UNIVERSITY OF CRETE
DEPARTMENT OF COMPUTER SCIENCE
FACULTY OF SCIENCES AND ENGINEERING

CaLmi: Stress Management in Intelligent Homes

by

Eirini Sykianaki

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of the Requirements for the Degree of

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To my family and friends.

Abstract

In today's fast-paced and demanding society, more and more people are suffering from stress-related problems. However, thanks to Ambient Intelligence (AmI), a vast array of technological tools can be applied in order to assist users in coping with stressful situations in domestic environments.

This thesis presents CaLmi, a system that allows the ubiquitous presentation of relaxation programs in AmI environments in order to manage the stress levels of inhabitants. In particular, people using the system will be able to monitor their stress levels in real time and either follow automatic personalized relaxation suggestions from the system, or voluntarily activate any of the system's relaxation programs.

To calculate the stress level, the following parameters are utilized: (a) data obtained from the Empatica E4 wearable wristband device that records physiological signals (e.g. electrodermal activity, skin temperature), and (b) information from the user profile and the overall context of use (e.g. user's daily activities, health, nutrition and sleep status). More specifically, the system continuously monitors the user's physiological signals and when a peak is identified, it uses contextual information to determine whether a stressful situation, which should trigger an intervention, has occurred.

In order to relieve stress, CaLmi is able to suggest to the user the most appropriate relaxation program according to his or her needs and preferences, and present it using one or more technology-enhanced items found indoors. In more detail, a pervasive relaxation player application has been created in order to provide appropriate interventions, which are presented in the form of relaxation programs, when necessary. By exploiting the

ambient facilities of the Intelligent Home, the player has the ability to create a relaxing experience by projecting multimedia to all room's display areas, playing appropriate sound(s) and music from the room's speakers, adjusting the ambient lighting conditions, releasing a pleasant scent into the room, etc. In comparison to existing work, CaLmi is the first stress management system that uses both biofeedback and contextual information in order to detect stress and offers ambient relaxation programs which are adaptable to the individual users' needs and environment.

Περίληψη

Στη σύγχρονη εποχή με τους γρήγορους και απαιτητικούς ρυθμούς ζωής, όλο και περισσότεροι άνθρωποι υποφέρουν από προβλήματα που σχετίζονται με το στρες. Ωστόσο, χάρη στη Διάχυτη Νοημοσύνη, ένα ευρύ φάσμα τεχνολογικών εργαλείων μπορεί να χρησιμοποιηθεί για την υποβοήθηση των χρηστών στην αντιμετώπιση στρεσογόνων καταστάσεων σε οικιακά περιβάλλοντα.

Η παρούσα εργασία αφορά το CaLmi, ένα σύστημα που επιτρέπει τη διάχυτη παρουσίαση προγραμμάτων χαλάρωσης σε «έξυπνα» περιβάλλοντα με στόχο τη διαχείριση του επιπέδου στρες των ατόμων που διαμένουν σε αυτά. Συγκεκριμένα τα άτομα που χρησιμοποιούν το σύστημα θα μπορούν να παρακολουθούν σε πραγματικό χρόνο τη διακύμανση του επιπέδου του στρες τους και είτε να δέχονται τις αυτόματες εξατομικευμένες προτάσεις χαλάρωσης από το σύστημα, ή να ενεργοποιούν οικειοθελώς κάποιο από τα προσφερόμενα προγράμματα χαλάρωσης του συστήματος.

Για τον υπολογισμό του επιπέδου στρες αξιοποιούνται: (α) δεδομένα που συλλέγονται από τη φορετή συσκευή-βραχιόλι Empatica E4, η οποία καταγράφει βιοσήματα (π.χ. ηλεκτροδερμική δραστηριότητα, θερμοκρασία δέρματος) και (β) πληροφορίες από το προφίλ του χρήστη και το γενικότερο πλαίσιο χρήσης (π.χ. καθημερινές δραστηριότητες, κατάσταση της υγείας, διατροφικές συνήθειες και ποιότητα ύπνου του χρήστη). Συγκεκριμένα το σύστημα παρακολουθεί συνεχώς τα βιοσήματα του χρήστη και όταν εντοπίσει υψηλές τιμές, χρησιμοποιεί πληροφορίες από το πλαίσιο χρήσης για να καθορίσει ποιες στρεσογόνες καταστάσεις θα πρέπει να ενεργοποιήσουν μια παρέμβαση.

Για την 'ανακούφιση' από το στρες, το CaLmi μπορεί να προτείνει στο χρήστη το καταλληλότερο πρόγραμμα χαλάρωσης σύμφωνα με τις ανάγκες και προτιμήσεις του και να το παρουσιάσει χρησιμοποιώντας ένα ή περισσότερα τεχνολογικά επαυξημένα αντικείμενα του δωματίου. Πιο αναλυτικά, έχει δημιουργηθεί μια διάχυτη εφαρμογή αναπαραγωγής προγραμμάτων χαλάρωσης με σκοπό να παρέχει κατάλληλες παρεμβάσεις όταν κρίνεται απαραίτητο. Αξιοποιώντας τις εγκαταστάσεις του Έξυπνου Σπιτιού, η εφαρμογή έχει τη δυνατότητα να δημιουργεί μια χαλαρωτική εμπειρία προβάλλοντας πολυμέσα σε διαθέσιμες επιφάνειες προβολής, αναπαράγοντας τους κατάλληλους ήχους και μουσική από τα ηχεία του δωματίου, ρυθμίζοντας τις συνθήκες φωτισμού, και απελευθερώνοντας μια ευχάριστη μυρωδιά χρησιμοποιώντας μια συσκευή αρωματοθεραπείας, κλπ. Σε σύγκριση με τις υπάρχουσες συναφείς εργασίες, το CaLmi είναι το πρώτο σύστημα διαχείρισης του στρες που χρησιμοποιεί τόσο βιοσήματα όσο και πληροφορίες από το πλαίσιο χρήσης για την ανίχνευση του στρες και προσφέρει προγράμματα χαλάρωσης, τα οποία είναι προσαρμόσιμα στις ανάγκες και στο περιβάλλον των χρηστών.

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Chapter 1

Introduction

In today's fast-paced and complex society, more and more people are suffering from stress-related problems. In Britain, for example, according to the AXA Stress Index 2018 [1], 72% of people feel stressed at least some of the time in their everyday lives and that might cause them, among others, lack of sleep (27%) and interest in activities (26%), unhealthy eating habits (25%), pre-occupation with their problems (18%), and unwillingness to leave the house (16%). Those behavioral changes, together with the endocrine response to stress, can influence disease risk and lead to physical and mental disorders [2]. Accordingly, it is important to keep stress under control. In order to achieve this purpose and improve the quality of our lives, we first need to keep track of how our stress levels change during the day, and second to find effective ways to calm down in stressful situations. Pervasive computing provides tools which can be used to accomplish the above and build a valid stress management application.

1.1 Problem Statement

Stress is a term of everyday life that everyone uses when feeling nervous, threatened or overwhelmed. But what does it really mean? There are many different definitions attached to the term stress in literature, including:

- “Stress is the nonspecific response of the body to any demand.” [3]
- “Psychological stress is a particular relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being.” [4]
- “In a medical or biological context, stress is a physical, mental, or emotional factor that can be acute or chronic, and causes body and/or mental tension. Stress can be induced in response to external (environmental or psychological) or internal (physical illness or injury) stimuli. It typically leads to a ‘fight or flight’ response, which involves broad activation of neurological and endocrinological processes.”[5]

Stress does not necessarily occur as a result of negative stimulus, and it does not always have a negative impact on people [6]. For example, a passionate kiss can be as stressful as a painful blow, and stress for meeting a project deadline can be either motivational or destructive.

Acute (short-term) stress is “a strong physiological response to a novel and unpredictable threatening event” [5] and is actually good for maintaining human survival and prosperity by increasing alertness in dangerous (e.g., escape from a lion) or demanding situations (e.g., complete a project by a certain date). However, if acute stress is repeatedly experienced (episodic acute stress), without adequate relaxation periods in between, it can become maladaptive [7] and turn into chronic (long-term) stress, which can have serious impact on physical (e.g., is associated with the metabolic syndrome, which is a cluster of risk factors that increase the chance of developing heart disease and type 2 diabetes [8]) and mental (e.g., depression [9]) health. Furthermore, beside adverse health effects, information processing (particularly memory and attention) [10] and decision making [11] skills can be decelerated by bad stress. Finally, traumatic stress is “is a particular type of stress involving an acute or chronic reaction to shocking and emotionally overwhelming situations generally involving a threat to physical or personal integrity”, and exist in form of Acute Stress Disorder (ASD) and Post-Traumatic Stress Disorder (PTSD) [5].

Summing up, the prevention of chronic stress is a critical part of living a happy and healthy life, and can be achieved by finding efficient ways to alleviate acute stress when it becomes excessive and difficult to deal with. Traumatic stress is a special case and probably needs expert support and treatment.

1.2 Thesis Contribution

Nowadays we have access to a vast array of technological tools which can be used to help us relax in stressful situations, improve our physical and mental health and help us achieve balance in life. Human behavior patterns can be studied outside the lab without the need for complex equipment. Similarly, it is no longer necessary to visit a meditation teacher or follow a yoga class to relax and reduce stress. We can accomplish these targets in the comfort of our home, on the way to work or basically everywhere, since pervasive computing creates environments where simple objects in the real world turn into source of information and communication.

This study addresses the question of how the use of pervasive computing can help efficiently those suffering from stress. The approach proposed is based on two steps: 1) first, the environment needs to observe when the problem occurs and what causes it; 2) subsequently, according to the collected information and taking into account individual characteristics and preferences, various ways to manage stress can be activated. During this process, Ambient Intelligence technologies help retrieve data and create suitable environments adapted to users' needs.

Ambient Intelligence (AmI) refers to "a vision of the Information Society where the emphasis is on greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions" [12]. In an AmI environment, intelligent and intuitive interfaces are embedded in various everyday objects, and the recognition and response to the presence of people is possible in a seamless, unobtrusive and usually invisible manner. AmI environments take advantage of sensors, networks, pervasive computing, and artificial intelligence in order to be sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent [13].

The smart home, which is an example of an environment enriched with AmI technologies, is a home that provides to its residents a variety of advanced services. In a smart home, numerous household items and artifacts (e.g., lights, sofa, and coffee table) embedded with sensors are used to gather information about their usage and to act without human intervention whenever needed [13]. Also, thanks to AmI, the home can possess intelligence and make decisions based on its state and interactions with its residents (intelligent home).

This thesis describes the vision of a system for a smart home that manages and reduces the stress of its residents. Stress is detected through specific biometric measurements collected from a wearable device, but also in conjunction with information about user's everyday life. A wristband with sensors, comfortable and easy to wear all day long, provides biometric data, namely measurements about the body's physiological responses to situations that the user experiences. Furthermore, the infrastructure of an Intelligent Home is used to retrieve data about the user's context and extract possible relevant information. For example, the system is informed about the user's stressful appointments and obligations through a smart calendar. The combination of physiological signals and contextual information can not only indicate that the stress level rises, but outline potential causes for that increase as well.

Moreover, the system offers various stress relief programs adapted to the smart home environment and real time counseling, offered following a gamification approach. Whenever high stress levels are detected or the user just wants to relax, the most appropriate relaxation program are suggested to him/her. The program is selected according to the current user needs and context of use, and can be customized to suit the user's preferences. In addition, appropriate messages appear to the nearest smart device in order to communicate urgent information to the user. These messages may include: guidelines to calm a user with stress levels higher than normal, details regarding stress levels after the completion of a relaxation program, notifications after winning a trophy, advices to manage time and pending tasks effectively in case the user's schedule seems to be overloaded, and instructions to request professional help in case a long period of high stress levels has been identified.

1.3 Thesis Structure

The remainder of this thesis is divided into the following chapters:

- **Chapter 2** describes the most common causes of stress and techniques being used for stress monitoring. Also, explains how exposure to nature, mindfulness-based stress reduction, listening to music, expressive writing, and proper ambient lighting and scent can relieve stress.
- **Chapter 3** presents related work on stress relief mobile applications for Android or iOS.
- **Chapter 4** examines the requirements which a stress management system should meet in order to fulfill its mission to help users manage stress.
- **Chapter 5** provides a general overview of CaLmi's approach to stress management, and presents the design and the implementation details of the system.
- **Chapter 6** describes the evaluation process and its results.
- **Chapter 7** presents the conclusion of this study and suggestions for future work.

Chapter 2

Background Theory

Before proceeding to the creation of a stress management system, it is crucial to understand what causes stress in one person, how stress can be detected, and how someone can relax in stressful times. All this information is valuable in order to establish an effective and intuitive system.

2.1 Common Life Stressors

A stressor is "a chemical or biological agent, environmental condition, external stimulus or an event that causes stress to an organism" [14]. Identifying the stressors in someone's life is important in order to manage stress effectively. Not all of the stressors can be easily detected or equally affect individuals; yet, some of them can be accurately measured and are known to highly impact people. An indicative list is presented below.

2.1.1 Urbanization

According to the Department of Economic and Social Affairs of the United Nations, around 55% of the world's population resides in urban areas today and 2.5 billion more people are expected to move in those areas until 2050 [15]. While living in urban areas is associated with greater access to economic and employment opportunities, education and health facilities, social services, and cultural activities, urbanization has also disadvantages and is related to higher stress [16]. The contemporary urban environments are so different from the natural environments, in which humans evolved. Vehicles, artificial lights, central heating, fatty diets and drugs are some of the aspects of modern life that the human body had too little time to adjust [17].

2.1.2 Financials, Work, and Studies

Financials, work or studies are well-known stressors [18]–[20]. Financial stress affects most of the people nowadays. The increasing financial obligations burden, worries about covering the daily living expenses, poor living conditions, dealing with debts or even making new investments have significant consequences on our mental state and lead to anxiety. Another stressor - also linked to financials - is work or studies duties. Losing a job or starting a new one, retiring, being unemployed for a long time, dealing with difficult issues and heavy workload, job insecurity, catching up with deadlines, exams, presentations and public speaking are some of the most popular factors. In addition, according to the European Agency for Safety & Health at Work (EU-OSHA) [21], stress is considered to be common in workplace (occupational stress) by around half of European workers, and it is responsible for around half of all working days lost.

2.1.3 Health

Good health is considered as the most important thing in life and, as the poet Virgil said, it is the greatest wealth. Strong willingness to achieve good health and unexpected health problems are likely to cause a lot of stress in people's lives [18]. Dealing with illness, injury or emotional problems, aging, weight gaining, poor nutrition, smoking cigarettes, alcohol and drug addiction, inactivity, menopause, pregnancy, menstruation and sleep deprivation can impact on stress levels.

2.1.4 Social Interaction

Humans are highly social beings. Interactions with family members, friends, coworkers and even complete strangers can have positive or negative impact on our mood. Empathy considers the action of understanding and sharing the feeling of others, and compassion the feeling of caring about others accompanied by the ambition to improve the others well-being [22]. Even though sharing positive feelings (e.g., happiness) can bring a lot of joy, sharing negative feelings (e.g., anxiety) can be burdensome, particularly for the loved ones. Compassion fatigue or secondary traumatic stress (STS) is a state of tension and preoccupation with the suffering of others and can turn into secondary traumatic stress disorder (STSD) [23].

Moreover, social and relationship problems are common stressors [18], [24]. Getting married or divorced, being in an unhealthy or a toxic relationship, starting or ending a relationship, becoming a parent, being bullied, organizing a social event, being late to a meeting, living in a deprived area, becoming overloaded by media, etc., are some of the relevant factors.

2.2 Stress Monitoring Techniques

Emotion recognition and stress detection is not a simple process because there is no single indication that reveals increased stress. However, stress can often be detected because of its impact on human body and mind by analyzing multiple combinations of questionnaires, body and speech tracking data, physiological signals, and context information.

2.2.1 Questionnaires

The simplest way to learn if someone is under stress is to ask. Many researchers have elaborated expert questionnaires (e.g., the Perceived Stress Scale - PSS [25], and the Standard Stress Scale - SSS [26]) as a stress diagnostic tool. This approach requires time, effort and mental health awareness from the user, since it lacks automatic detection and constantly asks for user input, and is not suitable in a smart environment. The environment should be able to detect stress mainly without directly asking the user, but if necessary in specific circumstances, it should be interactive and pose questions to the user about his/her stress levels in order to ensure proper operation (e.g., validate system's decisions).

2.2.2 Body and Speech Tracking

Emotions are often expressed through different body movements [27] and speech signals [28], which inspired researchers to focus on stress recognition from speech and body tracking. Speech spectral analysis and analysis of lexical choices [29], facial expressions, gestures [30] and iris and pupil attributes [31] have been tested. A combination of these methods can deliver quite accurate results, however tracking of the relevant parameters cannot be achieved in real-life situations (e.g., while on the move) and the reactions, which are based on the somatic nervous system, can be faked [32].

2.2.3 Physiological Signals

Multiple physiological signals (e.g., heart rate, respiratory rate, skin conductance, muscle current, brain electrical activity) are generated by the human body as it is "operates" [33]. Those signals includes information that can be used for emotion recognition [34]. Differently from questionnaires and body/speech tracking, physiological signals are more suitable for a system that constantly tracks people during their daily activities, as they can be measured using stylish and comfortable wearable devices equipped with multiple connected sensors [35]. Moreover, such signals are controlled by the autonomic nervous system, which is subdivided into sympathetic (associated with energy expenditure and stress) and parasympathetic (associated with energy conservation and relaxation) [36], and it is almost impossible to be suppressed, which makes physiological signals more reliable and accurate [32]. The mostly used physiological signals for stress recognition are blood pressure (BP), heart rate (HR) and its variability (HRV) [37], electrodermal activity (EDA) [38], skin temperature (ST) [39] and breathing rate (BR) [40]. Electroencephalogram (EEG) [41] and hormonal signals, such as Salivary Cortisol (SC) [42], are also great choices, but they cannot be measured using a wearable device.

2.2.3.1 Electrodermal Activity (EDA)

This work primarily relies on electrodermal activity. Electrodermal activity (EDA), also known as galvanic skin response (GSR) or skin conductance, is one of the measurements we often come across in researches related to psychophysiological responses in humans correlated with a wide range of behavioral changes. EDA defines skin's electrical activity, which is affected by the activity of sweat glands [43]. Emotional arousal and increased attention are closely associated with this measurement.

In 1849, the German physiologist Emil du Bois-Reymond discovered that human skin is electrically active [44]. Later in the same century (19th century), in the laboratory of the French neurologist Jean Charcot, Romain Vigouroux measured tonic skin resistance levels in various patient groups with emotional distress as a clinical diagnostic sign and Charles Féré found a basic method for measuring EDA. This method is based on the property of the skin to become a better conductor of electricity when external stimuli occur (exosomatic method), and it uses two electrodes placed on the surface of the skin between which a low electrical current is passing. In 1890, the Russian physiologist Ivan Tarchanof discovered a new method of measuring EDA, similar to Féré's but without the external source appliance of a current (endosomatic method). These two methods observe the same physiological mechanism and are still in use today.

Skin resistance follows Ohm's law [45], which can be expressed as follows:

$$\mathrm{I} = \frac{V}{R} \Leftrightarrow \mathrm{R} = \frac{V}{I}$$

R stands for skin resistance, V for voltage applied between the two electrodes on the surface of the skin and I for current being passed through the skin. Commonly, the available devices on the market for skin conductance recording use constant voltage system [46]. EDA measures the skin conductance in micro-Siemens (μS) units.

As electrodes play a crucial role in monitoring of EDA signals, it is essential to choose the right ones. Generally, electrodes are made of metal but other materials can be used too (e.g., carbon) [47]. The same metal must be used on both electrodes in order to avoid polarization. Silver–silver chloride (Ag/AgCl) electrodes are suggested because of their ability to reduce the bias potential and the polarization of the electrode. Moreover, the skin-electrode contact area effects the recordings [46]. Double-sided adhesive collars can be used to attach the electrodes and control the contact area. Also, the application of a gel or paste (e.g., agar-agar paste), which is similar to sweat in its salinity, between the electrodes and the skin is recommended, as it is prevents instability, increasing conductance and low resistance [45]–[47].

Before placing the electrodes, they should not be cleaned with alcohol or abrasive because those might decrease the natural resistive/conductive properties of the skin [46], [47]. Furthermore, the part of the skin where the electrodes are going to be placed must be clean and dry. Washing this part with an abrasive soap prior to the electrodes placement is not recommended, since this might cause swelling of the epidermis. Just lukewarm water or non- abrasive soap and water can be used for skin cleansing.

EDA is based on the fact that skin participates in the maintenance of body's homeostasis by helping to regulate body temperature and water balance, through vasoconstriction or vasodilation and through the production of different amounts of sweat [48]. Before proceeding with these actions, skin receives signals, from control centers in the brain, whose arrival provokes measurable electrical changes that we call EDA [49].

It is important to understand that EDA is not about the sweat on the skin per se but rather the activity of sweat glands [50]. If the sweat in the glands' ducts increases, then resistance in the variable resistor decreases and electrical conductivity increases. This mechanism outputs noticeable changes in EDA.

Sweat glands come in two types: apocrine and eccrine. Eccrine sweat glands are the ones of special interest to psychophysiologist, and usually their primary function is thermoregulation [46]. Thermoregulatory sweating is controlled by the same hypothalamus which incorporates patterns of sympathetic emotions and limbic structures. All of the eccrine sweat glands are involved in physiological sweating. However, on the palmar and plantar surface of the hands and feet there are higher gland density and thus sweating is usually most conspicuous there than in other surfaces of the body [51]. The values obtained from different parts of the body are not comparable to each other.

EDA consists of two basic components, the phasic or skin conductance response (SCR) and the tonic or skin conductance level (SCL). SCR refers to the peaks (sudden and steep increases) of skin conductance, and SCL to the base line which varies from person to person [38]. Consequently, SCR peaks indicate an emotional arousal, which however can be equally the outcome of a positive or a negative stimulus, and is not always stress-related [52]. Thus, further information is needed to confirm stress as the root of the SCR.

SCRs can also be divided in two categories depending on the identification of the stimulus which caused the response. If the stimulus is non-identifiable, it is referred to as a "spontaneous" or "nonspecific" SCR (NS-SCR). If the stimulus is identifiable, it is referred to as a "specific" SCR [46].

The environment where monitoring takes place can influence EDA. Ambient temperature and humidity are some of the environmental factors that should be taken into consideration. In a typical room temperature range, as the temperature increases, the SCL tends to rise [46]. A room temperature of 23°C with stable humidity is recommended for conducting an experiment more efficiently [53].

Tonic SCL can vary widely among different psychological states of the same person and between individuals. Age, gender, ethnicity and the physiology of the skin are individual differences which have effects on EDA. In general, an older person has lower SCLs than a younger one, because the active sweat glands and the volume of sweat produced by each gland decrease with aging [54]. However, in children up to 7-8 years old, SCLs can be higher over the time as their sweat glands are growing [55]. With regard to gender, females seems to have higher SCLs and males greater electrodermal reactivity under conditions of stimulation [51]. However, depression, temperature, season, relative humidity, age, woman's menstrual cycle and postmenopausal hot flushes can influence this distinction. Ethnicity also affects EDA. The amount of skin pigmentation varies among races and darker skins have a lower number of active sweat glands. Thus, African-Americans tend to have lower SCLs than Caucasians. Differences in sweat electrolytes and hereditary influences are also possible factors of these differences.

In spite of that, SCL and NS-SCL frequency increase (at least for a moment) in any individual with the anticipation and performance of any external (e.g., watching a horror movie) or internal (e.g., math problem-solving) task. The more significant the task, the higher the increase. In general, tonic SCL is lower while sleeping or resting and higher in the activated states (e.g., mental work, expressing anger or range) [56]. It tends to gradually decline during resting periods and rapidly rise in response to novel stimulation and gradually decline again after the stimulus fades away and disappears [46]. Additionally, people would become familiar with a repeated stimulus and less responsive. Even though EDA response system is considered relatively slow, it can be used efficiently for real time monitoring.

Customarily, a stimulus do not cause just an EDA response but a complex of responses mediated by the autonomic nervous system (ANS) [46]. For instance, increases in SCL caused by a stressful event are usually accompanied by increases in heart rate level and blood pressure. Nevertheless, EDA, in contrast to most other ANS responses, offers a relatively direct and undiluted representation of sympathetic activity. This occurs because tonic or phasic sympathetic activation results in SCL increases, since the eccrine sweat glands are completely under sympathetic control. Besides that, EDA is not affected by the parasympathetic nervous system (as most physiological signals do) and for this reason it is considered by many as the best choice for stress recognition [51]. Another major benefit of EDA is that it is affected mainly by the activation of a neurophysiological behavioral inhibition system which is participating in responding to punishment, passive avoidance and frustrating non-reward (anxiety system). Hence, it is used for detecting reactions when no active avoidance response can be made [46].

But there are more advantages of using EDA [46]. Firstly, SCRs are fairly discriminable and can be determined by a rapid inspection of the signals. Moreover, individual differences in EDA are primarily correlated with psychopathological states. Finally, EDA recording systems are comparatively inexpensive, totally harmless and risk-free, and can be used repeatedly even by young children and at very short time intervals.

2.2.3.2 Secondary Physiological Signals

Stress detection accuracy can be further improved by using multiple physiological signals. Increases in heart rate (HR) are often associated with stress, but are also highly influenced by physical activity and heart disease [57]. HR refers to the number of heart beats per minute and it is more suitable for monitoring physical activity [58]. Heart rate variability (HRV) measures the variation in the time interval between successive heartbeats and it can be used to detect mental stress. EDA and heart rate signals in combination have been proven to recognize three stress levels with 88% [52] and over 97% [59] accuracy. High blood pressure (BP) levels are associated with stress too. However, BP responses are usually linked to HR changes (an increase in HR leads to increase in BP) [35] and are also effected by local conditions in the working muscles [60], thus minimizing the benefits of such measurements. Likewise, breathing rate (BR) becomes higher under stressful situations and in combination with heart signals could be 85% accurate [40], but there is no efficient and comfortable wearable device to measure both signals, since respiratory monitoring sensors must be placed on the chest or torso. On the contrary, skin temperature (ST) is easier to be measured using a wearable and it also increases during stress periods [38].

2.2.4 Context-Awareness

The term "context" is used to mean any type of information (location, time, events, people nearby, etc.) that can be used to identify the current situation of an entity [61]. Context-aware systems are capable of adapting their operations to context changes, without an explicit user intervention [62]. Their purpose is to increase usability and effectiveness by taking into consideration the environmental context.

Context information can be retrieved by applying sensors, browsing user profiles and using other source (e.g., networks, and devices) [62], and it can be internal or external [63]. Internal context information describes user state (e.g., user's goals, tasks, work context, busyness, personal events, and cognitive, emotional, physical and communication state), whereas external context information describes environment state (e.g., location, proximity to other objects, temperature, and time) and it is generally easier to be retrieved.

By correctly interpreting the retrieved context information, additional knowledge about a persons' affective state and levels of stress can be extracted [64]. Context-based stress detection is possible through the detection of the presence of stressors (see section 2.1) and behavioral stress responses (e.g., increased smoking behaviors [65], overeating or undereating [66], and increase alcohol consumption [67]). The following are some of the context information most frequently used in literature for stress recognition:

- **Through smartphones:** location (GPS, Wi-Fi), social interaction (Bluetooth), call and SMS behavior [68], [69]
- **Through public sources:** weather parameters (temperature, pressure, total precipitation, humidity, visibility and wind speed metrics) [69]
- **Through digital calendars:** events and daily routine [70]
- **Through interaction with technological devices**: touch pattern, accuracy and duration, amount of movement, and acceleration [71].

2.3 Stress Reduction Methods

After understanding stress and its possible sources, the next step is to find better ways in order to deal with it effectively. Numerous researchers have extensively examined many different calming strategies for several years. Scientifically proven relaxation techniques in combination with a created relaxing space can reduce the effects of stress and improve people's mental well-being and physical health. In the context of this work, the following strategies are applied either individually or combined.

2.3.1 Relaxation Techniques

There may be differences in how each person experience recovery (e.g., from stress) through specific activities, but the basic psychological experiences crucial for recovery (e.g., relaxation) may be comparably uniform for everyone [72]. Relaxation is “a state of relative freedom from both anxiety and skeletal muscle tension” [73] and relaxation response is “a state of decreased psychophysiological arousal: a calming state” [74]. Several relaxation techniques consisting of various behavioral therapeutic approaches with significant differences in philosophy, methodology and practice can be used to reduce arousal [75]. The chosen techniques are presented and justified below.

2.3.1.1 Exposure to Nature

As we saw in section 2.1.1, living in urban areas has been associated with higher stress levels. On the contrary, being in nature has been associated with numerous benefits on health and well-being for hundreds of years and across different countries and cultures around the world. In the earliest cities of Persia, China and Greece, vegetation, water and other natural elements were believed to alleviate stress and be therapeutic [76]. Sanctuary of Asklepios at Epidaurus in Greece was an ancient famous dream healing center whose location was within the hollow hills, away from life stressors, and its natural settings was particularly important to the formation of physical and mental well-being [77].

In the last three centuries, urban green spaces (e.g., parks) are used to meet the need for contact with nature. During the 19th century, the first urban parks were designed. In the 20th century, Edward Wilson formulated the Biophilia hypothesis according to which humans tend to have a positive responsiveness to nature [78] and Roger Ulrich proposed the stress reduction theory which explains how natural landscapes help decrease stress [79]. In that same century, in Japan, Shinrin-Yoku (SY) or Forest Bathing (FB) arose as a healing and stress reduction practice of mindfully engaging with nature through all five senses [80]. Lastly, in the current (21th) century, many researches have recognized the healing power of nature and they are trying to understand how this mechanism works [81], [82].

Today, most people spend too much time in front of screens, and too little or no time in contact with nature. According to the WHO (World Health Organization) Regional Office for Europe, Europeans spend, on average, 90% of their time indoors [83]. While taking a break and spending some time in nature is one of the most effective ways to relieve stress, many people do not have much time to do that. So, if people cannot go to nature, can we bring a little bit of nature in their place (e.g., home, office, car)?

Research has shown that visual exposure to slides [84], images [85], [86], or videos [79], [87] of nature scenes also reduces stress and leads to higher levels of positive affect in comparison with urban scenes. Additionally, auditory stimulation (e.g., sounds of running water and birdsong) offers more efficient recovery after a stressor [88]. Moreover, essential oils can be used in the space to create smells of nature that stimulate the olfactory system. Some of the scents that promote relaxation are Hinoki cypress leaf oil [89] and lavender aroma [90]. By combining those visual, auditory and olfactory stimulations, a relaxing atmosphere can be created indoors. Finally, a different research approach uses virtual reality to provide exposure to nature and proves that an exploration of a virtual forest with both visual and auditory nature stimuli speeds up recovery after virtually induced stress [91], [92].

2.3.1.2 Mindfulness-Based Stress Reduction

Mindfulness-based stress reduction (MBSR) was developed in 1979 by Jon Kabat-Zinn at the University of Massachusetts Medical Center for an outpatient stress-reduction clinic [93]. Although the primary purpose of MBSR was the relief of body and mind suffering (e.g., stress, pain, illness) of medical patients, research has shown that it can reduce stress and improve and maintain a mental well-being in a wide range of people with significant differences, since it can be adaptable to specific needs [94]–[99].

MBSR programs enhance the innate capacity for mindfulness (i.e., for attending to the present moment in a nonjudgmental and accepting manner) [100] and improve the mental health by helping to gradually detach from negative self-focused thoughts and emotions [101]. While mindfulness practice has its origins in Buddhist meditation teachings, MBSR is devoid of cultural, ideological and religious elements [93]. The aim of this practice is to teach conceivably efficient techniques for facing, exploring, and alleviate mental and physical suffering, and becoming conscious of the powerful inherent connection between mind and body.

MBSR incorporates several different kinds of mindfulness practices. The following are the most commonly used [100]:

- **Body scan**: Guided meditation in which attention slowly shifts through the whole body and focuses on body's different parts.
- **Sitting meditation**: Sitting in a comfortable upright balanced posture, focusing the attention on breathing and observing thoughts and feelings in a nonjudgmental and neglectful manner.
- **Mindful Hatha Yoga**: Simple yoga stretches along with awareness of breath and body.

Additional mindfulness practices that can be used to reduce stress are progressive muscle relaxation [102], diaphragmatic breathing [103], guided imaginary [104] and many more meditation practices.

Nevertheless, a large number of people struggle to quiet mental chatter and thus to be mindful. Therefore, continuous practice and effort is needed in order to be able to calm themselves with MBSR [105]. At least forty-five minutes of practice per day, six days a week for eight weeks has been recommended by Kabat-Zinn [100] in order to achieve mindfulness. Generally, the most common length of formal meditation practices is about twenty or forty minutes, once or twice a day [106]. However, a more recent study [107] has shown that five minutes of mindfulness meditation per day has beneficial impact on mental health, including significant stress reduction.

2.3.1.3 Listening to Music

Music is an important part of individual's everyday life and serves many different functions in society. Alan Merriam proposed emotional expression, aesthetic enjoyment, entertainment, communication, symbolic representation, physical response, enforcing conformity to social norms, validation of social institutions and religious rituals, contribution to continuity and stability of culture, and contribution to the integration of society as the ten main functions of music in terms of the cognitive, emotional and social domains [108], [109]. With regard to social domains, music provides support for the management of self-identity, interpersonal relationships, and mood [109]. Moreover, it is believed that music is a healing tool and holistic therapists use it to achieve mental and physical health through music therapy [110].

The response to a musical stimulus depends on the musical attributes (e.g., type, tempo, energy), the people who are involved (e.g., listener, composer, performer), and the current listening situation (e.g., place, time, other people being present) [111]. In the context of the current work, interest has been focused on the potential musical attributes that promote relaxation on the listener in stressful situations.

A meta-analysis [112], [113] of researches investigating the use of music on decreasing stress-induced arousal has shown that music, alone or as part of a relaxation technique, plays an important role in reducing stress in various settings and has drawn the following conclusions:

- Music tends to have more positive effects on females and those under age 18.
- The type of stress affects the efficiency of music relaxation.
- Music based on research can reduce stress more effectively than music based on listener's preference, which might be distracting.
- As the exposure to music in everyday life increases, the relaxation effects also increase.
- Listeners who have musical experience, or have learned to play and read music, have an increased ability to relax while listening to music.
- Music therapy for relaxation is more efficient in individual-based interventions than in group-based.

Generally, listening to music prior to stress boosts ANS recovery afterward [114], and listening to relaxing music after stress leads to quicker recovery in comparison with silence [115].

There are also several studies that compare the effects of different types of music on the relaxation response. Classical music appears to be more beneficial for stress management compared to other music types (e.g., hard rock [116], heavy metal [117], jazz and pop [118]). Furthermore, instrumental music accompanied by nature sounds seem to be another great choice [119].

2.3.1.4 Expressive Writing

In modern societies, people are often taught to hide their emotions, in particular the negative ones (e.g., anger and distress). However, suppressing and inhibiting a negative emotion might increase and intensify that emotion [120], [121]. On the contrary, expressing, communicating and accepting might lead to less negative emotion and greater well-being overall.

The most common way of emotional expression in daily life is through talking to someone (e.g., friend, family member, or psychologist) and letting out all the negative feelings of some upsetting or stressful experience. But notwithstanding the fact that there may be a forceful need to express stressful events, sometimes people are incapable or reluctant to share their personal experience and feelings for fear of being embarrassed, punished, or judged [122], [123]. So, expressing emotions through writing is a good practice, especially when expressing through interpersonal communication is not possible.

Expressive and reflective writing have a central role in therapy in various theoretical models aside from narrative approaches [124]. Besides therapy, writing can also be a preventative and self-help tool for stress reduction. Though, it is important to keep in mind that expressive writing does not provide immediate stress relief. Writing down unpleasant experiences might be painful at the present time but provides long-term improvements in mood and reductions in levels of stress [122], [125].

During a writing session, the participants should express their deepest thoughts and feeling about an important problem of their everyday life that has affected their mood, without worrying about spelling, sentence structure, or grammar [125]. Writing sessions usually last around 15 to 30 minutes once a day and the more the sessions, the better the results. In addition, one session per week over a month seems to be more beneficial than four sessions in a single week.

2.3.2 Relaxing Atmosphere

Creating a relaxing space around people when they are practicing a relaxation technique can improve the effectiveness of that technique. More specifically, besides ambient temperature (i.e., moderately warm conditions lead to relaxation [126]), by properly changing the ambient lighting and scent settings, which are easily adjustable, in a room, the perceived atmosphere of that room can be perceived as relaxing and have a positive effect on the mood.

2.3.2.1 Lighting

Lighting is one of the factors that affects the perceived atmosphere [127]. Color temperature, brightness, contrast, glare and sparkle are some of the most important lighting attributes. Solid-state lighting technologies, especially LED (Light Emitting Diodes) based lighting sources, makes possible the control of color temperature, and spectral, spatial, temporal and polarization properties [128].

Lighting design decisions in interior spaces can influence or modify a human's impression of perceptual clarity, spaciousness, relaxation or tension, prominence or anonymity, pleasantness, and spatial complexity [129]. With regard to impression of relaxation, peripheral and non-uniform spatial lighting with low brightness helps to create a relaxing atmosphere [127].

At the same time, the right color temperature lighting can be advantageous to human health, well-being, and productivity [128]. Under most circumstances, cool colors (e.g., blue, green, purple) have been associated with peaceful, calm, and restful environments, while warm colors (e.g., red, orange, yellow) are physically and emotionally arousing, exciting, and distracting [130]. More specifically, blue is mainly experienced as calming and relaxing color because reminds people of the sky, ocean, beach or water, and green as calming, relaxing, happy, comforting, peaceful, and hopeful because reminds people of outdoors, nature, grass, trees, and springtime [131]. Another research suggests self-chosen relaxing color for relaxation promotion, as each individual knows best what makes him/her calm [132].

2.3.2.2 Scent

Another way to make a room feel relaxing is through ambient scent, since specific scents have been shown to have a positive impact on mood [133] and induce relaxation [134]. Aromatherapy, particularly, is used as a complementary therapy for stress relief and uses essential oils to activate the olfactory system [135]. In order to tune the ambient scent, a smart aromatherapy diffuser, which spreads the essentials oils through air without human intervention, can be used.

Scents of essentials oils that can induce relaxation, except from hinoki and lavender which have been mentioned in section 2.3.1.1, are: bergamot, chamomile, sweet marjoram, sandalwood, clary sage [136], [137], rose [138], ylang-ylang [139], orange [140], spiced apple [141] and muguet [142]. Still, it should be noted that if someone does not like a certain scent, relaxing properties are not going to be experienced [136].

Chapter 3

Related Work

Many studies report their finding on stress recognition or reduction and there are several apps available, on both iOS and Android, attempting to help users manage their stress. Nevertheless, only a few are trying to build a complete stress management system, combining both stress monitoring and stress reduction techniques, and even less take advantage of what pervasive computing has to offer.

3.1 Literature Review

Westerink's [52] research in well-being through psychophysiology presented stress as a state of non-well-being. The authors monitored and categorized stress into 3 levels with 88% accuracy, using skin conductance and heart rate signals, and provided stress awareness with mostly positive results. They also presented examples of training people's well-being. Specifically, breathing exercises had immediate and long term positive effects and personalized music for mood enhancement.

Hänsel [143] aims to detect the emotions and stress levels of co-workers, using a wearable device and pervasive sensors, and increase mental awareness to improve social connectedness and well-being. For detection, an app for stress self-assessments is deployed on the Apple Watch that measures HR, physical activity, location, and ambient noise. Another app is installed on the phone for additional stress-related questionnaires. Then, a personalized web dashboard presents the collected data to users. Future additions include using more pervasive context awareness methods and ambient feedback.

Kocielnik et al. [144] proposed to track stress at work in relation to daily life events. They used the Discrete Tension Indicator (DTI-2) wristband by Philips Research for continuous sensor measurements, a calendar application, which either stands alone or extracts information from MS Outlook, for collecting information about events at the current time and a short questionnaire for collecting subjective feedback. In their study, they noticed that even limited information about user's everyday life makes a difference in achieving stress balance.

Bakker et al. [70] had a similar proposal for managing stress at work. They collected information about the calendar events, daily schedule and stress-related physiological signals measurements of the workers, including additional information from incoming and outgoing mails and messages. All these data were processed to retrieve knowledge and provide personalized feedback to each worker about the relationship of his/her stress levels and everyday life events.

Yu et al. [145] designed a pervasive system for stress reduction at home named DeLight. They used inter-beat interval (IBI) and HRV biofeedback to control the lighting in order to provide real time stress response information and help users relax by regulating their breath, since HRV is related to breathing and breathing exercises can lead to relaxation. Similarly, RESonance [146] is a system that follows the same logic, but this time audio biofeedback has also been added, through natural soundscape, and Inner Flower [147] is a flower-shaped device, which is embedded with color LEDs for berthing guidance based on HR.

De Aquino Lopes et al. [148] proposed the use of serious games associated to virtual and augmented reality for Stress Management in the workplace. Their proposal scheme is made up of two distinct phases. In the first phase (Building Moment), the employee's profile is created, which is a collection of information associated with identifying stressors and coping strategies. In the second phase (Application Moment), it is suggested to the employee to use the game developed based on his/her profile. Nevertheless, their proposal is embryonic, and additional information and research is needed.

Osman et al. [149] also proposed serious games for Stress Management. They present the concept of Ubiquitous Biofeedback Serious Games (UBSGs) and developed a stress management game for mobile phones, which is called "Botanical Nerves". Botanical Nerves uses HRV biofeedback to detect stress and a tree as game character. Whenever the user becomes stressed, the tree leaves gradually turn yellow and drop off, and when user relaxes the tree becomes healthy again with more leaves and new flowers. Botanical Nerves seems to effectively reflect and reduce or better control stress.

Chen et al. [150] developed a self-paced learning environment, which is called FishBuddy which aims to reduce student anxiety or stress. FishBuddy consists of a self-paced learning system (SPLS), an Apple Watch application called e-Fish, and a physiologically aware performance evaluation model. The e-Fish application is responsible for detecting stress and anxiety during an exercise, based on student's heart rate and perform analysis, and reminding the student to watch the fish swimming on the Apple Watch when he/she is stressed. FishBuddy appears to reduce student anxiety and improve their performance.

Trevia [151], in collaboration with Philips Design, designed and built an adaptive relaxation space inspired by nature to help people cope with occupational stress in the workplace. As a person moves across that space, environment adjusts its dimensions, light and sound, relying on his/her position and needs, in order to create a personal or a shared experience of relaxation. This proposal requires a specific installation to be built and the user must go to that particular space if he/she wants to relax.

3.2 Mobile Applications

There are many stress relief apps in the global market, which some people might find very useful, but they do not use pervasive computing. Some of the most popular are:

- **Calm (Meditate, Sleep, Relax)** [152]**:** The leading app for meditation and mindfulness. Calm offers guided meditations, sleep stories, music tracks, video lessons on mindful movement and gentle stretching, nature scenes and sounds, and audio programs. Its aim is to reduce stress, anxiety, and improve sleep quality.
- **Pacifica (Stress & Anxiety)** [153]**:** The leading app for stress, anxiety, and depression. Pacifica offers relaxation and mindfulness meditation audio tools, guided self-help paths, mood and health tracking, daily challenges, and a peer support community. Its purpose is to manage negative thinking and emotions.
- **Mood Triggers (Anxiety Depression Insomnia Tracker)** [154]**:** A diary of user's mood, reactions, heart rate, number of steps and sleep duration with the aim of identifying the sources of stress and negative emotions.
- **Stress & Anxiety Companion** [155]**:** Companion offers breathing exercises, relaxation recordings, and information about stress, anxiety and cognitive behavioral therapy. Its aim is to help those who suffer from stress and anxiety.
- **Happify** [156]**:** It offers activities, games, and progress tracking with the aim of managing negative thinking and emotions.
- **Headspace (Meditation & Sleep)** [157]**:** It offers themed sessions, guided meditations, and SOS exercises with the aim of improving users' health and happiness.
- **Stop, Breathe & Think (Meditation & Mindfulness)** [158]**:** A personalized mindfulness coach with the aim of building emotional strength and confidence.
- **Digipill (Guided Meditation)** [159]**:** It offers audio recordings with the aim of unlocking users' subconscious in order to change their mood.

There are also some mobile apps that use biofeedback devices for stress management, such as:

- **Pip (Stress Tracker)** [160]**:** The Pip is a small wireless device that monitors EDA signals. It works together with mobile apps which use audiovisual feedback to present users' stress levels. Furthermore, the My Pip platform syncs with all Pip Apps and users are able to inspect their data at any time.

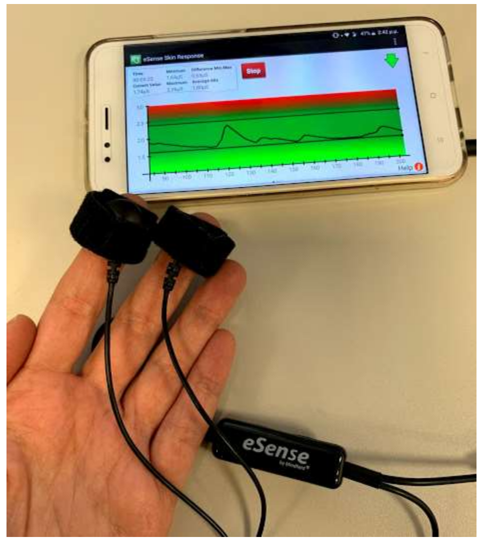

Figure 3.1: eSense Skin Response app

- **Airo Health** [161]**:** Airo uses HRV signals obtained by a wearable wristband device to monitor stress. When it detects high stress levels, the device vibrates and the user is able to release tension by starting a built in exercise. Also, users are able to inspect their stress levels at any time.
- **Spire Stone** [162]**:** Spire Stone is a wearable device that clips to users' belt or bra and monitors their breathing. Then, the Spire app analyzes and categorizes their breathing into three categories: calm, tensed, or focused. When sudden changes are detected, users are notified in order to reset their breath. Moreover, the Spire app offers real time breathing visualization, guided meditations, and breath, activity, step and calorie tracking.
- **Bellabeat** [163]**:** The Bellabeat app calculates women's sensitivity to stress based on their sleep duration, number of steps, current time in cycle or pregnancy, meditation and breathing exercises, and the time that they went to bed. The data is obtained from a wearable device, which can be worn as a bracelet, clip, or necklace, and the results are visualized in a graph whose color indicates the possible stress level (i.e., red = high, orange = medium, and green = low).
- **Mindfield eSense Skin Response** [164]**:** The eSense Skin Response is a sensor that monitors EDA signals using two electrodes attached to users' index and

middle fingers and the microphone input of their mobile device (Figure 3.1). The eSense app offers real time feedback using dynamic charts, audiovisual content, and a bulb (Magic Blue smart bulb).

3.3 Progress Beyond the State-of-the-Art

As analyzed above, detecting stress levels and making attempts toward reducing it has been a topic of growing research interest, as well as commercial interest. Most existing systems are able to identify a user's stress levels, but they refrain from utilizing some important ambient intelligence factors in order to make stress detection more accurate. For example, when the user is excited, because his/her favorite TV show is just beginning, the identification of a peak in physiological signals may lead to misleading results (i.e., detecting high stress levels), if the system does not take context into consideration. In addition, most existing approaches include mechanisms to reduce stress when identified, but they rely on a single device application or they require the user to be in a specific setting. The CaLmi's approach enhances the aforementioned implementations by trying to build a complete and robust system whose main aspiration is to identify when a user feels stressed and offer options to relieve the tension by utilizing Intelligent Home facilities.

The Table 3-1 presents the overall functionalities of the currently implemented systems in comparison with CaLmi. As can be seen, CaLmi uses both biofeedback and contextual information in order to detect stress and, in contrast with other implementations, offers sophisticated mechanisms able to adapt to the individual users' needs and current environment. Moreover, CaLmi is the only system that relies on an already existing Intelligent Home infrastructure and does not obligate users to move to a specific custom-made space in order to relax.

Table 3-1: Comparison matrix between existing systems and CaLmi

	Stress Detection		Stress Reduction	
	Biofeedback	Context	Methods	Environment
Westerink, 2017 [52]	EDA, HR	-	Affective Music Player, paced breathing, HRV biofeedback exercises	-
Hänsel, 2016 [143]	HR	physical activity, location, ambient noise, questionnaires	personalized web dashboard	-
Kocielnik et al., 2013 [144]	EDA	acceleration, calendar	-	-
Bakker et al., 2011 [70]	EDA	calendar	personalized coaching	-
Yu et al., 2018 [145]	HRV, IBI	-	biofeedback relaxation training	ambient light
Yu et al., 2018 [146]	HRV, IBI	-	biofeedback relaxation training	ambient light, nature soundscape
Hamon et al., 2018 [147]	HR	-	biofeedback relaxation training	-
De Aquino Lopes et al., 2014 [148]	-	user context profile	personalized serious games	-
Osman et al., 2016 [149]	HRV	-	biofeedback serious games	-
Chen et al., 2017 [150]	HR	perform analysis	e-Fish	-
Trevia, 2013 [151]	-	user position	guided mediation, paced breathing	ambient dimensions, light and sound
Calm [150]	-	-	meditation, sleep stories, music tracks, video lessons, nature scenes and sounds, audio programs	-
Pacifica [151]	-	mood and health questionnaires	meditation	-
Mood Triggers [152]	HR (manually)	mood questionnaires, number of steps, sleep duration	-	-
Companion [153]	-	-	breathing exercises, recordings	-
Happify [154]	-	mood questionnaires	activities, games	-
Headspace [155]	-	-	themed sessions, meditation, SOS exercises	-
Stop, Breathe & Think [156]	-	-	meditation, breathing exercises	-
Digipill [157]	-	-	audio recordings	-
Pip [158]	EDA	-	audiovisual feedback	-
Airo Health [159]	HRV	-	exercises	-
Spire Stone [160]	breathing	-	breathing visualization, meditation	-
Bellabeat [161]	breathing	user activity tracking	meditation, breathing exercises	-
eSense Skin Response [162]	EDA	ambient noise	audiovisual feedback	ambient light
CaLmi	EDA, ST	acceleration, calendar, bank account, health, nutrition, user activity tracking, profile	exposure to nature, meditation, relaxing music, expressive writing, customizable programs	stationary and portable displays, ambient sound, light, scent

Chapter 4

Requirements Elicitation

Following the bibliographic study, the next step was to define the requirements of the new system. During brainstorming sessions, numerous ideas, regarding how a stress management system should be, were collected and discussed. By properly shaping those ideas, the requirements were extracted which are grouped into three categories: intelligent environment services, system functions and end user operations.

4.1 Intelligent Environment Services

4.1.1. **Observing stress-related parameters:** The intelligent environment should monitor parameters that can determine the current stress level.

- 4.1.1.1. The environment should monitor users' physiological signals.
- 4.1.1.2. The environment should retrieve knowledge regarding users' daily activities, responsibilities, duties and appointments.
- 4.1.1.3. The environment should retrieve knowledge regarding users' health, nutrition and sleep status.

4.1.2. **User tracking:** The intelligent environment should track users' position.

- 4.1.2.1. The environment should determine if users are indoors or outdoors.

4.1.2.2. In case of users being indoors, the environment should determine their exact location inside the house and if someone else is in the same room as they are.

4.1.3. **Offering features (indoors):** The intelligent environment should offer several features that can create a relaxing space.

4.1.3.1. The environment should have multiple display areas and projectors.

4.1.3.2. The environment should have a smart system for soundscape streaming.

4.1.3.3. The environment should have a smart lighting system.

4.1.3.4. The environment should have a smart scent diffusion system.

4.1.3.5. The environment should have a speaker and voice assistant.

4.2 System Functions

4.2.1. **Detecting stress levels:** The system should detect when users are experiencing stress.

4.2.1.1. The system should process the information received from the environment in order to determine users' current stress level.

4.2.1.2. The system should be able to define users' state (i.e. calm, balanced, or stressed).

4.2.2. **Offering relaxation programs:** The system should be able to provide a relaxing immersive experience that stimulates many user senses (e.g., sight, hearing, smell).

4.2.2.1. The system should display visual content on the available display areas.

4.2.2.2. The system should play audio content from the available speakers.

4.2.2.3. The system should adjust the lighting conditions.

4.2.2.4. The system should release a pleasant smell using the available scent diffuser.

4.2.2.5. The system should provide users with tools for creating their own relaxation program.

4.2.3. **Notifying user:** The system should send users notifications when necessary.

4.2.3.1. Users should be notified when their stress level is significantly higher than normal.

4.2.3.2. Users should get a notification after finishing a relaxing session about its stress relieving effectiveness.

4.2.3.3. Users should get a notification after winning a trophy.

4.2.4. **Stress relieving:** The system should make appropriate decisions when users are stressed.

4.2.4.1. The system should choose the most appropriate relaxation program to each user.

4.2.4.2. Each relaxation program should be adjust depending on the users' location.

4.2.5. **Keeping history Log:** The system should keep records containing necessary information required to help users understand when they tend to get stressed and what can help them relax.

4.2.5.1. The system should store stress-related measurements (i.e. physiological signals, and users' stress levels and states).

4.2.5.2. The system should store all available data associated with a noticeable increase or decrease in stress levels (e.g., time, day, location, people nearby, and scheduled events).

4.2.5.3. The system should keep notification history records.

4.2.5.4. The system should store users' recorded observations.

4.2.6. **Offering recommendations:** The system should give users tips for precautionary purposes and advices when suspicious stress patterns occur.

4.2.6.1. The system should advice users, when their schedule for the next few days seems overwhelming, to properly organize their tasks.

4.2.6.2. The system should give users tips for a less stressful life (e.g., do not drink too much coffee, eat healthy, and sleep well).

4.2.6.3. The system should advice users to seek out professional help when they are extremely stressed over a long period of time.

4.2.6.4. New recommendations should be easily added to the system.

4.2.7. **Motivating Users:** The system should feature a gamified reward mechanism to motivate users to interact.

4.2.7.1. The system should assign certain tasks (e.g., complete specific number of relaxation sessions, and achieve stress reduction during a particular period of time) to users.

4.2.7.2. Tasks should have different levels of difficulty (e.g., easy, normal, hard, single action, repeating actions).

4.2.7.3. The system should award trophies.

4.3 End User Operations

4.3.1. **Managing stress:** Users should get a clear picture of their stress levels.

4.3.1.1. Users should be able (at any time and place, and on multiple devices) to view their stress levels for a given year, month, week or day and to observe fluctuations.

4.3.1.2. Users should be able to view the stress levels of other house residents if they are authorized (e.g., see nothing, see single indication, see detailed report).

4.3.2. **Starting a session:** Users should be able to practice relaxation techniques.

4.3.2.1. Users should be able to start a relaxation session at any time, either using their mobile device when outdoors or utilizing intelligent home's facilities when at home.

4.3.2.2. Users should be able to choose an existing relaxation program or to create their own.

4.3.2.3. Users should be able to enable or disable specific program features (e.g., lights, scent, music).

4.3.2.4. Users should be able to add a session to favorites.

4.3.2.5. Users should be able to monitor stress fluctuations during a session.

4.3.2.6. Users should be able to stop a running session whenever they want.

4.3.3. **Earning trophies:** Users should be rewarded for their progress.

4.3.3.1. Users should be able to earn different trophies for completing certain tasks.

4.3.3.2. Users should be able to view trophies that have been already won as well as locked trophies that they have not earned yet.

4.3.4. **Changing settings:** Users should be able to change certain settings.

4.3.4.1. Users should be able to enable or disable notifications in specific rooms.

4.3.4.2. Users should be able to enable or disable notifications on specific devices.

4.3.4.3. Users should be able to disable notifications for a specific period of time.

4.3.4.4. Users should be able to specify whether their stress levels are visible to other house residents or not.

4.3.5. **Recording their perception:** Users should be able to report their experience of stress.

4.3.5.1. Users should be able to add their own stress-related observations.

4.3.5.2. Users should be able to report inaccurate notifications about them getting stressed.

4.3.6. **Managing history records:** Users should be able to view details and information about their past interactions with the system.

4.3.6.1. Users should be able to view their history log.

4.3.6.2. Users should be able to delete all or some of their history records.

4.3.7. **Reacting to notifications:** Users should be able to react to system notifications.

4.3.7.1. Users should be able to take a certain notification-specific action.

4.3.7.2. Users should be able to ignore notifications.

Chapter 5

CaLmi’s Approach

The vision of CaLmi is to create a pervasive system for intelligent homes that reduces the stress of their inhabitants. Particularly, the system aims to detect, in the most unobtrusive way possible, whenever a user is stressed and try to help him/her relax by exploiting a variety of devices. The end users will be able to monitor their stress levels in real time and accept automatic personalized relaxation suggestions from the system, or voluntarily activate any of the system's relaxation programs. In the long run, the system aims to help users live a less stressful life and improve their mental well-being.

The following brief scenario shows how the system works. John is a marketing manager and was just informed that his company is going to launch a new very important campaign. The system detects peaks in his physiological signals and inspects any other contextual information to check if he is stressed. The result is positive; he also has added many business appointments on his calendar for the next days. A notification pops up on his smartphone, which is near him, and informs him that his stress levels are high and asks him if he wants to launch the recommended relaxation program or choose his own. He decides to select the recommended one. Since he is alone in the living room and the system has observed in the past that works of art that depicts the forest and relevant sounds calms him down, it creates a relaxed atmosphere with a forest waterfall theme in the room. The light intensity decreases and takes the blue hue of the waterfall’s water, bird singing and running water sounds are heard from the room’s speakers, the scent diffuser fills the space with Hinoki (Japanese Cypress) scent, and a video of a waterfall in the heart of the lush forest is displayed on the wall. John can stop the program at any time, and upon completion a notification popup will inform him about the new stress levels and any trophies won (e.g., relax within five minutes).

5.1 Key Features

The following features contribute to the creation of the innovative, effective and practical stress management system that is described above. More specifically, pervasive stress monitoring, adaptable stress reduction programs, and real time counseling are key features in the development of CaLmi. The number of the requirement, as provided in chapter 4, which is fulfilled by each of those features, is given in parentheses.

5.1.1 Pervasive Stress Monitoring

For the detection of stress state (requirements 4.1.2.1-4.1.2.2), a wireless wearable device and the technological equipment and installations of the smart home have been used. In more details, CaLmi employs a wristband that collects user biometrics (requirement 4.1.1.1), while it utilizes various contextual data in order to better understand the user's daily activities, health, nutrition and sleep status (requirements 4.1.1.2-4.1.1.3).

5.1.1.1 Wearable Wireless Device

Wearable devices, which are "technological devices that are worn on a user's body" [165], have seen a surge in popularity over the past years. The International Data Corporation (IDC) predicts that, by 2021, the wearable devices market will nearly double [166]. One of the most important uses of wearable technologies is in the healthcare field [167], since they allow direct, high resolution and continuous monitoring of body functions. In the context of this work, CaLmi employs a wristband with sensors, comfortable and easy to wear all day long, that provides biometric data, namely measurements about the body's physiological responses to situations that the user experiences.

The specific wearable device that has been selected for collecting physiological signals for stress monitoring in this study is an Empatica E4 wristband (Figure 5.1) [168]. E4 is a wearable wireless device that is designed specifically for researches that are conducted both inside and outside the lab. The main reasons for choosing E4 over other devices are:

- It combines Photoplethysmography (PPG) and EDA sensors, 3-axis accelerometer, and optical thermometer into one small, comfortable and wireless device (Figure 5.1).
- It obtains accurate and precise physiological data.
- It provides access to real time data via a customizable platform with APIs for developers.

Figure 5.1: Empatica E4 wristband [166]

CaLmi uses the E4's PPG sensor to obtain blood volume pulse (BVP), from which the HRV can be derived, the EDA sensor to obtain EDA data, and the infrared thermopile to derive peripheral body temperature. That data is used in monitoring stress (see section 2.2.3). Moreover, it uses the accelerometer, which captures motion, to disambiguate whether changes in physiological signals are caused by stress or physical activity [58].

In daily life, users need to wear the E4 on their wrist in order to allow system access to their physiological signals. In spite of the fact that EDA signals, during certain kinds of stress, may be much stronger on the dominant side [169], it is a good practice to wear the device on the non-dominant hand. The reason is that we mainly tend to use the dominant hand for different daily tasks and this can induce many motion artifacts.

5.1.1.2 Ambient Monitoring Facilities of the Intelligent Home

Most research efforts so far have been focused on stress detection from body language and physiological signals, but they do not take into account the context of the user. Still, context is a great source of information that can be exploited to confirm the results of physiological signals monitoring. Since this system targets a smart home environment, a variety of sources is used to that end (Figure 5.2).

Figure 5.2: Context-sensitive stress detection facilities.

More specifically, CaLmi introduces custom context-sensitive micro-reasoners that are used to identify stressful situations or behaviors which indicate that the user is stressed. The identification process is based on the analysis of data about the user's daily activities, habits, responsibilities, duties and appointments, which has been retrieved from the ambient facilities of the intelligent home. The information extracted from each source by its micro-reasoners is presented below.

Calendar

One key input source is a smart calendar application, where the users keep track of important dates. As they get closer, it is very likely for users to become more and more stressed. Each calendar registration can have different impact on stress levels. People tend to be more stressed about deadlines for payments and producing material (project, homework, etc.), work meetings, important doctor appointments, presentations and exams. Therefore, the micro-reasoner must not only check if there is a registration in the next days, but also identify its purpose, participants and location. Moreover, the user can also annotate (i.e., color-code) a calendar entry in terms of how stressful it is: green for "not stressful", yellow for "stressful" and red for "very stressful". Otherwise, the micro-reasoner implicitly extracts this information.

Bank account

A different way to get useful context information is by checking bank account transactions and payments. Removing large amounts of cash from a bank account can indicate that a stressful financial event takes place (e.g., an expensive repair, a new investment) and low balance can be linked to financial problems and therefore to stress. Consequently, a micro-reasoner checks daily activity to detect any possible removal of large sums of money without a corresponding increase in income and a second micro-reasoner checks if the account balance falls below a minimum.

Health

As mentioned in the section 2.1.3, dealing with illness, injury or emotional problems, aging, smoking cigarettes, drug addiction, inactivity, menopause, pregnancy, menstruation and sleep deprivation can cause an increase in stress levels. Thus, three different micro-reasoners have been created: i) a micro-reasoner checks the medication tracker to detect any possible new prescription, medicine overdose and drug abuse, ii) in case of female users, a micro-reasoner checks the period tracker to detect the current stage of menstrual cycle or pregnancy, iii) a micro-reasoner checks the sleep tracker to detect sleep duration and quality.

Nutrition

Diet and eating habits can also affect stress levels negatively. More specifically, sudden weight changes, poor nutrition (e.g., diets high in fat and junk foods), overeating or undereating, high caffeine and alcohol consumption can have negative effects. Accordingly, a micro-reasoner checks users' calorie intake to detect any significant increase or decrease in calories and a second micro-reasoner checks the food log to detect any possible caffeine, alcohol or junk food consumption.

User activity tracking

Furthermore, the current conditions at home and user behavior are inspected as well. Unusual or unexpected situations (e.g., an extensive stay of a relative, a high-profile visitor), another stressed individual being around, abnormal user behaviors (e.g., paces back and forth in a room), being in an unhealthy or a toxic relationship (e.g., fighting with others continuously), becoming a parent are some condition the system is able to track that indicate high stress levels. Therefore, a micro-reasoner checks current home conditions to detect any new resident or unidentified visitor and a second micro-reasoner checks users' current location inside the house to detect any abnormal movements or other people being around them.

User profile

Finally, the user profile is taken into consideration since not all of the stressors equally affect individuals. Thus, it is beneficial to know whether a user is prone to feel stressed under pressing circumstances. For this reason, a micro-reasoner checks users' previous stress reaction in dealing with similar circumstances.

5.1.2 Adaptable Stress Reduction Programs

Upon detection, CaLmi offers different relaxation programs in order to reduce stress and accommodate multiple users. It must be taken into consideration that something relaxing for one person can be annoying for another. Therefore, the right choice and use of a program is crucial. Additionally, the stress management application distributes across multiple devices and cooperates with other smart facilities (e.g., ambient lighting, notifications system, entertainment system) according to user preferences, so as to create a relaxing environment at home.

5.1.2.1 Pervasive Relaxation Player

A pervasive relaxation player application has been created in order to provide appropriate interventions when the user needs help or support. Those interventions are presented in the form of relaxation programs. Each program is created by defining specific attributes (Figure 5.3).

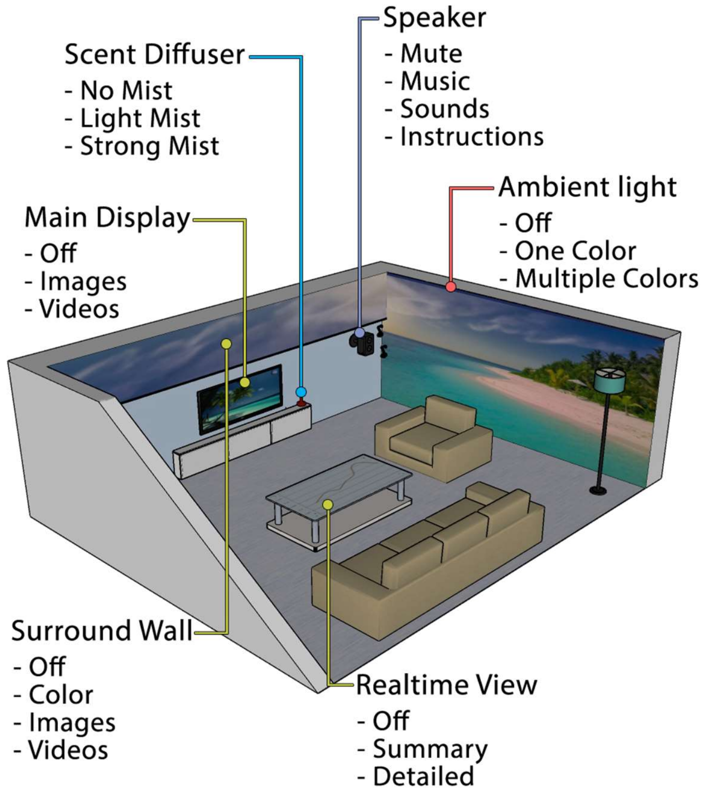

Figure 5.3: Attributes of relaxation programs.

In more details, exploiting the ambient facilities of the Intelligent Home (requirements 4.1.3.1 - requirement 4.1.3.4) the player has the ability to:

a) Project multimedia to a room's display areas (requirement 4.2.2.1), such as ceiling, wall, coffee table, or TV (see yellow points in Figure 5.4).
b) Play sound and music from the room's speakers (requirement 4.2.2.2; see purple point in Figure 5.4).
c) Adjust a room's lighting conditions (requirement 4.2.2.3), such as light temperature, color, and intensity, to create a relaxing environment (see red points in Figure 5.4).
d) Release a pleasant smell into the room using a scent diffuser (requirement 4.2.2.4; see blue point in Figure 5.4).

Figure 5.4: Ambient facilities of the Intelligent home

Before executing any program, the user is prompted to get in a comfortable position. Also, except from the case where natural light is necessary for reading and/or writing, the motorized blinds of the room are closed. When the system identifies that the user is ready to begin, the program is launched. The relaxation programs as justified in section 2.3.1 are:

Program-1. Exposure to Nature

The main aspiration of this program is to make users feel they are outdoors in a natural environment, such as a forest. In order to achieve this, when inside the intelligent home, the system can utilize all the available artifacts of the user's current room location. A collection of slideshows or videos is displayed in the largest and most convenient display area, while lights adapt to a natural color, according to the displayed pictures or videos (e.g., when a sunset by the sea video is shown, lights take an orange hue). In addition, corresponding sounds can be heard from the sound system and the room is filled with a natural essence (e.g., when simulating a forest, the room takes a cypress scent).

Program-2. Meditation

This program gives the user the opportunity to practice a variety of meditation techniques, such as body scan, sitting meditation, and mindful hatha yoga. It consists of audio instructions and, when needed, guided meditation videos. Some of the techniques may require the user to have closed eyes, in which case meditation instructions are only given through the sound system, otherwise an instructional video is displayed on the screen closest to the user. In addition, the intelligent home automatically lowers the lights and a relaxing scent (e.g., sandalwood) fills the room.

Program-3. Relaxing Music

The sound system takes center role in this program. Relaxing songs (e.g., classical music tracks) can be heard from the room's speakers and the lamps generate lighting patterns in real time based on the sound. Moreover, the user may choose to additionally use the aromatherapy system.

Program-4. Expressive Writing

This program consists of textual forms with questions that help the user express their thoughts and feelings about problems of his/her everyday life that have affected their stress levels. The system supports multimodality by enabling the user to either express himself/herself in writing form or in a more natural way using his/her voice (requirement 4.1.3.5), which is then automatically transformed to text. While the user is interacting with the system, his/her written thoughts are displayed on the most convenient display. Additionally, the lighting in the room should be at appropriate levels for reading and writing. In the same manner as the previous program, the user can also use the aromatherapy system.

Program-x. Customizable Programs

The developed relaxation player can be employed to support any of the aforementioned programs, either individually or in combination. For example, the user could be meditating (Program 2), or listening to music (Program 3) while he/she is writing about his/her feelings (Program 4). This is possible since the user is able to create his/her own relaxation program by combining the existing components (requirement 4.2.2.5). For example, the user could choose to display old family photographs on TV and his/her current stress level chart on the coffee table (which are two of the available display areas in the room he/she is currently in), to play Bach's Prelude from the room's speakers, not to use the scent diffuser, and to reduce the brightness of the lights.

5.1.2.2 Context-Aware Customization of a Relaxation Program

CaLmi employs the relaxation programs described above in order to offer various interventions. Particularly, whenever high stress levels are detected or the user just wants to relax, the most appropriate relaxation program (e.g., exposure to nature) is selected (requirement 4.2.4.1). Measuring and comparing user's stress levels before and after each program execution allows to observe their effectiveness and make appropriate decisions.

The available programs can be customized according to the user's preferences. For example, some people enjoy better videos of natural landscapes rather than a beach view (see Figure 5.5), to this end, when employing the technique "exposure to nature", the system has the ability to adapt according to the characteristics of the individual user.

Figure 5.5: Exposure to nature adaptable to each user.

In addition, the program is selected according to the current user needs and context of use (e.g., user's current state, time constraints). For example, if a user is lying in bed and he/she wants to relax before trying to sleep, even though "meditation" seems to be the most relaxing program for him/her, "relaxing music" (the second most effective program for him/her) is selected since user does not need to get out of bed to start it. Furthermore, the user can optionally configure (de-) activate various features (see Figure 5.6) of the predefined programs.

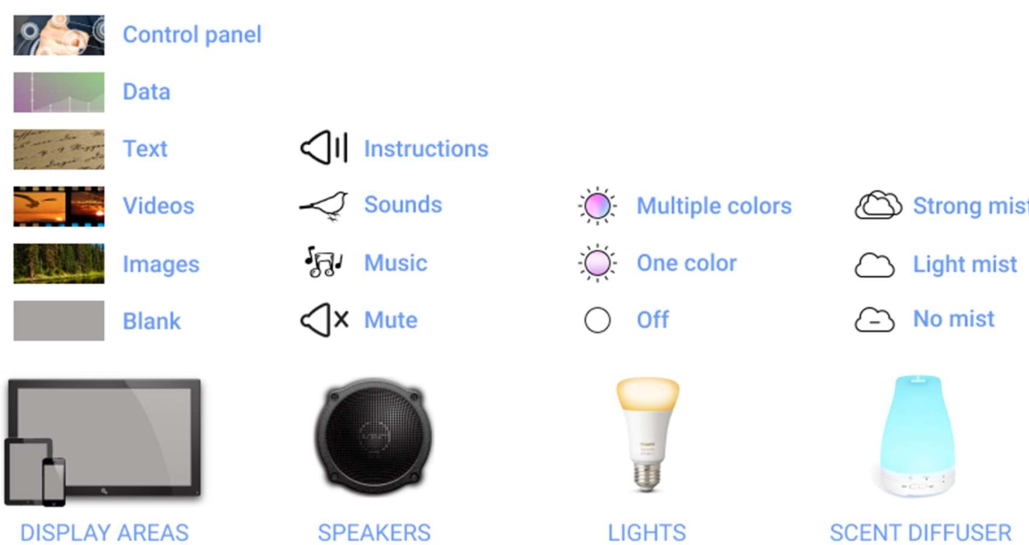

Figure 5.6: Relaxation program features

However, the process of selecting an appropriate intervention does not end by selecting a relaxation technique. The system must also decide on the appropriate hosts for the selected program. Using the ambient facilities of the intelligent home, CaLmi is aware of the user's location inside the house (requirement 4.1.2.2) and can easily select the nearest appropriate artifacts (e.g., TV, speakers, Wall Projector) to create a relaxing experience (requirement 4.2.4.2). Likewise, CaLmi is aware if there are other people in the same room as the user, and can suggest to him/her to move into another room if it considers it possible or take no action otherwise (e.g., the other person is an important guest). In case the user is not at home (requirement 4.1.2.1), the selected program can be displayed on his/her mobile smart device.

5.1.3 Real Time Counseling

CaLmi employs the pervasive notification system of the intelligent home in order to communicate information to the user (see section 5.2.1.6). Particularly, appropriate messages appear in the nearest smart device including: (i) guidelines to calm a user with stress levels higher than normal (requirement 4.2.3.1), (ii) details regarding stress levels after the completion of a relaxation program (requirement 4.2.3.2), (iii) notifications after winning a trophy (requirement 4.2.3.3), (iv) advices to manage time and pending tasks effectively in case the user's schedule seems to be overloaded (requirements 4.2.6.1-4.2.6.2), and (v) instructions to request professional help in case a long period of high stress levels has been identified (requirement 4.2.6.3).

5.1.3.1 Notification for High Levels of Stress

CaLmi notifies users when their stress level is significantly higher than normal and advises them to start a relaxation program. The right moment to display a notification to a user should be chosen appropriately; otherwise, it might have the effect opposite to the desired one. For example, if during a busy day a user receives a notification every hour letting him/her know that he/she is stressed, he/she might get annoyed or even more stressed. Also, notifications should not interrupt users when they are focused on important tasks (e.g., a business video conferencing) or when stress makes them become more productive (e.g., helps to complete a project on time). On the contrary, notifications are displayed when stress leads to procrastination and reduced productivity. CaLmi is able to distinguish the moments that people need guidance and support to cope with stress by using information from the context of use. For example, if a user paces back and forth in the living room then notifications are enabled, while if visitors are present in the room, interacting with the user, notifications should be disabled.

After a user received a high stress level notification, different actions can be taken. Firstly, the user could follow CaLmi's advice and start a relaxation program (requirement 4.3.7.1). In that case, he/she could start the recommended program or choose his/her own (see section 5.1.2). Alternatively, if for any reason the user is not willing to start a relaxation program, he/she could just ignore the notification (requirement 4.3.7.2). Finally, if the system has made an incorrect estimation (that is possible particularly during the first month of use), the user could report that he/she is not stressed in order to help system adapt and improve the accuracy of future estimations (requirement 4.3.5.2). Although, if there are strong indications from the physiological signals and the context of use that the user is stressed, that action should not be taken into consideration, since self-judgment about stress is not always accurate.

5.1.3.2 Information about Relaxation Program Effectiveness

After the completion of a relaxation program, it is useful to the users to know how effective it was in order to better understand how their body, mind and spirit work together and be able to handle stressful situations in the future. Thus, when a guided relaxation session is completed, CaLmi informs the user about its effectiveness. The information being presented to the user includes his/her stress values before and after the completion of the session and details about session's type (e.g., meditation), duration and structure (e.g., videos were displayed and artifacts were used).

5.1.3.3 Motivation and Reward

CaLmi employs a reward mechanism (i.e., gamification) that aims to motivate the user in following the suggested relaxation methods and thus learn to relieve tension and live a less stressful life. The mechanism works as follows: certain tasks, which have various levels of difficulty, are assigned to users, who have to fulfill these tasks in order to earn trophies (requirements 4.2.7.1-4.2.7.3). A trophy corresponds to the completion of one task. Some tasks are: have your first relaxation session, try every relaxation program, have sessions several days (i.e., 5, 10 or 20) in a row, complete specific number of relaxation sessions (i.e., 10, 20 or 30), and achieve stress reduction during a particular period of time (i.e., one week, month or year).

5.1.3.4 Preparation for Stressful Days

Since CaLmi utilizes various contextual data and observes behaviors, it is quite possible to predict which scheduled future event or situation might cause the user a lot of stress and attempt to properly prepare him/her in advance. In order to accomplish that, CaLmi advices users when their upcoming schedule (according to the smart calendar) seems overwhelming to prepare ahead of time and thus to avoid the last minute stress. Moreover, CaLmi gives users general tips on reducing stress in their daily lives (e.g., do not drink too much coffee, eat healthy, and sleep well). New recommendations and tips can be easily added to the system (requirement 4.2.6.4).

5.1.3.5 Recommendation to Request Professional Help

Even though CaLmi provides great support to its users for managing stress, it cannot deal with all types of stress. In some cases, where the condition is more serious (e.g., chronic stress and stress-related disorders), professional help and treatment (e.g., psychotherapy or/and medication) may be required. CaLmi is able to detect user's possible dangerous stress patterns (i.e., consistently high stress levels over a longer period of time) and behaviors (e.g., loss of interest in previously enjoyable activities) and then advise him/her to request professional help.

5.2 System Design

CaLmi obtains, manages and creates large amounts of data on a daily basis. Some of that data contains useful information to users and must be present to them in the best possible way. The information visualization involves the visual disclosure of information behind the data in a proper display [170]. In order to achieve a usable and pleasant system which is easy to learn, visualizations must be effortlessly understood by the users and have a natural intuitive mapping with what they represent. The fundamental types of visualization that CaLmi uses to present the desired information to its users are:

- **Charts:** Pie charts and bar charts illustrating users' stress levels and allowing them to see overall trends (e.g., increases or decreases in levels over time).
- **Calendar:** An individual calendar to each user to visualize stress-related events and let him/her add entries.
- **Relaxation Player:** A multimedia-player to present the relaxation programs and let users directly manage images, videos, audio, text, lights, scent and displaying areas.

5.2.1 Mobile Application

In recent years, mobile devices have become extremely popular and people believe there should be an app for everything [171]. Using those applications, users can access various types of information and control different processes from everywhere and at any time (requirement 4.3.1.1). In particular, with regard to smartphones, according to IDC's research [172], 79% of owners keep their phone near them for all but two hours of their waking day. Moreover, the use of mobile health and well-being apps has been growing rapidly in the last few years [173]. For those reasons, CaLmi provides a user-friendly mobile application that has been developed to facilitate control over the system and assist users. In this chapter, snapshots of the current implementation of the mobile application are presented.

5.2.1.1 Login

Users visiting the CaLmi app for the first time need to use the username and password of their smart home account to login and have access to the app (Figure 5.7). From this page, users can already perceive the app's look and feel. White or light blue text and icons on a dark background to create high contrast and thus high readability, and in general use of cool colors, which promote calmness.

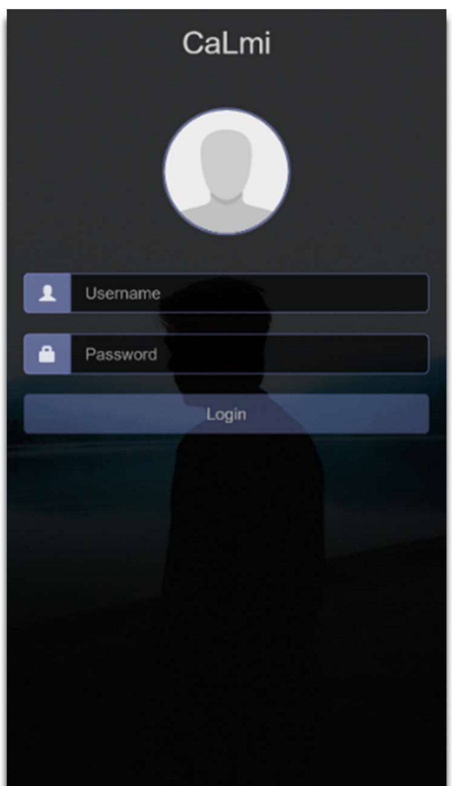

Figure 5.7: Login form

5.2.1.2 Homepage

The homepage is the first page users see when they enter the app, while being already logged in, and contains the most important information related to their present-day stress state (Figure 5.8). In more details, user can inspect the two charts that are being displayed to identify how stressed they are throughout the day. The first one is a donut chart and presents the percentage of stressful moments in the day, compared to calm and balanced moments (requirement 4.2.1.2). This chart uses three colors to define the different stress states. The red color represents stress, the green represents calmness, and the blue represents emotional balance. The second one is a bar chart and represents the user's level of stress for the last five hours (requirement 4.2.1.1). Furthermore, the homepage contains information about the number of relaxation sessions that the user has finished and the trophies that he/she has won.

Figure 5.8: Homepage

5.2.1.3 User Profiles

The end user is able to navigate to the user profiles (Figure 5.9). This is a list of people who are living in the same home as the user and contains information about their dominant mental state (i.e., stressed, balanced, or calm), the recommended relaxation program for them, and the time that has passed since their last relaxation session. The user can select a person from that list (including himself/herself) to view his/her profile, if it is not private (requirement 4.3.1.2). A user profile consists of the following tabs: calendar, log, chart, and trophies.

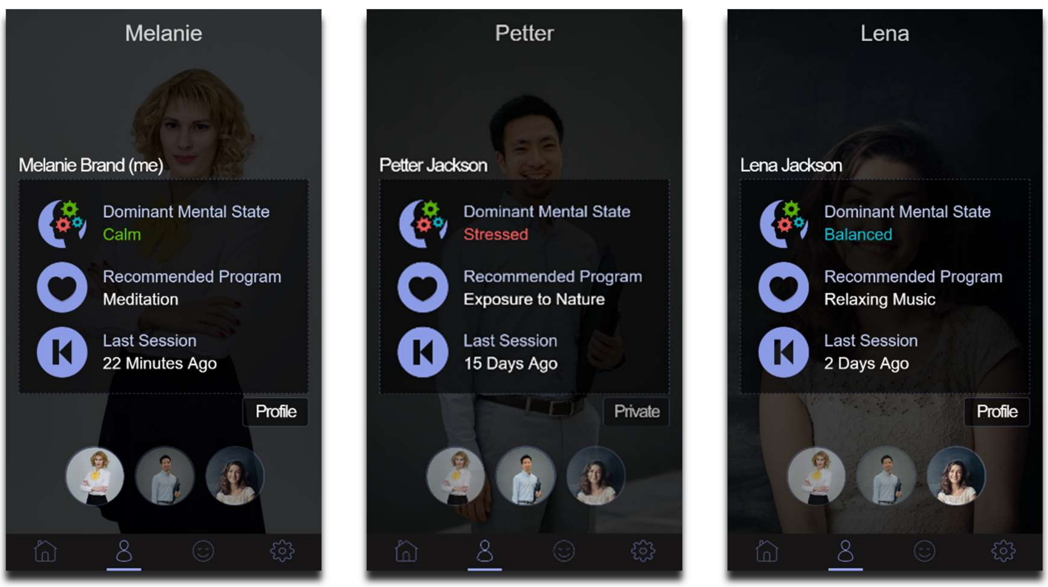

Figure 5.9: User profiles

Calendar

On the Calendar tab, users are able to preview their stress state for every single day of the selected month, and track, delete, or add stress-related events (Figure 5.10). The calendar is designed in such way that a donut chart appears around each day number to present the percentage of user's stressful moments in that day, compared to calm and balanced moments. In addition, the light purple colored number represents the current day, and the yellow number represents the selected day. The selected day is also presented below the calendar together with the entries for that day (requirement 4.2.5.4). If the user is on his/her profile, he/she is able to create a new entry by tapping the "+" button (requirement 4.3.5.1).

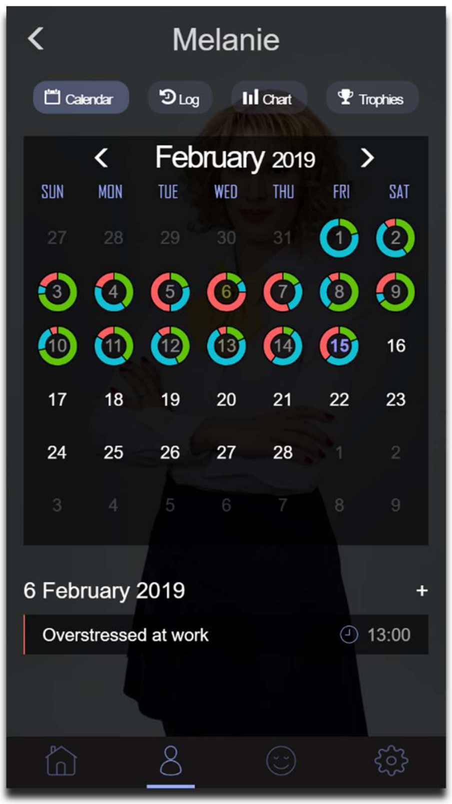

Figure 5.10: Calendar

Log

In the Log tab the notification history log is presented (i.e. all user's notifications in order from newest to oldest; requirement 4.3.6.1), which contains information that help users understand when they tend to get stressed and what can help them relax (Figure 5.11; requirements 4.2.5.2-4.2.5.3). Users are able to delete all or some of their notifications, and view further information about any of them by tapping its title (requirement 4.3.6.2). Also, the red color is used for negative notifications and the green for positive ones.

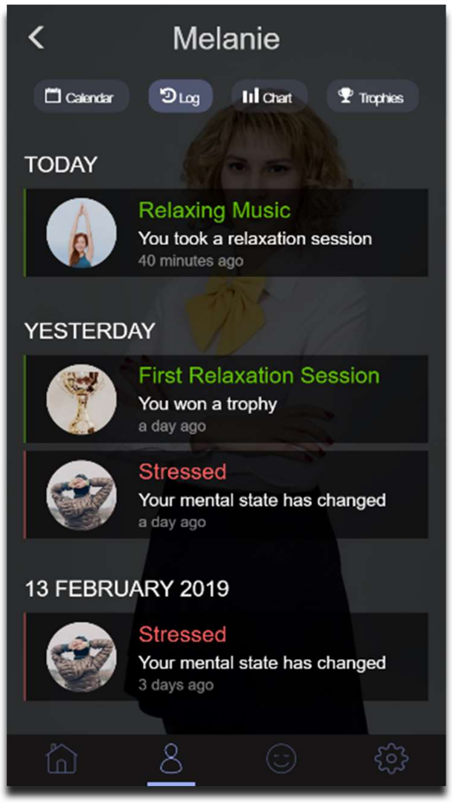

Figure 5.11: Log

Chart

On the Chart tab, users are able to view their stress levels for a given day, week, month or year and to observe fluctuations (Figure 5.12; requirement 4.2.5.1). More specifically, a bar chart represents user's level of stress for the chosen tab (e.g., month) and period of time (e.g., February 2019).

Figure 5.12: Weekly, monthly and yearly charts

Trophies

On the Trophies tab, users are able to view the trophies that have been already won as well as locked trophies that they have not earned yet (Figure 5.13; requirement 4.3.3.2). In particular, a progress bar shows users how far they are from wining a trophy. The implemented trophies are: “Have your first relaxation session”, “Try every relaxation program”, and “Have sessions 10 days in a row” (requirement 4.3.3.1).

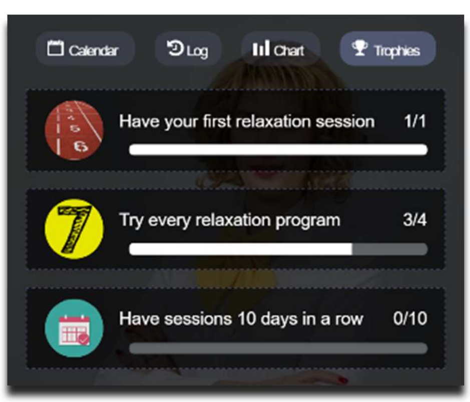

Figure 5.13: Snippet of trophies page

5.2.1.4 Relaxation Programs

End users are able to select any relaxation program from a responsive carousel slider (Figure 5.14; requirement 4.3.2.2). In order to make the selection easier, for each program, the following information is presented: title, description, efficiency percentage, duration, and the number of sessions that have been completed by the user. The implemented programs are: Relaxing Music, Exposure to Nature, Meditation, and Expressive Writing. More relaxation programs can be added to that list by the user.

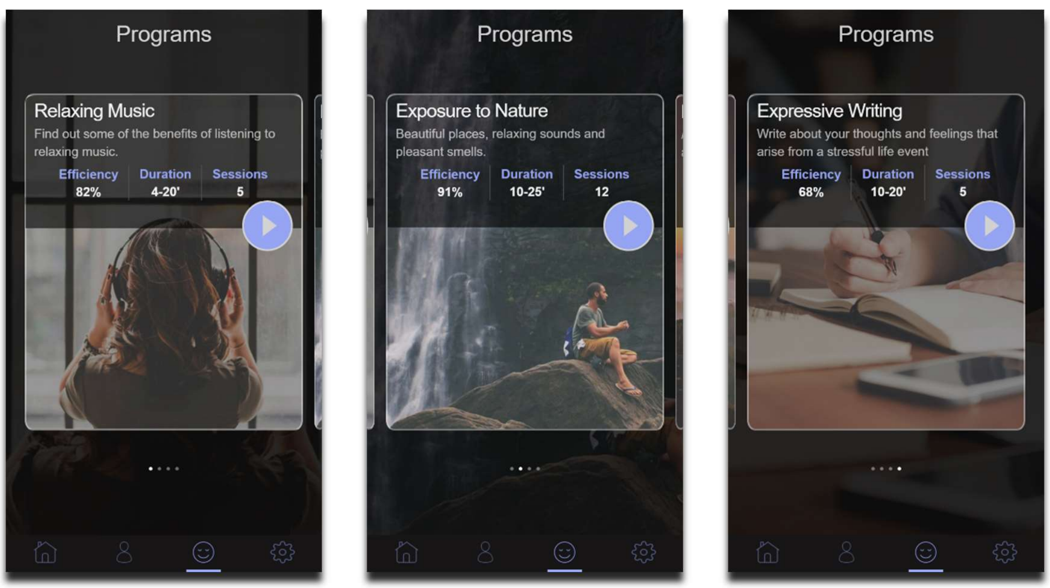

Figure 5.14: Relaxation programs

When users select one of the first three programs (i.e., Relaxing Music, Exposure to Nature, Meditation), a list of the available sessions for that program appears (Figure 5.15). For each session, the following information is displayed: thumbnail, title, duration, and if it is added to user's favorites. Users can choose to initiate any desired session from that list (requirement 4.3.2.1).

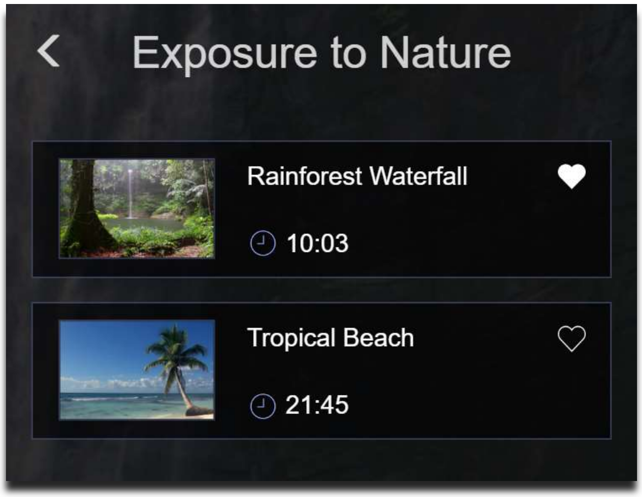

Figure 5.15: Snippet of available sessions for a specific program

The page of the selected session consists of audiovisual content, a quick settings bar, live visualization of stress fluctuations, and a list of similar sessions (Figure 5.16). The audiovisual content (e.g. a video of a waterfall, a classical music playlist) is responsible for the promotion of users' relaxation. From the quick settings bar, users are able to add the current session to their favorites (requirement 4.3.2.4), to stop the session at any time (requirement 4.3.2.6), and when they are at home to activate or deactivate the ambient light, scent, and display areas (requirement 4.3.2.3). If a user chooses to activate the ambient display areas, the audiovisual content stops displaying through the mobile device and is displayed on the most convenient display in the room he/she is currently in. Throughout the session, the user's stress fluctuations are visualized by two arrows (requirement 4.3.2.5). The glaring red arrow pointing up shows an increase in users' stress level, and the glaring green arrow pointing down shows a decrease. Finally, users are able to change the audiovisual content quickly by choosing another similar session.

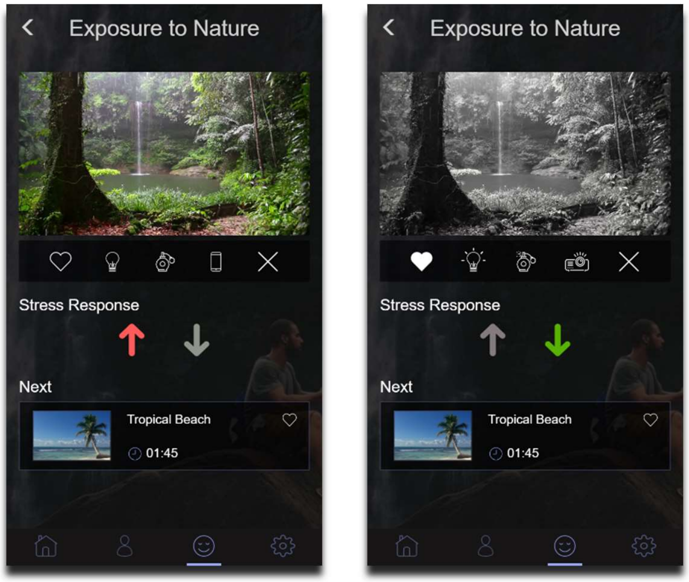

Figure 5.16: Current session

Alternatively, when users select the last program (i.e., Expressive Writing), a list of their entries, based on previous expressive writing sessions, appears (Figure 5.17). For each entry, the following information is presented: title, date, a short text snippet that describes the stressful situation, and an emoji that represents the user's emotional state (i.e., very stressed, stressed, a little stressed, normal, calm) during that session. Users are able to delete all or some of their entries, view further information about any of them, and add a new entry by starting a session.

During an expressive writing session, users are encouraged to fill in a form in 5 steps. In the first step, users must choose the emoji that represents their current emotional state and give a title that is descriptive of the subject matter. In the next steps, users can optionally answer to the four following question: "How would you describe the current situation?", "How this situation affected you?", "Is there really a problem?", and "Something else?".

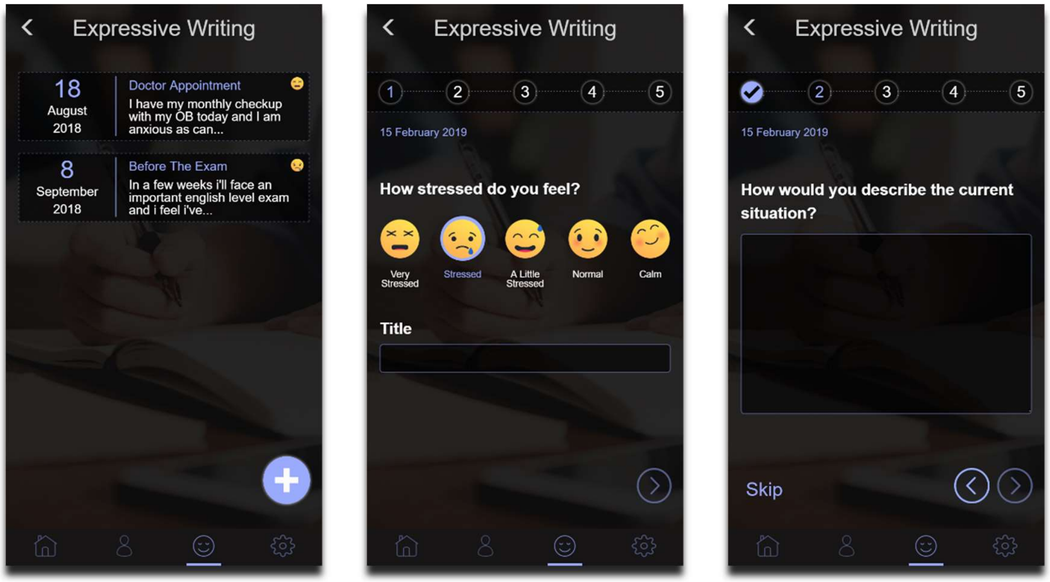

Figure 5.17: Expressive writing

5.2.1.5 Settings

In the settings page, users are able to access their notification and privacy settings, and log out of their account (Figure 5.18).

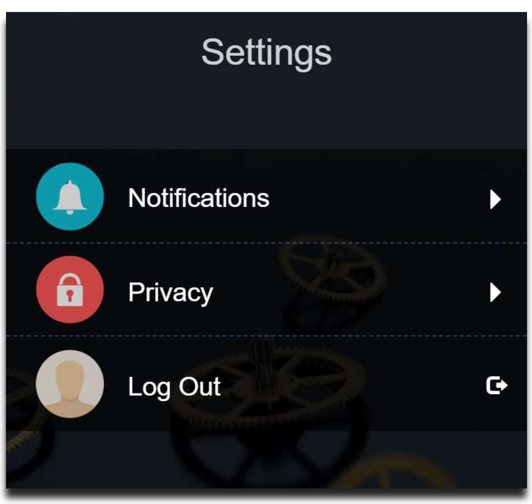

Figure 5.18: Settings

Notifications

Notification settings allow users to turn on or off notifications (Figure 5.19) in specific rooms of the house (requirement 4.3.4.1), users' devices (requirement 4.3.4.2), and hours (requirement 4.3.4.3).

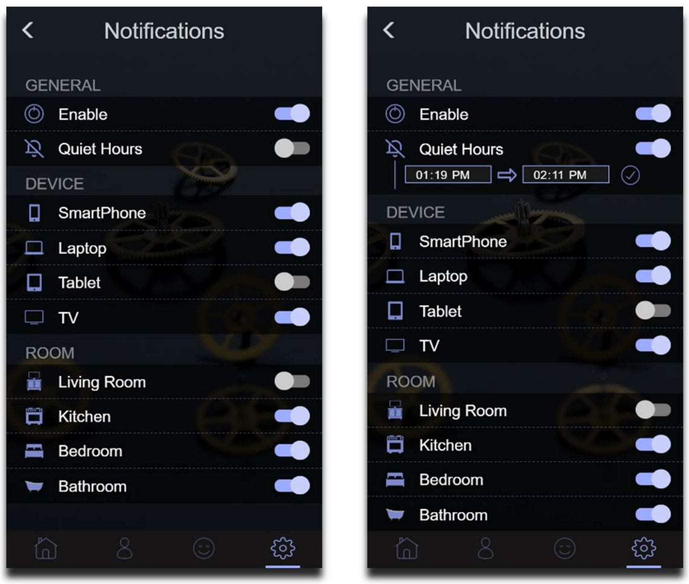

Figure 5.19: Notification settings

Privacy

Privacy settings allow a user to make his/her account private so that only approved users can have access to his/her profile (Figure 5.20; requirement 4.3.4.4).

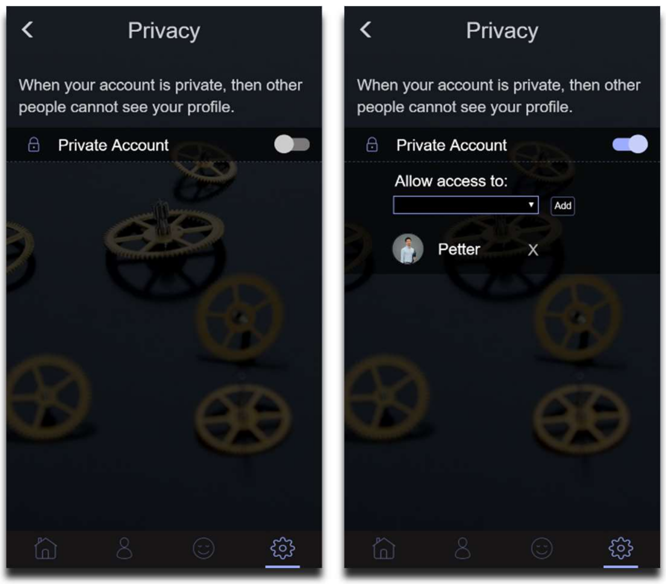

Figure 5.20: Privacy settings

5.2.1.6 Notifications

App notifications are shown up on the mobile device when it is necessary to communicate information to a user. The Figure 5.21 represents three snapshots of different types of notifications. The first one notifies the user that his/her stress level is significantly higher than normal and advises him/her to start a relaxation program (see section 5.1.3.1). The second one informs the user, after completing a relaxation session, about its effectiveness (see section 5.1.3.2). At last, the third one notifies a user that he/she have just won a new trophy (see section 5.1.3.3).

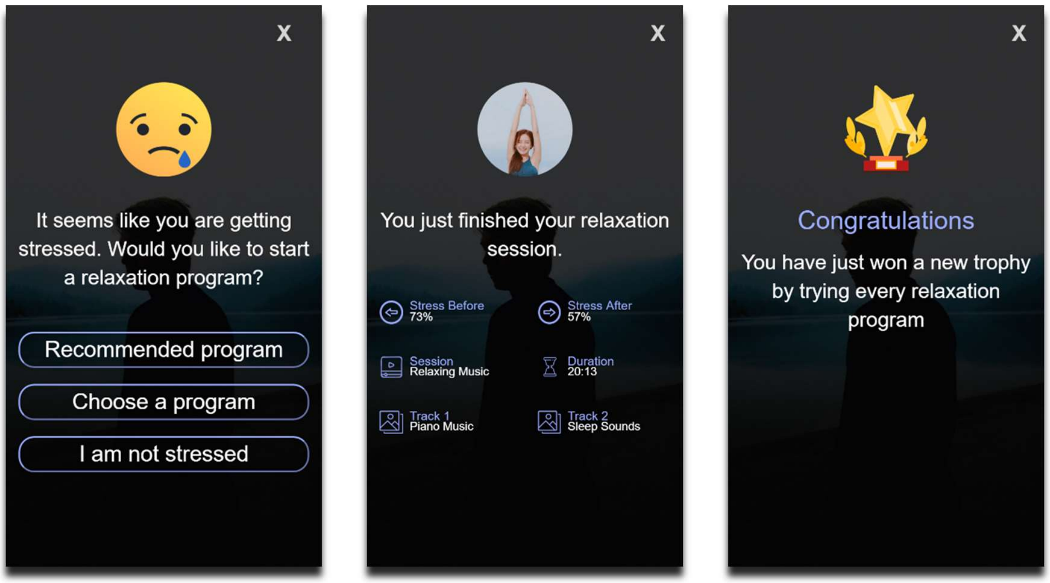

Figure 5.21: Notifications

5.2.2 Other Display Areas

Even though using the mobile application is the preferred approach to facilitate control over the system and assist users (as mentioned in the previous section), sometimes when users are at home, there may be a more convenient display area for them to use, especially when there is no mobile device near them or their hands are busy doing something else. For example, if users want to check their previous week's stress levels in the morning, while they are brushing their teeth over the bathroom sink, the desired chart is going to be displayed on the mirror ahead of them (Figure 5.22). Likewise, during a relaxation session, which takes place in the living room, users are able to view the real time visualization of their stress fluctuations and the session's control menu on the coffee table (Figure 5.23).

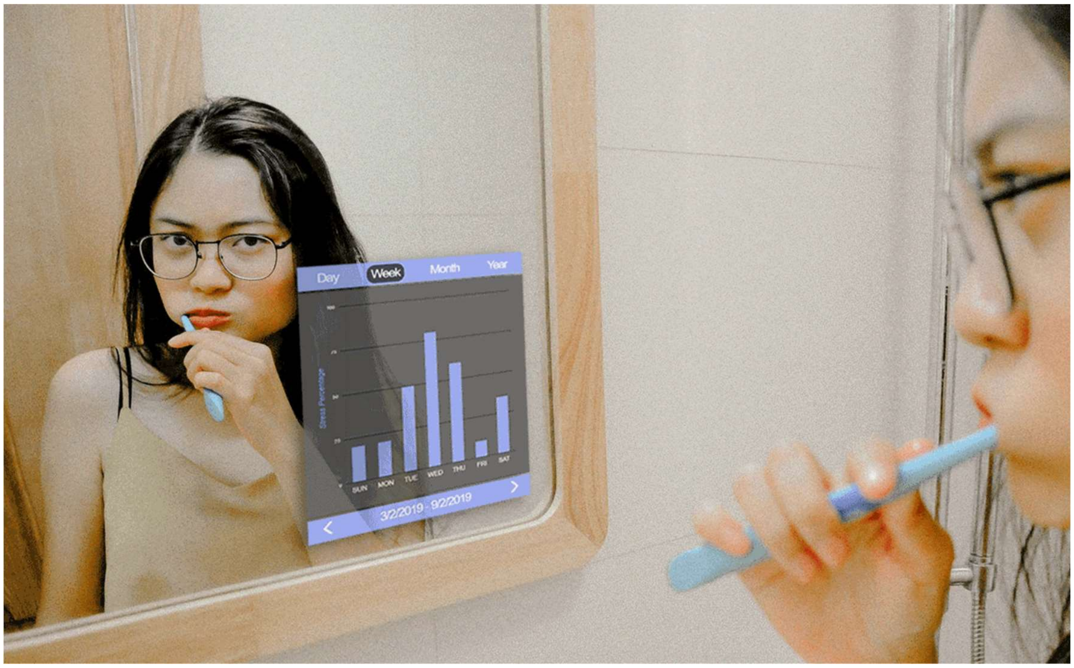

Figure 5.22: Previous week's stress levels displayed on the mirror

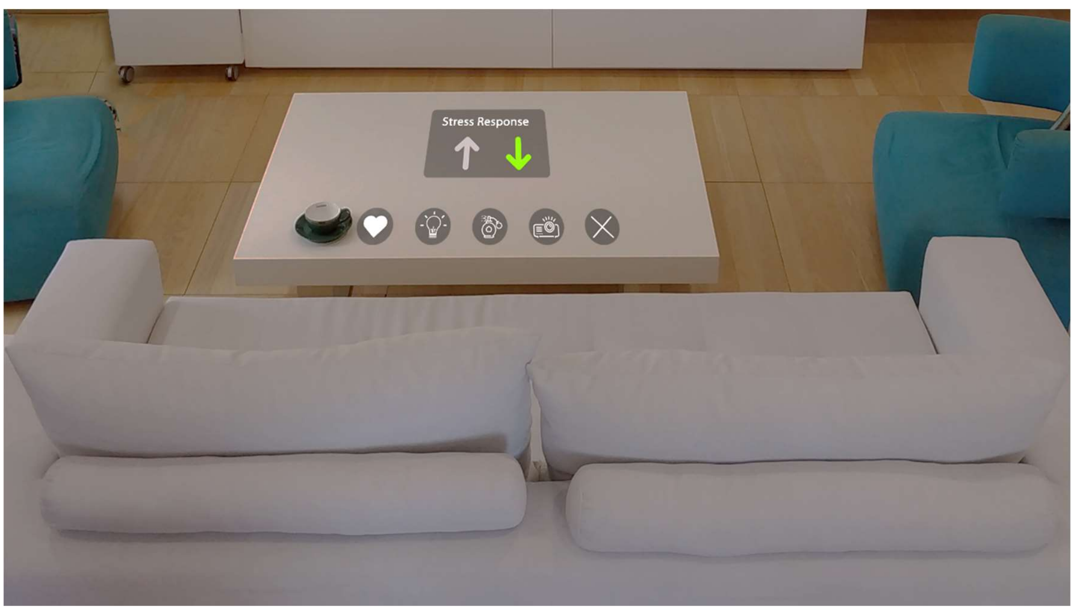

Figure 5.23: Session's control menu and real time stress response on the coffee table

5.3 System Architecture

CaLmi is deployed in an in-vitro technologically augmented home located at the FORTH-ICS AmI Research Facility. The Intelligent Home enhances every day activities with the use of pervasive and mobile computing, sensor networks, artificial intelligence, multimedia computing, middleware and agent-based software [174]. In more details, the hardware infrastructure includes both commercial (e.g., diffuser, speakers) and custom-made artifacts (e.g., smart coffee table), which are embedded in conventional home equipment and furniture. Furthermore, various ambient facilities are employed for monitoring the environment and the inhabitants' actions (e.g., microphones, user-tracking devices).

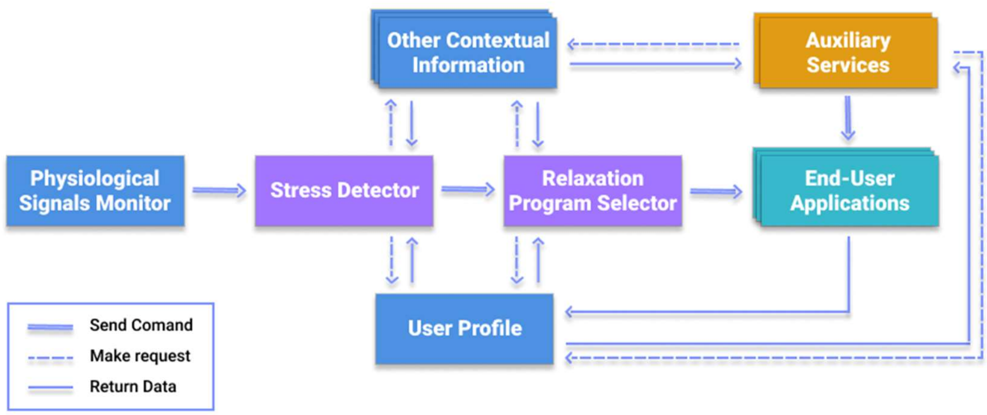

Figure 5.24: High level system architecture

The Figure 5.24 illustrates an overview of CaLmi's architecture. Firstly, the system continuously monitors the physiological signals of the user and informs the stress detector when it identifies peaks. After receiving a peak detection notice, the stress detector requests user profile and current context information to determine whether or not it is caused by stress. In case of stress detection, the relaxation program selector is informed in order to select the appropriate relaxation program based on the user's preferences and the current context. Once the program has been selected, the user is advised to start it and interaction with the system begins. Upon completion of the program, the end-user applications return valuable data to the user profile in order to update it. Additionally, the auxiliary services periodically request user profile and context information to detect situations where users need stress-related advice.

5.3.1 Physiological Signals Monitor

CaLmi employs the Empatica E4 wristband to obtain user's physiological signals and make a first estimate of his/her stress level. More particularly, the E4 streaming server connects to the E4 wristband and forwards its data streams to the E4 client that stores them in the InfluxDB database (Figure 5.25). Then the E4 client and EDA explorer retrieve data from the InfluxDB in order to calculate the user's stress percentages and search for peaks.

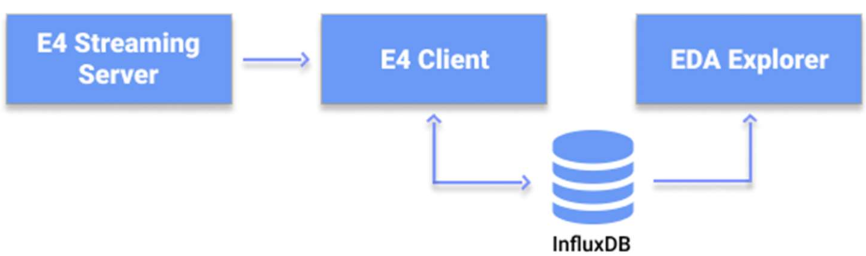

Figure 5.25: Physiological signals monitoring process

5.3.1.1 E4 Streaming Server

The E4 streaming server is a Windows application (Figure 5.26) [175], provided by Empatica, that can connect to multiple Empatica E4 devices using the Bluegiga Bluetooth Smart Dongle (i.e., a Bluetooth Low Energy Dongle) [176] and forward their real time data streams to clients connected over TCP (Transmission Control Protocol). The IP address the server bind to and the port is listening on can be adjusted from the setting panel.

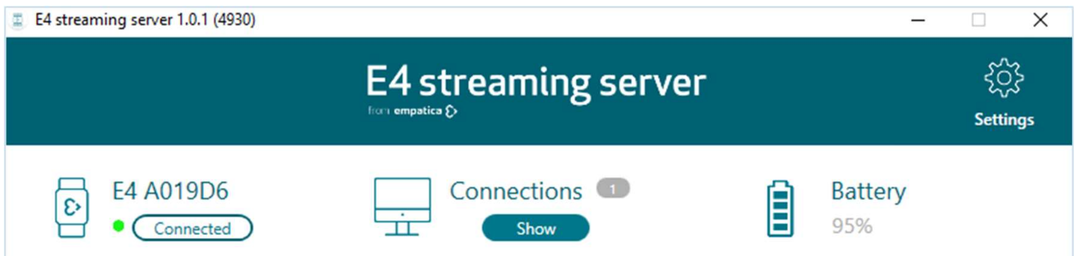

Figure 5.26: E4 streaming server

5.3.1.2 E4 Client

The E4 client is based on a sample asynchronous client provided by Empatica and developed in C# [177]. The sample client has to connect to the IP address and port of the E4 streaming server and the specific E4 device from which the real time data is going to be obtained. Then it sends commands and receives data from that device using the E4 streaming server.

Table 5-1: Measurements in the InfluxDB database

Name	Field keys				
	timestamp	value	axisX	axisY	axisZ
acc (3-axis acceleration)	✓		✓	✓	✓
bvp (blood volume pulse)	✓	✓			
gsr (galvanic skin response)	✓	✓			
temperature (skin temperature)	✓	✓			
ibi (inter-beat interval)	✓	✓			
hr (heartbeat)	✓	✓			

By expanding the existing sample, the E4 client parses the received data and stores it in the InfluxDB database. InfluxDB was selected because it is an open source time series database that offers a SQL-like query language for interacting with data and it is highly suitable for time-stamped data [178]. The Table 5-1 presents the field keys of the six measurements that have been created while inserting data into the InfluxDB database.

Moreover, the E4 client retrieves data from the InfluxDB in order to calculate the stress percentage for a given year, month, week or day. The percentage is calculated by normalizing the data, taking into account the user's minimum and maximum values.

5.3.1.3 EDA Explorer

EDA explorer is a batch Python 2.7 script, developed by the Massachusetts Institute of Technology (MIT), that can accurately distinguish artifacts and detect peaks in EDA signals [179]. EDA explorer loads EDA.csv (i.e., EDA signal), TEMP.csv (i.e., skin temperature signal), and ACC.csv (i.e., data from the 3-axis accelerometer) files outputted by the E4 device, detects noise within the EDA signal (with 95% accuracy) and EDA responses, and visualizes the results.

By editing the existing code, CaLmi's EDA explorer continuously retrieves EDA (Figure 5.25), skin temperature, and acceleration data stored in the InfluxDB database from the E4 client, instead of loading files. Also, when it detects a new peak, which occurs at least four hours after the previous one, and there were no more than two peaks on the current day, it sends an HTTP request to the stress detector in order to inform it.

5.3.2 Stress Detector

The stress detector starts the process of confirming that the user is stressed, when it receives an HTTP request from the EDA explorer. In more details, it requests user profile and current context information from the custom context-sensitive micro-reasoners (see section 5.1.1.2) to determine if the peak detected in the physiological signals from the EDA explorer is caused by stress. Therefore, the question that must be answered (with 1 or 0, where 1 = yes and 0 = no) by the stress detector based on the data obtained from the current context and the user profile is: “Is the user under enough stress to require a remedial action?”

Table 5-2: Data for stress detection through the binary logistic regression

ID	Calendar	Bank Account	Health	Nutrition	User Activity tracking	User Profile	Is the user under enough stress?
1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0
3	0	0	0	1	1	0	0
4	1	1	1	0	1	1	1
5	1	0	1	0	1	1	1
6	1	0	0	0	1	1	1
7	0	0	0	1	0	1	0
8	0	0	0	1	0	0	0
9	0	0	0	0	1	0	0
10	1	0	0	0	0	1	1
11	1	1	0	0	0	1	1
12	1	0	1	1	1	1	1
13	0	0	0	0	0	1	0
14	1	1	1	1	0	1	1
15	0	1	1	1	1	1	1
16	1	1	1	0	0	1	1

The stress detector uses the binary logistic regression algorithm to answer that question. Logistic regression [180] is a commonly used machine learning algorithm for predicting the probability of an event occurring based on previous given data. The data set to which the logistic regression algorithm was trained is presented in the Table 5-2.

In order for the user to be classified as highly stressed, the probability, which has been calculated by the algorithm, must be greater than 75%. In that case, the stress detector sends an HTTP request to the relaxation program selector in order to select the appropriate intervention. Otherwise, the user is not classified as highly stressed and there is no need to select a relaxation program.

5.3.3 Relaxation Program Selector

The relaxation program selector starts the process of choosing the most suitable relaxation technique based on the user's preferences and the current context, when it receives an HTTP request from the stress detector. More specifically, it requests user profile and current context information in order to select the most appropriate relaxation program, customize that program according to the user's preferences, and choose the appropriate hosts for it.

Firstly, the most appropriate relaxation program must be selected. Time constrains and the desired activity level play a critical role in that decision. Data obtained from the smart calendar (e.g., a nine o'clock appointment) and processed by a micro-reasoner (e.g., user has ten minutes available) determines the maximum duration of the session. In addition, data obtained from the user activity tracking (e.g., user is lying in bed) and processed by a micro-reasoner (e.g., low activity level is desired) determines the desired activity level. Thus, the relaxation program selector chooses the most efficient program for the user based on his/her profile that satisfies the timing and activity level constraints and customizes it according to his/her profile preferences. However, if there is no time for starting a session, the process stops.

After making the program selection, the appropriate hosts must be chosen. Data obtained from the user activity tracking determines the user's current room location and if there are other people in the same room. In case he/she is alone in the room, the appropriate hosts (e.g., TV, speakers, Wall Projector), which are nearest to him/her, are selected. Otherwise, the appropriate hosts of the nearest available room are selected and it is suggested to the user to move into that room.

5.3.4 End-User Applications

The end-user applications are associated with any procedure responsible for the intercommunication between the system and the user. These applications are developed using a MEAN stack architecture (Figure 5.27) [181]. MEAN takes its name from the four technologies that are used: **M**ongoDB (i.e., the database), **E**xpress.js (i.e., a server-side framework), **A**ngular (i.e., a client-side framework), and **N**ode.js (i.e., a JavaScript runtime environment).

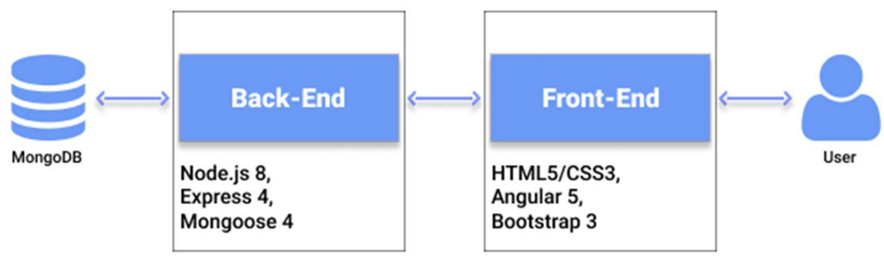

Figure 5.27: The MEAN stack architecture of the end-user applications

5.3.4.1 Back-End Development

The back-end handles the following tasks: validates and processes submitted data and requests, stores and retrieves data from the MongoDB, and sends the requested data to the front-end client. The procedures followed for the data modeling, database interactions, and data processing are analyzed below.

Data Modeling

Data modeling is "the process of representing data, their relationships, and their semantics in a way which is processable by humans and machines" [182]. In MongoDB, data has a flexible schema, where a collection does not require its documents to have the same structure [183]. More particularly, the collections that have been created to store user data are described below.

- A collection of **users** where for each user the following data is stored:
  - ID number
  - First name
  - Last name
  - Username
  - Password
  - Profile image
  - Privacy settings (i.e., private or public)
  - Array of users prohibited from viewing his/her profile
  - Array of days
  - Array of trophies won
  - Array of active notifications
  - Array of programs
  - Array of favorite sessions

- A collection of **days** where for each day the following data is stored:
  - ID number
  - Corresponding user
  - Date
  - Percentage
  - Calm moments percentage
  - Balanced moments percentage
  - Stressed moments percentage
  - Stress percentage
  - Array of hours
  - Array of events

- A collection of **hours** where for each hour the following data is stored:
    - ID number
    - Corresponding user
    - Corresponding day
    - Time
    - Stress percentage

- A collection of **events** where for each event the following data is stored:
    - ID number
    - Corresponding user
    - Corresponding day
    - Event type (i.e., manual or automatic)
    - Image
    - Title
    - Category
    - Description
    - Time

  Depending on the event, additional data is stored as listed below.

  In case of high stress level notification:

    - User's location
    - Stress percentage
    - Stressors
    - Stressed people being around user

  In case of notification after completing a relaxation session:

    - Corresponding Sessions
    - Stress percentage before the session
    - Stress percentage after the session

- A collection of **trophies** where for each trophy the following data is stored:
    - ID number
    - Title
    - Image

- A collection of **notifications** where for each notification the following data is stored:
  - ID number
  - Title
  - Category

  In case of "quiet hours" notification, the following additional data is stored:

  - Start time
  - End time

- A collection of **programs** where for each program the following data is stored:
  - ID number
  - Title
  - Description
  - Array of sessions

- A collection of **sessions** where for each session the following data is stored:
  - ID number
  - Corresponding Program
  - Title
  - Duration
  - Visual content
  - Audio content
  - Scent
  - Ambient lighting
  - Natural lighting
  - Instructions

Database Interactions

Node.js and Express have been used to build a RESTful API in order to get, add or delete the requested data from the MongoDB using typical HTTP methods (i.e., GET, POST, PUT, and DELETE).

Data Processing

The back end development also involves the processing of data obtained from user interaction with the system. The main objectives of this phase are to measure the effectiveness of the relaxation programs, return valuable data to the user profile, and check if a new trophy has been won.

Firstly, the system processes data obtained after the completion of each relaxation session in order to determine different programs' effectiveness. The overall effectiveness of a program for a specific user is calculated according to the percentage of his/her actually effective sessions of such program. In order for a session to be effective, the user's stress percentage should be reduced by at least ten percent after its completion. In case the user does not complete the session for any reason (e.g., he/she was bored), it is considered ineffective.

Furthermore, valuable data is sent to the user profile in order to update it and help the system make better decisions in the future. Since each user has different stress reactions to specific conditions and responds differently to corresponding programs, it is important to keep user profiles up to date. More specifically, data based on user interaction with the system helps to improve the accuracy of the stress detection. For example, if the system notifies the user about high stress level but the user responds that he/she is not stressed and there is no any strong indication showing otherwise, the user profile is going to be updated and the user is not going to be again identified as stressed under the same circumstances. Moreover, data related to programs' effectiveness helps the relaxation program selector to choose the most suitable relaxation technique for a particular user.

Lastly, data obtained from user interaction with the system gives the ability to track user activity and reward him/her for following the suggested relaxation methods (see section 5.1.3.3). In order for the system to detect if a new trophy has been won, it counts the number of the different relaxation programs that the user has tried, the completed sessions per user, and the consecutive days that the user had a relaxation session.

5.3.4.2 Front-End Development

The front-end handles the following tasks: builds the user interfaces and forwards requests to the back-end. The front-end development implements the structure, design, behavior, and animation of everything users see on the screen [184]. More particularly, Single Page Applications (SPA) have been built using Angular 5. SPAs are designed to improve user experience by minimizing page load time [185]. That is made possible by refreshing particular areas of a page instead of reloading it entirely. Also, data is requested from or sent to the server (i.e., to the back end).

5.3.5 Auxiliary Services

The auxiliary services give users tips for precautionary purposes and advices when suspicious stress patterns occur. The schedule tracker and the chronic stress detector detect situations where users need stress-related advices and display the appropriate messages to them through the end-user applications.

5.3.5.1 Schedule Tracker

The purpose of the schedule tracker is to detect when users' upcoming schedule seems overwhelming in order to advise them to prepare ahead of time and thus to avoid last minute stress. The schedule tracker runs once a day and notifies users to properly organize their tasks or gives them general tips on reducing stress if it detects a hectic schedule for the next twenty days based on data obtained from the smart calendar (e.g., four upcoming events) and processed by a micro-reasoner (e.g., all of them are stressful). In order for the schedule to be characterized as hectic, at least three stressful upcoming events are required, but the number may differ depending on the user profile.

5.3.5.2 Chronic Stress Detector

The chronic stress detector is responsible for the detection of suspicious stress patterns that may require professional help and treatment. The chronic stress detector runs once a month and notifies users to request professional help if it detects possible unusual stress patterns and behaviors based on context information (e.g., the user has not left the house in two weeks, the user consumes too much alcohol) and data obtained from the user profile (e.g. constantly high stress levels in the last month). In order for the user to be notified, his/her stress levels must be high for at least one month and there must be at least one context indicator.

Chapter 6

Evaluation

The pilot evaluation of the CaLmi system was coordinated by the Human-Computer Interaction Laboratory (HCI) of the Institute of Computer Science of the Foundation for Research and Technology – Hellas (ICS-FORTH).

6.1 Objectives

The purpose of this process is to determine if the CaLmi system can really reduce users' stress levels as recorded by the Empatica E4 wristband. More specifically, the main objectives are to:

- Gather information about the fluctuations in physiological signals (and hence in stress levels) and how the user feels before, during, at the end of the relaxation session, and one hour later.
- Identify the differences that occur between multisensory and monosensory relaxation sessions.
- Prove that a relaxation session is more effective when the intelligent environment is properly adapted in order to activate different senses (multisensory mode) and is not limited to the visual sense alone (monosensory mode).

- Examine whether end users believe that CaLmi's relaxation sessions are effective and whether they would like to use CaLmi in their everyday lives.

6.2 Participants

A total of 8 users participated in the evaluation, 3 females and 5 males. The age of the participants varied from 25 to 54 years old. People who were allergic to lavender oil and to the materials of the Empatica E4 wristband (i.e., plastic, silicone, silver, gold, and brass) were excluded from the evaluation. Furthermore, in order to ensure that the signals were reliable, from the evaluation were also excluded people who [186]–[188]:

- had been given medication that could affect the physiological signals (e.g., anxiolytics, antidepressants, diuretics, and blood pressure, thyroid, diabetes or heart disease medications).
- had been suffering from substance abuse that could affect the physiological signals (e.g., alcohol, drugs).
- traveled across more than one time zone the week before the evaluation.

6.3 Process

The evaluation process consisted of the three following phases:

Phase 1 – Data Collection

The participants were requested to wear the Empatica E4 wristband for as long as possible in their daily lives for two consecutive days. During that time, they were also requested to write down, in two printed forms (one for each day), the times of the day they thought that there were increases in their physiological signals due to (a) a stressful event, (b) physical exercise, or (c) some other cause without specification (Figure 6.1). The above information was later (a-posteriori) used in the analysis of the data to determine the range of the physiological signals for each participant and identify the values that are likely to signal high stress levels.

Events that might have affected physiological signals			
Time	___:___ (HH:MM)	**Type**	☐ Stress ☐ Exercise ☐ Other

Figure 6.1: Event note format

Phase 2 – Relaxation Program Testing

During the following three days, the participants were requested to continue wearing the Empatica E4 wristband and whenever they were feeling stressed to try (according to their time preference) the offered relaxation program in two sessions, with different way per session (multisensory or monosensory mode), and in random order for each participant. Both sessions took place in the living room of the Intelligent Home located at the AmI Facility Building within the FORTH-ICS campus.

The relaxation program offered (through the CaLmi system) to the participants was the "Exposure to Nature" and the two sessions were structured as follows:

- **Multisensory mode:** This session aimed at activating (a) the sense of sight by displaying a video of a forest waterfall on the main living room wall and adjusting the color (i.e., it takes a greenish-blue hue of the waterfall's water) and the intensity (i.e., it decreases) of the room lighting, (b) the sense of hearing by reproducing relaxing music and forest sounds (e.g., running water and birdsong) via the room's speakers, and (c) the sense of smell by diffusing the lavender scent using the scent diffuser.
- **Monosensory mode:** This session aimed at activating only the sense of sight by displaying a video of a forest waterfall on a tablet device without sound.

The participants continued to wear the Empatica E4 wristband during the sessions and one hour after their completion in order to record their physiological signals and thus possible changes in stress levels. Moreover, after each session, the participants filled in the following questionnaire (Figure 6.2):

Instruction: The questionnaire consists of word pairs of contrasting attributes that may apply to the relaxation program. The boxes between the attributes represent gradations between the opposites. Please tick the box that most closely reflects your viewpoint.

Evaluation								
	1	**2**	**3**	**4**	**5**	**6**	**7**	
Stressed								**Relaxed**
Excited								**Calm**
Satisfied								**Unsatisfied**
Sleepy								**Alert**
Annoyed								**Pleased**

Figure 6.2: Post-session questionnaire

Phase 3 – Final Interview (Debriefing)

Upon completion of Phase 1 and 2, the participants were interviewed about their experiences with the system. The interview questions were:

- Which session did you find more relaxing?
- Which session would you rather to use in your daily life?

- What did you find most relaxing about CaLmi?
- What did you dislike about CaLmi?
- What else would you like to add to CaLmi?

6.4 Moral and Ethical Issues

During the evaluation period, only the absolutely necessary data was collected and processed through the “pseudonymization” process, while participants' identities will remain confidential and not be revealed. More specifically, the following data was recorded:

- Personal data (i.e., name, age, gender, and contact details)
- Data relating to the determination of the user’s stress level (i.e.., BVP, HR, IBI, EDA, and ST)
- User specific context information (i.e., acceleration, caffeine intake, sleep duration, physical activity, and perceived stress)
- Comments, reactions, and user responses to questions and questionnaires.

In the context of the evaluation process, the European Union (EU) regulation on General Data Protection (GTPR; 2016/679) has been properly taken into account and approval has been obtained by the FORTH Ethics Committee. In addition, participants were given information about the nature of the evaluation and all aspects of participation, and a consent form was signed, which has been prepared in collaboration with the Data Protection Officer (DPO) of FORTH.

6.5 Results

The evaluation results confirm that a relaxation session is more effective and satisfying when using the technological equipment and installations of the intelligent home in order to activate different senses (multisensory mode) and is not limited to the visual sense alone (monosensory mode). However, the sample size was small, so further investigation is planned.

6.5.1 Subjective Perception

According to the information provided by the questionnaires (ratings on a scale from 1 to 7), 62% of the participants thought that they were less stressed after the multisensory session in comparison with the monosensory (Figure 6.3), while all participants felt more calm, satisfied, sleepy and pleased after the multisensory one (Figure 6.4). Moreover, the participants would use CaLmi in their everyday lives in order to receive multi-sensory, context-aware, personalized innervations for stress reduction.

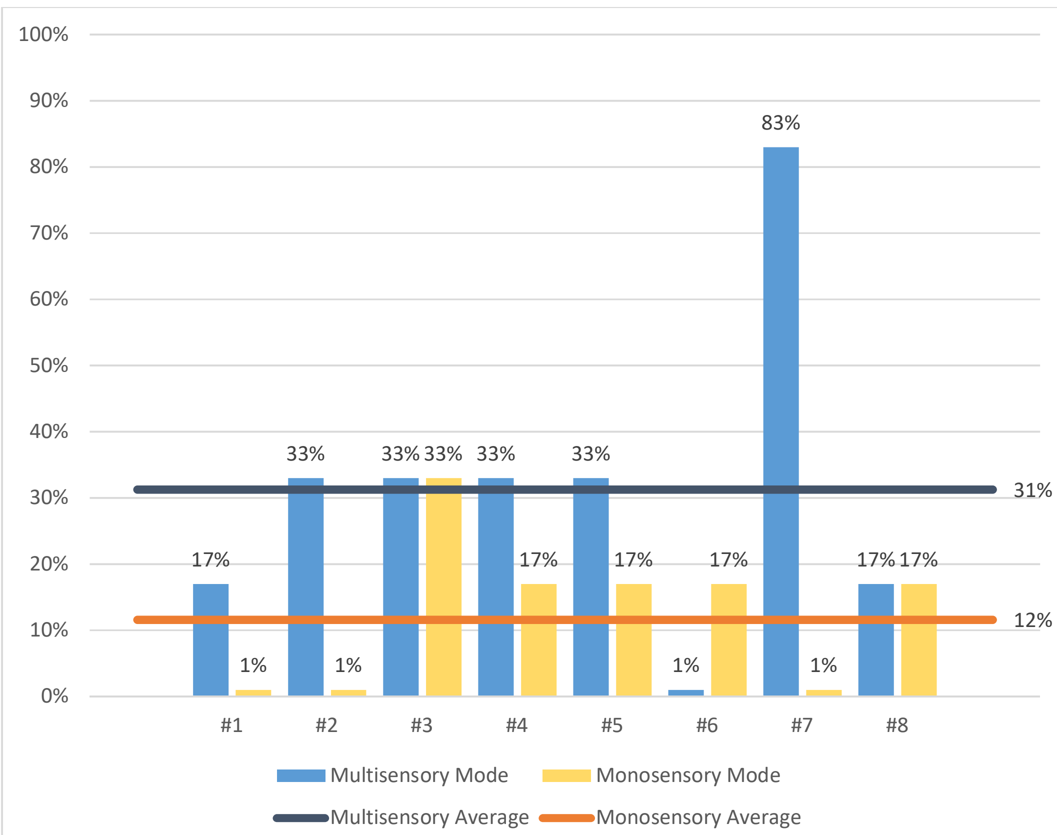

Figure 6.3: Subjective stress reduction per participant

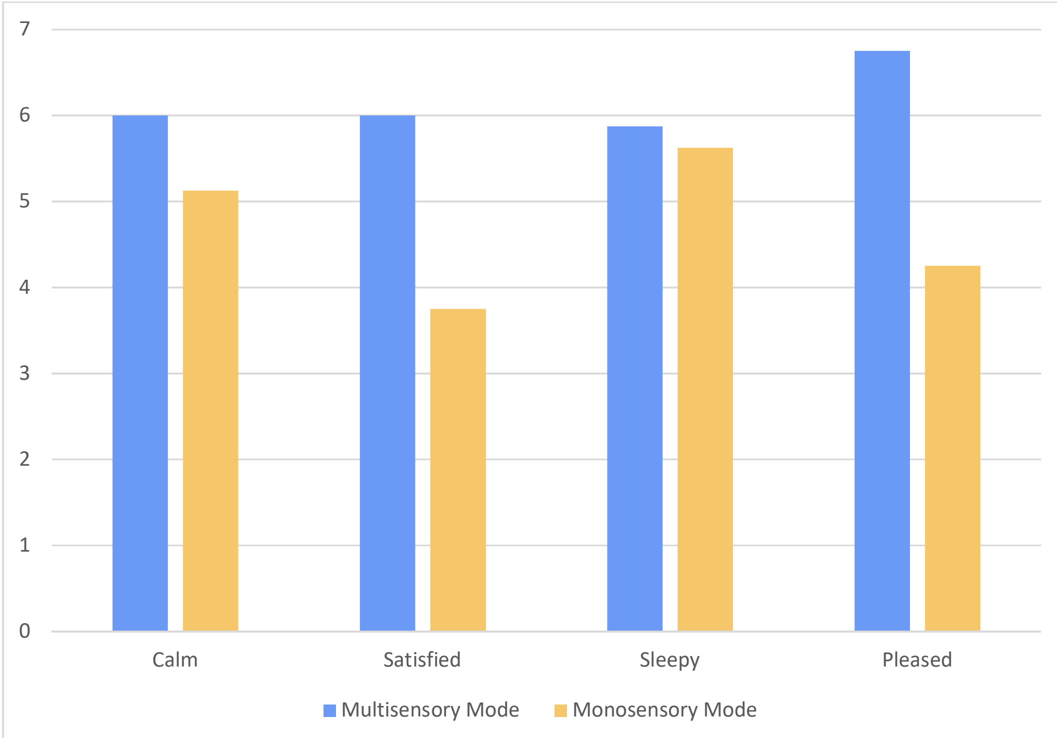

Figure 6.4: How participants felt right after each session

6.5.2 Objective Perception

EDA signals revealed that 62% of the participants were calmer after the multisensory session in comparison to the monosensory (Figure 6.5). In more details, all participants, except one, seemed to be more relaxed after the relaxation sessions and their EDA values were reduced by at least 29% and on average by 49% after the multisensory session, while in the best case reached 92%. Below follows an analytical presentation of the EDA fluctuations during the evaluation for each participant separately.

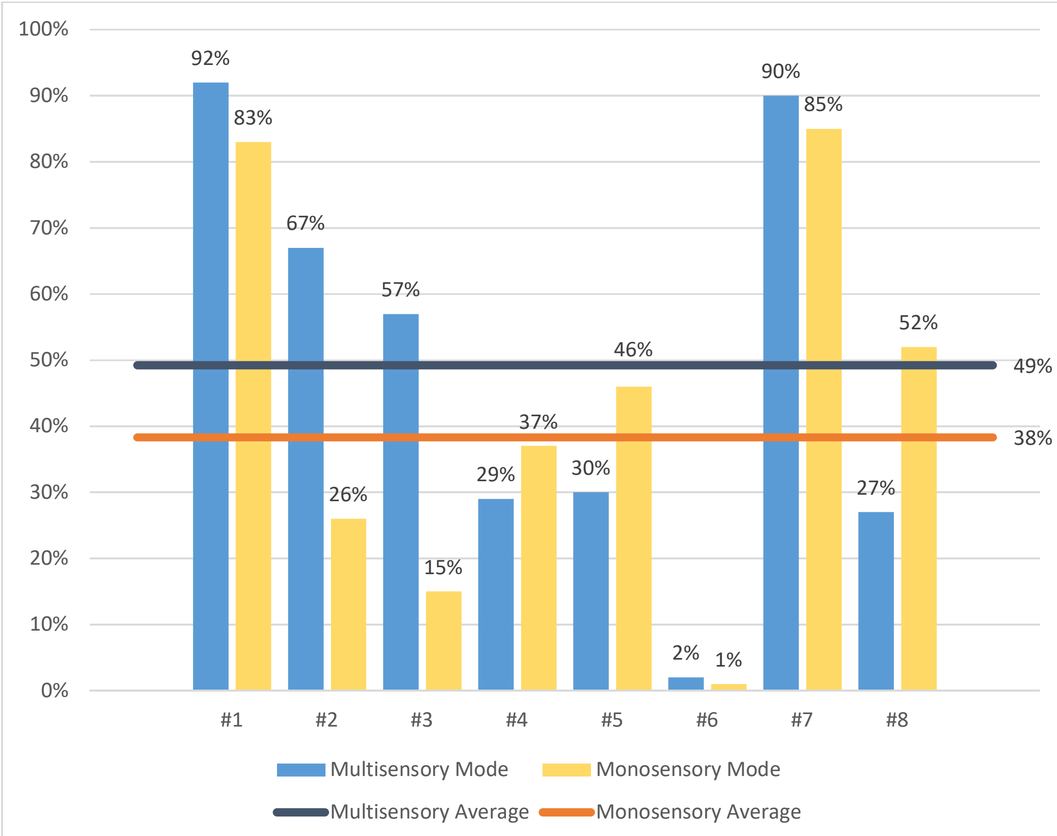

Figure 6.5: Objective stress reduction per participant

Participant 1

As can be seen from Figure 6.6, Participant 1 had an average EDA value of 0,51µS and he was more stressed during the second day, which he pointed out in the forms as well. In addition, the two moments where he thought were increases in his physiological signals are marked on the graph. EDA signals were clearly increased in those moments. According to the participant, the second increase is caused by a combination of stress and excitement and the EDA value reached above 4µS.

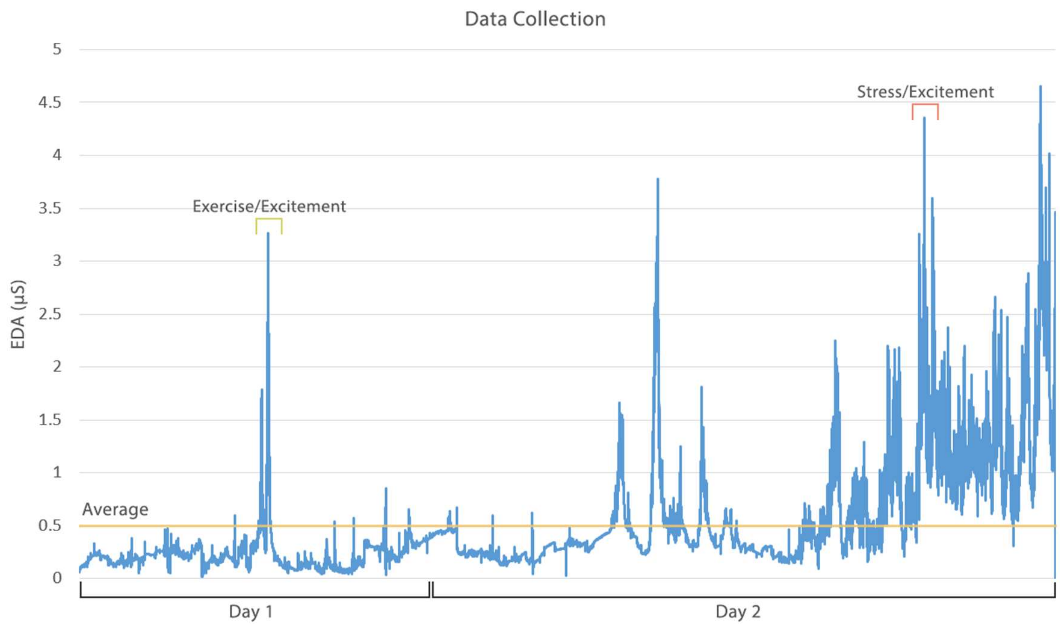

Figure 6.6: EDA signals of Participant 1 for two consecutive days

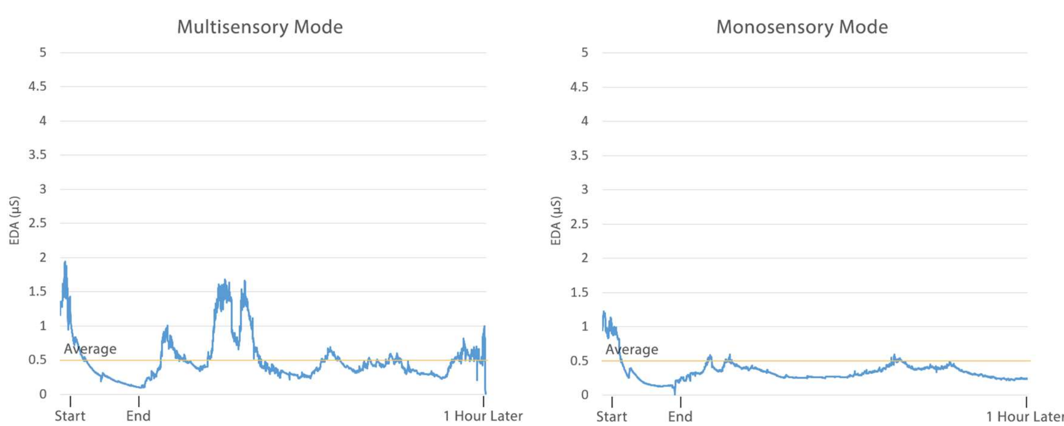

Figure 6.7: EDA signals of Participant 1 during the relaxation program testing

Figure 6.7 shows participant's EDA fluctuations during the relaxation program testing and one hour after their completion. As illustrated, EDA was above his average value when both relaxation sessions started and decreased below that value after their completion. In particular, EDA reduction reached 92% in the multisensory mode and 83%

in the monosensory. Then, there were increases in the signals but EDA remained lower than the starting point. In more details, EDA was 46% lower one hour after the multisensory session compared with the starting point and 63% after the monosensory. Summing up, EDA value decreased more with the multisensory session, but it remained lower and more stable one hour after the monosensory.

Participant 2

Participant 2 had an average EDA value of 0,17μS and that value reached above 0,5μS when she felt stressed (Figure 6.8).

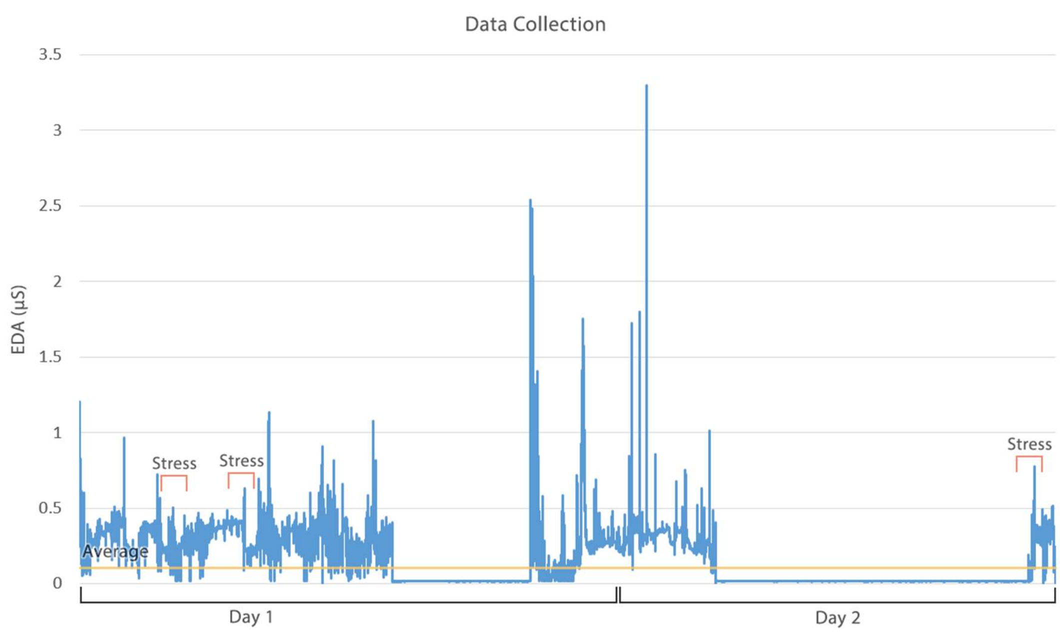

Figure 6.8: EDA signals of Participant 2 for two consecutive days

As illustrated in Figure 6.9, EDA was above her average value when both relaxation sessions started and there was a decrease after their completion. In particular, EDA reduction reached 67% in the multisensory mode and 26% in the monosensory. Moreover, EDA was 33% lower one hour after the multisensory session compared with the starting point and 47% (even lower than the initial decrease after the completion) after the monosensory. Similar to the previous participant, EDA value decreased more with the multisensory session, but it remained lower and more stable one hour after the monosensory.

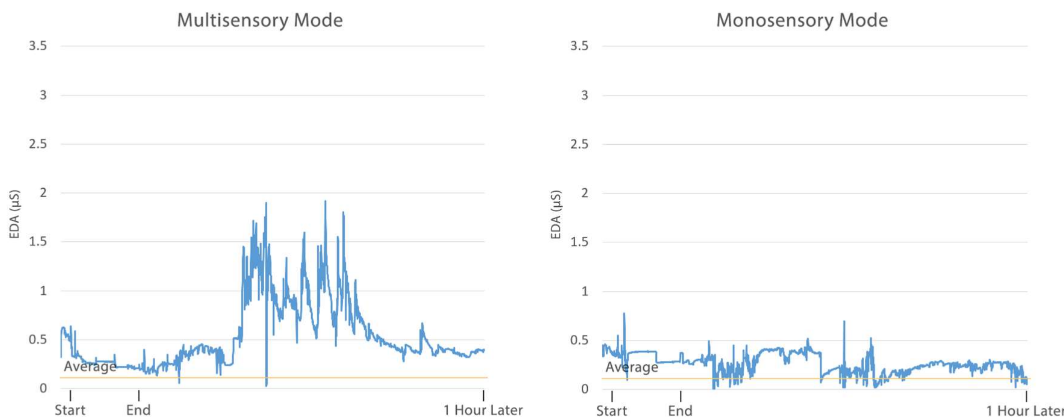

Figure 6.9: EDA signals of Participant 2 during the relaxation program testing

Participant 3

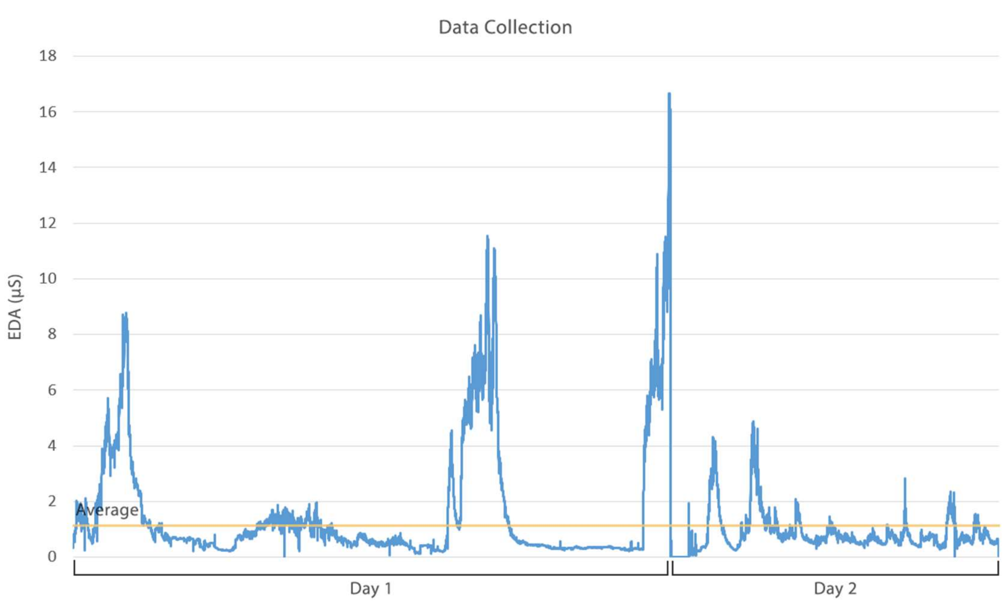

Figure 6.10: EDA signals of Participant 3 for two consecutive days

Participant 3 had an average EDA value of 1,37μS (Figure 6.10) and he did not indicate any stressful moment.

As illustrated in Figure 6.11, EDA was above his average value when multisensory session started. In both cases after the completion of the sessions EDA value decreased, although the participant was not stressed before the monosensory session. Moreover, EDA reduction reached 57% after the multisensory mode and 15% after the monosensory. Afterwards, EDA was 58% lower (even lower than the initial decrease after the completion) one hour after the multisensory session compared with the starting point and it had slightly increased one hour after the monosensory.

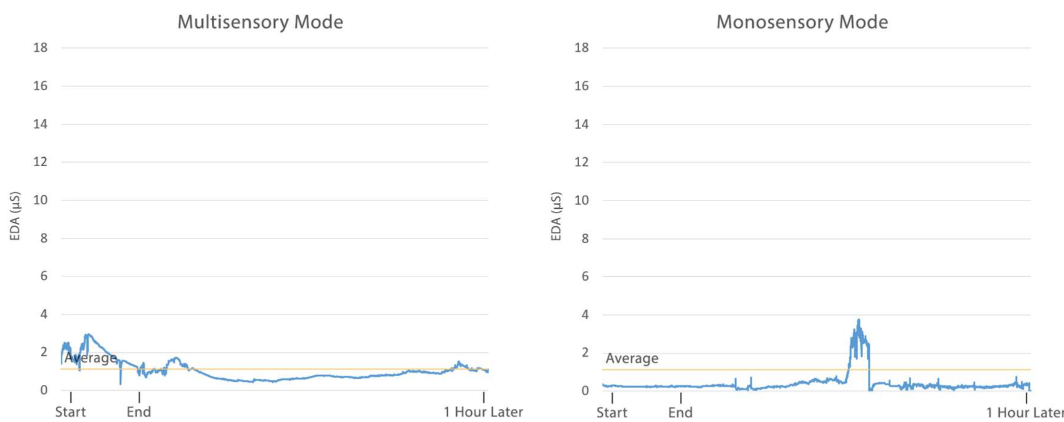

Figure 6.11: EDA signals of Participant 3 during the relaxation program testing

Participant 4

Participant 4 had an average EDA value of 0,52μS and that value reached above 2μS when she felt stressed (Figure 6.12). Additionally, as Participant 4 also pointed out, the second day was more stressful.

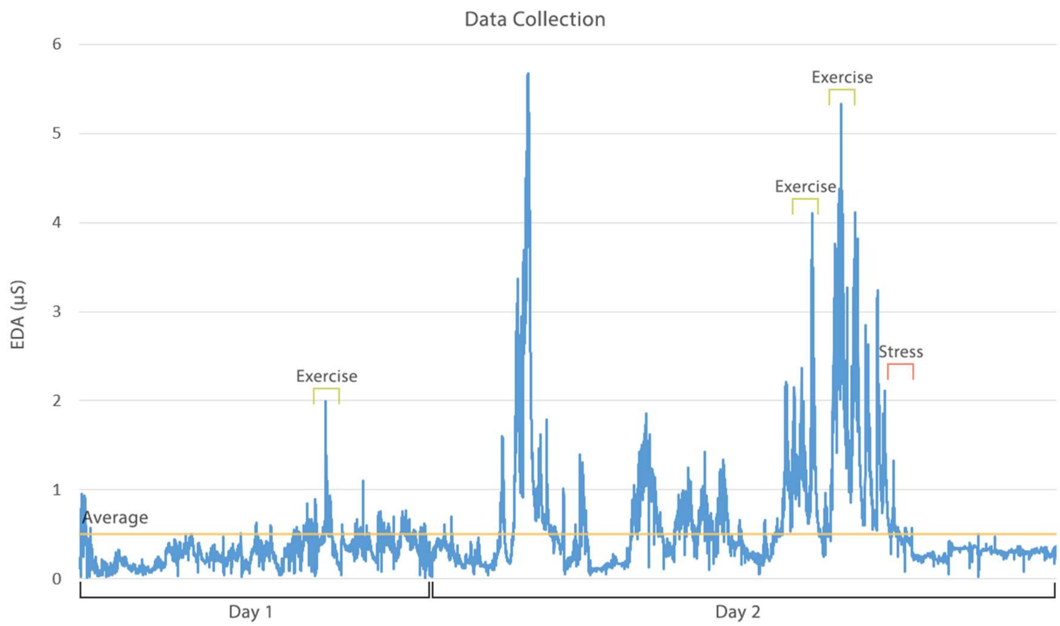

Figure 6.12: EDA signals of Participant 4 for two consecutive days

Figure 6.13 shows that Participant 4 was not so stressed before the relaxation sessions and her EDA value was higher before trying the monosensory mode. Thus, EDA value decreased more after the monosensory session (37%), but there was also a decrease after the multisensory (29%). However, EDA value increased one hour later in both cases.

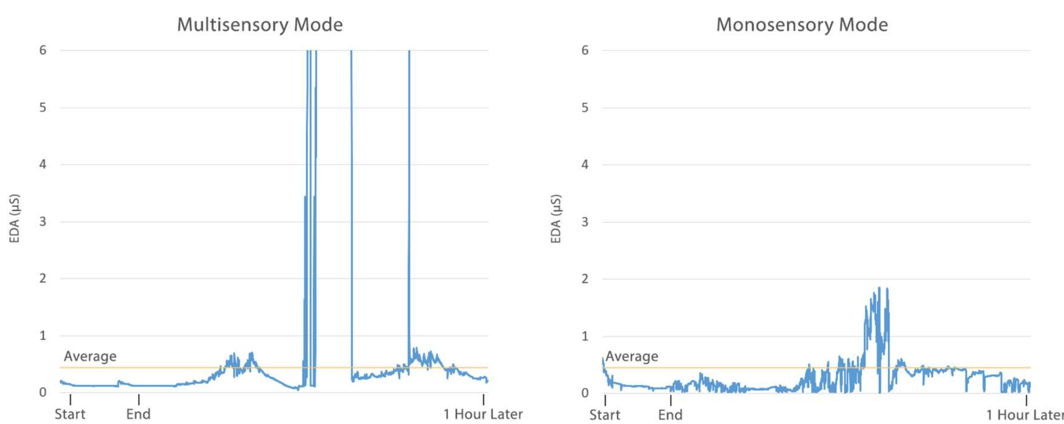

Figure 6.13: EDA signals of Participant 4 during the relaxation program testing

Participant 5

Participant 5 had an average EDA value of 0,47μS and that value reached above 6μS when she felt stressed (Figure 6.14).

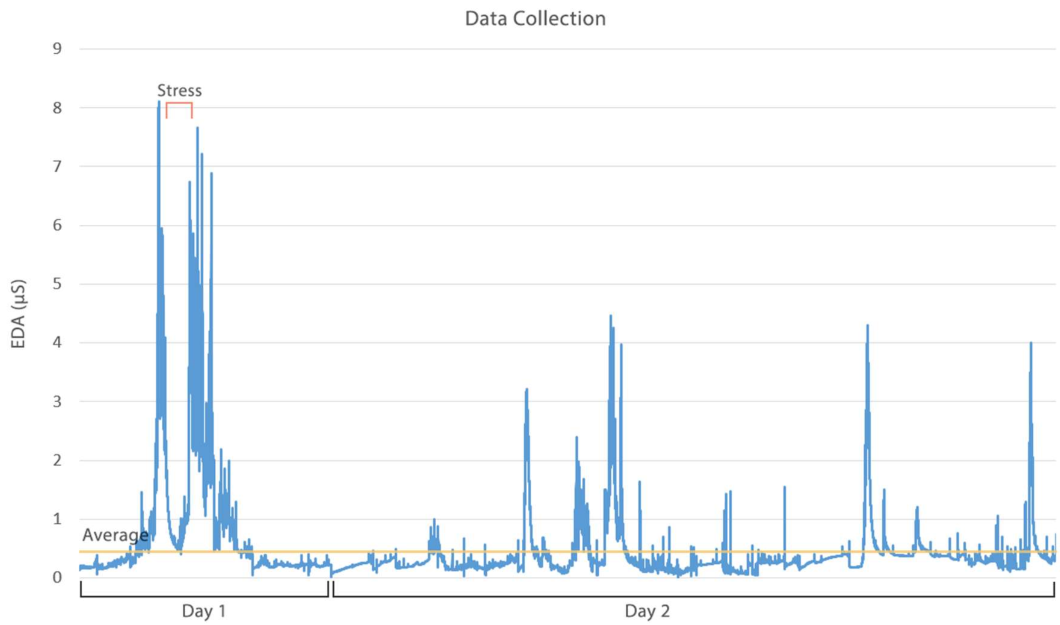

Figure 6.14: EDA signals of Participant 5 for two consecutive days

Figure 6.15 shows that Participant 5 also was not so stressed before the relaxation sessions and her EDA value was higher before trying the monosensory mode. Thus, EDA value decreased more after the monosensory session (46%), but there was also a decrease after the multisensory (30%). Furthermore, EDA value increased one hour after the multisensory session and was slightly lower one hour after the monosensory.

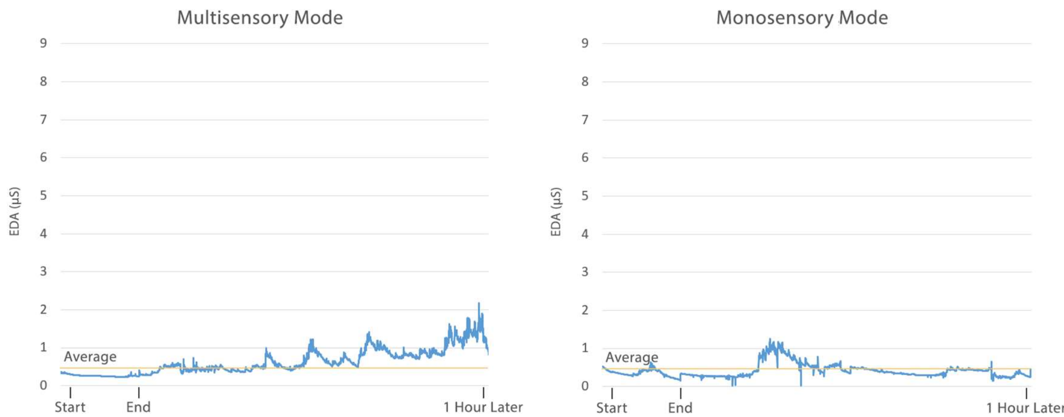

Figure 6.15: EDA signals of Participant 5 during the relaxation program testing

Participant 6

Participant 6.16 had an average EDA value of 7,98µS and that value reached above 25µS when he felt stressed (Figure 6.16).

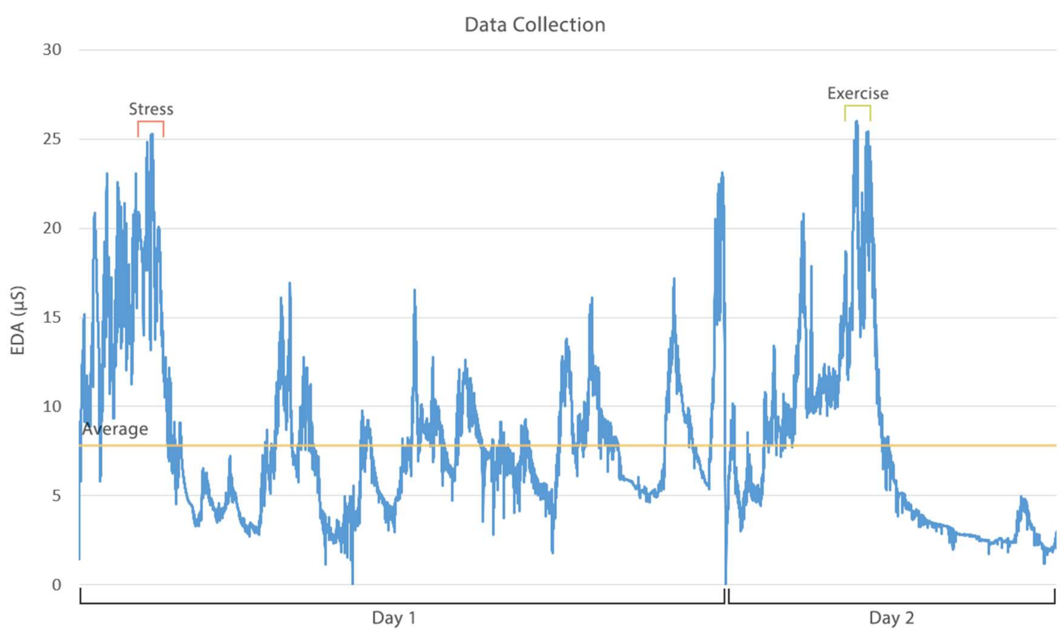

Figure 6.16: EDA signals of Participant 6 for two consecutive days

As illustrated in Figure 6.17, Participant 6 was the only participant whose EDA value did not decrease after the relaxation sessions. On the contrary, there was a slight increase right after the sessions and a significant increase one hour later.

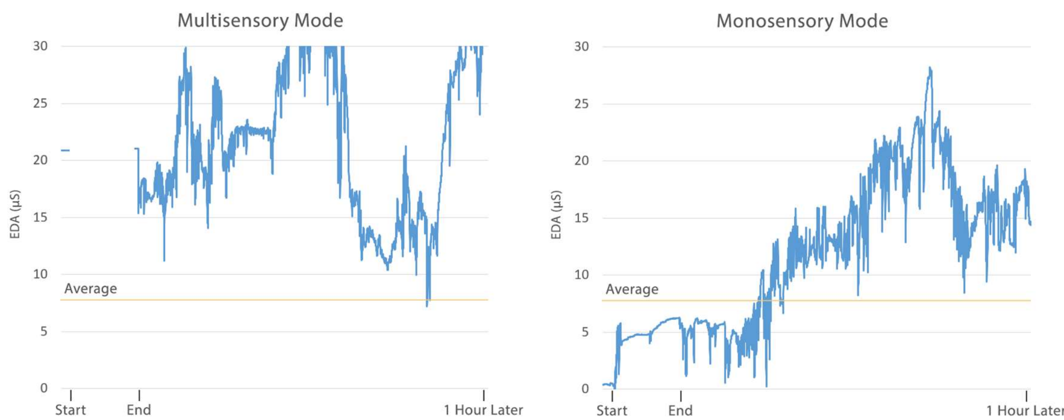

Figure 6.17: EDA signals of Participant 6 during the relaxation program testing

Participant 7

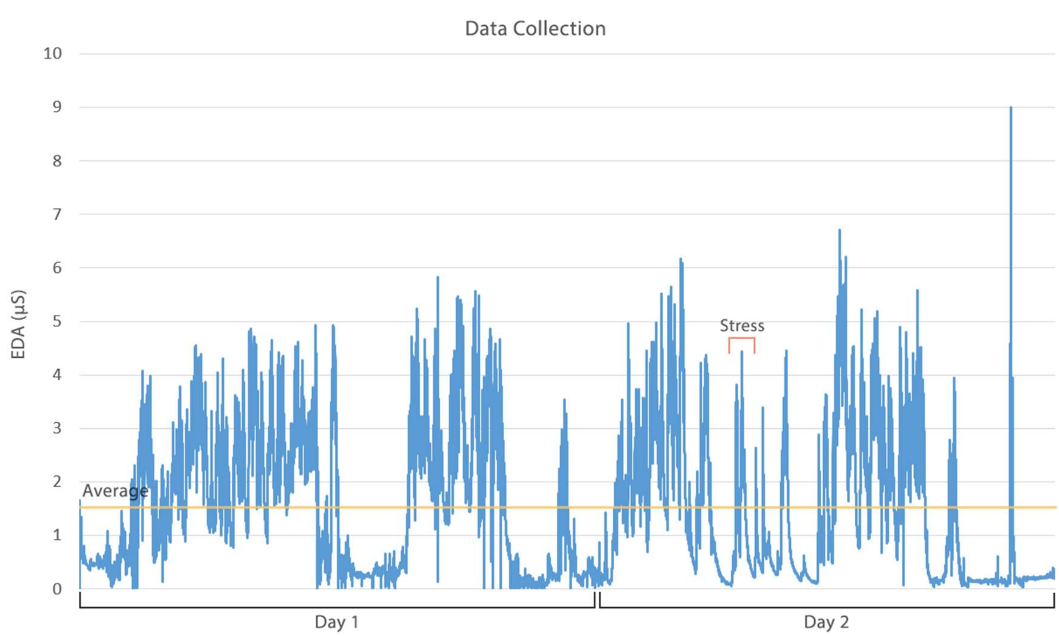

Figure 6.18: EDA signals of Participant 7 for two consecutive days

Participant 7 had an average EDA value of 1,52μS and that value reached above 4μS when he felt stressed (Figure 6.18).

As Figure 6.19 shows, Participant 7 was not so stressed before the monosensory session, in contrast to the multisensory, where EDA was above his average value. However, there was a significant reduction in both cases. In particular, EDA reduction reached 90% in the multisensory mode and 85% in the monosensory. Then, there were increases in the signals, but EDA remained lower than the starting point. In more details, EDA was 23% lower one hour after the multisensory session and 55% after the monosensory. Summing up, EDA value decreased more with the multisensory session, but it remained lower one hour after the monosensory.

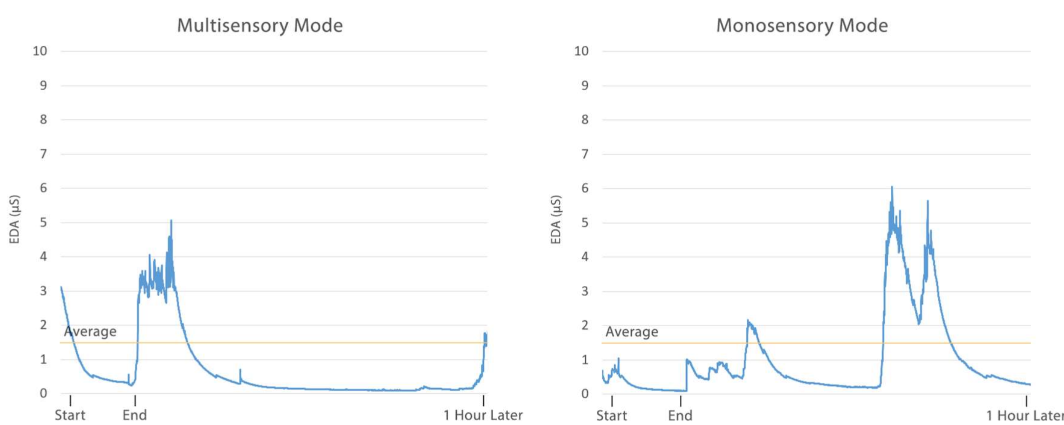

Figure 6.19: EDA signals of Participant 7 during the relaxation program testing

Participant 8

Participant 8 had an average EDA value of 4,5μS and that value reached above 5μS when he felt stressed (Figure 6.20).

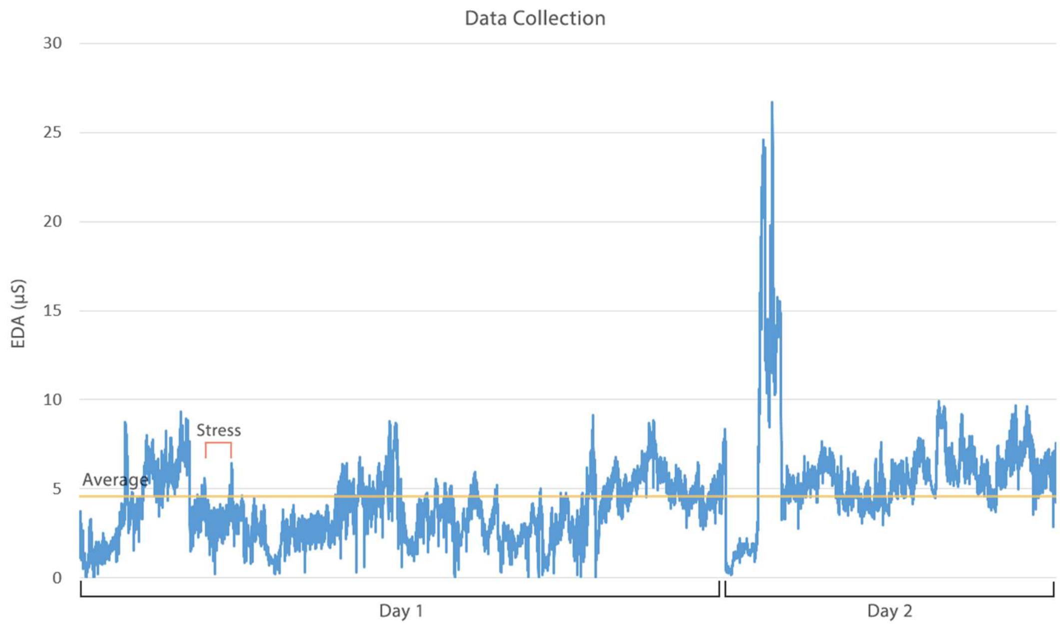

Figure 6.20: EDA signals of Participant 8 for two consecutive days

As Figure 6.21 illustrates, EDA was above his average value when both relaxation sessions started and decreased after their completion. In particular, EDA reduction reached 27% in the multisensory mode and 52% in the monosensory. However, EDA value increased one hour later in both cases.

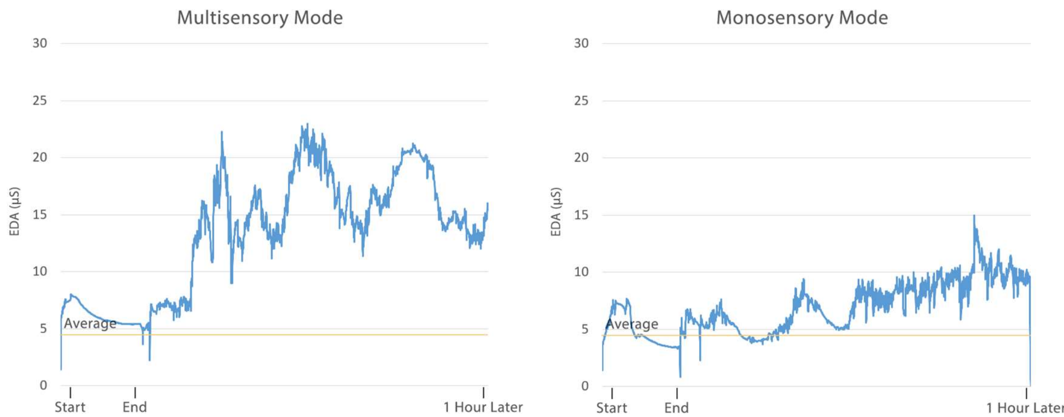

Figure 6.21: EDA signals of Participant 8 during the relaxation program testing

Chapter 7

Conclusion and Future Work

Since stress can negatively affect our physical and mental health, it would be useful to have at our disposal a 24/7 stress management coach. This thesis has proposed a pervasive stress detection and reduction system for intelligent environments. In order to address the challenges of stress detection, the system combines various sources of information, giving more emphasis to EDA signals and context information. As an intervention step, it offers adaptable programs for stress reduction and a pervasive relaxing environment. The ultimate goal is for the system to be able to help people relax by allowing the ubiquitous presentation of relaxation programs.

CaLmi is the first proposed stress management system that uses both biofeedback and contextual information in order to detect stress and offers relaxation programs, which are adaptable to the individual users' needs and current environment. An important aspect of the CaLmi system is that it relies on existing intelligent home infrastructure and does not obligate users to move to a specific custom made space in order to relax.

Furthermore, based on the evaluation process, CaLmi seems to be a promising system for stress management in intelligent environments. The reason is that a relaxation session showed to be more effective and satisfying when the intelligent environment is properly adapted in order to activate different senses and is not limited to the visual sense alone.

When it comes to the discussion of future work, there are some improvements and additions that could be done. Apart from improvements on existing aspects of CaLmi (e.g., the design of user interfaces, the precision of the stress detection and relaxation program selection algorithms), future work can include new additions to the system.

Firstly, in the future, the system could be able to operate with any developed stress detection algorithm. This could be made possible if the developers follow certain predefined coding guidelines. Those guidelines should provide information on the input and output parameters in order for the algorithm to be compatible with the system.

Furthermore, an addition could be the support of multiple users on a single relaxation session. That means that two or more users should be able to start together a session, whether or not they are in the same room. In case they are in the same room, the selected relaxation program could be customized in such a way that it best meets the preferences of all participants. Otherwise, the main content of the selected program remains the same, but its additional features (e.g., light, scent) and hosts (e.g., ambient lights, scent diffuser, displays) differ for each user according to his/her preferences and current room. By adding the aforementioned functionality to the system, a user could motivate another to start a relaxation session and thus release any tension.

Another extension of this work could be the ability to create relaxation programs whose content is not static. In that case, the new relaxation program should be created in steps. At each step, its duration, content, and additional features should be defined. Thus, a relaxation program will represent a series of predetermined steps executed one after another in sequence. For example, a program could display a running waterfall during the first five minutes and a rainforest for the next three minutes, while the blue lighting progressively becomes green. Also, the system could automatically adjust the content of a program during its execution based on users' physiological stress reactions. For example, if the recommended program has the opposite effect (i.e., makes the user feel more stressed), the system should take action and change that program or customize it differently.

Finally, another addition could be the introduction of an expert figure (e.g., a psychologist) collaborating with the decision mechanisms in order to better support the user. The expert should be able to monitor the users' stress levels, create customized relaxation programs for each user, and determine when a relaxation program should be suggested to a specific user.

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