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Long-Term Measurement of EDA in Natural Settings Concerning Anxiety, Chronic Stress, and Depression: a Systematic Literature Review

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Abstract

The purpose of this thesis is to complete a literature review on the long-term measurement of electrodermal activity in natural settings with ambulatory measurement sensors. In more detail the search is limited to scenarios concerning anxiety, depression, and other possible chronic stress related disorders. The studies must include a study sample that consists of people with the diagnosis or people presenting with symptoms. This will give insight into the possibilities of the use of EDA in research and give ideas for future research.

The thesis was conducted as a systematic literature review. The process of gathering the data was done systematically. Literature was collected from peer-reviewed articles from Pubmed, Finna, Cinahl and Science Direct. The research limits were articles between 2005 and 2021, English as the language, and had to be relevant to the chosen topic. The articles were critically analyzed with the JBI Critical Appraisal Checklist for Qualitative Research. Finally, 5 articles were included in the review.

The articles discussed anxiety, burnout, panic disorder and post-traumatic stress disorder (PTSD). Three different sensors were used to measure skin conductance. All studies were conducted outside the laboratory, measurement times varied from 8 hours to 24 hours. Due to a small article sample drawing conclusions was difficult. While the data does partially support a relationship between skin conductance and the diagnoses, more research is needed to gather generalizable results. There is an indication of skin conductance measurement to be used as a supplementary tool to study mental health conditions as an addition to more traditional interviews and questionnaires, as both provide information the other cannot.

While the data supported the relationship between burnout and skin conductance (SC), anxiety and SC, and panic disorder and SC, these studies are not enough to generalize findings. More studies having EDA measurement as a focus point are needed to support or disprove the findings of this review.

Key words
Electrodermal Activity, Skin Conductance, Ambulatory Measurement, Anxiety, Chronic Stress, Depression.

CONTENTS

LIST OF ABBREVIATIONS

AC	Alternating Current
AMP	Amplitude of Peaks
ANS	Automatic Nervous System
ART	Ambulatory Relaxation Test
AUC	Area Under Curve
BVP	Blood Volume Pulse
DC	Direct Current
DEC	Decay Time of Peaks
EDA	Electrodermal Activity
EI	Emotional Intelligence
ER	Electrodermal Response
GAD	Generalized Anxiety Disorder
GSR	Galvanic Skin Response
HR	Heart Rate
Hz	Hertz
MDD	Major Depressive Disorder
MSSD	Mean Squared Successive Differences
NSF	Non-specific Fluctuations
PD	Panic Disorder
PPM	Peaks Per Minute
RIS	Rise Time of Peaks
RSA	Respiratory Sinus Arrythmia
SC	Skin Conductance
SCL	Skin Conductance Level
SCR	Skin Conductance Response
SCV	Skin Conductance Variability
SD	Standard deviation
SNS	Sympathetic Nervous System
μS	Micro siemens
WID	Width of Peaks

1 INTRODUCTION

Electrodermal activity (EDA) has been studied in psychophysiological research since 1879. The first inventors of something close to the modern measurement tools were made by Féré and Tarchanoff. Féré discovered a way to measure differences in skin resistance with two electrodes that have a small electrical current, whereas Tarchanoff found a way to measure changes without an external current. In the last few decades, he use of EDA in pathophysiological scenarios, such as stress assessment, has become a bigger practice. (Posada-Quintero & Chon, 2020, p. 1; Dawson et al., 2000, p. 200.)

Previously there haven't been sufficient wearable devices to conduct long-term measurements in natural settings. This has limited the clinical applications of EDA measurements. However, with new technology, emerging devices make clinical use and ambulatory research a possibility. The devices are more traditional wristbands or smartwatches, along with rings, gloves, and socks. Wearable sensors make it possible to complete measurements in natural settings and allow for relatively low-cost monitoring in health care. (Jussila et al., 2018, p.1.) There are a variety of different sensors on the market, that measure and track heart rate, sleep, and activity. Sensors that measure EDA are an addition since they give insight into the user's emotions and mental state. (Heikkilä et al., 2018, p. 1.)

The aim of this thesis was to determine the extent of ambulatory EDA measurement in previous research and to describe the different content of the selected articles. It focused on specified mental health scenarios and discussed the possibilities of EDA measurement.

2 BACKGROUND OF ELECTRODERMAL ACTIVITY (EDA)

2.1 Electrodermal measurement

The measurement of the electrodermal activity, or EDA, also known as galvanic skin response (GSR), is an old, noninvasive method that measures the electrical resistance of the skin. It is sensitive to emotional changes, moods, and stress. The eccrine sweat glands are activated by sympathetic nerve activity, where they, as a response to stressful stimuli, increase activity. This increases or decreases the GSR signal, depending on the type of stimuli, stressing or calming. The GSR reacts to the intensity of the emotion and therefore, is an indication of the activity of the autonomic nervous system. The electrodermal responses are considerably easy to differentiate, making it easier to evaluate effects of stress to different stimuli that cause mental load. However, EDA only presents information about the cholinergic part of the sympathetic system, and it is influenced by multiple nervous processes. The most eccrine sweat glands are located on the palmar and plantar surfaces hand and foot; therefore, measurements are most reliable there. (Pop-Jordanova & Pop-Jordanov, 2020, pp. 6-7; Mestanik et al., 2014, pp. 5-6.)

Electrodermal Activity indicates the sympathetic activity in the autonomic nervous system (ANS). The ANS is connected to the emotions of a person, it activates the eccrine sweat glands through unconscious actions of the body. The sweat glands are connected to the sympathetic nervous system (SNS). This makes measuring sympathetic activation through skin conductance optimal. EDA measurements can be affected by certain conditions such as hyper- or hypothyroidism (unusual activity), anxiety disorders (heightened activity) and depression (decreased activity). (Jussila et al., 2018 p.2.) It is important to note, that emotional arousal and intense emotions should not be considered equal. Low arousal can mean a peaceful joyous moment or crushing depression, whereas high arousal can mean exiting joy or a highly stressful situation. (Picard et al., 2015, p. 1.) Also, EDA measurements can differ in comparison due to age and gender of participants (Benita & Tunçer, 2019, p. 4).

There are three different ways to measure EDA, one endosomatic method, where there is no application of an external current and two exosomatic methods where either direct current (DC) or alternating current (AC) is applied to the skin. (Boucsein et al., 2012, pp. 1017-1018.) Boucsein (2012, p. 245) adds, that the AC method is used rarely in studies as the data is harder to interpret. However recent studies suggest AC measurement to be superior as the AC does have advantages over the DC, for example electrode polarization issues can be avoided and further avoid corrupting gathered EDA data (Posada-Quintero & Chon, 2020, p. 5).

Since EDA is measured from sites that (such as the palm) have a high likelihood of interference or signal corruption, special consideration should be taken in choosing the right electrodes, gels, devices, and sensors. The electrodes must be of the same material, usually silver-silver chloride (Ag/AgCL), to avoid potential differences and polarization. Hydrogel lowers impedance and improves signal quality, but it has a short shelf life, as the hydrogel dries over time and dehydration causes signal corruption. (Posada-Quintero & Chon, 2020, pp. 5-6.) Corruption can also be due to movement, or the electrode not being connected properly, or, for example, a wrist worn sensor being loosely attached (de Looff et al., 2019, p. 311). Dry electrodes can avoid this issue, as the gel is added separately. Electrodes can be reusable or single use, with the latter being cheaper. Usually, electrodes are made of metal or carbon. Stainless steel is strong and ideal for wearable devices, whereas carbon reduces polarization but is also ideal for use during MRI measurements. However, there are other materials in development, such as flexible, conductive foam and textiles. In exosomatic DC measurement the electrodes are polarized via electrolysis, and they can sometimes degrade in use due to the AgCl layer being compromised by the charge. (Posada-Quintero & Chon, 2020, pp. 5-6.)

2.1.1 Laboratory vs ambulatory

The major difficulty with measuring ambulatory EDA in natural settings is lack of technology. One issue is the lack of necessary portable storage capacity, another is the use of electrodes and wires. Also, palmar, and plantar test sites cause some issues, since the skin is constantly moving. In studies both wet and dry electrodes have been used successfully, but study on this matter needs to continue. (Boucsein, 2012, pp. 130-134.) Electrodes falling off the skin and skin irritations have been the biggest issues in long-term measurements previously (Boucsein, 2012, p.143). New technology will allow for long-term measurement of EDA in natural environments. Measurements done in a short timeframe in laboratory settings do not reflect the trends that a person's psychological state goes through at home, in natural settings and in longer periods of time. Clinically the wearable sensor will allow for ambulatory measurement and can be used in several different settings, such as diagnostic and therapeutical purposes. (Poh et al., 2010, pp. 1243-1244.) Technology today has made it possible to measure EDA without wires and separate, traditional electrodes.

2.1.2 Measurement sites

Palms and plantar areas are generally considered to be the most ideal measurement sites. However, they are not always the most ideal functionally, since electrodes can wear off, be damaged or feel uncomfortable. This rises the need for additional sites. New wearable sensors try to overcome this challenge, by being comfortable and good looking, but the sites they are used in are not always the best sites for measuring EDA. Wrists are viewed as a practical long-term measurement site. It has been widely studied with varying results, from low to high correlation in comparison to palmar sites. A possible reason for the discrepancy is differing hydration times, a longer time might mean a better correlation. Other locations for ambulatory measurement are the shoulders and lower calves. Lower calves have been reported to be a comfortable and functional measurement site with high correlation to forearm measurement. (Kasos et al., 2020, p.2.) It should also be considered that different sides of the body show different results in EDA measurement. The multiple-arousal theory explains that different emotions have a different effect on the body and the brain. This means that the right hand can have a higher arousal reaction to a stressor than the left hand. Therefore, information might be lost with unilateral measurement. (Picard et al., 2015, p. 12.)

2.1.3 Different ambulatory sensors

Designers of high-quality wearable sensors must consider factors, such as battery life, when designing a functional and unobtrusive but high-performance sensor. Often high data rates and need for large data storage call for external memory storage or wireless transmission. (Pope & Halter, 2019, pp. 1-2.) There are different sensors on the market available for commercial use and they have been utilized in research. Three of these listed in table 1.

The Moodmetric smart ring has been proven to be a valid research tool in natural, ambulatory settings (Torniainen et al., 2015, p.1). The measurement accuracy, when compared to laboratory measuring, is 88%. The ring's current version has a memory storage of about 12h with battery life lasting up to a week. It uses Bluetooth to connect to a phone with the Moodmetric application. (Moodmetric, 2020.) The Empatica E4 is a wrist worn device that measures using four sensors. It identifies skin conductance, motion, skin temperature and blood volume pulse (BVP). The device has a battery expectancy of up to 48 hours with a 60-hour storage capacity. It weighs 23 grams, and its dimensions are 44x40x16 mm. (Menghini et al., 2019, p. 3; Empatica, 2022.) The EdaMove is described by Borovac et al. (2021, p. 18) as being potentially suitable for research use, however as the subjects were sitting still during the study, so it does not give a clear image of true ambulatory measurement. The EdaMove has a wrist worn strap that attaches the case with electronics. This is further connected with wires to two electrodes, that are attached to the palm. (Movisens, 2022.)

Table 1. Wearable EDA sensors on the market today (Moodmetric, 2020; Movisens Docs, 2022; Empatica, 2022.)

Name	Company	Worn on	Technical features	Measures
Moodmetric Smart Ring	Vigofere Oy	Finger	12h memory storage, battery life up to 1 week, Bluetooth connection, not waterproof	EDA, includes step counter
E4 Wristband	Empatica	Wrist	Up to 60h memory storage, up to 32h battery life, charging time 2h, 23g, 44x40x16 mm, Bluetooth connection, splash resistant	SC, motion, skin temperature, BVP
EdaMove 4	Movisens	Wrist and palm	4GB internal Memory, 4 week recording capacity, batter life about 4 days, 1 hour charge time, 62,3x38,6x11,5 mm, 26g, waterproof	EDA, Movement, and step count

There are other sensors used in research, that could possibly be used to measure skin conductance, one example is placing the sensors in clothing, as is done with the Smart Vest. The Smart Vest measures many different physiological parameters, such as heart rate, blood pressure, temperature and GSR. (Appelboom et al., 2014, p. 2.) As stated before, the most reliable measurement sites are palmar and plantar, there is a need to develop something that doesn’t interfere with daily activities (Kasos et al., 2020, p.2). Researchers have developed a patch that could be worn on the shoulder or chest. (Kang & Chai, 2022, p.7.) Kim et al. (2014, pp. 6632-6633) suggest a soft, flexible sensor that could be attached to a chest belt or a brassiere and worn on the back, where it would not disturb daily activities. The study shows a strong correlation in EDA measurement, between the finger and the back, albeit with a small test sample. Whereas Setz et al. (2010, p .413) uses a sensor called Emotion Board. It has two finger straps with reusable dry electrodes on the distal fore and middle finger, with wires attaching them to the Emotion Board (casing that stores collect the data), strapped to the forearm. It uses Bluetooth to transfer the data.

Another sensor is the SPRBox, that records the skin potential response. Two single use electrodes are applied to the palmar surface with the SPRBox on the wrist, transferring data through wi-fi. (Affanni, 2020, pp. 4-5.) SKINTRONICS is described as a flexible, wireless, and skin conforming patch type sensor. It can be directly laminated on the wrist or posterior shoulder without the need for additional straps or bandages, where it has relatively little hindering effect in daily activities. It uses Bluetooth for data transfers. (Kim et al., 2020, pp. 6-8.) The ARTEC program uses a sensor that is integrated to a glove with a wrist strap to house the electronic device. Also, they used another sensor on the upper arm, with textile electrodes and the measuring device. (Seoane et al., 2013, pp. 9004-9005.) An EDA sensor could even be copper tape mounted to a steering wheel of a car, as described in Baek et al. (2009, pp. 182-183).

2.1.4 EDA signal, quality, and analysis

The EDA signal is complex and used to be scored manually. This usually took a lot of time and was highly subjective but gave the inspector a close look at the data. Now, new technological advancements, algorithms, and new techniques used to analyze the signal are providing more information easier and faster. (Posada-Quintero & Chon, 2020, p. 1.) The processing of the signal begins with a visual inspection to identify necessary parameters that influence the signal. These are, for example, measuring errors or changes in the signal due to the completion of a task or skin conductance responses (SCR) can overlap. (Posada-Quintero & Chon, 2020, p. 7-8; Gersak, 2020, p.179.) EDA measurement can also be affected by motion artifacts, such as motion during measurement, skin temperature changes and noise. The difficulty between distinguishing these and the actual SCRs limit data analysis and interpretation, especially in ambulatory measurement. Possible errors in the signal can be manually or automatically corrected or removed. Filters, algorithms, and different tools have been made to remove disruptions in the data and to make data processing easier. (Posada-Quintero & Chon, 2020, pp. 10-11.)

The EDA signal is made of two components: the tonic component, a slow-changing skin conductance level (SCL) and the phasic component, a fast-changing skin conductance response (SCR). The SCL indicates the level of physiological arousal and is dependent on a person's skin properties, such as skin structure or sweat gland density along with their psychological state. When measured from the distal part of the palmar surface of the hand the range of SCL is from 1 μS (micro siemens) to 20 μS. The SCR represents the number of pulses in the signal. The SCR is also a defined time in which the signal pulses exceed a threshold. The number of SCR pulses per minute indicate the measure of arousal, generally a few SCR in a minute indicates a relaxed state, or baseline measurement, whereas 20 or more SCR per minute indicate psychological arousal. Generally, the SCR amplitudes are measured from the threshold (usually 0.01 to 0.05 μS) to a few micro siemens. (Gersak, 2020, pp.179-180.)

The raw EDA signal and the baseline EDA levels differ from person to person, therefore there is a need to normalize the signal to make comparisons between people. This is done by calculating the difference in skin conductance levels during baseline and during the task either in absolute terms or relatively. The baseline measurement takes usually 3 to 5 minutes but can be shorter. During this period the participant is instructed to relax. Often questionnaires and interviews are conducted during baseline, which can affect a persons' mental state causing stress and therefore can influence the measurement. (Gersak, 2020, pp.179-180.)

Two different types of stimuli can be identified in EDA measurement, discrete and continuous. The discrete stimulus is a sudden event, such as a sound or unexpected change in an activity whereas the continuous stimuli are usually actions such as reading, watching tv or other longer tasks. A specific SCR can be identified from a discrete stimulus, meaning the reaction of SCR is directly related to the stimuli. The SCR latency is between 1 and 4 seconds, where as the rise time is between 1 to 5 seconds, as demonstrated in figure 1. In cases of a continuous stimuli, the number of SCR pulses are measured throughout the stimuli exposure as shown in figure 2. However, due to the tonic part influencing the baseline SCL averaging the skin conductance signal overtime can be unreliable, therefore subtracting SCR from the tonic signal gives a more reliable SCL value. (Gersak, 2020, pp.180-181)

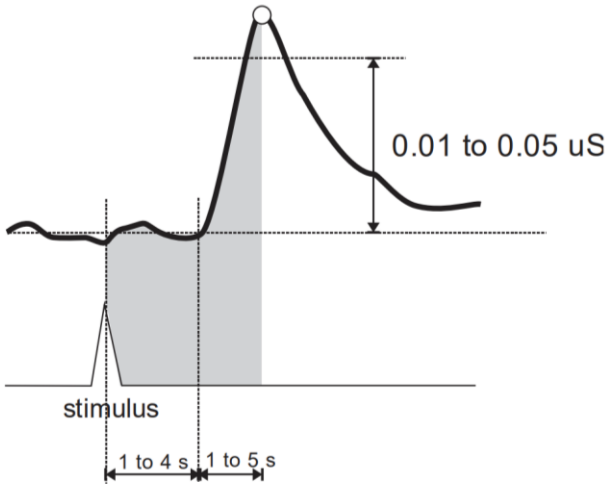

Figure 1. The figure depicts a specific SCR pulse during a discrete stimulus where SCR latency is between 1 and 4 seconds and rise time is between 1 and 5 seconds. (Gersak, 2020, p. 180).

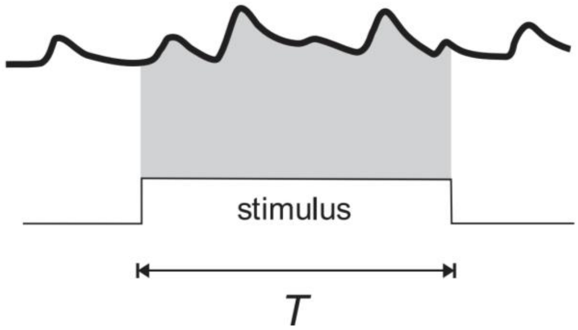

Figure 2. SCR pulse measurement over time, during a continuous stimulus (Gersak, 2020, p. 180).

The benefit of using EDA measurement over heart rate measurement should be noted. Even though they both react to autonomic arousal skin conductance is at an advantage. Skin conductance increases with tension and arousal, whereas heart rate reacts depending on the situation and what is most beneficial in handling the situation. Another factor to consider is ambient temperature. Heightened temperature influences sweating which then affects the skin conductance. This indicates the need to monitor activity, as physical movement causes perspiration as well. (Roth et al., 2008, pp. 207-208.)

2.2 Mental health and EDA

The studies considered for the review discuss the following mental health scenarios. The chosen diagnoses are anxiety (including post-traumatic stress disorder, or PTSD), chronic stress (including burnout) and depression.

2.2.1 Anxiety

Anxiety is an umbrella term for many several different conditions. The main diagnosis is Generalized Anxiety Disorder or GAD. Other common conditions include Panic Disorder, Social Phobia and phobia of public, uncontrollable places, also known as Agoraphobia. These conditions can occur simultaneously in a person, and all involve feelings of anxiety, irrational fears, restlessness, lack of concentration, disruption in sleep, palpitations, nausea, and lack of air. They are debilitating disorders than usually causes the person to avoid symptom inducing situations. (Käypähoito, 2019.) According to Naveteur et al. (2005, pp. 261-262, 267-268) when compared to a control group, the electrodermal activity is often reduced with people who suffer from anxiety. Instead of a heightened autonomic sympathetic activation, negative findings are common. In addition, tonic and phasic EDA are reduced, instead of decreased. This is most likely due to anxious individuals developing coping strategies that lessen their reactions. This study was completed in a laboratory setting. Doberenz et al. (2010 pp. 1137, 1140) note that people who have panic disorder have lower skin conductance variability (SCV) and that panic attacks can occur during daytime as well as nighttime. Alpers (2009, p. 481) writes that ambulatory measurement has an advantage concerning anxiety disorders. First, situations that cause symptoms usually do not occur in laboratories and second, symptoms (such as panic attacks) occur at random times. This means that having long-term measurement available gives more insight into the symptoms as they appear.

PTSD or Post Traumatic Stress Disorder is defined as a psychiatric anxiety disorder that occurs in people who have been exposed to, have experienced, or seen a traumatic event, that have threatened them with grave physical harm. These situations are traumatic, such as abuse, war, acts of nature, sexual violence, or a serious accident.

The diagnostic criteria have been changed over the years on more than one occasion. The diagnosis itself requires the patient to be exposed to the trauma inducing factor. Symptoms of PTSD are including but not limited to intrusive thoughts and flashbacks, avoidance of triggering factors, changes in cognition and mood which shows as distorted thoughts and unstable behavior. (American Psychiatric Association, 2022; NIH, 2019.) Patients with PTSD have a higher autonomic arousal when exposed to triggering images or sounds. Also, even without triggering stimuli, patients with PTSD have higher heart rate, blood pressure and skin conductance, along with decreased respiratory sinus arrhythmia (RSA) in laboratory settings, when compared to people without PTSD. (Bertram et al., 2014, p. 610.)

2.2.2 Chronic Stress

Stress is a physical, chemical, and emotional event that appears as tension in the mind or body, but mainly stress is an emotion. It can also be defined as a state of disharmony within the body effecting behavioral and psychological responses. In medicine, stress has been noted to have a strong connection in disease pathogenesis. Interest in emotions and evaluating stress has risen in the field of research from psychology to other fields, such as neuroscience, computer science and product design. Various theories have been presented, but the prevailing perception about emotional states is that they are physiological and cognitive responses to specifiable stimuli. Stress reactions of the autonomic nervous system can be studied with invasive and noninvasive methods. Invasive methods raise concern in an ethical sense, but also the procedure itself can arouse a stress reaction. (Pop-Jordanova & Pop-Jordanov, 2020, pp. 5-6; Mestanik et al. 2014, pp. 5-6.)

Acute stress is caused by short lasting events, and it is something our body should be able to handle. Whereas chronic stress causes more harm which can lead to physiological symptoms, such as high blood pressure. In addition, chronic stress can lead to the development of depression or other mental health problems. To prevent these situations measures should be taken to manage and monitor stress. Today stress level is most often measured with subjective and timely methods, such as interviews and filling out questionnaires. These methods also require a professional, usually a doctor, who understands the collected data and can make decisions concerning treatment. (Kang & Chai, 2022, p. 2.)

Burnout is discussed in this section, as it is a long-term stress related condition. Burnout is defined as the result of prolonged occupational stress, that has not been managed correctly. Burnout consists of exhaustion, disinterest of work and negative feelings and reduced productivity and performance. It should not be used to describe other instances of exhaustion, as it is purely work-related. (WHO, 2022.) There are factors that can aid in prevention of the development of burnout. One factor is Emotional Intelligence (EI), which seems to have a major influence and it moderates the association between stress and burnout. The second is personality, in which neuroticism has been noted to have positive association. Whereas diligence, being agreeable and sociable has been noted to have a negative association with the development of burnout. Third, social support, especially from supervisors, lessened the risk of burnout. However, relationships between causes of burnout should be done with a longitudinal study and today most of the information is available from cross-sectional studies. Since stress can be monitored by measuring skin conductance and stress is a major cause of burnout it is logical that measuring SC could be used to detect burnout symptoms along with more traditional questionnaires. The measurements can provide more objective results in comparison to questionnaires. (de Looff et al., 2019, p. 307.)

2.2.3 Depression

Kim et al. (2018, pp. 1-2) state that depression, when diagnosed by a physician, is called Major Depression. It is a condition that effects individuals of all ages and can affect work performance. The symptoms are generally irritability, sleep disturbance, sadness, loss of interest, feeling of being tired despite rest, anxiety, loss of appetite and physical pains. It also increases the risk for suicide and is a major health concern. Diagnosing depression is done by interviewing patients and using pre predefined criteria. This poses an issue in objectivity, since the only measurements are the patient’s own subjective feelings and reports. Therefore, an interest into finding ways of helping with the diagnostic accuracy has risen, and the use of EDA. They continue, that the findings of their study suggest that EDA is altered in people with depression, their skin conductance levels were lower than the control group and the arousal of EDA in stressful situations was lower.

3 PURPOSE AND RESEARCH QUESTION

The purpose of this research is to complete a literature review on the long-term measurement of electrodermal activity in natural settings with ambulatory measurement sensors. In more detail the search is limited to scenarios concerning anxiety and depression and other possible chronic stress related disorders and should include a study sample that consists of people with the diagnosis. This will give insight into the possibilities of the use of EDA in study and treatment and give ideas for future research.

The main research question is:
How can long-term ambulatory EDA measurement be applied in cases of anxiety, chronic stress, and depression?

To be able to answer this these smaller supporting questions were formed:
How is EDA measured in ambulatory scenarios?
What type of technology is used?
What is the measurement time?
How does the EDA signal look in ambulatory measurement with the chosen diagnoses?

4 RESEARCH PROCESS AND METHODS

The thesis will be conducted as a systematic literature review as the aim is to provide an overview on the selected subject. The purpose of a systematic review is to gather and review the collected empirical evidence that is suitable for the stated criteria to answer a particular research question and its sub questions (Snyder, 2019, pp. 334-335), which fits the purpose of the research.

4.1 Data collection

The research limits were studies between 2005 and 2021. The time frame has been defined as such to have relatively recent research and yet a wide enough timeframe to gather enough information, as ambulatory measurement is a relatively recent technological development. The articles could only be in English, and they must be peer reviewed. Finnish was excluded due to viewing English as the most important language concerning sources. The search terminology that was used is listed next, but more terminology will be added as needed. Electrodermal activity (EDA) was used synonymously with Electrodermal Response (ER), Galvanic skin response (GSR), Skin conductance response (SCR), Skin conductance (SC), anxiety, depression, long-term, natural settings, ambulatory and chronic stress. Boucsein (2012, p. 3) notes that GSR is no longer a recommended term to use due to it having an outdated view on EDA. However, it will be included in the search terms since previously it has been a widely used term in the field of EDA study.

The data used in the thesis was collected from peer-reviewed articles from Pubmed, Finna, Cinahl and Science Direct. Title and abstract were used as the next inclusion criteria: they must pertain to electrodermal activity (or its synonymic terms), and mental health (depression, anxiety, chronic stress), the measurements had to be completed outside of a laboratory including only adults in the study sample. Any other articles were excluded. After this the articles that remained were read and reviewed, any articles that did not specify the results concerning EDA measurement, duration of the measurement or the measurement protocol were excluded. The chosen articles were then read, and their content was analyzed with the Johanna Briggs (JBI) Critical Appraisal Checklist for Qualitative Research, seen in Appendix 1. Table 2 defines the exclusion and inclusion criteria.

Table 2. Defined Inclusion Criteria

Inclusion criteria	Exclusion criteria
Published between 2005-2021	Published before 2005 or after 2021
In English	Non-English literature
Peer reviewed	Non peer reviewed, incomplete articles
Relevant to the search terms and research question	Irrelevant to search terms or research question
Research articles	Other than research articles: Books, commentaries, and reviews etc.
Found from selected search engines	Not found on the selected search engines
Defines, sensor, measurement time and results on EDA	Lacks information, such as type of sensor, measurement time and/or results on EDA.

An ethical pre-approval in the data collection process was not needed, as the data review is from articles and reviews that are already published, and no private or confidential data is handled. However, the articles were processed ethically with ensuring reliability and integrity trough using correct forms of citing and not declaring as any thoughts as my own. (Suri, 2020. p. 1; ARENE pp. 19, 23.) In addition, the data was analyzed impartially and objectively by excluding irrelevant data (data outside search limits) and refraining from making conclusions before all data is gathered and evaluated. This includes that no data was excluded due to my own views or subjective assumptions. Also, the ethical process was reviewed during the writing process and changes were made when needed.

4.2 Search strategy

A total of 1810 articles were initially found through the selected search engines. Number of articles from each search engine can be seen in table 3. The search was completed from January 7th to March 2nd of 2022. The same search terms were used in all of them except science direct, which only accepts 8 Boolean connectors, and therefore “Electrodermal response” was removed from the search words to make the search viable. In addition to this, SAMK Finna stopped showing articles after a 1000, so this meant that 306 articles were excluded from the original 1810, bringing the total down to 1504. For the next phase 205 articles were included based on relevance of the title and the abstract, meaning 1299 were deemed irrelevant. After review 23 articles were removed as duplicates, leaving 182 for further consideration. Following reading the whole texts 52 articles were removed due to the EDA measurement not being ambulatory, 39 articles were removed due to being completed solely in a laboratory setting despite involving ambulatory technology. Then 25 articles were removed due to not specifying the measurement method, measurement time, or EDA measurement results. Finally, 60 articles were removed due to not being relevant to selected mental health scenarios and 1 for not being peer reviewed. A total of 5 articles were included. Figure 3 shows the process of gathering the articles.

Table 3. Number of articles from the final search

Search engine	Number of articles:
Pubmed	59
SAMK Finna	1306
Cinahl	8
Science Direct	437
TOTAL	1810

- Search terms: ("electrodermal activity" OR "electrodermal response" OR "Skin conductance" OR "galvanic skin response") AND ("ambulatory" OR "Natural-settings") AND ("anxiety" OR "depression" OR "stress" OR "mental health")
- Search engines: PubMed, Science Direct, Cinahl and SAMK Finna
- Limits: Published between 2005-2021, Peer-reviewed, in English, relevant to research question and parameters.
- **1810 articles were chosen for closer review**. However, only 1504 articles were available, due to malfunction in the search engine SAMK Finna.

↓

- **205 articles were retained based on relevance of abstract** after 1299 irrelevant were excluded.

↓

- **182 articles were retained after** 23 multiples were excluded.

↓

- 52 articles were excluded due to the measurement not being ambulatory.
- 39 articles were excluded due to the measurement being done in a laboratory setting despite ambulatory technology.
- 25 articles were excluded because the measurement method or time, or EDA measurement results were not specified.
- 60 articles were excluded because they were not accurately relevant to selected health care scenario.
- 1 article was excluded due to not being peer reviewed.
- **5 articles were included in the review.**

Figure 3. Chart visualizing the article search process.

4.3 JBI Checklist for Qualitative Research

The articles were analyzed with the JBI Qualitative Research Checklist, and the results are shown in table 4 below. The checklist can be seen in Appendix 1. All the articles showed congruity in most of the questions. Questions 1 through 5 was analyzed as a yes for all 5 articles: philosophical perspectives were clearly stated, the research methods fit the questions, objectives and data collection methods, and the data was represented and interpreted in accordingly. The most information was missing concerning the cultural and theoretical orientation of the researchers, question 6, and their influence on the research, question 7: none of the articles made clear statements concerning these questions. Question 8 was well achieved, all articles contained data illustrations to support the explanation of the findings. Bertram et al. 2014 and Roth et al. 2008 were missing an ethical statement from their article, question 9. The final question was analyzed as yes, for all the articles, as the conclusion reflect on both the hypotheses and the findings. Unclear and not applicable were not used, as the articles were quite clear cut regarding the questions.

The conclusion of the analysis is that all the articles reached a minimum of 7 out of 10 yes answers. The checklist itself does not grade the reviewed articles based on the answers, but as it is in discretion of the analyzer the articles are deemed to be reliable. The data is clearly, evaluated, explained, and represented, ethical considerations are considered in 3 of 5 articles and conclusions are drawn on the findings.

Table 4. Analysis of the research articles using the JBI checklist for Qualitative Research. Y= Yes (1 point), N= No (0 points), UC=Unclear (0 points) and NA= Not Applicable (0 points).

	Bertram et al., 2014	De Looff et al., 2018	De Looff et al., 2019	Doberenz et al., 2010	Roth et al. 2008
1	Y	Y	Y	Y	Y
2	Y	Y	Y	Y	Y
3	Y	Y	Y	Y	Y
4	Y	Y	Y	Y	Y
5	Y	Y	Y	Y	Y
6	N	N	N	N	N
7	N	N	N	N	N
8	Y	Y	Y	Y	Y
9	N	Y	Y	Y	N
10	Y	Y	Y	Y	Y
TOTAL	7	8	8	8	7

5 RESULTS

5.1 Ambulatory sensors in selected research articles

The following sensors were used in the selected articles. A summary of their general features is shown in table 5.

5.1.1 Affectiva Q

The Affectiva Q sensor, shown in picture 1, was used by Bertram et al. (2014). It was worn on the non-dominant hand with electrodes attached to the palmar surface of the third and fourth finger. (pp. 611-612). The sensor has since been discontinued and through corporate acquisitions has become Empatica. The Affectiva Q sensor is described as the first wearable sensor that can measure EDA, skin temperature, and movement, which is measured through a 3-axis accelerometer. It was designed for medical use to be worn by people of all ages and used widely in autism research. (Picard, n.d.) No further technical features were obtained.

Picture 1. The discontinues Affectiva Q sensor (iMedicalApps, 2011)

5.1.2 “Digital Recorder”

Roth et al. and Doberenz et al. (2008, p. 207; 2010, p. 1142) used the same, non-commercial 3-channel recorder, referred to a “digital recorder”. One channel measured EDA through circular 10mm disposable electrodes that were attached to the 2nd and 3rd finger. A 0.5 V of DC was applied to the electrodes. The electrodes with prefilled isotonic gel and additional Biopac isotonic gel was added to ensure 24-hour skin contact. The second channel measured physical movement and the third ambient temperature. The size of the device is 3.3x7.1x12.7 cm and it weighs 230 grams, including the battery and it was worn in a handbag or waist pack. No pictures or graphs depicting the sensor were available.

5.1.3 Empatica E4

Empatica E4, shown in picture 2, was used in the two separate studies by de Looff et al. (2018, p. 508) and de Looff et al. (2019, p. 308). The latter instructed the participants to wear the sensor on the non-dominant wrist. The sensor measures SC, motion, skin temperature and blood volume pulse. The technical features are detailed in table1.

Picture 2. A picture of the Empatica E4 sensor (Empatica, 2022).

Table 5. Summary of the sensors' general features used in the selected articles

Affectiva Q	"Digital recorder"	Empatica E4
Discontinued	Availability not specified	Commercially available
Worn on wrist	Carried in a separate pack, attached via electrodes	Worn on wrist
Used for 24 h	Used for 24h	8 hours
Used in one article	Used in two articles	Used in two articles
Measures EDA, Skin temperature, and movement	Measures EDA, movement and ambient temperature	Measures EDA, movement, skin temperature and BVP

5.2 Variation in measurement times

The distribution of measurement times was not particularly abundant in the selected studies. Bertram, F., et al., (2014, p. 611) averaged 22.67 hours, whereas both articles done by de Looff et al (2018, p. 508; 2019, p. 308) had a measurement time of one full day or evening shift (or 8 hours). However, the specific number of hours were not mentioned in de Looff et al. (2018).

Doberenz et al (2010, p. 1141) designed the measurement to last from 14:00 to 14:00 the next day, and recording time varied from 18 hours and 40 minutes to 25 hours and 50 minutes, with a mean value of 23 hours and 40 minutes. And finally, Roth et al. (2018, p. 207) completed one approximately 24-hour recording, averaging from day one 13:40 to 12:30 the next day.

5.3 Measurement protocols and hypotheses

The measurement scenarios are described as how they are seen relevant to the measurement of EDA, not all conducted interviews, questionnaires or measurements are mentioned.

5.3.1 PTSD

One of the articles discussed PTSD patients and their autonomic arousal. For the study a total of 159 people were interviewed. After exclusions 56 male veterans suffering currently from PTSD were chosen along with a control group of 54 men who did not have PTSD. Women were excluded because there were not enough of them to form a separate yet large enough group for statistical analysis. The participants were 18 to 65 years old in both groups. Additionally, they came from similar backgrounds, either military service or had experienced other traumatic events. Half of the control group reported at least one symptom of hyperarousal, such as insomnia. Certain diagnoses, such as bipolar I disorder, substance abuse and use of beta blockers excluded candidates. However, many of the participants took medicine that can have an anticholinergic or antihistaminic side effect, but they were not excluded due to there being so many medicated participants. In comparison the PTSD group indicated experiencing more depression, had experienced more mild traumatic injuries to the head, detailed more sleep disruptions and used more medications. (Bertram et al., 2014, pp. 611.)

The procedure of the study started with gathering the necessary background and health information through completing the Structured Clinical Interview, the Clinician-Administered PTSD Scale and Life Events Checklist. The participants also filled questionnaires regarding their physiological state and mental health. Next the participants were given the Affectiva Q sensor. The sensor was attached to the nondominant wrist with a strap and the electrodes were attached to the palmar side of the third and fourth finger via wires. The participants were instructed to wear the sensor over the approximate 24h measurement time and to fill out pre-determined questionnaires Exclusion of participants was done due to missing data, use of affecting medications or compromised recordings. This affected the collected data of 11 PTSD group participants and 8 from the control group and SC data from 5 PTSD and 1 control group participant. (Bertram et al., 2014, pp. 611, 613-614.) The study hypothesized whether autonomic arousal during waking and sleep would be higher in PTSD patients in comparison to a control group. Bertram et al. (2014, pp. 611.)

5.3.2 Burnout

The relationship between skin conductance and burnout symptoms was studied in two articles, de Looff et al. 2018 (referred to as the first study) and de Looff et al. 2019 (referred to as the second study). The first study had a sample of 114 nurses, aged 21 to 59 years, working in a psychiatric hospital with patients with intellectual disabilities that exhibited aggressive behavior. 41% of the participants were male, and out of the total 105 completed all given questionnaires. After the chosen participants gave consent, they were asked to complete personality and Emotional Intelligence (EI) questionnaire and to follow with wearing the Empatica E4 for one working shift. Additionally, they were asked to complete separate questionnaires concerning stress, burnout and the aggressive behavior exhibited by the patients at work. The results were then scored to organize the data and participants in, for example, subgroups such as low, medium, or high concerning burnout. The measurement and answering of questionnaires took place within two days of each other. (de Looff et al., 2018, pp. 508-509.)

The second study was conducted as a longitudinal study, over a two-year period and included four waves of data collection, 110 participants in the first wave, 95 in the second, 74 in the third and 68 in the last. The participants were nurses in forensic psychiatric hospitals from 21 to 59 years of age. On average there was a 1:2 ratio of nurse to patient, averaging 6 nurses and 12 patients in each ward. After consenting to the study, the participants were asked to fill out an emotional intelligence and personality questionnaire and then to wear the Empatica E4 sensor for one day or evening shift at work. After the measurement the participants filled out varying questionnaires concerning burnout symptoms, job related stress and frequency and experiences of patient aggression. Burnout symptoms, personality, emotional exhaustion, depersonalization, personal accomplishment, job stress, patient aggression and emotional intelligence were analyzed through different questionnaires and inventories and their results were scored into numeric values that can be compared. (de Looff et al., 2019, p. 308-311.)

The first study was done to research if ambulatory measurement of SC could be useful in the detection of burnout symptoms. Three research questions were initially set, but only the third one mentioned above was relevant to EDA measurement. (de Looff et al. 2018 p. 508.) The second study set two research questions the second one pertaining to EDA research. They wanted to find out whether SC and heart rate correlate with burnout symptoms on an individual level. (de Looff et al. 2019 p. 308.)

5.3.3 Anxiety and panic disorder

The two studies Doberenz et al. (2010) and Roth et al. (2008) had nearly identical measurement protocols and the sensor used in both studies was the “digital sensor”. They are therefore discussed simultaneously in this section. The study sample for Roth et al. (2008, p. 208) consisted of 18 participants, 9 women and 9 men. Their mean age was 42.3 years old. Out of the whole sample 5 fit the GAD DSM-IV criteria and 13 are inclined towards persistent anxiety (broader than the DSM-IV criteria). Out of these 18, there were 3 diagnosed with Major Depressive Disorder and 3 with PTSD. A control group of 18 persons, 11 women and 7 men, with a mean age of 39.7 years old. Doberenz et al. (2010) was conducted with 22 patients with a mean age of 42.7, who are diagnosed with panic disorder were requited along with 29 healthy controls, with a mean age of 42.1 years. The panic disorder and control groups were homogeneous. (pp. 1141, 1143.)

Both used the same sensor and began the study similarly with an interview to find out eligibility. If nothing was found to be a reason for exclusion the participant was asked to wash their hands and the sensor was the applied. Various autonomic and respiratory measurements were then taken from the participants while they were asked to relax and breath in accordance with instructions. (These results are not reported in the studies in question.) After the laboratory session the ambulatory sensor was connected.

The participants performed the first of Ambulatory Relaxation Tests or ARTs, where they walked for 3 minutes the sat and relaxed for 8 minutes, as instructed. This part was conducted partially at home, overnight. The participants had a portable, pre-recorded instruction cassette that they played at specified times: approximately 13:40, 19:00, 9:30 and 12:30 in Roth et al. (2008) and approximately 14:25, 18:40, 9:40 and 13:25 in Doberenz et al. (2010) The study continues to describe that the participants were instructed to find a quiet and undisturbed place to sit during the ART, when outside the hospital. In both studies the first and last listening session were conducted at the hospital, the two in the middle at home. (Roth et al., 2008, pp. 207-208; Doberenz et al., 2010, pp. 1141-1142.)

A short questionnaire was filled before and after each of the listening sessions in both studies, but Doberenz et al. asked the participants to additionally fill the questionnaire at 16:00, 20:00 and 8:00. The participants were asked to assess their emotional state on a scale of 0 to 10 (from “not at all” to “extremely”) before and during the last minute of relaxation. Doberenz et al. added a query of number of panic attacks during the measurement period, as well as describing sleep quality and duration. Additionally, in both studies the participants were asked to fill out several questionnaires at home and return them to the hospital the next day. These included, for example, the Penn State Worry Questionnaire, the Perceived Stress Scale, and the Pittsburgh Sleep Quality Index, with specified timeframes of consideration in Roth et al. and Beck anxiety inventory, Mobility inventory for Agoraphobia and Pittsburgh Sleep Quality Index with specified timeframes of consideration in Doberenz et al. (Roth et al., 2008, pp. 207-208; Doberenz et al., 2010, pp. 1141-1142.)

Physical movement was measured by a UFI 1110 Jitterbug Actigraph at 1 Hz. It was attached on the same side of the body as the SCL sensor. Ambient temperature was measured from a sensor in the pack. It was sampled at 0.1 Hz at a 0.1 Celsius accuracy. The sensor had a button that the participants were instructed to press to pinpoint significant events, such as going to bed, emotional arousal, or any noteworthy event. These events were then noted on paper, along with the time of the event. (Roth et al., 2008, p 207; Doberenz et al., 2010, p. 1142.)

The hypothesis set by Roth et al. (2008, p. 208) was that the tense subjects' SCL would be higher and the SCL declines would be shorter, the skews would be less positive in the calm subjects as well as their skews of run lengths of SCL decline would be more positive. Concerning skin conductance Doberenz et al. (2010, pp. 1140-1141) set 3 hypotheses. First, that during waking the SCLs and measures of non-specific SC fluctuations (NSF) would be higher in the PD group than in the control group. Second, that the PD group find it harder to sit and relax during the ART measurements, resulting in higher SCL and more NSFs along with less negative SCL slopes. And third, they hypothesized that there would be differences in SC measurements and actigraphy during sleep between the groups. In addition, there were more exploratory analyses planned for confirmed hypothesis, such as finding if there is a relationship between SC and anxiety related symptoms and study the run lengths of ascending and descending SC activation to reflect another representative measure of SC activation.

5.4 EDA signal analysis and key findings

For the purposes of this review other measured variabilities (such as heart rate) are left out of the analysis if the study does not indicate a direct relationship or dependency between EDA and that variability which would affect the results.

5.4.1 PTSD

The collected data was analyzed with Matlab programs and was organized into 30 second segments. The activity threshold was calculated by evaluating one that was preferable for most of the participants. It was set slightly higher than traditionally in night-time measurements, but lower than the minimum threshold used during daytime measurements. The total measurement time was determined by combining over 20-minute runs, that were below the threshold, however intervening runs of threshold exceeding activity had to be less than 45 minutes. Those over the 45-minute marks were considered specifically as periods of sleep. The data was divided into periods of waking and sleep, the waking period was further separated into before and after sleeping, or day one and day two. Calculations, that were completed for each selected and analyzed segment, were the mean and median value of SCL and skin conductance variability (SCV), SCV as the interquartile range of SCL's at 8 Hz. (Bertram et al., 2014, pp. 612-613.)

The hypothesis of a heightened SCV in the PTSD group was tested by using analysis of variance (ANOVA) with the factors Group (PTSD or control) and State (wake and sleep), whereas some variables were analyzed in an exploratory manner. SCL was normalized with log transformation, after examining the data skew and kurtosis with the Shapiro-Wilk test of normality. The recorded data was compared through two tests: parametric for data of normal distribution and nonparametric for data that was highly skewed (for example variables with low baselines in the control group). Multiple regressions were conducted for both groups separately to determine the role of PTSD hyperarousal symptoms in relation to HR variation in during sleep and wake segments. (Bertram et al., 2014, pp. 613-614.)

The study was not successful in presenting a pattern of hyperarousal. SCL and SCV were not elevated, nor were they affected by antihistamine use. Only heart rate shows a clear difference between the groups. This could be due to prolonged stress represents itself in different pattern, in comparison to acute stress. People who with PTSD lack norepinephrine transporter availability, which is linked to greater hyperarousal symptoms. Additionally, it should be noted that medications used in the treatment of PTSD, such as anticholinergic medications decrease SCL and SCV. (Bertram et al., 2014, p. 616.)

5.4.2 Burnout

Both studies by de Looff et al. (2018 & 2019) studied the relationship between burnout symptoms and skin conductance, amongst other hypotheses. In both studies the data was evaluated visually and Eda Explorer with the help of Python 2.7 detection script was used to remove artefacts, also known as corrupt segments, from the skin conductance data. After this, parameters shown in table 6 were extracted from the data. A difference being that de Looff et al. (2019) specified the parameters to be averages and of SCL peaks. Further, the data was controlled for temperature to determine whether it was an influencing factor and additionally controlled for movement in de Looff et al. (2019). The same study added that measurements with more than two hours of artefact-free data were included. The artefact-free data added up to ranging from 4.91% to 99.7% and in total 341 recording days data was artefact free. The total collected number of days for the study was 347. Temperature data was omitted due to a malfunctioning sensor from 5 participants. An analysis was done on responses with an amplitude of 0.02 μS and the threshold was decided at 0.05 μS respectively (de Looff et al., 2018, p. 509; de Looff et al., 2019, pp. 311.)

Table 6. A listing of the parameters extracted from the SC data in the two burnout related studies (de Looff et al., 2018, p. 509; de Looff et al., 2019, p. 311).

de Looff et al. 2018	de Looff et al. 2019
SCR	SCL
Rise and decay time	Skin conductance peaks per minute
Amplitude (AMP)	Area Under Curve (AUC)
Width (WID)	Amplitude (AMP)
Non-specific responses per minute	Width (WID)
SCL	Rise and decay time

The findings of the first study to the question of the significance of the association between burnout symptoms and skin conductance was done with Spearman's rank correlations, since the SC's distribution was not normal. This showed no significant effect and further the results remained non-significant, even after they were controlled for temperature. A relationship between skin conductance and burnout symptoms was not found. (de Looff et al., 2018, pp.511, 514.)

The modeling done with the collected data in the second study provided information concerning SC. An important finding from the modeling is that when a time-varying predictor was implemented it showed a negative effect in AMP and AUC. (AUC was not specified as AUC and AMP have a high correlation.) In addition, they have significant effects concerning SC, they decrease as the burnout increases. (de Looff et al., 2019, pp. 312, 315)

5.4.3 Anxiety

The data in Roth et al. 2008 was divided into two segments: sleeping and wake. These were further analyzed separately and first examined visually for artifacts. The artifacts were then removed from further analysis. Skin conductance fluctuation was calculated as standard deviations of SCL after digital filtering with a bandpass of 0.1-4Hz to reduce tonic activity in favor of phasic activity. The sleep and wake segments were analyzed in two different ways. First, the mean, minimum, maximum, standard deviation, and skew (based on the cube of SD rather than square of differences of mean) from each participants run lengths of continued SCL decline (1-minute averages) were calculated. Following this the descending runs where the minutes following *n*th minute were of equal or lesser value than the one before were calculated. Second, the 1-minute averages of these parameters were calculated to compare results between the calm and tense participants. The data collected from the four separate 8-minute sitting parts of the ART measurements was used to calculate the means of the measures and run lengths of SCL. However Maximum and minimum measures were not closely analyzed as they can be affected by some disruptions during the measuring whereas standard deviations were considered to depend on events and activities. Skin conductance fluctuations support the SCL data in similarity, so it was considered as secondary information (Roth et al., 2008, p 208.)

To avoid having to adjust the statistics for multiple comparisons due to the amount of data, means on waking SCL, ART SCL and run length of SCL decline in addition to skews of waking SCL and run length of SCL decline were chosen for testing the hypothesis. Sleep disruptions were calculated from how many 30-minute segments there were, during which threshold maximum SCL or above threshold maximum activity appeared. (Roth et al., 2008, p 208.)

The main findings are a bigger positive skew and bigger maximum in the calm group. Figure 4 shows that the calmer individuals have a longer run length. Sleep disruptions were analyzed from the actigraphy measurements and through how many 30-minute periods had above maximum SCL. The SCL was similar in both groups, whereas the calm group had noticeably less disruptions in terms of activity (tense disruption 3.8 ±

3.1 and calm disruptions = 1.6 ± 2.1). The calm group had a positive skew in run lengths and a longer maximum length during sleep. The skews are substantially more positive for the calm group, which supports the finding of descending run lengths. Lower SCL's are likely a result of increased number of sustained runs. Ambient temperature could affect SCL, but did not differ in the groups, aside from the skew of waking temperature (tense group 0.27 ± 0.76 and calm group = 0.37 ± 0.68), but interestingly was in the wrong direction to justify the variation in SCL levels. During the sleep segment 1 minute skin conductance fluctuation was less in the calm group (tense group 0.13 ± 0.25 and calm group 0.00 ± 0.00), even though other parameters were similar. (Roth et al., 2008 pp. 209-210.)

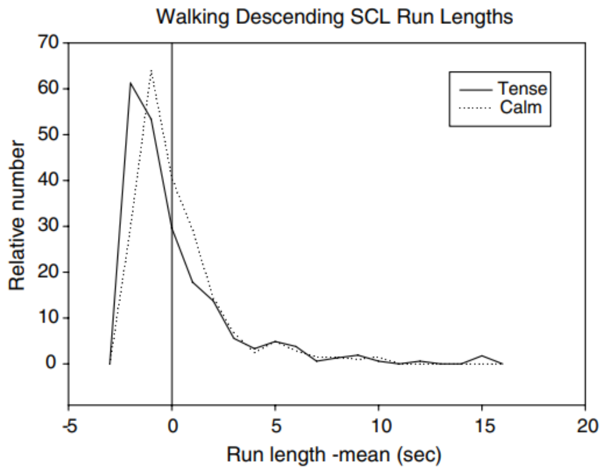

Figure 4. The run lengths are longer in the calm group (Roth et al., 2008, p .210).

5.4.4 Panic Disorder

The data from the measurements were run through a customized software made by Matlab and was first analyzed visually, and artifacts removed from further analysis. Then the data was analyzed using linear mixed models and a top-down strategy. One-tailed and two-tailed measures were used on primary and secondary measures respectively. The data was divided into sleep and wake segments, based on data from the activity channel and participant reported factors. The waking segment was further analyzed in daily living activities and ART measurements. Raw SC data was filtered with a 0.05Hz frequency and provided four measurements: mean SCL of 1 minute mean of filtered SC, and three that represent SC variability. The total number of NSFs ignores the effect of amplitude, when 1-minute SC SD's and measure of fluctuations are in fact affected by the number of and amplitude of SC fluctuations. (Doberenz et al., 2010, p.1142.)

The degree of association (Spearman's correlation) between the different SC variabilities was measured to be considerable at the 0.01 level. The data was further analyzed pooled and sequentially, to find out measures such as means of SCL, number of NSFs, segment differences (asleep versus awake), amount of activity during sleep and ascending and descending run lengths of SCL. The latter meaning the value after the minute before was either greater (for ascending) of lesser (for descending) than the one after and this continued until the *n*th minute when the value reversed and started from the beginning. These runs are considered indicators of increasing (ascending run) or decreasing (descending run) of sympathetic activation. (Doberenz et al., 2010, pp.1142-1143.)

The PD group reported 4.5 full and 17.4 limited symptom panic attacks occurring in the past month. The same group scored higher in the depression scales and anxiety inventories they were more agoraphobic and had more problems with sleep. The PD group had a variety of diagnoses (such as MDD, GAD and PTSD) and two psychoactive medications, while the control group had history of none of these. (Doberenz et al., 2010, p. 1143.)

The initial first hypothesis of higher SCLs and measures of NSFs in the PD group was partially confirmed by mean SCL being elevated during waking. The difference correlated further when factors such as gender, age and medication were adjusted and the adjusted model showed that mean SCL was considerably decreased by age and use of antidepressants, and a tendency toward a higher SCL was seen in women. However, mean SCL was not affected by the mean of activity or temperature. The measures of SC variability were not elevated. The self-reported heightened anxiety in the PD group had an association with the mean SCL being higher. Mean SCL was bigger between the groups on day 1, as it mostly disappeared on day 2. This is demonstrated in figure 5. Antidepressants taken by the participants of the PD group reduced the mean SCL. Daytime panic attacks and state anxiety increased mean SCL. The mean number of NSFs showed a tendency of being higher in PD patients after covariant adjusting. The number of NSF's or MSSD's and measures of SCV's were not significantly different between the groups when sampled at 4Hz. It should be noted that there may be SC variability that is unrelated to anxiety. SC can be affected by for example unexpected events and emotions. An unexpected occurrence can interrupt a descending run and therefore misrepresent the relaxation abilities of the PD and control group. (Doberenz et al., 2010, p. 1143.)

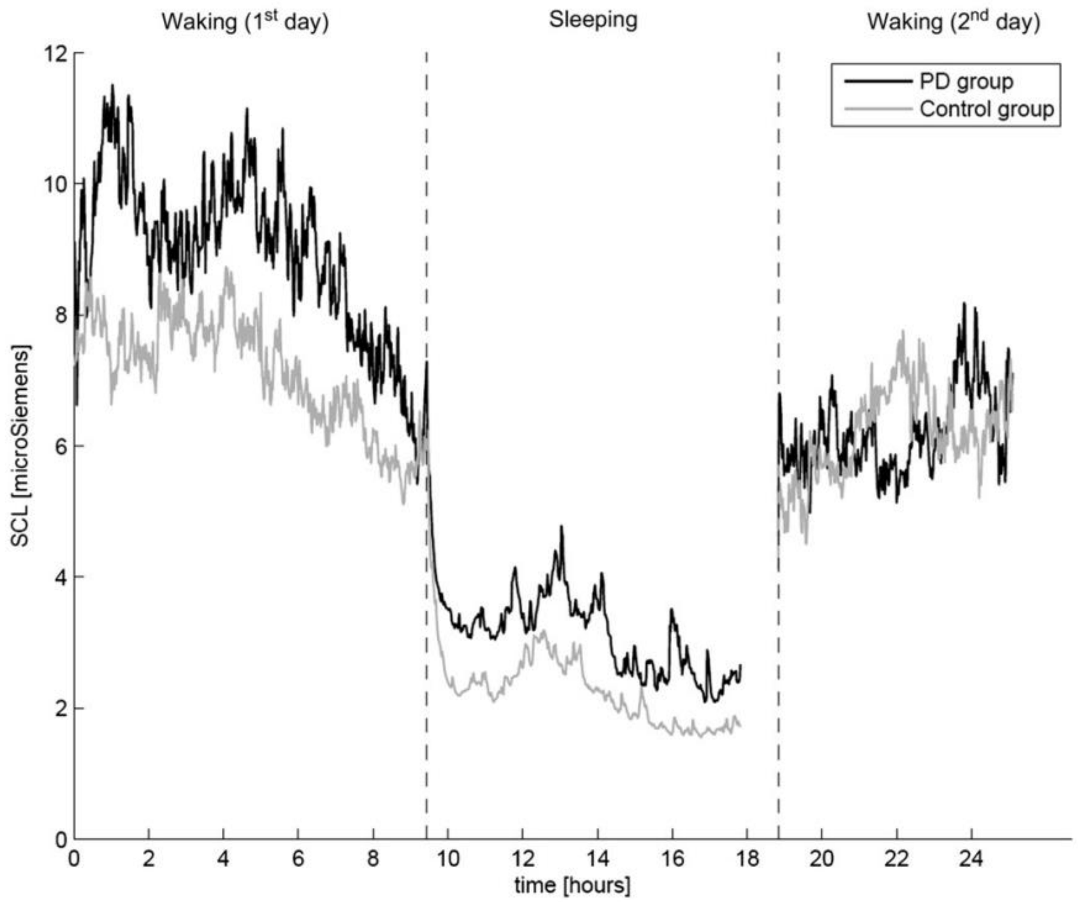

Figure 5. Comparison of mean SCL between the control group and PD group of 1-minute segments. Synchronization was done by the beginning of the sleeping period. (Doberenz et al, 2010, p. 1144.)

The second hypothesis concerned the ART measurements. PD patients reported feeling more anxious while trying to relax, in comparison to the control group. ART measurements were similar concerning mean SCL and decline rate. As these show little SC variance between the groups, results may indicate that PD patients have a capability of sitting and relaxing in controlled environments just as well as non-PD patients. This means that SC's validity as a measure of relaxation is not clear or that ART is not a valid test. (Doberenz et al., 2010, pp. 1143, 1145.)

The third hypothesis correlated with the first, as the parameters were run through the same model with both sleep and waking period as a factor. The PD group did not report experiencing poor quality sleep, but the mean SCL was higher while sleeping. This could be due to having more disruptive sleep or due to the influence of depression experienced during the day. Definitive reason for sleep disruptions was not reached. Due to missing data no definitive result could be made. (Doberenz et al., 2010, pp. 1143, 146.)

The additional analyses provided information that the PD group had a considerably higher mean activity while sleeping, but this was weakened after adjustments in the model, for age, gender, medication, and mean temperature. PD patients felt less relaxed, and more worried, tense, and sad. Marginal model analyses were conducted to find the relationship between these feelings and positive SCL findings and each period was adjusted for the different variables, like age and medication. The mean SCL was higher during waking due to high state anxiety and higher during sleep due to higher daytime state depression. Agoraphobia experienced by the PD group had no significant effect on the mean SCL, but the findings support a lower SCL when more agoraphobic symptoms are present. The data of reported panic attacks was limited due to missing reports, but no clear correlation was found between the number of daytime panic attacks and waking mean SCL nor the number of nighttime panic attacks and sleeping mean SCL. (Doberenz et al., 2010, pp. 1143-1144.)

Between the groups no influential differences were reported concerning sleep duration or disruptions. However missing data, especially self-reports, limited the sample, and influenced generalizability negatively. The 1-min span run lengths of SCL, both ascending and descending were similar, the first 30 minutes included a steep decline and then that decline slowed. However, the PD group had shorter descending run lengths, meaning the PD group had more recurrent interruptions in the descent of SCL runs. (Doberenz et al., 2010, pp. 1144-1145.)

5.5 Challenges in measurement

The studies faced varying challenges. Bertram et al. (2014, p. 616) found that singularly male sample with multiple comorbidities limited the generalization possibilities of the findings and that the used sensors did not provide information on all variables, such as factors that influence sleep, such as, sleep apnea. Additionally, to gather more accurate data during sleeping actigraphy could be substituted with polysomnography.

The association of SC and burnout symptoms was not confirmed in de Looff et al. (2018, p. 513). It was suggested that the current study was not long enough to confirm such an association, as the SC varies daily, despite there being a 48-hour window between the assessment and measurements. The questionnaires concerning burnout collected information from a much broader time frame than the physiological measurements. de Looff et al. (2019, p.315) explain that data loss and measurement accuracy were noted as factors limiting the accuracy of results. However, the Empatica E4 was noted to seem useful in skin conductance detection.

The study done by Doberenz et al. (2010) faced several limiting factors. Controlling of affecting factors (such as interaction between people) is difficult in ambulatory measurement. Only SC was used to assess PD, the use of more varied variables (such as HR or respiratory sinus arrythmia) might have given more indication towards a relationship of stress activation and SC findings. Polysomnography would have given indication towards the structure of sleep. The medications used by the participants might have influenced the results but finding participants without medications would have distorted the representativeness, as unmedicated PD patients are a rarer occurrence in developed populations. A small sample limits generalizability and missing data, due to missing self-reports, limits the statistical relevance even further. (Doberenz et al., 2010, pp. 1145-1146.)

Roth et al. (2008, p. 211) discuss that a weakness in their process was the measurement of just one variable to describe sympathetic activation. Ambient temperature was measured at lowest to be 13.8 C. Certainty was not reached as to whether even colder temperatures might influence SC, when coldness would cause vasoconstriction in the hands. Additionally, a small sample of anxious individuals with recruitment through advertisements conclude to a certain type of sample, other recruitment methods might collect more or different type study subject leading to differing conclusions.

5.6 Applications of EDA measurement

Only two direct suggestions toward the possibilities of EDA measurement were presented. de Looff et al. (2019, p. 315) suggest that physiological monitoring could be used to gather objective and unobtrusive data to indicate a risk of oncoming burnout. They specify that calculating AMP and AUC are useful. This should be done in addition to face-to-face monitoring and providing social support in stressful and aggressive situations. Providing means to increase EI may decrease the chance of developing burnout. Early recognition of changes in AMP levels might be indicators of burnout symptoms. Additionally ambulatory SC measurement shows promise in evaluating PD severity and can be used to support findings in addition to interviews and questionnaires (Doberenz et al., 2010, p. 1146).

6 DISCUSSION

The purpose of this systematic literature review was to map how long-term measurement of EDA can be utilized in cases of anxiety, chronic stress, and depression. The review ended up including 5 relevant articles. Those discussed 3 separate EDA sensors, and 4 mental health cases, anxiety, burnout, panic disorder, and PTSD, as a broader view of anxiety and chronic stress was adapted to ensure more information was gathered on the subject.

6.1 Discussion of results

This thesis ended up reviewing the use of 3 different sensors, despite there being a variety of sensors available for research use. Affectiva Q and Empatica were commercial grade, however Affectiva has been discontinued. The “digital recorder” was assumed to be solely for research use, as any other information on it was not found. All the electrodes of the sensors were attached to the wrist and/or palmar area. The three sensors measured SC, movement, skin temperature, ambient temperature and BVP. Also, questionnaires and interviews were used to increase, and supplement collected data. Roth et al. (2008, p. 206) noted including a combination of a verbal report of anxiety to supplement the psychophysiological measurements. This can be applied to all the chosen mental health diagnoses, as physiological measurements solely are not enough to draw reliable conclusions on.

The studies were conducted outside laboratories as long-term ambulatory measurements. Two studies focused on burnout symptoms experienced by nurses and took measurements during one working shift. Three studies focusing on PTSD, anxiety and panic disorder had the patients complete a part of the measurements at home to ensure daily living conditions. Studies focusing on anxiety and panic disorder included ART measurements, that required the subject to intentionally relax at selected times. These were noted to not necessarily be reliable in studying the relationship of skin conductance and relaxation (Doberenz et al., 2010, pp. 1145). Bertram et al. 2014, de Looff et al 2018 & de Looff et al. 2019 studies discussed the results related to skin conductance quite scarcely, giving little to work with in analyzing the differences each diagnosis makes in the structure of EDA. This was due to the studies conducting research into other aspects and measuring EDA was a tool to help reach that goal.

The study samples consisted of adults who are either diagnosed or symptomatic of the condition in question. Control groups were utilized in PTSD, anxiety, and panic disorder studies to provide a comparative result. Bertram et al. (2015, p.616) raised a notion of medication influencing SCL, and that finding unmedicated patients was difficult. This is supported by Doberenz et al. (2010, p. 1146.), concerning PTSD. They also suggested that future studies should note the potentiality of agoraphobia, depression and medication having surprising effects.

With burnout, amplitude, and AUC of SCL decrease as burnout increases, meaning the variation in the peak to peak of the signal decreases. (De Looff et al., 2019, pp. 312, 315) Findings by Roth et al. support this as the control group had more variation in SCl, as skews and maximums were bigger. Roth et al. (2008, p. 211) indicated that the anxious group could relax when asked, just as well as the control group. Additional studies are needed to research whether the same could be replicated with panic disorder patients, as they experience from constant heightened sympathetic activation. Doberenz et al. (2010, p. 1146)

The studies faced challenges. One being that the study samples were not versatile enough for generalization or had other limiting factors such as multiple medications or comorbidities. The sensors did not always collect all the data that would have been necessary. Heart rate could provide more information on arousal and polysomnography on the structure of sleep. Medications also have unclear effects on skin conduction (Bertram et al., 2014, p. 616; Doberenz et al., 2010, p. 1145; Roth et al., 2008, p. 211.) Longer measurement periods might have given more information to confirm relationships between burnout and skin conductance (de Looff et al., 2018, p. 513) Missing data was noted in all articles as a hindering factor. The uncontrolled ambulatory measurement scenarios made data interpretation more difficult, as the participants faced situations unknown to the researchers. (Doberenz et al., 2010, p. 1145.)

The applications suggested by the articles were few, as they did not largely discuss the future possibilities. Measuring skin conductance was seen as a supportive tool in research, since it provides information a patient cannot disclose themselves. Burnout could be prevented if interventions during rising skin conductance amplitudes are taken. (de Looff et al., 2019, p. 315; Doberenz et al., 2010, p. 1146.)

Why have so few studies been done in a truly ambulatory manner, despite the available, constantly developing technology and vast knowledge of skin conductance measurements possibilities? Future research should continue to utilize ambulatory sensors in long-term and longitudinal studies. As mental health issues are an increasing stressor on an individual as well as communal level, a need for non-invasive and relatively inexpensive way to measure autonomic arousal is needed. Bigger and more varied study samples are a requirement to make the results generalizable on a larger scale. The influence of medication on skin conductance was pointed out, and needs more research to be thoroughly explored, as unmedicated participants are hard to find with certain diagnoses.

6.2 Limitations of a systematic literature review

This literature review had far less articles than systematic reviews traditionally have. This is mainly due to the technology being so new and the search parameters concerning the protocols and diagnoses being so specific. Opening the review to more languages, such as Chinese, would have likely made more information available, had it been possible. The lack of variety in information could also be considered a limitation, as this review shows only a small part of the possibilities of EDA measurement.

The process of a systematic literature review usually involves having at least two writers review articles. Having only one writer limits the time availability and increases the risk of negligent errors due to a topic that is not thoroughly familiar. Inexperience of the author in literature reviews could be considered a limitation.

6.3 Ethics and trustworthiness

The writer did extensive research on the subject and studied the technology used in the reviews before beginning writing, however expertise cannot be claimed. Only reliable databases were used as a source for the review articles. Inclusion and exclusion criteria were closely followed throughout the process and a discussion on the matter was held with advisors to obtain only factual and relevant information.

The collection of data was documented carefully, so that it could be repeated. However due to the review being completed by one person, who is not an expert in the subject, negligent errors may affect the result. No subjective choices were made in selection and interpretation of data. All used sources were clearly cited, and the sources were chosen based on trustworthiness and reliability of information and source. The review articles were analyzed with the JBI Qualitative Research Checklist to ensure their quality and to view the articles in the same light. All articles obtained a minimum of 7 out of 10 yes answers and were deemed acceptable for the review.

The field of ambulatory measurement develops quickly, and the situation depicted in this review describes the situation today. With a high probability the information will be outdated after a period of time.

7 CONCLUSION

This literature review has sought the answer to how long-term ambulatory EDA measurement could be applied in cases of anxiety, chronic stress, and depression. To support this, smaller questions were also answered:
How is EDA measured in ambulatory scenarios?
What type of technology is used?
What is the measurement time?
How does the EDA signal look in ambulatory measurement with the chosen diagnoses?

The main question focused on how EDA measurement could be applied. The articles provided very few direct suggestions. However, long-term EDA measurement was seen as a possibility to support and supplement face-to-face interactions, questionnaires, and interviews in mental health studies. More specifically in cases of burnout and panic disorder. Burnout could potentially be avoided, if skin conductance is followed continuously or at least periodically and interventions are done at early stages of changing amplitude levels. More studies need to be done, as the data does support correlations between skin conductance variation and symptomatic patients, but provides little information.

EDA was measured with sensors attached at the wrist or palmar surface of the hand, one worn in a waist pack. These are ideal for ambulatory measurement, as they are compact, but not all of them were commercial grade nor a likely fit for continuous or prolonged use. Why these sensors were selected was not disclosed, as the selection of sensors is ample. Reasoning behind the selections might have given indications to note for future research.

The measurement times were from 8 hours to 24 and happened in daily living situations. Longer measurements could give more precise and generalizable results. The research does indicate a connection between the selected mental health scenarios and skin conductance variability, but more studies, with bigger samples and longer measurements are needed, to make definitive conclusions.

Since the results on the behavior of skin conductance in the studies were limited, drawing conclusions was difficult. While the data supported the relationship between burnout and SC, anxiety and SC, and panic disorder and SC, these studies are not enough to generalize findings. More studies having EDA measurement as a focus point are needed to support or disprove the findings of this review.

There is a great possibility to utilize EDA measurements in mental health studies, as it is a non-intrusive, long-term, and low-cost method. However, more studies need to be done to draw reliable and generalizable conclusions, as the article sample for this review was limited and focus was not solely on SC measurement. Studies involving the comfort of use of long-term measurement sensors are needed, as this angle was not discussed at all. Comfort of use can influence data gathering, as sensors might be loosened or moved as discrepancies and errors in measurement due to poor attachment are common. Studies should utilize newer sensors, as recent developments have made it possible to measure from other locations in addition to the distal upper extremity. Another review expanding parameters to include other languages is recommended.

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APPENDIX 1

JBI CRITICAL APPRAISAL CHECKLIST FOR QUALITATIVE RESEARCH

Reviewer______________________________________ Date______________________________

Author_______________________________________Year_________ Record Number_________

		Yes	No	Unclear	Not applicable
1.	Is there congruity between the stated philosophical perspective and the research methodology?	☐	☐	☐	☐
2.	Is there congruity between the research methodology and the research question or objectives?	☐	☐	☐	☐
3.	Is there congruity between the research methodology and the methods used to collect data?	☐	☐	☐	☐
4.	Is there congruity between the research methodology and the representation and analysis of data?	☐	☐	☐	☐
5.	Is there congruity between the research methodology and the interpretation of results?	☐	☐	☐	☐
6.	Is there a statement locating the researcher culturally or theoretically?	☐	☐	☐	☐
7.	Is the influence of the researcher on the research, and vice- versa, addressed?	☐	☐	☐	☐
8.	Are participants, and their voices, adequately represented?	☐	☐	☐	☐
9.	Is the research ethical according to current criteria or, for recent studies, and is there evidence of ethical approval by an appropriate body?	☐	☐	☐	☐
10.	Do the conclusions drawn in the research report flow from the analysis, or interpretation, of the data?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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