Master Thesis

The Use of Wearable Devices in the Treatment and Detection of Anxiety: A Systematic Scoping Review

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Abstract

Introduction: Anxiety disorders are one of the most prevalent disorders and are substantially undertreated and underrecognized, which has negative consequences on individual and societal levels. Recent technological developments with the potential to support conventional care models have received increased attention in technical and mental health research lately. Wearable devices, such as bracelets that monitor physiological signals e. g., have been shown to be a promising adjunct in the treatment and detection of anxiety by offering the possibility to deliver interventions and detect symptoms of anxiety. By exploring different databases on this subject, the present scoping review aims to provide an orientation and overview of the current research on the use of wearable devices in the treatment and detection of anxiety. **Methods:** Literature was collected searching four different databases: Scopus, Web of Science, PsycInfo and Wiley Online Library. A total of 11 studies were selected after an extensive search and analysed to explore study characteristics, type of anxiety complaints targeted, type and role of wearable devices used in detection and treatment of anxiety, data collected by the wearable devices and interventions that were delivered through wearable devices to mitigate anxiety. Data was extracted, summarized, and partly presented in tables to provide an overview of the findings. **Results:** Studies varied greatly in their sample sizes. Almost all studies focused on anxiety symptoms and complaints. A variety of wearable devices were used of which a majority were consumer grade products such as wrist-worn devices. While most studies focused either on detecting or treating anxiety, some papers employed wearables that combined both roles. A great variety of physiological signals was measured by the different wearable devices. Different approaches to the sense-making of collected data were taken. Most interventions delivered by the wearables consisted of biofeedback in combination with conventional breathing- or mindfulness exercises. **Discussion:** The great variety of consumer grade wearable devices used to detect or treat anxiety complaints could be beneficial for user compliance and acceptance. The different measurements and sense-making methods used by wearable devices indicate that there is no golden standard regarding the detection of anxiety through wearables. In the treatment of anxiety, wearable devices could be of use as tools in complementing conventional psychotherapy. In line with a prior literature review, wearables used to treat anxiety were mainly employed to deliver biofeedback-based interventions in combination with common relaxation techniques. Future systematic reviews and meta-analyses could focus on the

effectiveness of wearable-based interventions and the application of wearables in treatment and detection of specific types and disorders of anxiety.

Keywords: Anxiety, wearable devices, biofeedback, treatment, recognition, detection

Table of Contents

The use of wearable devices in the treatment and detection of anxiety disorders: A systematic scoping review

Psychological disorders that remain untreated are a global problem (Hunkin et al., 2020). Anxiety disorders are one of the most common and prevalent disorders, with a global lifetime prevalence rate of approximately 16.6% and are substantially undertreated and under-recognized, meaning that many people suffering from anxiety must wait for years until they receive a diagnosis and the needed treatment. (Somers et al., 2006; Cornelius et al., 2013). Wearable devices have recently been in the focus of mental health care as they are a potential adjunct that can help to reduce the treatment gap. They have been shown to be promising helpers for mental health care as they can collect relevant, detailed health related data about individuals and deliver psychological interventions to the user (Debard et al., 2020; Evmenova et al., 2019). Considering the promising potential wearables have regarding the treatment gap of anxiety disorders, this literature review aims to explore available research about the use of wearable technology in the detection and treatment of anxiety disorders. The present review investigates available literature regarding the kind of anxiety related complaints that are targeted by the wearable device, the role of the wearable device, what type of wearable devices are used and what kind of data the devices collect. Furthermore, the present review aims to explore the interventions that are applied with the help of wearable devices to mitigate anxiety.

Anxiety Disorders

Barlow (2004) defined anxiety as a future-oriented mood state associated with preparation for possible, upcoming negative events. Anxiety is a normal reaction and can be of advantage when a threat is approaching because it enables us to be alert and prepared to react. Feeling anxious or nervous can thus be useful in certain situations. Anxiety disorders, however, exceed normal feelings of anxiousness and are defined by excessive states of anxiety and fear (Baldwin et al., 2014). People that suffer from an anxiety disorder are troubled by severe and persistent anxiety symptoms that cause significant personal distress, reduce functionality and quality of life (American Psychiatric Association [APA], 2021). According to the Diagnostic and Statistical Manual of Mental Disorders, the experienced anxiety must be out of proportion to the situation and hinder the person to function normally, to diagnose an anxiety disorder (APA, 2013).

Anxiety disorders are one of the most frequent disorders in the world (APA, 2021). About 30% of the adult population deals with an anxiety disorder at least once in a lifetime

(Bandelow & Michaelis, 2015). In addition to the high prevalence rate, anxiety disorders are frequently comorbid with other chronic health conditions, especially with depression (Chung et al., 2021). Forms of anxiety disorders are the generalized anxiety disorder, social anxiety disorder, panic disorder, agoraphobia, separation anxiety disorder and other specific phobias (APA, 2021). In addition to the high prevalence rate, anxiety disorders are substantially undertreated and underrecognized (Cornelius et al., 2014; Kasper, 2006). A reason for that might lie in that people feel ashamed to admit that they suffer from anxiety or other mental health problems, due to the stigma that is associated with mental illness (Layard, 2013). Another factor is the unavailability of respective local care facilities. Many patients suffering from anxiety must wait for years until they receive treatment from a respective specialist (Baldwin et al., 2012). A survey among psychiatrists that are experienced in the treatment of anxiety disorders revealed that almost the half of their patients suffered from anxiety symptoms for 2 years or longer before they were diagnosed with the disorder, which illustrates the lack of psychological care (Baldwin et al., 2012). The treatment gap regarding anxiety disorders has severe consequences, not only for the client but also on a societal level (Kasper, 2006). These consequences range from disability, to reduced ability to work and loss of productivity, as well as a higher risk of suicide.

Treatment of Anxiety Disorders

Effective treatments for anxiety and anxiety disorders are medication and psychological therapies like cognitive behavioural therapy (CBT) (Baldwin et al., 2014). Especially exposure-based therapy has been proven to be effective for mitigating anxiety (Maples-Keller et al., 2017). Exposure therapy aims to modify cognitive fear structures by exposing the individual to the fear to reappraise and restructure cognitive information about the feared stimuli. Besides traditional CBT, there are also therapy formats available that are based on or complemented by technology, which have shown promising results (Fairburn & Patel, 2017). Such digital treatments are either self-help formats or blended treatments whereby the client receives professional support and guidance besides the technological component. One example of a technology that has been used in blended-treatment formats are Virtual Reality (VR) based techniques. VR technology can be used in exposure-therapy for instance, as it provides the opportunity to simulate the feared environment and can thereby be used to expose the client to the fear stimuli (Maples-Keller et al., 2017). Besides blended-treatment approaches, other recent technological developments move towards designing self-help tools for mental health problems, potentially providing ubiquitous, flexible, and more easily

accessible mental health care. One of these promising developments are wearable devices (Hunkin et al., 2020)

Wearables Devices and Anxiety Disorders

Wearable devices, also called "wearables" are sensor-enabled technologies that are designed for specific purposes and are worn in a specified and consistent manner. (Mohr et al., 2017). Common types of consumer grade wearable devices are fitness bands, smart watches and other jewellery that can log users' activity metrics and other physiological and behavioural factors (Phillips et al., 2018). Many wearable devices function in combination with a personal computer or smartphone (Wright & Keith, 2014).

Over the last years, wearable devices have developed further and received increased attention from the mental health field. One aspect that makes wearables interesting for the application in mental health care is that they consist of sensors and systems which can be worn on the body and are able to collect longitudinal and continuous physiological data, in a non-invasive way (Debard et al., 2020). Thereby, wearables can be used to collect health-related data outside of lab settings (Debard et al., 2020). Depending on the type of device, wearables contain a broad range of sensors that can collect information on heart rate (HR), heart rate variability (HRV), electrodermal activity (EDA), skin temperature (ST), movement, and location (Ueafuea et al., 2021; Debard et al., 2020). As wearables enable the continuous collection of physiological and other data, they can help to obtain relevant information at different stages of mental health disorders like identifying risk factors, guiding, and monitoring the treatment process, up to recovery (Haberer et al., 2013).

Wearable devices could thus potentially play a supportive role in the detection of anxiety as anxiety is partly characterized by physiological symptoms, which can be captured by respective sensors. Physiological characteristics of anxiety are the increased activity of the autonomous nerve system which causes an increased HR, decreased HRV, higher blood pressure and respiration (Jung & Chung, 2013). HRV is defined as the fluctuation of heart rate over time and is considered an important marker of psychological well-being (Chalmers et al., 2014). Furthermore, electrophysiological signals, such as muscular activity, galvanic skin response and brain activity can also be used to identify signs of anxiety (Massot et al., 2012). Especially HRV has been shown to be correlated with stress and anxiety in several studies (Chalmers et al., 2014). Depending on the type of device, wearables can measure one or several of these anxiety symptoms.

The information that wearables capture using sensors result in large amounts of raw data which are, unprocessed, often not sufficient to draw inferences about mental states (Mohr et al., 2017). To make use of the raw data, it can be transformed into meaningful information about behaviours, thoughts, and emotions, through machine learning algorithms. Mohr et al. (2017) referred to this process as personal sensing. Regarding the objective to detect anxiety using wearables, personal sensing could exemplary be described as follows. A wearable device used to detect anxiety, eventually includes sensors that measure acceleration and HR. Using algorithms, the raw data about the HR in combination with movement would then be transformed into feature information about the cardiovascular activity and movement intensity. The derived features can than lead to information about fatigue, hedonic activity, and stress, which are called behavioural markers. The behavioural markers can indicate symptoms which can then be potentially translated into clinical states, similar to diagnosing a disorder. It is expected that a larger number of behavioural markers and features leads to a better prediction of clinical states (Mohr et al., 2017).

Prior research has shown that wearable devices can collect physiological signals and use them to draw inferences about mental states such as anxiety (Chalmers et al., 2014; Massot et al., 2021; Mohr et al., 2017). However, the information physiological signals provide about anxiety are based on inference. A major challenge that remains is thus the direct measurement of the subjective ground truth of anxiety. A wearable device might draw conclusions about anxiety based on physiological signals, while the user does not feel anxious at all or perhaps does not even recognise his own emotions. The subjective variability of the ground truth of anxiety might decrease the capability of the wearable device to detect anxiety (Chen, Mermel & Liu, 2021). It is thus questionable whether measuring objective physiological signals alone is suitable to detect the presence or absence of anxiety when its ground truth is based on subjective mental states of the user.

Besides potentially being able to detect somatic indicators for anxiety, wearable devices have also been shown to be of help in the treatment of anxiety. One example is the application of biofeedback, which has been shown to be effective in reducing anxiety in prior research (Goessl et al., 2017). Biofeedback provides the user with information about certain somatic states and can thus indicate when symptoms of anxiety are present. Research has shown that biofeedback can enhance self-regulatory strength and self-awareness which enables individuals to regulate their physiological functioning and reduces negative emotions (Goessl et al., 2017). Depending on the wearable device, biofeedback provides information about ST, HR, or muscle potential, and recently also HRV, EDA and respiration (Schoenberg

& David, 2014). A smart patch used in the study of Chung et al. (2021) for instance provides the user with feedback in form of vibrations in case of a decreased HRV, which was shown to be correlated with an increase in anxiety. In addition, it guides the users breathing to promote relaxation and decrease anxiety. Another study by Evmenova et al. (2019) has shown that wearable devices can support adolescents during anxious moments by delivering short prompting messages to the user that increase self-regulation.

Current Study

The previously mentioned research revealed a treatment gap regarding anxiety disorders and indicated that wearable devices have the potential to support mental health care in the treatment and detection of anxiety. Prior studies showed that wearables can potentially be used to collect anxiety related data using a variety of sensors and are able to employ different interventions to mitigate anxiety. This indicates the need for a scoping review that provides an overview and orientation about recent research regarding the use of different kind of wearable devices in the detection, as well as the treatment of anxiety disorders. This is even more relevant considering the technological nature of this topic. It is likely that reviews from prior years are outdated and do not represent the current state of the art anymore, due to the fast development of technology. In addition, prior reviews about the present topic either focused on specific types of wearables or merely on how wearable devices could be used in the treatment of anxiety (Hunkin et al., 2019; Elgendi & Menon, 2019). Therefore, this review aims to explore how different kinds of wearable devices are used in the detection of anxiety, besides looking at how wearables are being used in the treatment of anxiety. This is of special importance as anxiety disorders are not only undertreated, but also underrecognized in mental health care (Cornelius et al., 2014; Kasper, 2006). Based on the previously mentioned literature and information, the following aspects of exploration have been chosen to ensure a directed and structured search of contemporary research:

1. Which kind of anxiety related complaints are targeted by the wearable devices?
2. Which type of wearable device is being used?
3. Which roles do the wearable devices play?
4. Which kind of data is collected by the wearable devices?
5. What kind of intervention is applied with the help of the wearable devices to treat anxiety?

Methods

The present paper is a scoping review. The aim of a scoping review is to synthesize and present the current base of knowledge on a specific topic regarding its nature, characteristics, and volume. Most scoping reviews summarize data from relevant studies in tabular form and draw conclusions from the literature by assessing quantity and quality of the data (Grant & Booth, 2009). This scoping literature review was conducted conforming to the preferred reporting items for systematic reviews and meta-analyses guidelines (PRISMA) (Page et al., 2020).

Search Strategy and Selection Criteria

To find relevant papers and articles, four different databases have been searched. The four databases included Scopus, Wiley Online Library, PsycInfo and Web of Science. The first three were chosen because of their broad scope and the high quantity of peer-reviewed articles they contain. The last database, PsycInfo, was chosen because of its special focus on studies from the psychological domain. Furthermore, all databases support the use of Boolean operators, which was a requirement for a systematic and structured search.

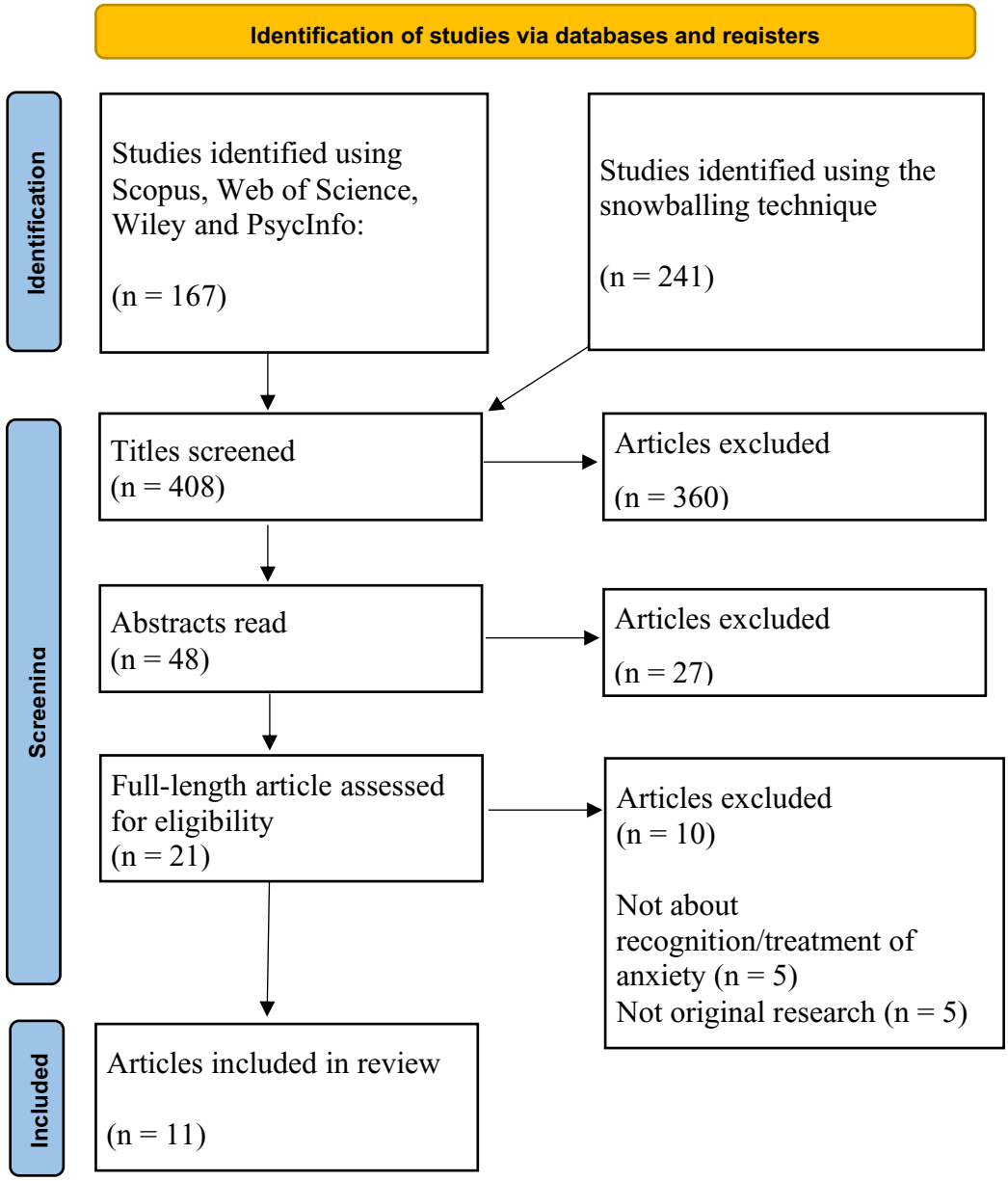
The Boolean chains that were used for the search differed slightly per database. The original search strings can be found in the Appendix of this review. They were, however, similar in their basic elements as described next. The first element of the search string was about wearable devices. Different terms for wearables have been included, such as “wearable device” or “wearable technology”. The second element of the search string was about how the wearable devices were used in the detection of anxiety. Therefore, terms like anxiety detection, anxiety recognition and other synonyms have been included. The third and last element of the search string was related to the use of wearable devices in the treatment of anxiety. This element thus included terms like “anxiety treatment” or “anxiety relief” and other synonyms.

Besides Boolean chains, the snowballing method was used. By applying the snowballing method, identified literature was screened for other relevant literature (Wohlin, 2014). There are two different kinds of snowballing which are referred to as backward snowballing and forward snowballing. Backward snowballing describes the process of identifying literature using the reference list of a paper, while forward snowballing is about finding papers that cite a specific paper. Using a function of Google Scholar, forward snowballing can be applied. In this review, both snowballing methods were used to increase the amount of relevant literature found.

The following section describes the inclusion and exclusion criteria which were established. A detailed overview of the selection process of relevant studies is provided in Figure 1. The first inclusion criterion was the language of the article. The articles had to be either in English or German. Secondly, only studies from peer-reviewed journals were included. Thirdly, only articles that were published in the year 2016 or later were included as this review aims to display results that reflect the contemporary knowledge base. The technological context of this literature review makes it likely that studies from before 2016 are outdated. Another inclusion criterion was the use of a wearable device as defined by Mohr et al. (2017). They defined wearable devices as sensor-enabled technologies that are designed for specific purposes and are worn in a specified and consistent manner. Furthermore, studies needed to include a wearable device that was in some form either involved in the detection of anxiety or in the treatment of anxiety. Lastly, studies had to include original research. This means that literature reviews or studies that e.g., merely included proposals for frameworks were excluded.

Figure 1

PRISMA flow diagram for article selection



Procedure and Data Extraction

The found studies were screened in a systematic way. At first, all titles were read, and duplicates were removed. Afterwards, the abstracts of eligible papers were read. Finally, the remaining papers were fully read to determine their eligibility for the review, whereby the established inclusion and exclusion criteria were applied. During every step, irrelevant articles were excluded. The reasons for exclusion are indicated in Figure 1.

After the selection process, the remaining papers that were found to be eligible to be included in the review were fully read and analysed in accordance with the specified aspects

of exploration for this research. The following section describes how the articles were screened and analysed in a systematic way two answer the five research questions of this literature review.

The first research question of this review was to explore the kind of anxiety related complaints that were targeted by the wearable devices. The respective information was extracted from each article and displayed in tabular form to provide a clear overview of the relevant aspects. In addition, information about study characteristics such as sample size and study design, as well as general demographical data of the participants, namely gender distribution and mean age, were extracted from the articles and presented in tabular form.

The second research question was to investigate the types of wearable devices that were used. The type of the wearable device referred to its form (e.g., wristband, necklace) and to whether the wearable device is a commercially available product, a research grade device, or a prototype device. Some of the wearable devices had names that indicate the type of device so that displaying the name of the device sufficed. Lastly, it was also checked whether the wearable devices functions on its own or in conjunction with another device (e. g. computer, smartphone application). The respective information was extracted from each article and displayed in tabular form.

The third point of exploration was about the role of the wearable device. By exploring the role of the wearable device, it was checked whether the device was used for the detection of anxiety, the treatment of anxiety, or the treatment and detection simultaneously. Per article, the role of the wearable device was identified, and the results were displayed in tabular form.

The fourth research question aimed to explore what kind of data the wearable devices measured. Each article including a wearable device that captured some form of data was read whereby the names of the measured variable were identified and displayed in tabular form. In addition, information about how the measured data was processed was extracted through identifying the method of sense-making the studies used to process the collected data (e. g., machine learning algorithms)

The fifth research question aimed to explore the kind of interventions that were applied with the help of wearable devices to treat anxiety. Each article including a wearable device that was involved in the treatment of anxiety was read and information about the nature and the working mechanism of the applied intervention or treatment were extracted and synthesized to provide an overview of the used treatment approaches.

Results

11 studies were included in this scoping review. Table 1 shows information about the kind of anxiety complaint targeted by the wearable device per study as well as general data about participants, mean age, gender distribution, and study design. The sample sizes of the included studies ranged from 7 to 215. The mean age of the included studies ranged from 8 to 73.36. Furthermore, every study expect one had a majority of female participants in their sample, while two studies did not provide any information about the gender distribution of their sample. Almost all studies had anxiety symptoms as the type of anxiety complaint that was targeted by the wearable device. The study by Shaukat-Jali et al. (2021) focused on social anxiety in their study. The study by Smith et al. (2020) additionally focused on stress symptoms, besides anxiety symptoms. Six articles performed longitudinal experiments in field settings of which two included a control condition. Five articles performed controlled laboratory experiments.

Table 1

Study characteristics

	Authors	Study Design	Sample size	Type of anxiety complaint	Gender	Mean age
1	Tiwari et al. (2019)	Longitudinal field experiment	196	Anxiety symptoms	66.3 % female	38.6
2	Shaukat-Jali, et al. (2021)	Controlled laboratory experiment	12	Social anxiety symptoms	58% female	19.75
3	Shruthi et al. (2021)	Controlled longitudinal field experiment	50	Anxiety symptoms	56% female	19

	Authors	Study Design	Sample size	Type of anxiety complaint	Gender	Mean age
4	Smith et al. (2020)	Controlled longitudinal field experiment	215	Stress and anxiety symptoms	55% female	33.2
5	Nath & Thapliyal (2021)	Controlled laboratory experiment	41	Anxiety symptoms	64% female	73.36
6	Chung et al. (2021)	Longitudinal field experiment	14	Anxiety symptoms	64% female	33
7	Turchetta (2019)	Longitudinal single-subject field experiment	7	Anxiety symptoms	71.4 % female	18-23
8	Crivelli et al. (2019)	Longitudinal field experiment	16	Anxiety symptoms	50 % female	44.38
9	Puli & Kushki (2020)	Controlled laboratory experiment	15	Anxiety symptoms	n. a.	8-16
10	Zheng et al. (2016)	Controlled laboratory experiment	20	Anxiety symptoms	n. a.	18-23
11	Costa et al. (2017)	Controlled laboratory experiment	67	Anxiety symptoms	64.2% female	19-30

Note. n. a = not available

Type and Role of the Wearable Devices

Table 2 shows the role of the wearable devices and the type and specific name of the wearable devices used in the articles. Furthermore, Table 2 indicates whether the use of the wearable device required an additional mobile application. Lastly, Table 2 shows the kind of data collected by the wearable devices.

Five of the included papers applied wearable devices to detect anxiety symptoms. Three studies included a wearable which was used for the detection as well as for the treatment of anxiety. Another three studies used a wearable device which was solely used for the treatment of anxiety. Seven of the used wearables were commercially available consumer grade devices, while five were research grade devices. Three studies used a wearable device in combination with mobile applications. Six out of the eleven included studies used wrist-worn devices such as wristbands or bracelets. One study used a small device that was attached to the wristband of the participants clothing, called “Spire stone”. One study included a wearable smart-shirt, while another study used a smart patch that was worn on the torso underneath the clothing. Another study used an eyeglasses and one study used an eyeglasses in combination with an EEG headset. Lastly, one of the studies used a wearable sensor that was attached to the participants chest.

Data Collected by Wearable Devices

All included studies used a wearable device that measured at least one physiological variable. Four studies additionally assessed the user’s movement, and one study measured the user’s orientation. Eight wearable devices measured at least two different variables to collect data from the user, while three wearables measured only one variable. The most frequent measured physiological signal was HR (n = 7). Two studies derived the users HRV. Three studies measured EEG activity and one measured the users’ respiratory patterns. EDA was measured by two studies. Measurements of blood volume pulse, ST and blood oxygen saturation occurred once among the wearable devices in the included studies. None of the studies used the same combination of measurements.

Data Processing

Five studies used machine learning algorithms to make sense of the data that was collected through the respective sensors to detect anxiety. The study of Smith et al. (2020) used the Spire stone device, which made sense of the measured respirational data through using algorithms trained to differentiate between calm, focused, tense and neutral breathing patterns

of the user. Through identifying different breathing patterns in relation to physical activity, the device detects specific respiration that indicates a potentially anxious state. In the other studies, machine learning algorithms were developed and used to differentiate between non-anxious and anxious states (Shaukat-Jali et al., 2021; Nath & Thapliyal, 2021; Zheng et al., 2016). Puli and Kushki (2020) developed a machine learning algorithm to detect anxiety during motion (Puli & Kushki, 2020).

Two studies used somewhat different approaches to identify symptoms of anxiety. Turchetta (2019) used a wearable device which indicated potentially anxious states through measuring the users heart rate in combination with measuring movement. Through incorporating these two factors, the device was able to differentiate whether the user was in motion or idle. The device was configured in such a way, that it did not indicate an anxious state when the users heart rate was increased during motion. A potentially anxious state was only indicated when the device detected a predetermined, abnormally high heart rate during a resting state. Shruthi et al. (2021) employed a similar method. The wearable device in their study also used acceleration and heart rate data, to distinguish between increased heart rates during motion and when the user is idle. A potentially anxious state was indicated by an increased heart rate while the user was idle.

Table 2

Wearable devices

	Authors	Wearable device	Consumer/Research grade device	Role of wearable device	Collected data	Type of Treatment
1	Tiwari et al. (2019)	Om Signal Smart shirt (1), Fitbit Charge 2 smart bracelet (2)	Consumer grade device (1, 2)	Detection of anxiety	HR, HRV	n. a.
2	Shaukat-Jali et al. (2021)	E4 Empatica multi-sensor wristband	Research grade device	Detection of social anxiety	HR, EDA, ST	n. a.
3	Shruthi et al. (2021)	Anxiety controlling wrist band MAX30102 (in combination with mobile application)	Research grade device	Detection and Treatment of anxiety	HR, blood oxygen saturation, movement, orientation.	Acupressure on the wrist
4	Smith et al. (2020)	Spire stone device (in combination with a mobile application)	Consumer grade device	Detection and Treatment of anxiety/stress	Respiration, movement	Respiration biofeedback combined with breathing techniques
5	Nath & Thapliyal (2021)	Wristband	n. a.	Detection of anxiety	EDA, BVP	n. a.

	Authors	Wearable device	Consumer/Research grade device	Role of wearable device	Collected data	Type of Treatment
6	Chung et al. (2021)	Lief Smart Patch (in combination with mobile application)	Consumer grade device	Treatment of anxiety	HR, HRV, movement	HRV biofeedback combined with cued breathing instruction
7	Turchetta (2019)	Wrist-worn heart rate monitor “Mio alpha 2”	Consumer grade device	Detection and Treatment of anxiety	HR	HR biofeedback combined with breathing techniques
8	Crivelli et al. (2019)	Lowdown Focus brain-sensing eyeglasses from SmithOptics Inc. (in combination with mobile application)	Consumer grade device	Treatment of anxiety	EEG	EEG biofeedback combined with mindfulness training
9	Puli & Kushki, 2020	Shimmer 2r sensor	Research grade device	Detection of anxiety during motion	Movement, EEG	n. a.

	Authors	Wearable device	Consumer/Research grade device	Role of wearable device	Collected data	Type of Treatment
10	Zheng et al. (2016)	MindWave Mobile EEG Headset (1), Photoplethysmogram glasses (2)	Consumer grade device (1), Research grade device (2)	Detection of anxiety	HR, EEG	n. a.
11	Costa et al. (2017)	EmotionCheck Device	Prototype device	Treatment of anxiety	HR	False HR biofeedback simulating a slow heartbeat through vibrations on the wrist

Note. n.a. = not available; HR = heart rate; HRV = heart rate variability; EDA = electrodermal activity; ST= skin temperature; BVP = blood volume pulse; EEG = electroencephalography

Interventions of Wearable Devices to Treat Anxiety

Six of the included papers investigated wearable devices used to treat symptoms of anxiety and applied different kinds of interventions. Four of these studies used wearable devices to deliver biofeedback about respiration, heart rate, EEG or HRV to the user in combination with breathing or mindfulness exercises. The study by Smith et al. (2020) used the Spire Stone device, which provided biofeedback by notifying the user through vibrations about respiration patterns that were found to be "tense" by the device. Turchetta (2019) used the heart monitor "Mio Alpha 2" to notify the user through a red flashlight in case of an increased heart rate. The biofeedback provided by the wearable devices was intended to increase the user's awareness of their current psychophysiological state so that they eventually apply previously learned breathing techniques. The breathing techniques were either trained beforehand with the help of a human instructor as it was the case in the study by Turchetta (2019), or it was delivered through a course in the accompanying mobile application (Smith et al., 2020). Besides delivering breathing training sessions, the mobile application was also used to provide visual biofeedback about the user's respiration (Smith et al., 2020).

The study by Chung et al. (2021) used the Lief Smart Patch which provided in the moment HRV biofeedback and notified the user in case of a specific HRV through vibration. In contrast to the other mentioned biofeedback-based interventions, the Lief Smart Patch guided the user through a breathing exercise by using vibration signals. The Lief smart patch started to vibrate when the users heart rate dropped, which cued the user to exhale. When the heart rate accelerates again, the vibration is turned off and the user is cued to inhale. The breathing exercise aimed to modulate the autonomous nerve system through slowed breathing whereby a coherent HRV can be achieved. During respiration, the heart rate increases while during exhalation, the heart rate decreases. This leads to an oscillation in heart rate called respiratory sinus arrythmia (RSA). An increased RSA can be accentuated through slowed breathing in resonance frequency, which is tried to be achieved by the vibration-led breathing exercise of the Lief smart patch (Chung et al., 2021). Similar to Smith et al. (2020), the study by Chung et al. (2021) also used a mobile application to visualize the user's physiological data during the breathing exercise. Furthermore, they used the application to provide a summary of the session data in the end of the exercise, including initial HRV before the exercise, final HRV of the last 30 seconds of the session and the change of HRV over the course of the exercise.

The study of Crivelli et al. (2019) used an EEG detecting eyeglasses to provide biofeedback during mindfulness training. Unlike the other devices mentioned here, Crivelli et

al. (2019) did not use the eyeglasses to notify the user in case of a certain physiological state. Instead, it was used to provide the user with real-time acoustic feedback trough a mobile application when the participants mind faded during the mindfulness training from the desired focused state into a more distracted, aroused state. The wearable-guided mindfulness sessions of 10 to 20 minutes were intended to increase users' concentration, ability to focus and self-regulation skills and thereby to mitigate anxiety.

Somewhat different approaches to mitigate anxiety were chosen by Costa et al. (2017) and Shruthi et al. (2021). Both studies used a wrist-worn device. Costa et al. (2017) employed a wearable called "EmotionCheck", which was used to simulate a slow, calm heartbeat (i.e., 60 bpm) in the form of vibrations at the user's wrist, caused by two small engines in the watch-like device. The authors assumed that the user would appraise the situation differently when he notices his heart rate to be slow, compared to when the heart rate is perceived to be high. They concluded that a slow, simulated heartbeat might make the individual feel calmer and thus reduce anxiety. The study by Shruthi et al. (2021) used a device that applied acupressure on a specific point at the user's wrist in case the device detected an increased heart rate. Derived from acupuncture, acupressure is a non-invasive technique of Chinese medicine, which entails the stimulation of acupoints by means of pressure (Chen & Chen, 2004). The acupressure was applied every three seconds until the user's heart rate normalized again. A connected mobile application was used to collect and visualize the users heart rate. The acupressure was intended to decrease symptoms of anxiety in the user.

Discussion

This scoping review aimed to provide an overview and orientation of current research about the use of wearable devices in the detection and treatment of anxiety disorders. To do so, five different points of exploration were followed. The first research question was about the type of anxiety complaint that was targeted by the wearable devices used in the selected studies. The results showed that all included studies focused on detecting and treating anxiety complaints and symptoms. None of the studies used a wearable to detect or treat a specific anxiety disorder or more specified symptoms of anxiety, expect one study which focused on the detection of symptoms related to social anxiety. This is rather surprising when looking at reviews that investigated other technologies that were used in the treatment of anxiety, such as Virtual Reality for instance. A review about the use of VR-Technology in anxiety disorders revealed a great body of literature that investigates its application and effectiveness in treating social anxiety, specific phobias, panic disorders and other anxiety disorders (Maples-Keller et al., 2017). These results imply that the current literature about wearable devices in the treatment and detection of anxiety lacks studies about the use of wearables in specific types and disorders of anxiety.

The second research question was about the types of wearable devices that were used. Results show that most of the wearable devices were consumer grade products. Furthermore, the results indicate that there is a broad range of different types of wearable devices available. The most frequent type of wearables among the included studies were wrist-worn devices like wristbands or bracelets. Other devices were body attached sensors, small clothing attached devices (e.g., Spire Stone), a smart shirt and a smart glasses. For clinical practice, the variety of wearable devices being available for consumers might be of benefit regarding the acceptance among users to use a wearable for e.g., continuous long-term monitoring, as it offers individuals the option to choose a device that fits their personal preferences and circumstances. In line with that, a prior study by Hunkin et al. (2020) suggested that the characteristics and features of wearable devices used in mental health care should match individual needs to increase the acceptance of such devices among clients. Specific characteristics of wearable devices such as the level of unobtrusiveness, discreteness, ease of use but also the look and the form of the device could be important factors for client's acceptance and willingness to use such devices. The results furthermore showed that many wearables function in conjunction with a smartphone application. This has already been indicated by previous research as well (Wright & Keith, 2014). This is not necessarily a limitation, as smartphones are widely prevalent (Poushter, 2016). However, it should be

regarded that especially older age groups are less familiar with smartphone usage, which could lead to difficulties when the wearable device requires the use of a smartphone (Rosales & Fernández-Ardèvol, 2019).

The third aspect of exploration was the role of the wearable devices. The results show that five wearable devices were used with the objective to detect symptoms of anxiety. Three of the studies included wearables that aimed to treat and detect anxiety simultaneously and another three wearables were merely used for the treatment of anxiety. At first stance, the combination of detection and treatment that some devices employed seems to be the most suited approach to help closing the mental health care gap regarding anxiety issues. The potential ability of these devices to detect anxious states and deliver immediately available interventions, provides the user with tools to manage the detected anxiety in real-time. In contrast, devices that only serve one function, so either the detection or treatment of anxiety, are rather a complementary tool as they still require the involvement of an external party. A wearable device that detects anxiety but does not provide treatment for instance, still requires the involvement of an external party that delivers the needed treatment to the client. Nevertheless, the different roles of the wearable devices can be employed for different purposes. Devices that are designed to deliver treatment, like the brain-sensing eyeglasses in combination with mindfulness-training for instance, could be used as a therapy tool in conventional psychotherapy. Prior research has shown that technological mental health interventions are more accepted and helpful when they are combined with therapeutic support (Hunkin et al., 2020). In addition, research implies that guided technological mental health interventions result in fewer dropouts and lead to better clinical outcomes in comparison to unguided interventions (Hunkin et al., 2020). In line with that, the use of self-help interventions without sufficient professional guidance can enhance the possibility of misdiagnosis and the greater likelihood of early dropout. Unguided self-help interventions might even be iatrogenic when they do not lead to any improvement of symptoms and thereby reinforce treatment avoidance (Hunkin et al., 2020). Consequently, it might be of special importance to regard wearable devices that function without professional guidance with caution and to explore how the above-mentioned risks can be decreased to make self-help interventions more efficient and less harming.

The fourth research question was about the kind of data that the wearable devices measured. Results showed that the different wearable devices measured a variety of physiological data. Not all wearable devices used the data to detect anxiety. Some devices merely measured physiological data to provide biofeedback as part of the intervention they

delivered. The most frequent measured physiological dimension was HR. Other measured dimensions were HRV, EDA, EEG, BVP, ST and blood oxygen saturation. Some studies also assessed movement in combination with another physiological dimension to differentiate between states of motion and rest. Most of these measured dimensions have been shown to be indicators of mental phenomena by previous research. Especially HRV has been shown to be correlated with stress and anxiety, as it is a physiological marker of increased ANS activity (Jung & Chung, 2013; Massot et al., 2012). Most of the wearable devices with the objective to detect anxiety, made use of machine learning algorithms to make sense of the collected data and to identify anxious states of the user. Some devices used less complex approaches to identify anxiety. One study used an increased heart rate during a resting state as an indicator for anxiety. These results illustrate that there is no common approach or golden standard regarding the measured dimensions and sense-making methods used to detect anxiety. Besides the benefits that might come with the potential ability to detect anxiety without the need to consult a clinician, there are also potential downsides of the continuous tracking of psychopathological symptoms. Prior research has shown that the constant tracking of physiological data can lead to increased rumination, self-focus, and emotional instability (Murnane et al., 2016). This indicates that future research in this field should be aware of negative consequences that continuous physiological tracking might have for individuals and explore how they can be mitigated.

Another point of discussion regarding the detection of anxiety is the subjective ground truth of mental states. It is questionable how reliable it is to draw inferences about anxiety from physiological data, when the ground truth of anxiety is based on subjective mental states. The variability of the subjective ground truth of anxiety might lower the wearable devices capability to detect anxiety in a reliable way (Chen, Mermel & Liu, 2021). A future challenge is thus to explore whether measuring the ground truth of anxiety can be improved, or how the remaining degree of error in detecting anxiety can be managed in a user-friendly way. Relatable, Mohr et al. (2017) stated that personal sensing systems like wearable devices will always have some degree of error. Hence, they argued that it is also of importance to deal with questions about how much uncertainty is acceptable and how errors can be mitigated to reduce potential harming effects on users (Mohr et al., 2017).

The fifth research question was about the kind of interventions applied by the wearable devices to treat anxiety. Results showed that most studies used the wearable as a biofeedback device in combination with breathing or mindfulness practice. Furthermore, four out of five wearable devices worked in conjunction with an application to deliver the

intervention. The applications were used to visualize the biofeedback, deliver breathing training sessions, or summarize session data, like initial and final HRV for instance. The finding that most wearables made use of biofeedback as an intervention to counteract anxiety is unsurprising when considering prior research about this topic. Biofeedback has been shown to be an effective technique for mitigating anxiety related complaints (Goessl et al. 2017). The findings further imply that most of the wearable devices do not deliver treatment or interventions independently, they are rather employed as complementary biofeedback tools in combination with evidence-based treatments such as mindfulness or breathing-techniques. This is in line with a previous literature review which suggested that the general role of wearable devices in anxiety treatment is to notify the user about aroused physiological states, which is intended to prompt the user to apply respective coping skills, such as breathing techniques for instance (Hunkin et al., 2019).

However, the results also showed that two of the studies used wearables which applied interventions without involving other treatment elements such as breathing techniques. One study used a wristband which applied acupressure on the user's wrist to mitigate anxiety (Shruthi et al., 2021) and another used a device to simulate a slow heartbeat in form of vibrations on the user's wrist to counteract anxiety (Costa et al., 2017). Such interventions might be beneficial because they are delivered in a way that is effortless for the user, as they do not require the user to engage and take action, in contrast to the previously described biofeedback interventions.

While wearables can be of use in the treatment of anxiety in the above-mentioned ways, their application should be seen with caution considering potential pitfalls and downsides. Prior research has suggested that the immediate and constant availability of interventions delivered by technology, such as wearables, might lead users to rely on the technology to provide them with an intervention (Murnane et al., 2016). Consequently, users' self-management abilities might be reduced (Murnane et al., 2016).

Strengths and Limitations

The present review provides a solid overview of recent studies that focus on the treatment or detection of anxiety using wearable devices, which is beneficial as it illustrates the potential scope and size of the topic. It explores the selected literature regarding several aspects of interest which might be useful for practitioners or researchers interested in the topic. Another strength of the present review is that only studies from the year 2016 or later were included.

This ensures that the results of this review are based on recent research. This is especially relevant considering the quickly developing technological nature of this field.

There are also some limitations of the present scoping review, which are important to identify and consider improving future research. One limitation of this study is the dimension and size of the literature search that was conducted for this review. The literature search could have led to a higher number of relevant studies by consulting more databases. A search throughout additional databases might have yielded to more relevant articles that could have been included, leading to a broader and more complete assessment of the topic. Instead of, or in addition to using a database that is focused on psychological research such as "PsycInfo", it could have been of benefit to include a more technical focused database, due to the technological nature of the topic addressed in this review. To conclude, the rather small scope of this review influences the generalizability of the results. Thus, the mentioned implications and findings should not be regarded as a general conclusion on the role of wearable devices in the detection and treatment of anxiety. Also, the implications for practice should rather be regarded as suggestions and not as evidence-based clinical implications.

A second limitation of the present scoping review is the number of researchers that were involved. This review was conducted by one researcher, which is why there was no inter-rater reliability. A second researcher involved in the selection process of studies might have led to a more reliable selection process.

A third limiting factor lies in the missing quality assessment of the included studies. There were no quality exclusion criteria established for the selection process of relevant studies. Quality exclusion criteria were not set as this review aimed to include as many adequate articles as possible, which was required to yield enough studies, due to limited nature of the literature search.

Conclusion and Directions for Future Research

This scoping review aimed to provide an overview of current research about the use of wearable devices in the detection and treatment of anxiety. The review showed that there is a deficit of studies investigating the use of wearables regarding specific types and disorders of anxiety. Thus, a recommendation for future research is to explore how wearables could be used for the detection and treatment of more specific anxiety complaints such as phobias or panic disorders for instance. Findings further showed that the detection of anxiety through wearable devices seems to be in an early stage of research, as there is no golden standard or common approach to the measured dimensions and applied sense-making methods available

yet. This field of research thus certainly requires further investigation, whereby the potential downsides of psychophysiological tracking and the challenges that come with the subjective ground truth of mental states should be considered (Murnane et al., 2016; Chen, Mermel & Liu, 2021). The great variety of different forms and types of wearable devices identified in this review could be beneficial for the acceptance of wearables among potential clients. Thus, future investigations could explore how certain features and characteristics of wearables influence the acceptance among clients to use such devices. The level of discreteness, unobtrusiveness, and ease of use of different types of wearable devices might be interesting aspects for further investigation.

Regarding the treatment of anxiety, the present review showed that most wearable devices used biofeedback interventions, in conjunction with mindfulness and breathing techniques, which has also been found by a prior review by Hunkin et al. (2019). However, there is also literature investigating wearables that deliver interventions independently to the user (Costa et al., 2017; Shruthi et al., 2021). Considering the benefits that guided technological interventions hold, it has been discussed that wearable devices used to treat anxiety could play a role as a tool or adjunct in conventional psychotherapy. Future meta-reviews could focus on examining the effectiveness of the applied wearable-based interventions to decrease anxiety, perhaps even in the context of blended treatment approaches. This could provide useful implications for the use of such interventions in clinical practice.

The generalizability of the present results should be validated in future research. This review made no conclusions about the effectiveness of wearable devices in the treatment and detection of anxiety. However, the nature of the reviewed literature and the present results suggest that they have a great potential to support conventional mental health care. One contribution of this study is that it raised a variety of recommendations to guide the direction of future investigations in this field. Besides that, the present scoping review provides an overview about recent literature dealing with how wearable devices could be used to support the treatment and detection of anxiety. The present findings and implications might inspire clinical psychologists and other mental health care professionals to use available wearable devices as an adjunct for conventional therapy approaches.

References

American Psychiatric Association. (2021). *What Are Anxiety Disorders?* https://www.psychiatry.org/patients-families/anxiety-disorders/what-are-anxiety-disorders

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (5th ed.).* https://doi.org/10.1176/appi.books.9780890425596.529303

Baldwin, D. S., Allgulander, C., Bandelow, B., Ferre, F., & Pallanti, S. (2012). An international survey of reported prescribing practice in the treatment of patients with generalised anxiety disorder. *The World Journal of Biological Psychiatry*, *13*(7), 510-516. https://doi.org/10.3109/15622975.2011.624548

Baldwin, D. S., Anderson, I. M., Nutt, D. J., Allgulander, C., Bandelow, B., Den Boer, J. A., Christmas, D. M., Davies, S., Fineberg, N., Lidbetter, N., Malizia, A., McCrone, P., Nabarro, D., O'Neill, C., Scott, J., Van der Wee, N., & Wittchen, H. (2014). Evidence-based pharmacological treatment of anxiety disorders, post-traumatic stress disorder and obsessive-compulsive disorder: A revision of the 2005 guidelines from the British Association for Psychopharmacology. *Journal of Psychopharmacology*, *28*(5), 403-439. https://doi.org/10.1177/0269881114525674

Bandelow, B., & Michaelis, S. (2015). Epidemiology of anxiety disorders in the 21st century. *Dialogues in clinical neuroscience*, *17*(3), 327-335. https://doi.org/10.31887/dcns.2015.17.3/bbandelow

Barlow, D. H. (2004). *Anxiety and its disorders: The nature and treatment of anxiety and panic*. Guilford Press.

Chen, H., & Chen, C. (2004). Effects of acupressure at the Sanyinjiao point on primary dysmenorrhoea. *Journal of Advanced Nursing*, *48*(4), 380-387. https://doi.org/10.1111/j.1365-2648.2004.03236.x

Chen, P. C., Mermel, C. H., & Liu, Y. (2021). Evaluation of artificial intelligence on a reference standard based on subjective interpretation. *The Lancet Digital Health*, *3*(11), e693-e695. https://doi.org/10.1016/s2589-7500(21)00216-8

Chung, A. H., Gevirtz, R. N., Gharbo, R. S., Thiam, M. A., & Ginsberg, J. (2021). Pilot study on reducing symptoms of anxiety with a heart rate variability biofeedback wearable and remote stress management coach. *Applied Psychophysiology and Biofeedback*, *46*(4), 347-358. https://doi.org/10.1007/s10484-021-09519-x

Cornelius, B., Van der Klink, J. J., Brouwer, S., & Groothoff, J. W. (2013). Under-recognition and under-treatment of DSM-IV classified mood and anxiety disorders among disability claimants. *Disability and Rehabilitation*, *36*(14), 1161-1168. https://doi.org/10.3109/09638288.2013.833310

Costa, J., Adams, A. T., Jung, M. F., Guimbretière, F., & Choudhury, T. (2017). EmotionCheck: A wearable device to regulate anxiety through false heart rate feedback. *GetMobile: Mobile Computing and Communications*, *21*(2), 22-25. https://doi.org/10.1145/3131214.3131222

Crivelli, D., Fronda, G., Venturella, I., & Balconi, M. (2019). Stress and neurocognitive efficiency in managerial contexts. *International Journal of Workplace Health Management*, *12*(2), 42-56. https://doi.org/10.1108/ijwhm-07-2018-0095

Chalmers, J. A., Quintana, D. S., Abbott, M. J., & Kemp, A. H. (2014). Anxiety disorders are associated with reduced heart rate variability: A meta-analysis. *Frontiers in Psychiatry*, *5*. https://doi.org/10.3389/fpsyt.2014.00080

Debard, G., De Witte, N., Sels, R., Mertens, M., Van Daele, T., & Bonroy, B. (2020). Making wearable technology available for mental healthcare through an online platform with stress detection algorithms: The Carewear project. *Journal of Sensors*, *2020*, 1-15. https://doi.org/10.1155/2020/8846077

Elgendi, M., & Menon, C. (2019). Assessing anxiety disorders using wearable devices: Challenges and future directions. *Brain Sciences*, *9*(3), 50. https://doi.org/10.3390/brainsci9030050

Evmenova, A., H. Graff, V. G. Motti, G. Giwa-Lawal & H. Zheng (2019). Designing a wearable technology intervention to support young adults with intellectual and developmental disabilities in inclusive postsecondary academic environments. *Journal of Special Education Technology,* 34 (2), 92–105. doi: 10.1177/0162643418795833.

Fairburn, C. G., & Patel, V. (2017). The impact of digital technology on psychological treatments and their dissemination. *Behaviour Research and Therapy*, *88*, 19-25. https://doi.org/10.1016/j.brat.2016.08.012

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, 26(2), 91-108. doi:10.1111/j.1471-1842.2009.00848.x

Goessl, V. C., Curtiss, J. E., & Hofmann, S. G. (2017). The effect of heart rate variability biofeedback training on stress and anxiety: A meta-analysis. *Psychological Medicine*, *47*(15), 2578-2586. https://doi.org/10.1017/s0033291717001003

Haberer, J. E., Trabin, T., & Klinkman, M. (2013). Furthering the reliable and valid measurement of mental health screening, diagnoses, treatment and outcomes through health information technology. *General Hospital Psychiatry*, *35*(4), 349-353. https://doi.org/10.1016/j.genhosppsych.2013.03.009

Hunkin, H., King, D. L., & Zajac, I. T. (2020). Perceived acceptability of wearable devices for the treatment of mental health problems. *Journal of Clinical Psychology*, *76*(6), 987-1003. https://doi.org/10.1002/jclp.22934

Hunkin, H., King, D. L., & Zajac, I. T. (2019). Wearable devices as adjuncts in the treatment of anxiety-related symptoms: A narrative review of five device modalities and implications for clinical practice. *Clinical Psychology: Science and Practice*, *26*(3). https://doi.org/10.1111/cpsp.12290

Jung, S., & Chung, W. (2013). Non-intrusive healthcare system in global machine-to-machine networks. *IEEE Sensors Journal*, *13*(12), 4824-4830. https://doi.org/10.1109/jsen.2013.2275186

Kasper, S. (2006). Anxiety disorders: Under-diagnosed and insufficiently treated. *International Journal of Psychiatry in Clinical Practice*, *10*(sup1), 3-9. https://doi.org/10.1080/13651500600552297

Layard, R. (2013). Mental health: the new frontier for labour economics. *IZA Journal of Labor Policy*, *2*(1), 1-16. https://doi.org/10.1002/9781118539415.wbwell103

Maples-Keller, J. L., Bunnell, B. E., Kim, S., & Rothbaum, B. O. (2017). The use of virtual reality technology in the treatment of anxiety and other psychiatric disorders. *Harvard Review of Psychiatry*, *25*(3), 103-113. https://doi.org/10.1097/hrp.0000000000000138

Massot, B., Baltenneck, N., Gehin, C., Dittmar, A., & McAdams, E. (2012). EmoSense: An ambulatory device for the assessment of ANS activity—Application in the objective evaluation of stress with the blind. *IEEE Sensors Journal*, *12*(3), 543-551. https://doi.org/10.1109/jsen.2011.2132703

Mohr, D. C., Zhang, M., & Schueller, S. M. (2017). Personal sensing: Understanding mental health using ubiquitous sensors and machine learning. *Annual Review of Clinical Psychology*, *13*(1), 23-47. https://doi.org/10.1146/annurev-clinpsy-032816-044949

Murnane, E. L., Cosley, D., Chang, P., Guha, S., Frank, E., Gay, G., & Matthews, M. (2016). Self-monitoring practices, attitudes, and needs of individuals with bipolar disorder:

Implications for the design of technologies to manage mental health. *Journal of the American Medical Informatics Association*, *23*(3), 477-484. https://doi.org/10.1093/jamia/ocv165

Nath, R. K., & Thapliyal, H. (2021). Machine learning-based anxiety detection in older adults using wristband sensors and context feature. *SN Computer Science*, *2*(5). https://doi.org/10.1007/s42979-021-00744-z

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology*, *2*(2), 175-220. https://doi.org/10.1037/1089-2680.2.2.175

Page, M. J., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., Tetzlaff, J., Akl, E., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E., Mayo-Wilson, E., McDonald, S., … Moher, D. (2020). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. https://doi.org/10.31222/osf.io/v7gm2

Parnandi, A., & Gutierrez-Osuna, R. (2017). Physiological modalities for relaxation skill transfer in biofeedback games. *IEEE Journal of Biomedical and Health Informatics*, 21(2), 361– 371. https://doi.org/10.1109/JBHI.2015.2511665

Phillips, S. M., Cadmus-Bertram, L., Rosenberg, D., Buman, M. P., & Lynch, B. M. (2018). Wearable technology and physical activity in chronic disease: Opportunities and challenges. *American Journal of Preventive Medicine*, *54*(1), 144-150. https://doi.org/10.1016/j.amepre.2017.08.015

Poushter, J. (2016). *Smartphone ownership and Internet usage continues to climb in emerging economies*. Pew Research Center. www.pewglobal.org/2016/02/22/smartphone-ownership-and-internet-usage-continues-to-climb-in-emerging-economies

Puli, A., & Kushki, A. (2020). Toward automatic anxiety detection in autism: A real-time algorithm for detecting physiological arousal in the presence of motion. *IEEE Transactions on Biomedical Engineering*, *67*(3), 646-657. https://doi.org/10.1109/tbme.2019.2919273

Rosales, A., & Fernández-Ardèvol, M. (2019). Smartphone usage diversity among older people. *Human–Computer Interaction Series*, 51-66. https://doi.org/10.1007/978-3-030-06076-3_4

Schoenberg, P. L. A., & David, A. S. (2014). Biofeedback for psychiatric disorders: A systematic review. *Applied Psychophysiology and Biofeedback*, 39(2), 109– 135. https://doi.org/10.1007/s10484-014-9246-9

Shaukat-Jali, R., Van Zalk, N., & Boyle, D. E. (2021). Detecting subclinical social anxiety using physiological data from a wrist-worn wearable: Small-scale feasibility study. *JMIR Formative Research*, *5*(10). https://doi.org/10.2196/32656

Shruthi, S., Dharshini, P., Ranjith Raj, B., Sarojini, V. L., Ezhilarasi, P., & Rajesh Kannan, S. (2021). Anxiety controlling wrist band. *Advances in Parallel Computing*, 145-154. https://doi.org/10.3233/apc210027

Smith, E. N., Santoro, E., Moraveji, N., Susi, M., & Crum, A. J. (2020). Integrating wearables in stress management interventions: Promising evidence from a randomized trial. *International Journal of Stress Management*, *27*(2), 172-182. https://doi.org/10.1037/str0000137

Somers, J. M., Goldner, E. M., Waraich, P., & Hsu, L. (2006). Prevalence and incidence studies of anxiety disorders: A systematic review of the literature. *Canadian Journal of Psychiatry*, *51*(2), 100–113. https://doi.org/10.1177/070674370605100206

Tiwari, A., Cassani, R., Narayanan, S., & Falk, T. H. (2019). A comparative study of stress and anxiety estimation in ecological settings using a smart-shirt and a smart-

bracelet. *2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2213-2216. https://doi.org/10.1109/embc.2019.8857890

Turchetta, L. (2019). Self-monitoring heart rate biofeedback: A secondary prevention strategy for managing anxiety in college students. https://doi.org/10.23860/diss-turchetta-louis-2019

Ueafuea, K., Boonnag, C., Sudhawiyangkul, T., Leelaarporn, P., Gulistan, A., Chen, W., Mukhopadhyay, S. C., Wilaiprasitporn, T., & Piyayotai, S. (2021). Potential applications of mobile and wearable devices for psychological support during the COVID-19 pandemic: A review. *IEEE Sensors Journal*, *21*(6), 7162-7178. https://doi.org/10.1109/jsen.2020.3046259

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. *Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering - EASE '14*. https://doi.org/10.1145/2601248.2601268

Wright, R., & Keith, L. (2014). Wearable technology: If the tech fits, wear it. *Journal of Electronic Resources in Medical Libraries*, *11*(4), 204-216. https://doi.org/10.1080/15424065.2014.969051

Zheng, Y., Wong, T. C., Leung, B. H., & Poon, C. C. (2016). Unobtrusive and multimodal wearable sensing to quantify anxiety. *IEEE Sensors Journal*, *16*(10), 3689-3696. https://doi.org/10.1109/jsen.2016.2539383

Appendix

Data Base: Web of Science

("wearable devices" OR "wearable Technology" OR wearables OR "unobtrusive device" OR wristband OR necklace OR bracelet) AND ("anxiety detection" OR "anxiety recognition" OR "anxiety symptoms" OR "anxiety diagnosis" OR "real-time anxiety monitoring" OR "stress detection" OR "anxiety disorder" or anxiety) AND ("anxiety treatment" OR "anxiety relief" OR "anxiety intervention" OR "anxiety reduction" OR "mental health improvement" OR intervention OR treatment)

Data Base: PsyInfo

("wearable devices" OR "wearable Technology" OR wearables OR "unobtrusive device" OR wristband OR necklace OR bracelet) AND ("anxiety detection" OR "anxiety recognition" OR "anxiety symptoms" OR "anxiety diagnosis" OR "real-time anxiety monitoring" OR "stress detection" OR "anxiety disorder" or anxiety) AND ("anxiety treatment" OR "anxiety relief" OR "anxiety intervention" OR "anxiety reduction" OR "mental health improvement" OR intervention OR treatment)

Data Base: Wiley

("wearable devices" OR "wearable Technology" OR wearables OR "unobtrusive device" OR wristband OR necklace OR bracelet) AND ("anxiety detection" OR "anxiety recognition" OR "anxiety symptoms" OR "anxiety diagnosis" OR "real-time anxiety monitoring" OR "stress detection" OR "anxiety disorder" or anxiety) AND ("anxiety treatment" OR "anxiety relief" OR "anxiety intervention" OR "anxiety reduction" OR "mental health improvement")

Data Base: Scopus

("wearable devices" OR "wearable Technology" OR wearables OR "unobtrusive device" OR wristband OR necklace OR bracelet) AND ("anxiety detection" OR "anxiety recognition" OR "anxiety symptoms" OR "anxiety diagnosis" OR "real-time anxiety monitoring" OR "stress detection" OR "anxiety disorder" or anxiety) AND ("anxiety treatment" OR "anxiety relief"

OR “anxiety intervention” OR “anxiety reduction” OR “mental health improvement” OR treatment)