions or mood. Close to this, Triantafillou et al. investigated a self-report study via mobile phone [Tri19]. They recruited 208 participants to complete daily questionnaires for 6 weeks. The questions were sent to their mobile phones and they had to fill out them in the morning, at noon and in the evening. In addition, phone sensor data was collected, such as microphone, accelerometer, GPS, call and short message service events. While the participants had to rate their mood, stress, energy and focus, the current weather forecast and the type of day (work or non-work day) were also included in this study. They found an effect of sleep quality on mood and vice versa, while the effect of mood on sleep quality was to be found significantly less pronounced [Tri19].

PSG has been widely used to study facial expressions during the night. Rivera-García et al. performed a study on six healthy volunteers with PSG recordings and 10 additional electrodes to detect facial muscle activity [RIV11]. All participants underwent two consecutive nights of recording, the first to adapt to the laboratory conditions and the second was analysed for this study. Facial muscle activity was also recorded during REM and non-REM sleep, but was significantly higher and lasted longer during REM sleep and could therefore be associated with emotional expressions of dream content [RIV11]. Clé et al. conducted a study of 174 patients focusing on nocturnal smiling [Clé19]. Volunteers underwent up to two video PSGs, including EMG recordings and an additional dream report in the morning. However, this study was limited by the use of multiple electrodes on the face, which were perceived as annoying by the sleepers and could also blur the facial expressions in the video recordings. In this study, out of 100 control patients, 8 % smiled during the night, while 7 % during REM sleep and 1 % during non-REM sleep. More than 50 % of the smiles were classified as Duchenne types. In summary, they postulate that the facial expressions during the night are associated with a real inner mirth [Clé19]. In addition, Maranci et al. studied grumpy facial expressions during the night in a total of 127 participants, also using video PSG and EMG [Mar21]. As well as facial expressions, they also took into account negative experiences during the night such as shouting, crying, emotional speech and fighting. They found a huge amount of corrugator activity and 97.8 % of the subjects showed frowning at least once during the night. Again, this facial activity was more frequently in REM sleep than in other stages of sleep. Situations that were rated as negative experiences during the night showed very few classic basic emotions in facial expressions such as sadness or anger. However, most had expressions of painful faces, but the question of whether facial expressions directly correspond to negative dreams remains unanswered [Mar21].

In another study, Rivera-García et al. performed a series of experimental awakenings of patients during the night after observing facial expressions during REM sleep [Riv19]. Therefore, 12 female volunteers underwent two nights of PSG recording, with the first night being used to calibrate clinically relevant parameters. The recordings and results from the second nights were then analysed for this study. In addition, the participants were awakened from each REM sleep stage and immediately asked questions about dream content and emotional experiences. 92.9 % of all REM sleep episodes contained dream content, while 80.4 % of these also included emotions. They were able to show that positive emotional dreaming is strongly associated with the activation of the zygomaticus muscles [Riv19]. In a slightly different study, Okabe et al. investigated odor induced negative dream emotions during REM sleep [Oka20]. 14 participants spent one night in a sleep laboratory with PSG and EMG to measure REM sleep state. The subjects were awakened twice during REM sleep and had to rate their dream experience and answer some additional questions about their dream memories. While the first awakening was for control conditions only, the second was after an olfactory stimulation with phenylethyl alcohol, which smells like roses. The results showed that the participants who were familiar with the odor had induced negative dream emotions. They concluded that olfactory stimulation during REM sleep can affect dream emotions [Oka20].

Facial expression recognition via a smart home system for environmental monitoring and sleep quality control was invented by Zhao et al. [Zha20]. They investigate a small Internet of Things (IoT) device with multiple sensors for light intensity, temperature and humidity, as well as a built-in camera. This allows the system to detect and track the faces and perform facial expression recognition through feature extraction and classification of the user's face. The IoT device uses an artificial neural network (ANN) to classify the facial expression into anger, anxious, happiness, sadness and neutral. The result is sent back to the central control system, which can play pure or light music based on the detected emotion to achieve a stable mood state for better sleep quality. As a result, they were able to develop a smart home device for monitoring the sleep environment that could automatically measure facial expressions and respond directly to the detected emotion by playing background music. Finally, they tested their system on two students and found an increase in deep sleep time and an improvement in sleep quality [Zha20].

Chapter 3

Fundamentals

The following chapter gives an overview of the important fundamentals needed for this work. For this purpose, the *Action Units (AU)* implemented in the *Facial Action Coding System (FACS)* and their evaluation are listed first. In addition, the functionality of the automated *digital biomarker application (OpenDBM)* and the resulting findings are described.

3.1 Facial Action Coding System

Paul Ekman and Wallace V. Friesen developed a robust and systematic framework for analysing facial expressions in the 1970s [Ekm78]. Previous coding systems required information about emotional states, making them somewhat subjective. Ekman and Friesen set out to create a more objective measurement system. In this context, an objective observer would not judge a smiling face as *'happy'* but rather as an upward, oblique movement of the lip corners.

To achieve this, Ekman and Friesen began by electrically stimulating individual facial muscles and then voluntarily replicating the observed movements. They defined the term *'Action Unit' (AU)* as the smallest distinguishable movement in the face. The FACS, updated in 2002 [Ekm02], considers 27 facial AUs, categorised into nine AUs in the upper facial region and 18 in the lower facial region. In addition, FACS considers nine specific eye positions and movements, along with 14 head positions and movements. It also includes nine action descriptors, five visibility codes, nine gross behaviours and five miscellaneous AUs. For the purposes of this work, the most relevant AUs are listed in Appendix B.1.

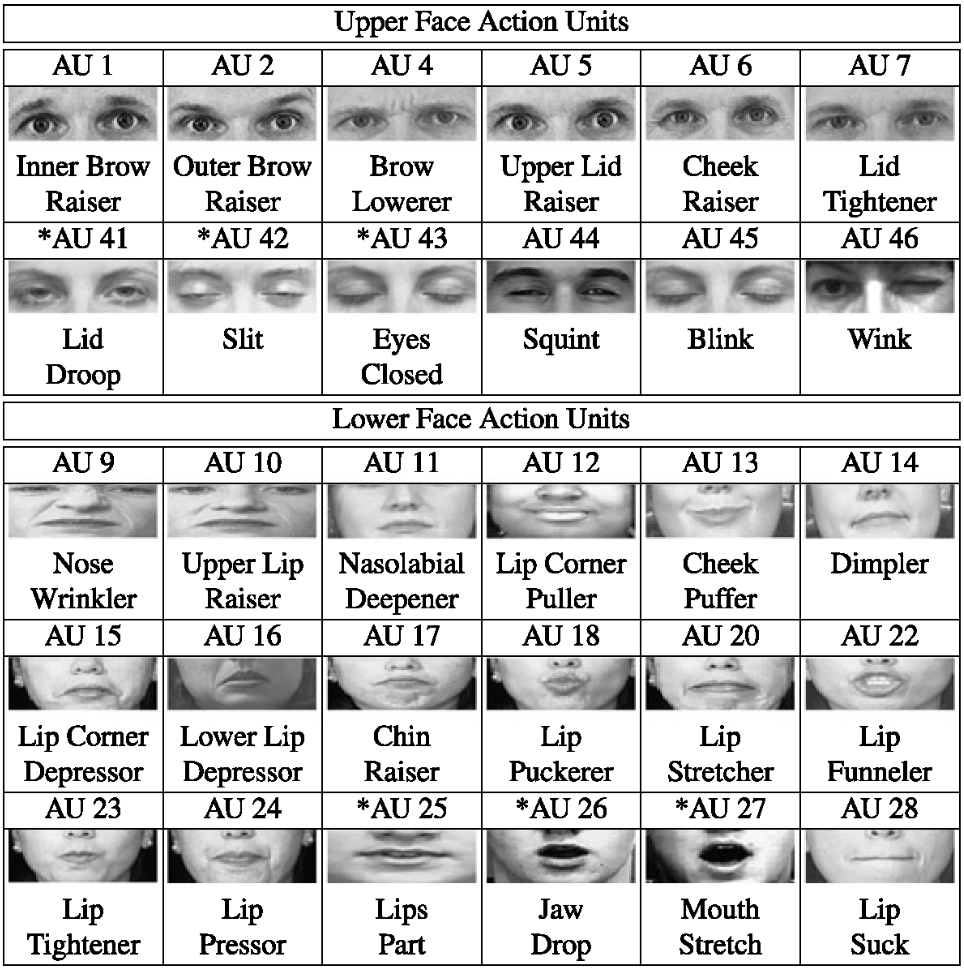

Figure 3.1: Example of 12 Action Units (AU) associated with the upper facial region and 18 AUs associated with the lower facial region [Zhi20].

Examples of 12 AUs for the upper facial region and 18 AUs for the lower facial region are shown in Figure 3.1. FACS provides several methods for evaluating AUs in scientific research. The simplest approach is to determine whether an AU is present or absent. For more detailed information, the presence of an AU can be assessed using five intensity levels, ranging from A (trace level) to E (maximum strength). Because facial expressions are dynamic and change over time, FACS divides expressions into three phases: onset (the beginning of a facial expression), apex (the peak intensity) and offset (return to a neutral state). While many automatic detection algorithms exist to improve the calculation of AUs and facial expressions, this work focuses on an *open digital biomarker (OpenDBM) application* [Flo22], which is described in more detail in the following section.

3.2 Digital Biomarker

The developers offer *OpenDBM*[1] as a tool for measuring specific digital biomarkers from video or audio. As the focus of this work is on facial behaviour from video, for a deeper understanding of speech characteristics, current literature on *DeepSpeech*[2] [Wu22] is referred. To extract all facial features, OpenDBM uses the freely available software package *OpenFace*[3] [Bal18] for detecting the positions of facial landmarks (see Figure 3.2). OpenFace provides the positions of each single landmark in x and y coordinates for each frame of the video. OpenDBM then computes the frame-by-frame displacement of the landmarks by calculating the Euclidean distance between two coordinate points. Furthermore, this information leads to specific AUs, based on FACS [Ekm02], including only the AUs highlighted in the previous section.

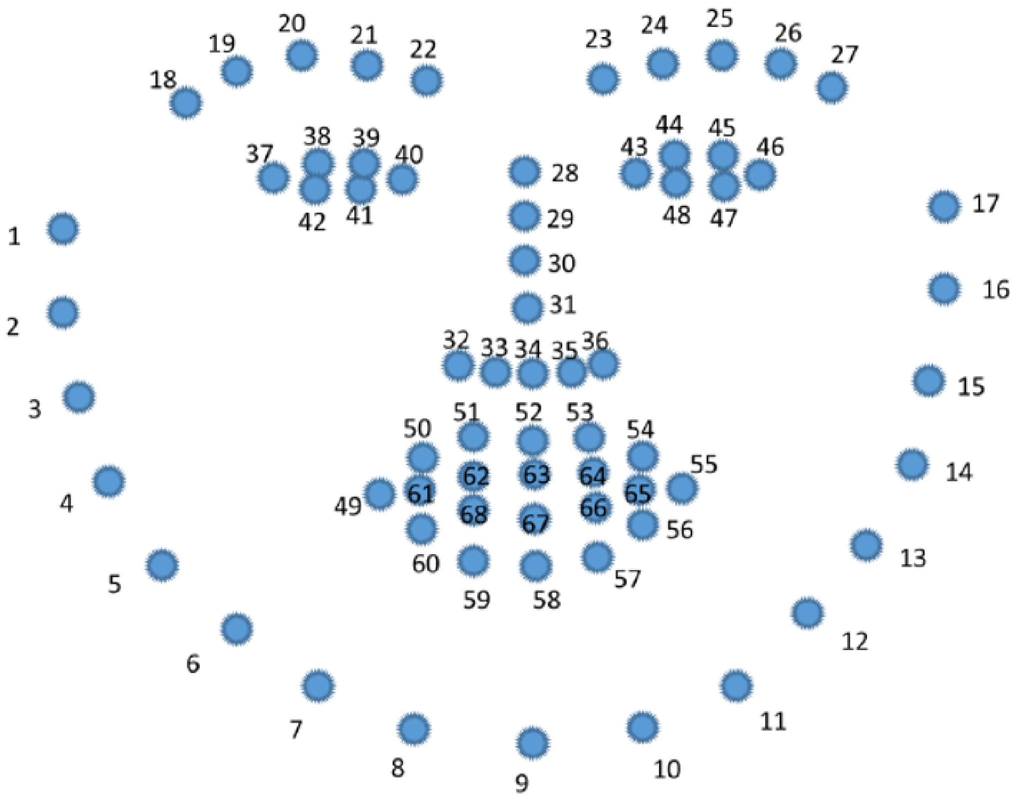

Figure 3.2: Overview of facial landmark positions that can be recognised by OpenFace and further processed by OpenDBM [Abb20].

[1] https://github.com/AiCure/open_dbm
[2] https://github.com/mozilla/DeepSpeech
[3] https://github.com/TadasBaltrusaitis/OpenFace

OpenDBM provides frame-by-frame information indicating whether the AU was present (value 1) or not (value 0), along with an intensity score ranging from 0 to 5, where 0 indicates no presence and 5 represents maximum intensity. In addition, OpenFace supplies a confidence score that indicates how certain it was that a face was detected in each frame of a video. Confidence is scored between 0 and 100 percent, with the program recommending exclusion of frames with a confidence level below 80 percent. However, AUs can still be extracted and used for frames with a confidence level below 80 percent.

Based on the provided AU intensity values and the confidence level, it is possible to calculate emotions based on FACS. OpenDBM pre-calculates some emotions that are used for further comparisons. The seven basic emotions that can be calculated directly are listed in Table 3.1. The output for each emotion indicates whether an emotion is present or not, along with an emotion intensity value, similar to the output of the AUs mentioned earlier.

Furthermore, OpenDBM distinguishes emotions into *'Soft'*, which indicates that at least one required AU was present in the current frame, and *'Hard'*, which indicates that all required AUs for the emotion were present in the specific frame. In addition, OpenDBM predicts the expressivity of pain using the combination of AUs 4+6+7+9+10+12+20+26 [Prk92] and provides intensity values for both *'Soft'* and *'Hard'* outputs.

It also provides some overall expressivity scores are provided. Therefore, all AU signals were considered to determine the overall expressivity for the whole face, as well as separately for the upper and lower facial regions. Although OpenDBM also provides information on facial asymmetry in relation to all facial features, this is beyond the scope of this work and will not be discussed in detail.

Table 3.1: Table showing all emotions, the corresponding variable names (EMO) for each emotion, and the combinations of AUs that OpenDBM considers for each emotion [Abb20].

Emotion	**EMO**	**Action Units**
Happiness	Hap	6 + 12
Sadness	Sad	1 + 4 + 15
Surprise	Sur	1 + 2 + 5 + 26
Fear	Fea	1 + 2 + 4 + 5 + 7+ 20 +26
Anger	Ang	4 + 5 + 7 + 23
Disgust	Dis	9 + 15 + 16
Contempt	Con	12 + 14

Chapter 4

Methods

The following chapter describes the algorithms developed in this thesis. It begins by explaining the dataset on which all the results of this work are based. It then outlines the process of converting the videos for each night in order to subsequently extract facial AUs and classify facial expressions using OpenDBM. Finally, the methodology used to determine correlations between the nightly video material and the patient questionnaires administered the following day is presented.

4.1 Data Set

The data set was already recorded before the work started. For this exploratory study, one participant was sufficient—a 32-year-old female student. The participant completed an initial survey to track emotions, mood, depressive tendencies and general sleep quality in the past (see Appendix A).

A total of 27 nights were then recorded using infrared cameras placed in three different spatial orientations: above, to the right, and to the left side of the bed. This arrangement ensured that the participant's face could be tracked even if she turned during the night. Each night's recording lasted approximately seven hours. This resulted in approximately 567 hours of video collected from the three cameras over the 27 nights. However, there were some problems with the data collection. On one occasion only the left camera recorded and on another occasion the camera above the bed failed to record.

In addition, the participant completed a survey three times the following day—in the morning, at noon, and in the evening. This involved rating sleep quality, emotions and mood throughout the day (see Appendix A). Note that on one day, the participant only completed the morning questionnaires, and on two days the participant forgot to complete the entire questionnaire.

4.2 Video Converting

The video material was stored as five-minute DAV files, which had to be converted to MP4 videos. For clarity, the DAV files were organised into folders named after the date of recording. These folders contained sub-folders corresponding to different camera positions: *'Links' ('Left')*, *'Oben' ('Above')*, and *'Rechts' ('Right')*. Each camera position subfolder was further divided into subfolders for each hour of the night, typically between 10pm and 7am.

Each individual DAV file had to be converted one at a time and then concatenated in the correct order to create a single, continuous MP4 video. Due to limitations in memory capacity and processing time, the video conversion process was performed on the MaD server Titan. To achieve this, the Python code was translated into a shell script and executed on the Titan server. The conversion was done using the *FFmpeg*[1] software package, which converted each DAV file to MP4 format. In addition, the camera positions had to be taken into account, as OpenDBM only recognises vertically oriented faces, and the videos from the side cameras had to be rotated.

Consequently, the DAV files from the left camera were rotated 90° counter-clockwise, while those from the right camera were rotated 90° clockwise to ensure that the recorded faces were always vertically oriented. Throughout the conversion process, the paths to each MP4 file were recorded in a text file, which was later used to concatenate all the files together.

4.3 Digital Biomarker Application

For this work, we used an open source digital biomarker application (OpenDBM), as previously discussed in chapter 3.2. The application was used to extract facial activity during the night. To do this, the MP4 videos from each night and camera position were uploaded to the MaD server Titan. A shell script was then used to automatically process all the videos, specifying the input path for the videos and saving the results to the specified output path.

Within OpenDBM, the specific group 'facial' was selected to ensure that the application focused solely on calculating facial behaviour. Typically, the results are stored sample by sample with in CSV files with a sampling rate of 25 Hz for each video. For the chosen DBM group *'facial'*, the results comprised four different files, providing information on the facial asymmetry, landmarks, AUs and expressivity. Of primary interest were the results for facial AUs, which were subsequently used for further classification of facial expressions. In addition, the results for facial expressivity were considered as they provide insight into human emotions based on the FACS,

[1] https://ffmpeg.org/

thus facilitating comparisons with our own calculations. However, the results for facial asymmetry and landmarks were not considered for the purposes of this thesis.

4.4 Facial Expression Classification

The aim of this thesis was to investigate whether facial expressions during the night are related to mood during the following day. Although there is no established relationship between nocturnal facial expressions and human emotions, the classification of facial expressions based on AUs in this work is related to emotions. Therefore, a wide range of AU combinations were considered, drawn from the current literature on emotions during the day. An overview of all used AU combinations can be found in the Table 4.1.

OpenDBM provides AUs for every frame in the video, so emotions were initially calculated on a frame-by-frame basis. Therefore, three different camera positions were evaluated separately from each other. Emotions were classified as *'Hard'* if all the required AUs were present in the frame, *'Mid'* if at least half of the required AUs were present, and *'Soft'* if at least one AU for the emotion was observed. In addition, a single value for the whole night had to be calculated for further comparisons. Several summation methods were considered for this purpose. A simple mean value was calculated over all frames, including those with a zero value (*'MeanTotal'*). Another specific mean value was calculated, this time excluding frames with a zero value (*'MeanSpec'*). Both methods were also calculated taking into account the confidence level on a frame-by-frame basis (*'ConfMeanTotal'* and *'ConfMeanSpec'*).

Due to the positioning of the cameras, it was expected that at least one camera would not capture the face but the back of the head resulting in no detectable AUs within this time period. Therefore, in addition to the results from each individual camera, the cameras were offset against each other frame by frame. Different calculation methods were considered for this purpose. Firstly, the frames from the three cameras were averaged and then a mean value was then calculated for the entire video, including all frames with zero values (*'AvgMeanTotal'*). In addition, the same averaging process was used, but this time the mean value was calculated over the entire length of the video, taking into account only non-zero values (*'AvgMeanSpec'*). In addition to averaging over all cameras, it was decided to extract only the camera with the maximum value for each frame and consequently mean values were estimated for the entire night with and without considering zero values (*'MaxMeanTotal'* and *'MaxMeanSpec'*). These calculations were also performed taking into account the confidence level taken into account (*'ConfAvgMeanTotal'*, *'ConfAvgMeanSpec'*, *'ConfMaxMeanTotal'* and *'ConfMaxMeanSpec'*).

Table 4.1: Table showing all the emotions, the corresponding variable names (EMO) for each emotion, and the different combinations of AUs which were used in this work.

<table>
<tr><th>Emotion</th><th>EMO</th><th>Action Units</th></tr>
<tr><td>Happiness</td><td>Hap</td><td>6 [Fri84] | 6+12 [Fri84] | 7+12 [Fri84] | 6+12+25 [Lan10] | 6+7+12+25+26 [Kel19]</td></tr>
<tr><td>Desire</td><td>Des</td><td>7+12+25 [Cor18] | 6+7+12+25 [Cor18]</td></tr>
<tr><td>Surprise</td><td>Sur</td><td>4 [Lan10] | 5+26 [Ekm02] | 1+2+5 [Fri84] | 1+2+26 [Fri84] | 1+2+5+26 [Fri84] | 1+2+5+25+26 [Kel19]</td></tr>
<tr><td>Contentment</td><td>Cont</td><td>6+17 [Cor18] | 6+7+17 [Cor18] | 6+7+25 [Cor18]</td></tr>
<tr><td>Interest</td><td>Int</td><td>1+2+12 [Kel19] | 4+7+12+17+24 [Cor18] | 1+2+5+12+17+25 [Cor18]</td></tr>
<tr><td>Awe</td><td>Awe</td><td>7 [Cor18] | 1+5+26 or 27+57 [Shi03] | 1+2+5+12+25+26 or 27+53 [Cor18]</td></tr>
<tr><td>Triumph</td><td>Tri</td><td>6+7+12+25 [Cor18]</td></tr>
<tr><td>Sadness</td><td>Sad</td><td>6+15 [Ekm02] | 1+4+5 [Ekm83] | 1+4+15 [Ekm02] | 1+4+15+17 [Ekm02] | 1+6+7+17+25 [Cor18]</td></tr>
<tr><td>Distress</td><td>Dist</td><td>15 [Fri84] | 6+15 [Fri84]</td></tr>
<tr><td>Fear</td><td>Fea</td><td>20 [Fri84] | 5+20 [Bar19] | 1+2+4 [Fri84] | 1+2+5 [Bar19] | 1+2+4+5 [Ekm02] | 4+6+12 [Cor18] |
1+2+4+5+7+20+25 [Kel19] | 1+2+4+5+7+20+26 [Ekm83]</td></tr>
<tr><td>Anger, Rage</td><td>Ang</td><td>23 [Fri84] | 4+5 [Fri84] | 4+7 [Fri84] | 4+5+7 [Fri84] | 4+5+7+23 [Bar19] | 4+5+7+17+23 [Ekm02]
4+5+7+23+25+26 [Ekm02] | 4+5+7+10+23+25+26 [Ekm02]</td></tr>
<tr><td>Disgust</td><td>Dis</td><td>9 [Fri84] | 10 [Fri84] | 9+17 [Ekm02] | 10+17 [Ekm02] | 9+15+16 [Ekm83] | 9+10+25 [Lan10] | 4+6+7+9+10+25+26 or 27 [Cor18]</td></tr>
<tr><td>Confusion</td><td>Conf</td><td>25 [Cor18] | 4+7 [Cor18] | 17+25+26+56 [Cor18]</td></tr>
<tr><td>Embarrassment</td><td>Emb</td><td>6+7+12+25+54 [Cor18]</td></tr>
<tr><td>Shame</td><td>Sha</td><td>6+7+25 [Cor18]</td></tr>
<tr><td>Pain</td><td>Pai</td><td>4+6+7+20+25+43 [Cor18] | 4+6+7+9+10+25+26+27 [Kun19] | 4+6+7+9+10+12+20+26 [Prk92]</td></tr>
<tr><td>Sympathy</td><td>Sym</td><td>1+4 [Hai99] | 1+4+7+17 [Cor18]</td></tr>
<tr><td>Contempt</td><td>Con</td><td>10 [Ekm02] | 14 [Ekm02] | 17 [Cor18] | 7+12 [Cor18] | 12+14 [Ekm83] | 4+14+25+26 or 27 [Cor18] | 6+7+9+12+43 [Cor18]</td></tr>
<tr><td>Disbelief, Scepticism</td><td>Disb</td><td>1+2+10+15+17+41 [Ekm02]</td></tr>
</table>

4.5 Correlation Matrix

For further evaluation of the results, correlations between the estimated emotions and the patient surveys were examined. To achieve this, all calculated emotions for the 27 nights and the patient survey were recorded separately for each camera perspective and calculation method in a single CSV file. These files were then analysed using SPSS software, which used the *Pearson correlation* method to determine whether there was a specific correlation existed between the questionnaires and the emotions. The Pearson correlation coefficient cor_{XY} is defined by the following equation [Geh22]:

$$cor_{XY} = \frac{cov_{XY}}{s_X \cdot s_Y} \tag{4.1}$$

Here, cov_{XY} represents the covariance of two variables, X and Y, and it can be estimated using the following formula:

$$cov_{XY} = \frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X}) \cdot (Y_i - \bar{Y}) \tag{4.2}$$

In this equation, $\bar{X}$ and $\bar{Y}$ are the mean values of the variables X and Y, respectively. The standard deviation, denoted as s_X or s_Y, can be calculated using the following equation:

$$s_X = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \bar{X})^2} \;\; or \;\; \sqrt{s_Y = \frac{1}{n-1} \sum_{i=1}^{n} (Y_i - \bar{Y})^2} \tag{4.3}$$

By inserting the equations 4.2 and 4.3 into the equation 4.1, we obtain the following formula for calculating for the correlation coefficient:

$$cov_{XY} = \frac{\sum_{i=1}^{n} (X_i - \bar{X}) \cdot (Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \cdot \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}} \tag{4.4}$$

Finally, SPSS provides additional information for each calculation, including the significance of the correlation coefficient, which is of interest for $*p < 0.05$ and $**p < 0.01$ significance levels, and the number of variables considered. In addition, the correlation coefficient may have a positive or negative sign. Based on this information, the results of this work are presented in the next chapter.

Chapter 5

Results

The results of this work are presented in the following chapter. First, an overview of the results of different algorithms and under considering different camera positions is given. Then, a detailed look is taken on the amount of correlations with respect to the whole questionnaires and specific questions, as well as to the calculated emotional expressions and the considered action unit combinations for facial expressions. Finally, correlations between specific emotions and mood on the following day are given.

5.1 Algorithms

The number of significant correlations for the different algorithms has been added together to estimate which calculation method gives the highest correlations. The Table 5.1 shows the results for each single camera (*'Left'*, *'Above'*, *'Right'*). It also distinguishes between positive (+) and negative (-) correlations with a significance level of $*p < 0.05$ and $**p < 0.01$. For the algorithms *'MeanTotal'*, *'ConfMeanTotal'*, *'MeanSpec'* and *'ConfMeanSpec'* the total number of correlations is given. The detailed description of each algorithm can be found in the Appendix B.2.

As can be seen in the Table 5.1, the number of correlations between the different camera perspectives varies constantly, e.g. for *'MeanTotal'* positive and negative correlations with $*p < 0.05$ show in camera *'Left'* 119 and 50, for *'Above'* 276 and 106, and for *'Right'* 195 and 208. For *'ConfMeanSpec'*, positive and negative correlations with $**p < 0.01$ are displayed in camera *'Left'* 91 and 39, in *'Above'* 158 and 26, and in *'Right'* 143 and 107. Although the differences between the same algorithm with and without the confidence level are smaller, the results vary greatly depending on the camera perspective.

Table 5.1: Total number of calculated Pearson correlation coefficients with significance $*p < 0.05$ and $**p < 0.01$, for positive (+) and negative (-) correlations respectively. Difference between each single camera (*'Left'*, *'Above'*, *'Right'*) and different algorithms (*'MeanTotal'*, *'ConfMeanTotal'*, *'MeanSpec'*, *'ConfMeanSpec'*, for further description see Appendix B.2).

	Left				**Above**				**Right**			
	+**	+*	-*	-**	+**	+*	-*	-**	+**	+*	-*	-**
MeanTotal	62	**119**	**50**	11	123	**276**	**106**	20	121	**195**	**208**	65
ConfMeanTotal	67	122	49	14	111	277	112	17	111	197	213	65
MeanSpec	91	293	130	39	168	251	167	17	148	234	180	107
ConfMeanSpec	**91**	306	143	**39**	**158**	266	201	**26**	**143**	246	183	**107**

Table 5.2 contains the results for the case where all three cameras are combined. The total number of Pearson correlation coefficients calculated distinguishes between positive (+) and negative (-) correlation with significance levels $*p < 0.05$ and $**p < 0.01$. The results include values for the calculation methods of *'AvgMeanTotal'*, *'AvgMeanSpec'*, *'MaxMeanTotal'* and *'MaxMeanSpec'*, each with and without consideration of the confidence level. In comparison, the number of positive correlations with $*p < 0.05$ is the highest, followed by negative correlations with $*p < 0.05$. Negative correlations with $**p < 0.01$ are the least represented.

Calculations of *'MeanTotal'*, whether with or without confidence level, and whether *'Avg'* or *'Max'* are calculated, give almost the same number of correlations, e.g. negative correlations with $*p < 0.05$ shown for *'AvgMeanTotal'* 145 and 138 (with and without *'Conf'*), and for *'MaxMeanTotal'* 147 and 139 (with and without *'Conf'*). The same trend can be observed for the

Table 5.2: Total number of calculated Pearson correlation coefficients with significance $*p < 0.05$ and $**p < 0.01$, for positive (+) and negative (-) correlations respectively. Offset of three cameras against each other, for different algorithms (*'AvgMeanTotal'*, *'ConfAvgMeanTotal'*, *'AvgMeanSpec'*, *'ConfAvgMeanSpec'*, *'MaxMeanTotal'*, *'ConfMaxMeanTotal'*, *'MaxMeanSpec'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2).

	Sum			
	+**	+*	-*	-**
AvgMeanTotal	93	209	**145**	17
ConfAvgMeanTotal	88	201	**138**	14
AvgMeanSpec	142	338	174	30
ConfAvgMeanSpec	141	325	202	27
MaxMeanTotal	79	**194**	**147**	22
ConfMaxMeanTotal	78	**179**	**139**	21
MaxMeanSpec	133	**314**	209	10
ConfMaxMeanSpec	135	**316**	217	12

calculations of *'MeanSpec'*. On the other hand, a comparison of the calculations of *'MeanTotal'* and *'MeanSpec'* in Table 5.2 shows considerable differences. For example, for positive correlations with $*p < 0.05$, *'MaxMeanTotal'* and *'ConfMaxMeanTotal'* give only 194 and 179 correlations, while *'MaxMeanSpec'* and *'ConfMaxMeanSpec'* give 314 and 316.

5.2 Questionnaires

The following section focuses on the calculated correlations in relation to the questionnaires. Further considerations were only made for the calculations of all three cameras together and with *'Conf'*. Table 5.3 shows the total number of calculated Pearson correlation coefficients, distinguishing between positive (+) and negative (-) correlations with significance levels $*p < 0.05$ and $**p < 0.01$. The results include values for the calculation methods of *'ConfAvgMeanTotal'*, *'ConfAvgMeanSpec'*, *'ConfMaxMeanTotal'* and *'ConfMaxMeanSpec'*. The detailed description of each category and the questionnaire questions it contains can be found in the Appendix B.3.

Most correlations can be found for *'Morning negatives'* and *'Noon negatives'*, and for *'ConfAvgMeanSpec'* and *'ConfMaxMeanSpec'* calculations. Here the values are 101 and 121 as well as 94 and 134 (Table 5.3). Similar to the results in Table 5.2, calculations with *'MeanSpec'* show more correlations than with *'MeanTotal'*. Noon questions showed the most correlations, followed by morning and evening questions with the fewest, while negative questions always showed more correlations than positive ones. It is also noticeable that negative questions give more positive than negative correlations, while the positive questions show the opposite trend.

Table 5.3: Total number of calculated Pearson correlation coefficients for different questionnaire categories (see Appendix B.3 for further description), with significance $*p < 0.05$ and $**p < 0.01$, for positive (+) and negative (-) correlations respectively. Offset of three cameras against each other, for different algorithms (*'ConfAvgMeanTotal'*, *'ConfAvgMeanSpec'*, *'ConfMaxMeanTotal'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2).

	ConfAvgMeanTotal				**ConfAvgMeanSpec**				**ConfMaxMeanTotal**				**ConfMaxMeanSpec**			
	+**	**+***	**-***	**-****	**+****	**+***	**-***	**-****	**+****	**+***	**-***	**-****	**+****	**+***	**-***	**-****
Introductory questions	12	22	2	0	2	26	40	7	13	20	2	0	2	26	17	1
Morning negatives	11	68	9	0	51	**101**	11	0	10	64	9	0	55	**94**	32	0
Morning positives	0	0	68	9	1	5	49	11	0	1	67	14	0	10	51	1
Noon negatives	19	40	15	3	67	**121**	8	0	20	32	22	3	63	**134**	23	0
Noon positives	1	26	32	1	2	29	52	9	2	17	31	3	4	19	56	7
Evening negatives	45	43	1	0	18	40	29	0	33	42	1	0	11	28	28	3
Evening positives	0	2	11	1	0	3	13	0	0	3	10	1	0	5	10	0

Table 5.4: Shortcut to specific questions with the most correlations within different categories, for different algorithms (*'ConfAvgMeanTotal'*, *'ConfAvgMeanSpec'*, *'ConfMaxMeanTotal'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2). For introductory questions, only the first place is shown, while for morning, noon and evening questions, the first, second and third places are shown (for further description see Appendix B.3).

		ConfAvgMeanTotal	**ConfAvgMeanSpec**	**ConfMaxMeanTotal**	**ConfMaxMeanSpec**
Introductory questions	1.	Pain	Pain	Pain	Pain
Morning negatives	1.	**Sadness**	Stress	**Sadness**	Stress
	2.	Stress	**Fear**	Depression	**Fear**
	3.	Depression / Mood	Depression	Stress	**Sadness**
Morning positives	1.	Mood	Mood	Relief	Relief
	2.	Relief	Relief / Proud	Mood	Gratefulness
	3.	Gratefulness	Gratefulness	Gratefulness	**Happiness**
Noon negatives	1.	Stress	Mood	Anger	**Fear**
	2.	Anger	**Fear**	Stress / **Sadness**	Anger
	3.	Mood	Stress	Mood	Mood
Noon positives	1.	Proud	Gratefulness	**Happiness**	Gratefulness
	2.	**Happiness**	**Happiness**	Gratefulness	**Happiness**
	3.	Relief	Contentment / Proud	Relief / Proud	Contentment
Evening negatives	1.	Stress	Stress	Stress	Stress
	2.	**Sadness** / Mood	**Fear**	Mood / **Sadness**	**Fear**
	3.	**Fear** / Contempt	Mood	**Fear** / Contempt	Depression
Evening positives	1.	Relief	Mood / Relief	Relief	Relief
	2.	**Happiness** / Contentment	Proud	Contentment / **Happiness**	Mood
	3.	Mood	**Happiness**	Mood	**Happiness**

Table 5.4 highlights the questions in order of highest correlation in each category, represented by a shortcut (see Apendix B.3 for further explanation of shortcuts). For *'Introductory questions'* only the most important question is shown, namely *'Did you have any pain last night?'* for all the different calculations. For the introductory questions *'Did you take any sleeping pills last night?'* and *'Did you sleep alone in bed last night?'* no correlations could be found because both questions were always answered in the same way, so there's no variation. For the morning, noon and evening questions, the first three most important questions are displayed.

The question *'How sad are you feeling right now?'* is strongly represented first in the morning and second in the noon and evening, but only for the calculations *'ConfAvgMeanTotal'* and *'ConfMaxMeanTotal'*. Also, the question for *'How anxious are you feeling right now?'* for morning, noon and evening is always second, but only for the calculations *'ConfAvgMeanSpec'* and *'ConfMaxMeanSpec'*. For the noon and the calculation *'ConfMaxMeanSpec'* it's the first and *'ConfAvgMeanTotal'* for evening it's the third. The question *'How happy are you right now?'* is also more represented. While it is only in third place in the morning for the *'ConfMaxMeanSpec'* calculation, it is in first and second place for all the calculation algorithms at noon, and in second and third place in the evening. It's also worth noting that the question *'How stressed are you feeling right now?'* is most often in the evening, but also in the morning and noon.

5.3 Action Unit Combinations

Table 5.5 gives an overview of the number of calculated correlations for different emotional representations. It takes into account the number of different AU combinations (Table 4.1) and the number of different calculation methods for the facial expressions (Table B.4). Several weighting factors are introduced to estimate the sum value. A detailed description, including the calculation of sums and means, can be found in the Appendix B.4.

The highest mean and sum value for positive and negative correlations is for *'Happiness'* and *'ConfMaxMeanSpec'* with 12.60 and 189 respectively. The second highest mean is 11.33 for *'Triumph'* and *'Embarrassment'* for *'ConfAvgMeanSpec'*, while both have a small sum of 34. The second and third highest sums of positive and negative correlations are found for the emotional expression of *'Contempt'* for *'ConfMaxMeanSpec'* with 178 and for *'ConfAvgMeanSpec'* with 164. This is followed by very high sums for *'Fear'*, which also has the highest number of calculated facial expressions with 24, with 144 for *'ConfAvgMeanSpec'* and 127 for *'ConfMaxMeanSpec'*. In line with previous results, the *'Avg'* and *'Max'* calculations don't differ much from each other, while the results for *'MeanSpec'* show more correlations than for *'MeanTotal'*.

Table 5.5: Sum (Σ) and mean (Ø) for positive (+) and negative (-) correlations with respect to the number of calculated facial expressions (N, for further description see Appendix B.3), for 19 different emotions and different algorithms (*'ConfAvgMeanTotal'*, *'ConfAvgMeanSpec'*, *'ConfMaxMeanTotal'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2).

		ConfAvgMeanTotal				**ConfAvgMeanSpec**				**ConfMaxMeanTotal**				**ConfMaxMeanSpec**			
	N	Σ^+	**Ø**$^+$	Σ^-	**Ø**$^-$	Σ^+	**Ø**$^+$	Σ^-	**Ø**$^-$	Σ^+	**Ø**$^+$	Σ^-	**Ø**$^-$	Σ^+	**Ø**$^+$	Σ^-	**Ø**$^-$
Happiness	15	64	4.27	86	5.73	**163**	**10.87**	96	6.40	68	4.53	85	5.67	**189**	**12.60**	93	6.20
Desire	6	20	3.33	6	1.00	56	9.33	9	1.50	16	2.67	9	1.50	47	7.83	12	2.00
Surprise	18	81	4.50	0	0.00	69	3.83	19	1.06	70	3.89	0	0.00	65	3.61	12	0.67
Contentment	9	5	0.56	6	0.67	32	3.56	28	3.11	6	0.67	8	0.89	24	2.67	26	2.89
Interest	9	16	1.78	3	0.33	15	1.67	3	0.33	14	1.56	3	0.33	16	1.78	3	0.33
Awe	9	11	1.22	0	0.00	17	1.89	4	0.44	12	1.33	0	0.00	19	2.11	3	0.33
Triumph	3	15	5.00	6	2.00	34	**11.33**	7	2.33	8	2.67	9	3.00	27	**9.00**	7	2.33
Sadness	18	66	3.67	26	1.44	64	3.56	12	0.67	66	3.67	24	1.33	65	3.61	9	0.50
Distress	6	27	4.50	9	1.50	57	9.50	6	1.00	27	4.50	9	1.50	51	8.50	3	0.50
Fear	**24**	104	4.33	25	1.04	**144**	6.00	52	2.17	90	3.75	26	1.08	**127**	5.29	54	2.25
Anger	24	27	1.13	19	0.79	44	1.83	33	1.38	30	1.25	32	1.33	60	2.50	36	1.50
Disgust	21	36	1.71	12	0.57	82	3.90	60	2.86	17	0.81	26	1.24	65	3.10	52	2.48
Confusion	9	24	2.67	0	0.00	29	3.22	6	0.67	22	2.44	6	0.67	28	3.11	12	1.33
Embarrassment	3	15	5.00	6	2.00	34	**11.33**	7	2.33	8	2.67	9	3.00	27	**9.00**	7	2.33
Shame	3	2	0.67	1	0.33	15	5.00	6	2.00	1	0.33	4	1.33	13	4.33	12	4.00
Pain	9	21	2.33	15	1.67	20	2.22	19	2.11	21	2.33	11	1.22	22	2.44	14	1.56
Sympathy	6	24	4.00	9	1.50	14	2.33	0	0.00	21	3.50	3	0.50	9	1.50	0	0.00
Contempt	21	64	3.05	60	2.86	**164**	7.81	99	4.71	53	2.52	61	2.90	**178**	8.48	73	3.48
Disbelief	3	1	0.33	3	1.00	1	0.33	0	0.00	1	0.33	3	1.00	1	0.33	0	0.00

Table 5.6: Specific Action Unit combinations with the most correlations within the different algorithms (*'Hard'*, *'Mid'*, *'Soft'*, for further description see Appendix B.3) and the corresponding calculation method (*'ConfAvgMeanTotal'*, *'ConfAvgMeanSpec'*, *'ConfMaxMeanTotal'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2).

Emotion	Action Unit Combination	Algorithm
Happiness	**6+12 (Mid/Soft)**	**ConfAvgMeanSpec**
Desire	6+7+12+25 (Mid)	ConfAvgMeanSpec / ConfMaxMeanSpec
Surprise	1+2+5 (Hard)	ConfAvgMeanSpec
Contentment	6+7+25 (Mid) / 6+17 (Mid/Soft)	ConfMaxMeanSpec
Interest	1+2+12 (Mid)	ConfAvgMeanTotal
Awe	1+5+26 (Hard/Soft)	ConfAvgMeanSpec / ConfMaxMeanSpec
Triumph	6+7+12+25 (Mid)	ConfAvgMeanSpec / ConfMaxMeanSpec
Sadness	6+15 (Mid/Soft) / **1+4+5 (Hard)**	**ConfAvgMeanSpec**
Distress	6+15 (Mid/Soft)	ConfAvgMeanSpec
Fear	**4+6+12 (Hard)**	**ConfAvgMeanSpec / ConfMaxMeanSpec**
Anger	4+5+7+10+23+25+26 (Mid)	ConfAvgMeanSpec / ConfMaxMeanSpec
Disgust	10 (Hard/Mid/Soft) / 4+6+7+9+10+25+26 (Mid)	ConfAvgMeanSpec
Confusion	17+25+26 (Mid)	ConfAvgMeanSpec
Embarrassment	6+7+12+25 (Mid)	ConfAvgMeanSpec / ConfMaxMeanSpec
Shame	6+7+25 (Mid)	ConfMaxMeanSpec
Pain	4+6+7+20+25 (Hard)	ConfAvgMeanTotal / ConfMaxMeanTotal
Sympathy	1+4 (Hard)	ConfAvgMeanTotal
Contempt	12+14 (Mid/Soft)	ConfAvgMeanSpec
Disbelief	1+2+10+15+17 (Hard/Soft)	ConfAvgMeanSpec / ConfMaxMeanSpec

Table 5.6 shows, for each emotional expression, the combination of AUs that gives the highest correlations, together with the algorithm used. For the emotion of *'Happiness'*, the AUs 6+12 for the *'Mid'* and *'Soft'* calculations gave the highest correlations. *'Sadness'* had the highest correlations with the AU combinations of 6+15 calculated by *'Mid'* and *'Soft'* and 1+4+5 calculated by *'Hard'*. For *'Fear'* AUs 4+6+12 in combination with algorithms for *'Hard'* are the most common. For these three emotions the calculation of *'ConfAvgMeanSpec'* gives the highest correlation, but for *'Fear'* also *'ConfMaxMeanSpec'* with the same amount.

For all emotions, calculations based on *'Mid'* are the most represented, while for AU combinations consisting of only two action units, *'Soft'* is also represented. Note that for *'Disgust'*, a combination of one and seven AUs shows the highest correlation. For the emotions of *'Desire'*, *'Triumph'* and *'Embarrassment'* the AU combination with the highest correlation is the same as 6+7+12+25 and the calculation *'Mid'*. The algorithms of *'Avg'* show slightly more combinations for the highest correlations than *'Max'*.

5.4 Facial Expression and Mood

As shown in Table 5.7, the question of *'How happy are you right now?'* at noon and the emotion *'Happines'* with AU combination 6+12 are significant for each algorithm with $**p < 0.01$, except for *'ConfMaxMeanSpec'* and *'Hard'* with $*p < 0.05$. The Pearson correlation coefficient shows values between -0.544 and -0.589 at noon. The same calculations show no significant correlation for the morning or evening questions. Furthermore, the coefficients in the morning have a negative sign, while those in the evening have a positive sign.

Calculations for the emotional state of *'Sadness'* from AUs 1+4+5 and the specific question of *'How sad are you feeling right now?'* are shown in Table 5.8. For the algorithms *'ConfAvg-MeanSpec'* and *'Soft'* a correlation coefficient of 0.420 with $*p < 0.05$ is found in the morning. At noon, for the calculations of *'Mid'* and *'Soft'*, correlations with $*p < 0.05$ and $**p < 0.01$ are found for both algorithms of *'Avg'* and *'Max'*. No significant correlations were found in the evening.

Table 5.7: Pearson correlation coefficient for *'Happiness'* with AUs 6+12 and different algorithms (*'Hard'*, *'Mid'*, *'Soft'*,*'ConfAvgMeanSpec'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2 and B.3) and the question of *'How happy are you right now?'* in the morning, at noon and in the evening.

	ConfAvgMeanSpec			**ConfMaxMeanSpec**		
	Hard	**Mid**	**Soft**	**Hard**	**Mid**	**Soft**
Happiness Morning	-0.030	-0.265	-0.265	-0.227	-0.361	-0.361
Happiness Noon	**-0.583****	**-0.558****	**-0.558****	**-0.589***	**-0.544****	**-0.544****
Happiness Evening	0.006	0.033	0.033	0.043	0.056	0.056

Table 5.8: Pearson correlation coefficient for *'Sadness'* with AUs 1+4+5 and different algorithms (*'Hard'*, *'Mid'*, *'Soft'*,*'ConfAvgMeanSpec'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2 and B.3) and the question of *'How sad are you feeling right now?'* in the morning, at noon and in the evening.

	ConfAvgMeanSpec			**ConfMaxMeanSpec**		
	Hard	**Mid**	**Soft**	**Hard**	**Mid**	**Soft**
Sadness Morning	-0.002	0.396	**0.420***	-0.028	0.295	0.337
Sadness Noon	0.021	**0.538****	**0.455***	0.002	**0.466***	**0.416***
Sadness Evening	0.114	0.248	0.192	0.106	0.194	0.148

Table 5.9: Pearson correlation coefficient for *'Fear'* with AUs 4+6+12 and different algorithms (*'Hard'*, *'Mid'*, *'Soft'*,*'ConfAvgMeanSpec'*, *'ConfMaxMeanSpec'*, for further description see Appendix B.2 and B.3) and the question of *'How anxious are you feeling right now?'* in the morning, at noon and in the evening.

	ConfAvgMeanSpec			**ConfMaxMeanSpec**		
	Hard	**Mid**	**Soft**	**Hard**	**Mid**	**Soft**
Fear Morning	**0.424***	**0.534****	**0.431***	**0.472***	**0.548****	0.400
Fear Noon	**0.577****	**0.642****	**0.601****	**0.650****	**0.684****	**0.641****
Fear Evening	-0.072	-0.083	0.117	-0.095	-0.101	-0.020

'How anxious are you feeling right now?' in combination with *'Fear'* from AUs 4+6+12 showed many significant correlations, as can be seen in Table 5.9. For the morning and noon questionnaires the Pearsons correlation coefficients take values between 0.400 and 0.684 with *$p < 0.05$ and **$p < 0.01$, except for the calculation for *'ConfMaxMeanSpec'* and *'Soft'*. In the evening, no significant correlations are found and with one exception, all coefficients are negative.

Chapter 6

Discussion

In order to find a relationship between facial expressions during the night and the mood of the following day, first different computational algorithms are first discovered and compared to find out which one might be the most suitable for evaluating nocturnal emotions. A first observation was made to consider the influence of different camera perspectives on the resulting correlations. It was found that the total amount of correlations deviate between the different perspectives because people move during sleep, which is a common human behaviour. Furthermore, most people tend to sleep in a preferred position, such as women as men generally prefer to sleep in the right lateral decubitus position [Arb18]. In order to eliminate the influence of different sleeping positions during the night, a summarised evaluation of all cameras was chosen for further processing. Nevertheless, a set of eight different algorithms were tested to validate the facial expression data (for further description see Appendix B.2). When comparing the total number of correlations found, it became clear that calculations with the confidence level gave almost the same number as those without. This could lead to the fact that timeframes with a confidence level of 0 don't detect almost any action unit intensity anyway. For timeframes with a confidence level below 80 percent, the number of action units found was also quite low, making it more difficult to find specific action unit combinations. As already mentioned, the developers of OpenDBM also refer to timeframes with a confidence level above 80 percent for further calculations (Section 3.2). Furthermore, it can be observed that *'MeanSpec'* calculations always result in more correlations, compared to *'MeanTotal'*, regardless of the camera perspective or the confidence level. It seemed that considering only non-zero frames weighted the facial expressions differently. With respect to the summarised camera perspectives, the *'Avg'* calculations gave almost the same number of correlations as *'Max'*.

The next step was to look at the correlations for different questions in the questionnaires to see which specific questions might give a good correlation to the sleep quality. For the introductory questions, the question on *'Did you have any pain last night?'* showed the highest correlations, regardless of the calculation algorithm, and could therefore be a good measure of sleep quality. However, the calculation of *'MeanTotal'* showed mainly positive correlations, while *'MeanSpec'* showed both positive and negative correlations. It was also be observed that in the morning and evening almost all negative questions had positive correlations and positive questions had negative correlations. This trend was also observed for the noon questionnaires, but less so for *'MeanTotal'* and more so for *'MeanSpec'*. In terms of specific questions, the emotional states of *'Happiness'*, *'Sadness'* and *'Fear'* were often found to have higher correlations. As a negative mood, *'Stress'* was often found, but as it cannot be related to a specific facial expression, it was further neglected in this work.

The FACS was not originally designed for sleeping people or for facial expressions with eyes closed [Ekm02]. Therefore, one of the tasks during this work was to test different AU combinations for well-known emotional expressions of awake people. The freedom of multiple combinations was only limited by the AUs provided by OpenDBM (see Appendix B.1). In order to cover a large number of common emotions (see Table 4.1), some AU combinations had to be reduced to those provided by OpenDBM. As a first quality criteria, the sum and the mean value over all correlations were chosen for the different calculation algorithms, including *'Hard'*, *'Mid'* and *'Soft'* calculations. The highest mean correlations were found for *'Happiness'*, but the different combinations of AUs used contain almost the same AUs, namely AU 6 and AU 12 (see Table 4.1). *'Desire'*, *'Embarrassment'* and *'Triumph'* also showed a high mean value for correlations, but this was not insignificant given that they used similar AUs to *'Happiness'*, while *'Triumph'* and *'Embarrassment'* were calculated with exactly the same AUs. *'Fear'* showed a high sum number of correlations but a lower mean, suggesting that not all the different implemented action unit combinations are relevant enough. With regard to the eight different combinations, it became clear that many different AUs were involved. Also *'Contempt'* showed a high sum value with a lower mean value of the correlations. As the calculated combinations of AUs were very different from each other, this may also lead to the fact that only certain combinations were present during the night and were relevant for emotional expression. Increased facial activity during sleep, especially during REM sleep, and a relationship with emotional dream content has already been proven in the literature [RIV11][Riv19]. For further investigation in this work, the focus was on the emotions of *'Happiness'* with AUs 6+12, *'Sadness'* with AUs 1+4+5 and *'Fear'* with AUs 4+6+12, as they belong to the basic emotions described by Eckman [Ekm92] and these AU combinations showed the most correlations in this work. It was obvious that the most common combinations contained almost the same AUs. AU 4 belongs to the corrugator muscle activity, which results in a brow lowerer, and it was already known that corrugator activity is high during REM sleep [Riv19]. AU 12 on the other hand belongs to the zygomaticus muscle and results in a lip corner puller, which was also a quite active muscle during REM sleep and was also correlated with positive dreams [Riv19]. On the other side, it was well known that during the night, regardless of REM sleep or non-REM sleep, twitching often occurs and can lead to brief unilateral lip corner raising, which could lead to incorrect AU recognition [Clé19]. On the other hand, one study also showed smiling during the night, while more than half of whom were Duchenne types, could lead to the suggestion of reflections of happy emotional expressions [Clé19]. In addition, one study found many frowns during the night, which were associated with overtly negative facial expressions including mostly painful expressions and rarely sadness and anger [Mar21].

In order to investigate the relationship between nocturnal facial expressions and mood, the correlation between specific emotions and questions will be addressed. Although there is a bidirectional relationship between sleep quality and mood, the focus is only on the effect of sleep quality on mood, as this has already been described as a more significant [Tri19]. As *'Happiness'*, *'Sadness'* and *'Fear'* were found to be a very common emotional expressions in this work, the correlations between these facial expressions and the corresponding questions were evaluated. In all cases there were at least significant correlations between the calculated facial expression and the questions from noon, while the correlations were negative for the positive emotion (*'Happiness'*) and positive for the negative emotions (*'Sadness'* and *'Fear'*). The calculation for the *'ConfAvgMeanSpec'* and *'ConfMaxMeanSpec'* algorithms, which were chosen as the most appropriate calculations in this work, showed almost the same results.

Chapter 7

Conclusion and Outlook

The aim of this work was to investigate the relationship of nocturnal facial expressions and the mood on the following day. For this purpose, a dataset of 27 video recordings was post-processed using OpenDBM to automatically extract the facial action units during the night. On the basis of this data, various algorithms were implemented to calculate the facial expressions that usually lead to emotional feelings in awake people. In addition, questionnaires on the following day which record the mood during the day were taken into account for the correlation calculations. The main focus was to evaluate whether sleep quality could be measured by facial expressions during the night and whether they could provide further clues to a person's mood.

As this type of research topic was almost unexplored, the first step was to compute a very large amount of data in order to scan a very wide range of possibilities in order to finally implement the most appropriate framework. It quickly became clear that the three camera perspectives should not be considered individually, but rather summarised together. It was also found that whether or not the confidence level was taken into account made almost no difference, even when summarising by averaging or considering only the camera with the highest intensity. A huge difference was found when calculating the mean value for the whole night, as a calculation without including non-zero entries seems to give considerably more correlations.

In relation to the different questions in the questionnaire, the negative questions show more positive correlations and the negative questions show more positive correlations. In addition, the emotions of *'Happiness'*, *'Sadness'* and *'Fear'* result in a large number of correlations, as do *'Pain'* and *'Stress'*. With regard to all calculated combinations of AUs, the facial expressions of *'Happiness'* showed the highest number of correlations. Besides the fact that all of these combinations contained almost similar AUs, it was found that AUs 6+12 resulted in the most correlations. *'Fear'* and *'Sadness'* did not had such high mean values, but high sum values, because their calculated AU combinations differed more from each other, and only some of the predicted ones showed many correlations. The AUs 4+6+12 for *'Fear'* and the AUs 1+4+5 for *'Sadness'* were those with the most calculated correlations.

The relationship between sleep quality and mood was investigated using specific questions and their corresponding facial expressions. The results showed significant correlations with the noon questions in all cases, and also with the morning questions for *'Fear'*. The correlations were negative for *'Happiness'*, but positive for *'Sadness'* and *'Fear'*.

As this work was one of the first in the field of automatic facial expression detection, there are many unanswered questions. Future work should further investigate the relationship between emotions with specific questions. Facial expressions of pain or stress should also be taken into account. In addition, the progression of facial expressions over time during the night could be studied in order to find typical patterns for sleep behaviour and quality.

Appendix A

Questionnaire

Vorbefragung:

Die folgenden Fragen beziehen sich auf Ihre Gefühle und Gedanken während des letzten Monats. Bei jeder Frage werden Sie gebeten anzugeben, wie häufig Sie in eine bestimmte Richtung dachten oder fühlten. Obwohl einige Fragen sehr ähnlich wirken, unterscheiden sie sich. Deshalb sollten Sie jede Frage für sich betrachten. Am besten beantworten Sie alle Fragen zügig und spontan. Versuchen Sie also nicht zu zählen, wie häufig Sie ein bestimmtes Gefühl hatten, sondern schätzen Sie einfach, welche Antwort am ehesten zutrifft.

Kreuzen Sie für jede der Fragen eine der folgenden Antwortmöglichkeiten an:

- niemals
- fast nie
- manchmal
- öfter
- sehr oft

	niemals	*fast nie*	*manch mal*	*öfter*	*sehr oft*
1. Wie häufig waren Sie im letzten Monat bestürzt über etwas, das unerwartet passierte?	☐	☐	☐	☐	☐
2. Wie oft hatten Sie im letzten Monat das Gefühl, wichtige Dinge im Leben nicht kontrollieren zu können?	☐	☐	☐	☐	☐
3. Wie oft fühlten Sie sich im letzten Monat nervös oder gestresst?	☐	☐	☐	☐	☐
4. Wie oft waren Sie im letzten Monat zufrieden darüber, wie Sie Ihre persönlichen Probleme gelöst haben?	☐	☐	☐	☐	☐
5. Wie oft hatten Sie im letzten Monat das Gefühl, dass die Dinge so laufen, wie Sie es gerne hätten?	☐	☐	☐	☐	☐
6. Wie oft hatten Sie im letzten Monat das Gefühl, dass Sie mit dem, was Sie zu bewältigen hatten, nicht zurechtkamen?	☐	☐	☐	☐	☐
7. Wie oft hatten Sie im letzten Monat das Gefühl, dass Sie Ärger in Ihrem Leben kontrollieren können?	☐	☐	☐	☐	☐
8. Wie oft hatten Sie im letzten Monat das Gefühl, dass Sie die Dinge in der Hand haben?	☐	☐	☐	☐	☐
9. Wie oft haben Sie sich im letzten Monat über Dinge geärgert, die außerhalb Ihrer Kontrolle lagen?	☐	☐	☐	☐	☐
10. Wie oft hatten Sie im letzten Monat das Gefühl, dass sich Aufgaben oder Probleme so sehr aufgestaut hatten, dass Sie diese nicht bewältigen können?	☐	☐	☐	☐	☐

EMO-Check	(Code-) Name: ____________	Alter: ____
Version-L-S 1/2008 04)	**Beruf:** ________________	**Geschlecht:**__

Liebe(r) Teilnehmer(in),

im Folgenden finden Sie eine Reihe von Fragen zu Ihrem emotionalen Befinden in der letzten Woche und Ihrem Umgang mit diesen. Bitte beantworten Sie die Fragen spontan, indem Sie die Antwort aussuchen und ankreuzen, die Ihnen am passendsten erscheint.

1. Gefühle & Stimmungen: *In der letzten Woche fühlte ich mich ...*

		überhaupt nicht	ein wenig	mittel-mäßig	ziemlich	sehr			überhaupt nicht	ein wenig	mittel-mäßig	ziemlich	sehr
1.)	mutig:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	26.)	traurig:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
2.)	wertlos:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	27.)	enttäuscht:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
3.)	dankbar:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	28.)	zuversichtlich:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
4.)	aktiv:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	29.)	geborgen:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
5.)	interessiert:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	30.)	beunruhigt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
6.)	freudig erregt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	31.)	niedergeschlagen:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
7.)	stark:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	32.)	betrübt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
8.)	inspiriert:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	33.)	angespannt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
9.)	stolz:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	34.)	gestresst:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
10.)	begeistert:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	35.)	hoffnungslos:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
11.)	wach:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	36.)	optimistisch:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
12.)	entschlossen:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	37.)	besorgt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
13.)	aufmerksam:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	38.)	angeekelt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
14.)	bekümmert:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	39.)	gedemütigt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
15.)	verärgert:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	40.)	wertvoll:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
16.)	schuldig:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	41.)	gelassen:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
17.)	erschrocken:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	42.)	zufrieden:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
18.)	feindselig:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	43.)	wohl:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
19.)	gereizt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	44.)	eifersüchtig:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
20.)	beschämt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	45.)	verliebt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
21.)	nervös:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	46.)	friedlich:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
22.)	durcheinander:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	47.)	ruhig:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
23.)	ängstlich:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	48.)	neidisch:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
24.)	sicher:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	49.)	glücklich:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$
25.)	peinlich berührt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$	50.)	entspannt:	O $_0$	O $_1$	O $_2$	O $_3$	O $_4$

Allgemeine Depressionsskala – ADS

Geben Sie bitte an, wie häufig die folgenden Reaktionen in den **letzten 7 Tagen** bei Ihnen auftraten.

Während der letzten sieben Tage…	Selten	Manchmal	Öfters	Meistens
… haben mich Dinge beunruhigt, die mir sonst nichts ausmachen.	☐	☐	☐	☐
… hatte ich kaum Appetit.	☐	☐	☐	☐
… konnte ich meine trübsinnige Laune nicht loswerden, obwohl mich meine Freunde/Familie aufzumuntern versuchten.	☐	☐	☐	☐
… kam ich mir genauso gut vor wie andere.	☐	☐	☐	☐
… hatte ich Mühe, mich zu konzentrieren.	☐	☐	☐	☐
… war ich deprimiert/niedergeschlagen.	☐	☐	☐	☐
… war alles anstrengend für mich.	☐	☐	☐	☐
… dachte ich voller Hoffnung an die Zukunft.	☐	☐	☐	☐
… dachte ich, mein Leben ist ein einziger Fehlschlag.	☐	☐	☐	☐
… hatte ich Angst.	☐	☐	☐	☐
… habe ich schlecht geschlafen.	☐	☐	☐	☐
… war ich fröhlich gestimmt.	☐	☐	☐	☐
… habe ich weniger als sonst geredet.	☐	☐	☐	☐
… fühlte ich mich einsam.	☐	☐	☐	☐
… waren die Leute unfreundlich zu mir.	☐	☐	☐	☐
… habe ich das Leben genossen.	☐	☐	☐	☐
… musste ich weinen.	☐	☐	☐	☐
… war ich traurig.	☐	☐	☐	☐
… hatte ich das Gefühl, dass mich die Leute nicht leiden können.	☐	☐	☐	☐
… konnte ich mich zu nichts aufraffen.	☐	☐	☐	☐

Bitte geben Sie an, welche Ereignisse Ihnen in den letzten 6 Monaten widerfahren sind. Innerhalb der letzten 6 Monate (Mehrfachantworten möglich):
1 = litt ich an einer ernsthaften Erkrankung, wurde ernsthaft verletzt oder angegriffen.
2 = litt ein mir nahstehender Verwandter oder ein enger Freund an einer ernsthaften Erkrankung, wurde ernsthaft verletzt oder angegriffen.
3 = ist mein Partner, mein Kind oder ein Elternteil gestorben.
4 = ist ein mir nahestehender Familienfreund oder ein Familienmitglied gestorben.
5 = ging meine Ehe zu Ende und mein/e Ehepartner/in trennten uns.
6 = ging meine Partnerschaft zu Ende.
7 = hatte ich ein ernstes Problem mit einem mir nahestehendem Freund, Nachbarn oder Verwandten.
8 = wurde ich arbeitslos oder war über einem Monat erfolglos auf Arbeitssuche.
9 = wurde ich entlassen.
10 = hatte ich eine große finanzielle Krise.
11 = hatte ich Schwierigkeiten mit der Polizei oder eine Gerichtsanhörung.
12 = ist etwas, was für mich großen Wert hatte, gestohlen worden bzw. habe ich es verloren.
13 = keine der Aussagen zutreffend.

Schlafqualitäts-Fragebogen (PSQI) [1]

Die folgenden Fragen beziehen sich auf Ihre üblichen Schlafgewohnheiten und zwar <u>*nur*</u> *während der letzten vier Wochen.* Ihre Antworten sollten möglichst genau sein und sich auf die Mehrzahl der Tage und Nächte während der letzten vier Wochen beziehen. Beantworten Sie bitte alle Fragen.

1. Wann sind Sie während der letzten vier Wochen gewöhnlich abends zu Bett gegangen?	übliche Uhrzeit:
2. Wie lange hat es während der letzten vier Wochen gewöhnlich gedauert, bis Sie nachts eingeschlafen sind?	in Minuten:
3. Wann sind Sie während der letzten vier Wochen gewöhnlich morgens aufgestanden?	übliche Uhrzeit:
4. Wieviele Stunden haben Sie während der letzten vier Wochen pro Nacht tatsächlich geschlafen? (Das muß nicht mit der Anzahl der Stunden, die Sie im Bett verbracht haben, übereinstimmen.)	Effektive Schlafzeit (Stunden) pro Nacht:

Kreuzen Sie bitte für jede der folgenden Fragen die für Sie zutreffende Antwort an. Beantworten Sie bitte <u>alle</u> Fragen.

5. Wie oft haben Sie während der letzten vier Wochen schlecht geschlafen, ...

a) ... weil Sie nicht innerhalb von 30 Minuten einschlafen konnten?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
b) ... weil Sie mitten in der Nacht oder früh morgens aufgewacht sind?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
c) ... weil Sie aufstehen mußten, um zur Toilette zu gehen?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche

d) ... weil Sie Beschwerden beim Atmen hatten?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
e) ... weil Sie husten mußten oder laut geschnarcht haben?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
f) ... weil Ihnen zu kalt war?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
g) ... weil Ihnen zu warm war?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
h) ... weil Sie schlecht geträumt hatten?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
i) ... weil Sie Schmerzen hatten?	❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
j) ... aus anderen Gründen? Bitte beschreiben:	Und wie oft während des letzten Monats konnten Sie aus diesem Grund schlecht schlafen? ❍ Während der letzten vier Wochen gar nicht ❍ Weniger als einmal pro Woche ❍ Einmal oder zweimal pro Woche ❍ Dreimal oder häufiger pro Woche
6. Wie würden Sie insgesamt die Qualität Ihres Schlafes während der letzten vier Wochen beurteilen?	❍ Sehr gut ❍ Ziemlich gut ❍ Ziemlich schlecht ❍ Sehr schlecht

7. Wie oft haben Sie während der letzten vier Wochen Schlafmittel eingenommen (vom Arzt verschriebene oder frei verkäufliche)?

- ❍ Während der letzten vier Wochen gar nicht
- ❍ Weniger als einmal pro Woche
- ❍ Einmal oder zweimal pro Woche
- ❍ Dreimal oder häufiger pro Woche

8. Wie oft hatten Sie während der letzten vier Wochen Schwierigkeiten wachzubleiben, etwa beim Autofahren, beim Essen oder bei gesellschaftlichen Anlässen?

- ❍ Während der letzten vier Wochen gar nicht
- ❍ Weniger als einmal pro Woche
- ❍ Einmal oder zweimal pro Woche
- ❍ Dreimal oder häufiger pro Woche

9. Hatten Sie während der letzten vier Wochen Probleme, mit genügend Schwung die üblichen Alltagsaufgaben zu erledigen?

- ❍ Keine Probleme
- ❍ Kaum Probleme
- ❍ Etwas Probleme
- ❍ Große Probleme

10. Schlafen Sie allein in Ihrem Zimmer?

- ❍ Ja
- ❍ Ja, aber ein Partner/Mitbewohner schläft in einem anderen Zimmer
- ❍ Nein, der Partner schläft im selben Zimmer, aber nicht im selben Bett
- ❍ Nein, der Partner schläft im selben Bett

Falls Sie einen Mitbewohner / Partner haben, fragen Sie sie/ihn bitte, ob und wie oft er/sie bei Ihnen folgendes bemerkt hat.

a) Lautes Schnarchen

- ❍ Während der letzten vier Wochen gar nicht
- ❍ Weniger als einmal pro Woche
- ❍ Einmal oder zweimal pro Woche
- ❍ Dreimal oder häufiger pro Woche

b) Lange Atempausen während des Schlafes

- ❍ Während der letzten vier Wochen gar nicht
- ❍ Weniger als einmal pro Woche
- ❍ Einmal oder zweimal pro Woche
- ❍ Dreimal oder häufiger pro Woche

c) Zucken oder ruckartige Bewegungen der Beine während des Schlafes

- ❍ Während der letzten vier Wochen gar nicht
- ❍ Weniger als einmal pro Woche
- ❍ Einmal oder zweimal pro Woche
- ❍ Dreimal oder häufiger pro Woche

4

d) Nächtliche Phasen von Verwirrung oder Desorientierung während des Schlafes

- ❍ Während der letzten vier Wochen gar nicht
- ❍ Weniger als einmal pro Woche
- ❍ Einmal oder zweimal pro Woche
- ❍ Dreimal oder häufiger pro Woche

e) Oder andere Formen von Unruhe während des Schlafes

Bitte beschreiben:

Machen Sie bitte noch folgende Angaben zu Ihrer Person:

Alter: ____ Jahre

Körpergröße: ....

Gewicht:...................

Geschlecht: ❍ weiblich ❍ männlich

Beruf:

- ❍ Schüler/Student(in)
- ❍ Arbeiter(in)
- ❍ Rentner(in)
- ❍ selbständig
- ❍ Angestellte(r)
- ❍ arbeitslos/ Hausfrau(mann)

Soziodemographische Daten

Bitte geben Sie Ihr Geschlecht an:

Bitte geben Sie Ihr Alter an:

Welcher ist Ihr höchster Bildungsabschluss?

Wie ist Ihr aktueller Beschäftigungsstatus?

Wie ist Ihr aktueller Beziehungsstatus?

Interventionstage:

Morgens:

Wie gut haben Sie geschlafen? SchlafQ_1

0 = sehr schlecht 10 = außerordentlich gut

Haben Sie in der letzten Nacht geträumt? SchlafQ_2
(Ja/Nein)
(Bei Ja – bitte notieren Sie ihren Traum in Ihrem „Traumtagebuch“)

Haben Sie in der letzten Nacht Schlafmittel genommen? SchlafQ_3
(Ja/Nein)

Haben Sie in der Nacht allein im Bett geschlafen? SchlafQ_4
(Ja/Nein)

Hatten Sie in der letzten Nacht Schmerzen? SchlafQ_5

0 = gar nicht 10 = außerordentlich

In welchem Ausmaß verspüren Sie gerade negative Stimmung? SchlafE_1

0 = gar nicht 10 = außerordentlich

Wie depressiv verstimmt fühlen Sie sich gerade? SchlafE_2

0 = gar nicht 10 = außerordentlich

Wie gestresst fühlst Sie sich gerade? SchlafE_3

0 = gar nicht 10 = außerordentlich

Wie ängstlich fühlen Sie sich gerade? SchlafE_4

0 = gar nicht 10 = außerordentlich

Wie verärgert sind Sie gerade? SchlafE_5

0 = gar nicht 10 = außerordentlich

Wie traurig fühlen Sie sich gerade? SchlafE_6

0 = gar nicht 10 = außerordentlich

Wie schuldig fühlen Sie sich gerade? SchlafE_7

0 = gar nicht 10 = außerordentlich

Wie sehr schämen Sie sich gerade? SchlafE_8

0 = gar nicht 10 = außerordentlich

Wie stark empfinden Sie gerade Verachtung? SchlafE_9

0 = gar nicht 10 = außerordentlich stark

In welchem Ausmaß verspüren Sie gerade positive Stimmung? SchlafE_10

0 = gar nicht 10 = außerordentlich stark

Wie entspannt sind Sie gerade? SchlafE_11

0 = gar nicht 10 = außerordentlich stark

Wie zufrieden sind Sie gerade? **SchlafE_12**

0 = gar nicht 10 = außerordentlich stark

Wie glücklich sind Sie gerade? **SchlafE_13**

0 = gar nicht 10 = außerordentlich stark

Wie dankbar sind Sie gerade? **SchlafE_14**

0 = gar nicht 10 = außerordentlich stark

Wie stolz sind Sie gerade? **SchlafE_15**

0 = gar nicht 10 = außerordentlich stark

Mittags:

In welchem Ausmaß verspüren Sie gerade negative Stimmung?

0 = gar nicht 10 = außerordentlich

Wie depressiv verstimmt fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie gestresst fühlst Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie ängstlich fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie verärgert sind Sie gerade?

0 = gar nicht 10 = außerordentlich

Wie traurig fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie schuldig fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie sehr schämen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie stark empfinden Sie gerade Verachtung?

0 = gar nicht 10 = außerordentlich stark

In welchem Ausmaß verspüren Sie gerade positive Stimmung?

0 = gar nicht 10 = außerordentlich stark

Wie entspannt sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie zufrieden sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie glücklich sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie dankbar sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie stolz sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Abends:

In welchem Ausmaß verspüren Sie gerade negative Stimmung?

0 = gar nicht 10 = außerordentlich

Wie depressiv verstimmt fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie gestresst fühlst Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie ängstlich fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie verärgert sind Sie gerade?

0 = gar nicht 10 = außerordentlich

Wie traurig fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie schuldig fühlen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie sehr schämen Sie sich gerade?

0 = gar nicht 10 = außerordentlich

Wie stark empfinden Sie gerade Verachtung?

0 = gar nicht 10 = außerordentlich stark

In welchem Ausmaß verspüren Sie gerade positive Stimmung?

0 = gar nicht 10 = außerordentlich stark

Wie entspannt sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie zufrieden sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie glücklich sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie dankbar sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Wie stolz sind Sie gerade?

0 = gar nicht 10 = außerordentlich stark

Appendix B

Descriptions

Table B.1: Table displaying Action Units and the description of the facial movements most relevant to this work.

Action Unit	**Description**	**Action Unit**	**Description**
AU1	Inner Brow Raiser	AU14	Dimpler
AU2	Outer Brow Raiser	AU15	Lip Corner Depressor
AU4	Brow Lowerer	AU17	Chin Raiser
AU5	Upper Lid Raiser	AU20	Lip Stretcher
AU6	Cheek Raiser	AU23	Lip Tightener
AU7	Lid Tightener	AU25	Lips Part
AU9	Nose Wrinkler	AU26	Jaw Drop
AU10	Upper Lid Raiser	AU45	Blink
AU12	Lip Corner Puller		

Table B.2: Description of different algorithms.

Shortcut	**Description**
MeanTotal	mean value over all frames, including zero values
MeanSpec	mean value over all frames, excluding zero values
Avg	average of three cameras, frame-by-frame
Max	maximum value of three cameras, frame-by-frame
Conf	considering confidence level, frame-by-frame

Table B.3: Description for different questionnaire categories.

Category	Question	Shortcut
Introductory questions	Wie gut haben Sie geschlafen?	Quality
	Haben Sie in der letzten Nacht geträumt?	Dream
	Haben Sie in der letzten Nacht Schlafmittel genommen?	Drug
	Haben Sie in der Nacht allein im Bett geschlafen?	Partnership
	Hatten Sie in der letzten Nacht Schmerzen?	Pain
Morning / Noon / Evening negatives	In welchem Ausmaß verspüren Sie gerade negative Stimmung?	Mood
	Wie depressiv verstimmt fühlen Sie sich gerade?	Depression
	Wie gestresst fühlst Sie sich gerade?	Stress
	Wie ängstlich fühlen Sie sich gerade?	Fear
	Wie verärgert sind Sie gerade?	Anger
	Wie traurig fühlen Sie sich gerade?	Sadness
	Wie schuldig fühlen Sie sich gerade?	Guilt
	Wie sehr schämen Sie sich gerade?	Shame
	Wie stark empfinden Sie gerade Verachtung?	Contempt
Morning / Noon / Evening positives	In welchem Ausmaß verspüren Sie gerade positive Stimmung?	Mood
	Wie entspannt sind Sie gerade?	Relief
	Wie zufrieden sind Sie gerade?	Contentment
	Wie glücklich sind Sie gerade?	Happiness
	Wie dankbar sind Sie gerade?	Gratefulness
	Wie stolz sind Sie gerade?	Proud

Table B.4: Description of different algorithms for calculating facial expressions.

Shortcut	Description
Hard	all required AUs must be present
Mid	at least half of the required AUs present
Soft	at least one required AU present
N	number of calculated facial expressions, taking into account the number of different AU combinations times the number of classifications (Hard, Mid, Soft)
Σ	sum value over all correlations, with weighting factors for Hard (3), Mid (2), Soft (1), $*p < 0.05$ (2) and $**p < 0.01$ (1)
Ø	mean of sum value across N facial expressions

Appendix C

Glossary

Ang Anger

ANN Artificial Neural Network

AU Action Unit

Awe Awe

BDM Digital Biomarker

Con Contempt

Conf Confusion

Cont Contentment

Des Desire

Dis Disgust

Disb Disbelief

Dist Distress

Emb Embarrassment

EMG Electromyography

FACS Facial Action Coding System

FAP Facial Animation Parameters

Fea Fear

Hap Happiness

Int Interest

IoT Internet of Things

MAX Maximally Discriminative Facial Movement Coding System

MP Monadic Phases Coding System

Pai Pain

PSG Polysomnography

REM Rapid Eye Movement

Sad Sadness

Sha Shame

Sur Surprise

Sym Sympathy

Tri Triumph

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