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**Wearable devices as adjuncts in the treatment of anxiety-related symptoms: A narrative review of five device modalities and implications for clinical practice**

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**Wearable Devices as Adjuncts in the Treatment of Anxiety-Related Symptoms:  
A Narrative Review of Five Device Modalities and Implications for Clinical Practice**

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### Abstract

Anxiety disorders are a major public health problem, and a range of wearable technological devices for addressing the somatic symptoms of anxiety are increasingly available. This narrative review summarises five distinct modalities underlying wearable devices and investigates clinical implications for managing clients using such devices. The literature suggests potential benefits of HRV biofeedback devices, whilst other modalities (aided meditation, false physiological feedback, electrodermal biofeedback and respiration biofeedback) are less supported. High-quality research on the efficacy of such devices is also lacking, particularly in clinical populations. Wearables could offer potential benefits, but may be contraindicated in some cases. Collaborative use of clinical evaluation tools, such as the American Psychiatric Association's app evaluation model, can aid in shared decision-making about device use.

*Keywords:* Anxiety; Anxiety Disorders; Biofeedback; Clinical Decision-Making;

Neurofeedback; Wearable Electronic Devices

**Wearable Devices as Adjuncts in the Treatment and Management  
of Anxiety-Related Symptoms: A Narrative Review  
of Five Device Modalities and Implications for Clinical Practice**

Anxiety disorders are a major public health concern, with a lifetime prevalence rate estimated to be 16.6% globally (Somers, Goldner, Waraich, & Hsu, 2006). After depressive disorders, anxiety disorders carry the greatest disease burden of the mental disorders (Abajobir et al., 2017). Yet despite longstanding recognition of the treatment gap in mental health, and substantial increases in the size of the mental health workforce and related government funding, the evidence suggests that the prevalence of anxiety-related complaints continues to increase, even in developed nations (Jorm, Patten, Brugha, & Mojtabai, 2017). Furthermore, of those who seek help for mood and anxiety disorders, only 26% receive an evidence-based treatment (Jorm et al., 2017). While early technological mental health interventions have shown some promise for scaling up treatments (e.g., O'Connor, Munnely, Whelan, & McHugh, 2017), a new generation of consumer-targeted wearable electronic solutions that present new possibilities and challenges in addressing anxiety are now becoming available.

Wearables are interactive computing devices, worn either as an item of clothing or as an accessory, and they are an important element of the new frontier of healthcare innovation (Nasir & Yurder, 2015). Wearables, like mobile technologies for health (mHealth), are part of a broader movement to democratise healthcare, potentially enabling ubiquitous, patient-centred health provision. With smartphones acting as an “extension of the self” (Morris & Aguilera, 2012, p. 622), it has been argued that there is promise for improving access, uptake, adherence and engagement with treatments, as well as potentially enabling clients to continually manage their condition outside of treatment, resulting in reduced costs and better outcomes (Clough & Casey,

2015). Products like smart watches or fitness bands, usually paired with smartphone applications ('apps'), have already been widely adopted in the move towards a "quantified self": increased self-understanding based on personal analytics (Piwek, Ellis, Andrews, & Joinson, 2016). Now, a first generation of wearable devices for addressing mental wellbeing are moving beyond quantification with the promise of an "augmented self", including EEG headbands to aid meditation, sensors that provide feedback on irregular or adaptive breathing patterns, and heart rate variability monitors that seek to achieve coherence of cardiac and respiratory rhythms.

A common theme across most of these devices is that they provide some form of relaxation training, by giving the wearer an indication of their degree of arousal and guiding them in exercises to achieve calm. Some devices are designed for short session-based use, while others are intended to be worn all day, providing moment-to-moment feedback to the user as required (so-called ecological momentary interventions). It has been proposed that wearable devices could help to reduce various access barriers by avoiding the need to attend a clinic in some cases (Lui, Marcus, & Barry, 2017), and their deployment on a large scale might even contribute to the collection of field data that can answer difficult research questions, given appropriate user consent (Moraveji, 2012). The use of mHealth platforms may allow for these wearable interventions to be more seamlessly integrated into everyday life, and regular use might be encouraged through gamification (Deterding, O'Hara, Sicart, Dixon, & Nacke, 2011; Fleming et al., 2016). Technological delivery could also mean that treatments are more consistently applied, compared to provider delivery (Riley, 2017). Of course, many of these potential benefits remain hypothetical for now, since there has been little research on the actual acceptability of wearable devices, while research into other e-mental health interventions

suggests that widespread adoption has not yet been achieved, despite there being evidence for the efficacy of some of these treatments (Apolinário-Hagen, Kemper, & Stürmer, 2017).

Wearable devices may be particularly suitable for tackling anxiety because somatic symptoms are a significant feature of various anxiety disorders, and many of these symptoms relate to over-activation of the sympathetic nervous system and corresponding under-activation of the parasympathetic nervous system (Friedman, 2007; Mallorquí-Bagué, Bulbena, Pailhez, Garfinkel, & Critchley, 2016). Practice with calming technologies might therefore help to increase self-efficacy, reduce aversive interpretations of somatic arousal (Meuret, Wilhelm, & Roth, 2004), or even lead to lasting physiological changes (for example, improved baroreflex function; Lehrer et al., 2003). Relaxation techniques already have an established place in the treatment of anxiety disorders (Manzoni, Pagnini, Castelnuovo, & Molinari, 2008), but given the rapid development and commercialisation of wearables, little knowledge has been generated thus far about whether they could facilitate this approach to treatment (Coffey & Coffey, 2016). Nonetheless, despite the lack of existing evidence, numerous online reviews and opinion pieces offer enthusiastic endorsement for the use of these devices in improving wellbeing and addressing clinical disorders such as anxiety. At the same time, strong growth in annual sales of wearable devices is projected to continue over coming years (CCS Insight, 2017). As with the proliferation of smartphone apps, the growing number of wearables presents a challenge for clinicians in terms of being able to provide up-to-date advice to clients who may be eager to use such technologies.

In the present review, we aimed to describe the range of modalities through which wearables ostensibly address anxiety, highlight some of the available evidence for those modalities and for specific devices, and summarise some of the potential implications of using

wearables in a clinical context. Importantly, given the broad nature of this issue in terms of the range of technologies available, their mechanisms of action, and the generally limited research material available, a systematic review was not considered appropriate. Instead, we undertook a narrative review to capture the diversity of devices and evidence available in one article (Dijkers, 2009).

In order to determine relevant devices for inclusion herein, literature and broader Internet searches were conducted using search terms such as “wearable device” or the name of specific device modalities once these had been identified. For inclusion, devices needed to (i) be currently available direct to consumers, (ii) cost less than USD \$500, (iii) comprise active intervention elements using physiological or neurological signals, and (iv) be oriented toward consumer use rather than research or specialised applications unrelated to anxiety symptoms. A total of 40 devices were identified, with 26 devices being excluded (research/specialised orientation: 11, no active intervention elements: 9, not presently available for purchase: 4, cost: 1, not wearable: 1). The remaining 14 devices (Table 1) were then grouped according to their assumed modalities. Each of these modalities is further described below, and, where available, the results of recent systematic reviews evaluating the evidence for each modality are summarised. Furthermore, where literature that specifically evaluated the identified devices could be found, it is also reviewed here. Following this discussion of different device modalities, the clinical implications of using these devices—including risks and unexpected effects, as well as approaches for clinical evaluation—are considered.

## **Device Modalities**

### **Heart rate variability biofeedback**

Many of the wearable devices for anxiety identified in this review ostensibly operate through biofeedback. Biofeedback training devices are thought to work by feeding back information about bodily signals to allow trainees to recognise and learn to control those signals. While early biofeedback research tended to focus on parameters such as skin temperature, heart rate and muscle potential, recent devices have been developed around bodily signals that require more sophisticated measurement and/or interpretation, such as heart rate variability, electrodermal activity, respiration and EEG (Schoenberg & David, 2014). Heart rate variability (HRV) is the variation in interval between heartbeats. It is an important signal because it has been shown to be a reliable predictor of physical health as well as an indicator of healthy parasympathetic functioning, which is associated with the ability to self-regulate emotions under stress (Caldwell & Steffen, 2018; Goessl, Curtiss, & Hofmann, 2017; Jester, Rozek, & McKelley, 2018). It is perhaps unsurprising, then, that reduced HRV has been observed in most types of anxiety disorder (Chalmers, Quintana, Abbott, & Kemp, 2014). HRV is influenced in large part by respiratory sinus arrhythmia, whereby heart rate accelerates during inhalation and decelerates during exhalation (Goessl et al., 2017). HRV biofeedback aims to maximize HRV by guiding trainees in breathing at their “resonance rate”—the number of breaths per minute that produces the largest variability in heart rate, usually around six—through feeding back information about their HRV (Kleen & Reitsma, 2011). The resonance rate causes maximal heart rate oscillation as a result of heart rate becoming in phase with breathing and out of phase with blood pressure oscillations (Lehrer & Gevirtz, 2014).



Individual HRV biofeedback devices may operate in slightly different ways, but they generally work by giving paced breathing cues while also displaying feedback about the level of coherence being achieved between heart rate and breathing. The range of available HRV devices are perhaps the most developed in terms of wearables for mental health. This may be in part because unlike most other wearables, non-proprietary communication protocols used by many HRV sensors mean that apps can connect with a range of different sensors, and vice versa. Perhaps for this reason, some HRV solutions can appear economical when compared to other wearables. Sensors come in multiple forms, from chest straps to optical ear or finger clip sensors. Future apps may even utilise the smartphone camera as a photoplethysmographic heart rate sensor, allowing for HRV to be trained without the use of an additional measuring device, and this technique has been shown to produce valid measurements (Plews et al., 2017). Some of the products on the market are entirely integrated offerings, which function either as standalone devices (e.g. HeartMath emWave 2) or as a paired sensor and smartphone app (e.g. HeartMath Inner Balance). HRV measurement is also incorporated into many recent fitness watch products such as some FitBit and Garmin devices, as well as the Apple Watch. However, these watch implementations are typically not compatible with standard communication protocols, meaning that only proprietary software can be used, and this often does not feature biofeedback options, but is used instead for quantifying fitness levels. Furthermore, the sensors used in wrist-worn devices can be prone to artefacts, and so accurate readings may only be produced when completely still (Baek & Shin, 2017).

**Support for HRV biofeedback.** A recent meta-analysis of 24 RCTs targeting stress and anxiety in clinical and non-clinical populations revealed large effects for HRV biofeedback overall, both within groups and when compared to a mix of passive and active controls (Goessl

et al., 2017). However, the authors of that review identified an unclear risk of study bias (according to Cochrane Handbook guidelines) in the majority of included studies, such that sub-optimal randomisation, blinding, and treatment of missing data may compromise the fidelity of the results. While Goessl et al. attempted to evaluate the impact of study bias with a moderation analysis, the non-significant results of this analysis cannot be interpreted for the intended purpose because only studies with a high or unclear overall risk of bias were included. Schmidt and Martin (2017) carried out a further qualitative systematic review of 21 RCTs using HRV biofeedback for physical and psychological problems, finding that increases in HRV were persistent, and effects on psychological variables like subjective stress were positive but generally not superior to active controls. However, they also note a lack of controlled studies showing effects of HRV biofeedback on psychological outcomes. Both reviews thus demonstrate that potential study bias is a major limitation of the evidence available at present. A second major issue is that few studies identified in these systematic reviews compared HRV biofeedback with active controls in clinical populations. This represents a significant concern for clinicians, who need to know whether a proposed intervention is likely to be at least as effective as current best practices for the treatment of a specific disorder or symptom cluster. Other limitations of existing research include a failure to observe a dose-response relationship in many studies, as well as differences in treatment protocols between studies. Most outcome measures rely on self-report, although physiological and neurological changes have also been observed, indicating that outcomes are not limited to subjective measures (Lehrer et al., 2003; Prinsloo, Rauch, Karpul, & Derman, 2013). Lastly, the long-term benefits of treatment, including how measured improvements translate into everyday coping, have not been well explored as yet (Wheat & Larkin, 2010). In summary, while recent systematic reviews suggest that HRV

biofeedback could lead to clinically significant improvements for people with anxiety through increased self-awareness and improved physiological and psychological self-regulation, higher quality research, and particularly studies within clinical populations that compare against active control treatments, are needed to further substantiate these claims (Goessl, Curtiss, & Hofmann, 2017; Schmidt & Martin, 2017). Since much of the research in these reviews was done with research-grade equipment, and given the difficulty in measuring HRV accurately, more evidence is also needed to show that these treatments can be effectively reproduced in consumer-grade wearable technology.

### **Respiration biofeedback**

Another bodily signal targeted by biofeedback devices is respiration. The dynamic two-way relationship between breathing patterns and affective state has already been well established (Ley, 1999). While stress may lead to hyperventilation—depending on the intensity of the stressor and the learned reactivity to stress—respiratory rate can also be controlled volitionally, and is therefore a potential therapeutic target (Moraveji, 2012). Irregularities in baseline respiratory rate have been observed in some diagnoses of anxiety (Grassi et al., 2014). Furthermore, a decreased baseline respiratory rate has been observed following clinical interventions like meditation (Pascoe, Thompson, Jenkins, & Ski, 2017). Acknowledging this connection, breathing training has been used as an effective clinical treatment, sometimes aided by feeding back information about respiratory parameters to trainees (Meuret, Wilhelm, & Roth, 2004). When combined, respiratory features such as breath rate, inhalation-exhalation ratio and tidal volume can discriminate stress with a similar level of power to ECG features, and closely predict self-reported measures of perceived stress in ecologically valid scenarios (Plarre et al., 2011). However, consistently monitoring the breath during everyday life is challenging as

constant attention is required, and respiratory patterns therefore represent a potential target for intervention with wearable devices.

Perhaps the first mass-market wearable device based on respiratory activity is the Stone (Spire, Inc), a small sensor that is attached to the belt or underwear. This device registers breathing patterns and categorises the user's state as normal, calm, tense, or focused. It can send alerts to the wearer when changes in breath indicate a rise in tension, and gives positive feedback when users achieve an extended period of calm. Guided meditations with respiratory feedback are also available on demand through the app.

**Support for respiration biofeedback.** To date, there appears to be little evidence around the effectiveness of respiration biofeedback. A recent systematic review of multiple biofeedback modalities identified only three studies where respiration biofeedback was used, all of which were for treatment of panic disorder, with only one study reporting statistically significant symptomatic change (Schoenberg & David, 2014). However, the treatments used in these studies were fundamentally quite different to that of devices that provide ecological momentary interventions based on respiratory features, such as the Stone, making it difficult to translate any conclusions. Little research evaluating such devices appears to have been conducted thus far. An unpublished study conducted by Spire in partnership with Stanford University and LinkedIn engaged 225 LinkedIn employees, around half of whom received a Stone device and used it over a one-month period (Moraveji et al., 2017). Compared to the group who did not receive a device, users demonstrated significant decreases in measures of anxiety, negative affect and perceived stress. While the amount of time spent in a 'calm' state (as classified by the device) increased by 37% on average over the course of the study, high variability between participants meant that this change was not statistically significant. The study's conclusions should be

considered with caution since it was not subjected to peer review, and the open-label nature of the trial means that expectancy effects were not controlled for. Furthermore, the participants did not represent a well-defined clinical population, and a 41% drop-out rate in the treatment group suggests that uptake of the device among users may be problematic.

### **Electrodermal activity biofeedback**

Electrodermal activity (EDA), also known as galvanic skin response, refers to the changes in conductance of the skin due to sweat glands being activated by the sympathetic nervous system (Parnandi & Gutierrez-Osuna, 2017). Changes in EDA are associated both with neural measures of arousal (Critchley, Eccles, & Garfinkel, 2013) and with psychological stress (Salafi & Kah, 2015; Visnovcova, Mestanik, Gala, Mestanikova, & Tonhajzerova, 2016). There are two primary characteristics of EDA: skin conductance level (SCL) is a baseline measure of sympathetic arousal, while skin conductance response (SCR) refers to momentary peaks in the signal which occur in response to episodic stressors such as startle events or affective arousal (Parnandi & Gutierrez-Osuna, 2017). Only one consumer-grade EDA biofeedback device was identified in the present review. The Pip (Galvanic Ltd) is a small device that is held between the thumb and forefinger, and it can be used with a number of included game-based apps in which the user makes progress toward goals by reducing their level of arousal.

**Support for EDA biofeedback.** Despite research showing the link with objective and subjective measures of arousal, a recent systematic review found a lack of quality evidence for the efficacy of EDA biofeedback for any mental disorder thus far (Schoenberg & David, 2014). Only one study evaluating an EDA-based wearable device could be identified, trialling the Pip in a group of healthy participants using game-based apps following a stress induction two after (Dillon, Kelly, Robertson, & Robertson, 2016). Compared to the control group who played a

game without biofeedback, participants using the Pip reported significantly lower heart rate and perceived stress. However, the observed effect size was small, and longer-term effects were not studied. Further studies therefore appear to be required in order to establish the credibility of this form of treatment, particularly with regard to anxiety disorders.

### **Neurofeedback and aided meditation**

Neurofeedback, also known as EEG biofeedback, is a specific form of biofeedback that works by giving users information regarding characteristics of the EEG signal measured over particular cortical regions (Demos, 2005). For some decades, neurofeedback has been used clinically to treat conditions such as attention disorders and epilepsy (Kopřivová et al., 2013). Neurotherapy typically involves taking quantitative EEG data which can be compared to normative data to identify cortical regions that are under- or over-active within specific frequency bands, after which neurofeedback protocols can be developed to reward normalisation of brain activity in these areas (Demos, 2005). Consumer-grade neurofeedback devices operate in a simpler way, often only having active sensors in the prefrontal area where hair does not preclude the use of dry electrodes. These devices typically have a range of manufacturer and/or third-party apps which function in various ways. Some apps simply quantify EEG state, while others attempt to infer associated mental state (e.g. focused, tense, relaxed), or include games where the objective is for the user to perform increasingly difficult tasks while controlling their level of arousal. However, the specific EEG patterns being targeted by these apps are often not disclosed, making it difficult to make any generalisations about the efficacy of treatments using this modality.

One specific way that neurofeedback might be used to improve mental health is through aiding meditation. Meditation-based interventions have been associated with significant reductions in physiological signs of stress, such as cortisol, blood pressure and heart rate (Pascoe et al., 2017). Limited early evidence suggests that mindfulness programs incorporating meditation could be comparable to gold-standard cognitive behavioural interventions when used to treat anxiety disorders (Singh & Gorey, 2017), although more research is needed to comprehensively address this question. Furthermore, stand-alone (i.e., used in isolation from other treatment) mindfulness exercises such as guided breathing meditation have been shown to have small-to-moderate effects on anxiety compared with stand-alone active controls (Blanck et al., 2018). Aided meditation employs algorithms that process EEG signals to detect mind-wandering, which has been associated with gamma power in the posterior cingulate cortex (van Lutterveld et al., 2017) and with theta power globally (Braboszcz & Delorme, 2011). Auditory or visual feedback can then be given to the user, for example by increasing the volume of background sounds to signal the mind becoming distracted. Because meditation can be difficult to learn, neurofeedback may help the learning process by giving objective feedback (van Lutterveld et al., 2017). Moreover, some clients feel they are “doing nothing” during meditation or that the instructions are ambiguous (Kleen & Reitsma, 2011), and real-time feedback based on cortical activity could overcome this problem. It should be noted that current implementations of aided meditation tend to be developed specifically for use with concentrative meditation, such as focusing on the breath, but may not necessarily support other meditative approaches such as mindfully being aware and accepting of all thoughts and feelings.

**Support for assisted meditation.** Few studies have assessed the efficacy of neurofeedback-assisted meditation devices, perhaps because of their relatively recent inception.

Several recent trials have evaluated the use of the Muse headband relative to similarly structured active controls in short (4-6 week) interventions (Balconi, Fronda, & Crivelli, 2018; Balconi, Fronda, Venturella, & Crivelli, 2017; Bhayee et al., 2016; Crivelli, Fronda, Venturella, & Balconi, 2018). The results of this early research suggest that compared to controls, regular use of Muse could lead to significant improvements in outcomes such as somatic symptoms, perceived stress, state anxiety, and mood modulation in healthy or moderately stressed adults. Crivelli et al. (2018) also reported significant changes in objective measures such as a reaction time task, N2 event-related potentials, and associated EEG measures. Preliminary results of another trial involving people with a mild-to-moderate traumatic brain injury suggest improvements in anxiety and depression symptoms, as well as measures of self-efficacy and mindfulness, although full analyses from this study are yet to be reported (Gray, 2017). Importantly, no published studies using participants with anxiety or other psychological disorders were identified and thus, the efficacy of such devices in clinical populations remains entirely unknown.

### **Entrainment and false feedback**

Another mechanism through which wearable devices can operate is entrainment. Entrainment is the synchronisation of one's brain or body with rhythmic stimuli found in the environment, either voluntarily or involuntarily (Ross & Balasubramaniam, 2014). Unlike biofeedback, entrainment does not rely on learning or even on paying attention to a stimulus, but can occur merely through exposure. For example, heart rate and respiration rate tend to be entrained by music, relative to the tempo (Larsen & Galletly, 2006). In false feedback approaches, a signal is provided which explicitly mimics a natural physiological rhythm, such as heart rate. This type of feedback may alter the perception of emotional arousal, including both



positive and negative affect (Crucian et al., 2000). Entrainment and false feedback technologies offer interesting avenues for exploration because they may have the potential to aid emotional regulation with no effort required from the user, reducing problems of compliance, and avoiding the possibility that managing the device itself will become an added stressor for the user (Costa, Adams, Jung, Guimbretière, & Choudhury, 2016).

**Support for false feedback.** The entrainment of neural rhythms (brainwave entrainment) has already received much attention from both researchers and consumers, and due to the fact that such devices are not novel, they will not be further explored here. However, recent research has also explored the potential for entraining other physiological characteristics through wearable devices. Costa et al. (2016) developed a prototype wristband device to deliver a heartbeat-like vibration at a consistent low tempo where the pulse is normally felt. Under induced stress, users who were told the device fed back their heart rate had a significantly lower increase in state/trait anxiety relative to the control group, who wore the device switched off. A third group who had the device switched on, but were told only that it created a vibration, did not differ significantly from the control group. These results suggest that the perception of the truthfulness of feedback is important. However, Azevedo et al. (2017) found different effects with the *doppel*—a very similar commercially available device—under comparable conditions. Here, participants who had the device switched on demonstrated an objectively and subjectively reduced stress response, even though they were told that it was simply a measuring instrument. While these early studies show promise, physiological entrainment needs to be researched much more thoroughly in order to answer the outstanding questions and generate sufficient evidence to warrant its use, particularly in clinical populations.

### **Clinical Implications**

As with many new or alternative therapies there is a growing interest in using wearable devices for mental health, however this has not been matched with adequate supporting evidence. In particular, researchers have not yet investigated whether any of the wearable devices identified in this review are effective for people experiencing clinically significant anxiety symptoms. This is a substantial limitation given that evidence-based approaches emphasise the importance of appropriate evidence being applicable to the specific patient or problem at hand (Gillam & Siriwardena, 2014). Nevertheless, failing to fully engage with clients who intend to use wearables as part of their treatment might lead to those clients seeking help elsewhere, or worse still, not at all (Coffey & Coffey, 2016). If nothing else, the use of wearables as an adjunct to therapy may potentially help through expectancy effects and increased engagement. Several devices also offer online practitioner portals which allow clinicians to monitor the data generated by the client's devices, given their consent—a feature which may be useful in monitoring progress, increasing adherence, and potentially in providing useful diagnostic information.

### **Risks and unexpected effects**

Little research has explored the implications of using biofeedback devices as an adjunct to therapy, although potential side effects such as fatigue and dizziness have been identified (Clough & Casey, 2011). For aided meditation, existing contraindications for meditative therapies might be considered, such as a history of trauma, psychosis, mania, suicidality, or seizures (Lustyk, Chawla, Nolan, & Marlatt, 2009). Anxiety about technology could mean that for some clients, attempts to use wearables exacerbates the very issue they try to address (Laxman, Krishnan, & Dhillon, 2015). It has also been suggested that relaxation techniques may

become counterproductive to therapeutic objectives if they begin to be used as a strategy to avoid unpleasant emotions rather than allowing them to be experienced (Allen, McHugh, & Barlow, 2007).

Cuijpers and Schuurmans (2007) report that self-help interventions, including relaxation techniques, are particularly useful in overcoming client barriers such as cost, distance and an anxiety of traditional mental health settings. However, the use of self-help interventions without sufficient professional guidance was a concern due to the possibility of misdiagnosis and the greater likelihood of early dropout. Evidence-based interventions could be iatrogenic if they are poorly implemented technologically, leading to no improvement and thereby reinforcing treatment avoidance (Torous, Levin, Ahern, & Oser, 2017). Concerns have also been expressed about whether the use of technology may compromise the therapeutic alliance, although there is some evidence for the opposite, at least where technology is used appropriately according to client preferences (Richards, Simpson, Bastiampillai, Pietrabissa, & Castelnovo, 2016). Furthermore, the use of mHealth technologies may be unsuited to clients who are at significant safety risk, and may cause unnecessary complications in complex therapeutic cases (Torous & Roberts, 2017).

Clinicians can educate clients about the fact that not all treatment approaches are beneficial for every person, and help them to understand the potential risk of iatrogenic effects. For some clients, an over-reliance on the information provided by devices could be a concern: one report indicates that clients may become fixated on wearable device data—which may be limited in accuracy and scope—resulting in the therapeutic relationship being compromised (Baron, Abbott, Jao, Manalo, & Mullen, 2017). It may therefore be important to emphasise to some clients that wearables are only one piece of the larger treatment picture, and to have an

open discussion about the limitations to the validity and effectiveness of such devices. On the other hand, perceptions of limited treatment efficacy may increase the risk of premature termination of therapy (Mojtabai et al., 2012), so having an overly negative attitude about wearables may become a self-fulfilling prophesy.

### **Clinical evaluation of devices**

While Clough and Casey (2015) contend that practitioners need to be familiar with mHealth technologies in order to effectively guide clients, Morris and Aguilera (2012) instead see the client as taking ownership, with clinicians guiding the discussion about how devices are being used and adding value to the treatment. Asking the client to demonstrate the use of the device may however be helpful in beginning a dialogue about possible risks and benefits, and about how use of the device might play a role in the treatment (Torous & Roberts, 2017). Because new wearables are constantly being developed, it may be almost impossible for practitioners to stay abreast of individual devices. Moreover, the information that manufacturers openly provide about the functionality of their devices and their scientific validity is often lacking. Having a basic understanding of the various modalities through which devices operate, as discussed in this review, may aid in navigating this new landscape and in providing guidance to clients. Nonetheless, treatment benefits may vary depending on the fidelity with which the treatment is implemented within each particular device. Much of the supporting evidence for particular modalities (in particular, HRV) is based on the use of research-grade equipment, and this raises questions over whether such treatments can be reproduced in much less robust consumer-grade devices. Furthermore, it is likely that other factors such as device design and usability could have a substantial effect on treatment outcomes.

While no evaluation resources appear to have been developed specifically for wearable devices, there are a number of evaluation frameworks and portals designed to aid clinicians in selecting appropriate mobile apps for mental health (Neary & Schueller, 2018), and these may be adopted for wearables too. Research suggests that apps for anxiety disorders predominantly do not employ evidence-based components and the uptake of apps based directly on academic research is low (Bry, Chou, Miguel, & Comer, 2018; Neary & Schueller, 2018), necessitating proper evaluation of potential interventions. At present, the PsyberGuide website ([psyberguide.org](http://psyberguide.org)) appears to be the only portal to list any wearable devices, with a review of the Muse headband. Another approach is to use evaluation frameworks which provide structured guidelines for the systematic appraisal of mHealth technologies, and these frameworks can readily be applied to devices. While some comprehensive scales have been developed to score technologies on a range of criteria (Baumel, Faber, Mathur, Kane, & Muench, 2017; Stoyanov et al., 2015), the American Psychiatric Association's app evaluation model (American Psychiatric Association, 2017; Torous et al., 2018) is a briefer hierarchical framework that may be more suitable for clinical decision making, as it is used to weigh up apps qualitatively according to individual priorities. Under this system, apps are subjected to a five-stage process beginning with the collection of background information, followed by the evaluation of risks, evidence, ease of use, and interoperability in turn (Figure 1). Each stage of the assessment leads to a decision to proceed, to proceed with caution, or not to proceed. This type of rapid evaluation may be useful in helping clinicians and clients orient to pertinent appraisal factors, instead of depending on unreliable information such as app store ratings and user reviews. Where the use of technology is initiated by the clinician, this shared evaluation can also serve to adequately inform the client before consenting to treatment (Torous & Roberts, 2017).

### **Conclusion**

While there is strong and growing interest in wearable technologies for mental health disorders like anxiety, this interest has not yet catalysed sufficient research into the efficacy and effectiveness of such devices. As with other mental health technologies, the introduction of wearable devices is bound to result in ongoing disruption in the way that treatments are delivered, at least for some. Due to the broad subject of the present review, a narrative review approach was taken, limiting inferences that can be made about levels of evidence. However, it was nonetheless apparent that overall, little evidence exists to support the use of specific devices for the treatment of anxiety disorders. This is perhaps due to the fact that technology is often superseded before it can be properly evaluated. What evidence for specific devices could be identified here was also largely limited by methodological constraints and narrow or non-clinical samples, making the implications for the treatment of clinically significant anxiety symptoms in real-world clinical settings unclear. Furthermore, general evidence for the modalities through which these devices are presumed to work also appears to be limited, though HRV biofeedback may be an exception to this. Despite this general lack of evidence, it is advantageous for clinicians to be aware of common wearable devices and how they ostensibly function, since it is increasingly likely that clients may independently adopt such technologies. However, the use of these devices as adjuncts should not supplant treatment with appropriate established therapies. Clinicians should be aware that there can be risks and unexpected effects resulting from the use of wearable devices. Using clinical evaluation tools such as the APA app evaluation model to weigh up risks and benefits together with clients can help to identify anticipated problems,

ensure both client and practitioner are fully informed, and determine how devices will help work towards therapeutic goals.

### References

- Abajobir, A. A., Abate, K. H., Abbafati, C., Abbas, K. M., Abd-Allah, F., Abdulkader, R. S., ... Zuhlke, L. J. (2017). Global, regional, and national disability-adjusted life-years (DALYs) for 333 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2016: A systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*, *390*(10100), 1260–1344. [https://doi.org/10.1016/S0140-6736\(17\)32130-X](https://doi.org/10.1016/S0140-6736(17)32130-X)
- Allen, L.B., McHugh, R.K., Barlow, D.H., 2007. Emotional disorders: A unified protocol, in: Barlow, D.H. (Ed.), *Clinical Handbook of Psychological Disorders: A Step-by-Step Treatment Manual*. Guilford Press, New York, pp. 216–249.
- American Psychiatric Association. (2017). App evaluation model. Retrieved June 4, 2018, from <https://www.psychiatry.org/psychiatrists/practice/mental-health-apps/app-evaluation-model>
- Azevedo, R. T., Bennett, N., Bilicki, A., Hooper, J., Markopoulou, F., & Tsakiris, M. (2017). The calming effect of a new wearable device during the anticipation of public speech. *Scientific Reports*, *7*(1), 2285. <https://doi.org/10.1038/s41598-017-02274-2>
- Baek, H. J., & Shin, J. (2017). Effect of missing inter-beat interval data on heart rate variability analysis using wrist-worn wearables. *Journal of Medical Systems*, *41*(10), 147. <https://doi.org/10.1007/s10916-017-0796-2>
- Balconi, M., Fronda, G., Venturella, I., & Crivelli, D. (2017). Conscious, pre-conscious and unconscious mechanisms in emotional behaviour. Some applications to the mindfulness approach with wearable devices. *Applied Sciences*, *7*, 1–14. <https://doi.org/10.3390/app7121280>
- Baron, K. G., Abbott, S., Jao, N., Manalo, N., & Mullen, R. (2017). Orthosomnia: Are some patients taking the quantified self too far? *Journal of Clinical Sleep Medicine*, *13*(2), 351–



354. <https://doi.org/10.5664/jcsm.6472>

Baumel, A., Faber, K., Mathur, N., Kane, J. M., & Muench, F. (2017). Enlight: A comprehensive quality and therapeutic potential evaluation tool for mobile and web-based eHealth interventions. *Journal of Medical Internet Research, 19*(3).

<https://doi.org/10.2196/jmir.7270>

Bhayee, S., Tomaszewski, P., Lee, D. H., Moffat, G., Pino, L., Moreno, S., & Farb, N. A. S. (2016). Attentional and affective consequences of technology supported mindfulness training: A randomised, active control, efficacy trial. *BMC Psychology, 4*(60), 1–14.

<https://doi.org/10.1186/s40359-016-0168-6>

Blanck, P., Perleth, S., Heidenreich, T., Kröger, P., Ditzen, B., Bents, H., & Mander, J. (2018). Effects of mindfulness exercises as stand-alone intervention on symptoms of anxiety and depression: Systematic review and meta-analysis. *Behaviour Research and Therapy, 102*, 25–35. <https://doi.org/10.1016/J.BRAT.2017.12.002>

Braboszcz, C., & Delorme, A. (2011). Lost in thoughts: Neural markers of low alertness during mind wandering. *NeuroImage, 54*(4), 3040–3047.

<https://doi.org/10.1016/j.neuroimage.2010.10.008>

Bry, L.J., Chou, T., Miguel, E., Comer, J.S., 2018. Consumer smartphone apps marketed for child and adolescent anxiety: A systematic review and content analysis. *Behaviour Therapy, 49*, 249–261. <https://doi.org/10.1016/j.beth.2017.07.008>

Caldwell, Y. T., & Steffen, P. R. (2018). Adding HRV biofeedback to psychotherapy increases heart rate variability and improves the treatment of major depressive disorder. *International Journal of Psychophysiology, in press*. <https://doi.org/10.1016/J.IJPSYCHO.2018.01.001>

CCS Insight. (2017). Forecast reveals steady growth in smartwatch market. Retrieved May 28,

2018, from <https://www.ccsinsight.com/press/company-news/2968-ccs-insight-forecast-reveals-steady-growth-in-smartwatch-market>

- 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*, 1–11. <https://doi.org/10.3389/fpsy.2014.00080>
- Clough, B. A., & Casey, L. M. (2011). Technological adjuncts to enhance current psychotherapy practices: A review. <https://doi.org/10.1016/j.cpr.2010.12.008>
- Clough, B. A., & Casey, L. M. (2015). The smart therapist: A look to the future of smartphones and mHealth technologies in psychotherapy. *Professional Psychology: Research and Practice, 46*(3), 147–153. <https://doi.org/10.1037/pro0000011>
- Coffey, M. J., & Coffey, C. E. (2016). The emerging story of emerging technologies in neuropsychiatry. *Dialogues in Clinical Neuroscience, 18*(2), 127–134. <https://doi.org/10.1097/BOR.0b013e32834b5457>
- Costa, J., Adams, A. T., Jung, M. F., Guimbretière, F., & Choudhury, T. (2016). EmotionCheck: Leveraging bodily signals and false feedback to regulate our emotions. In *UbiComp 2016 - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (pp. 758–769). <https://doi.org/10.1145/2971648.2971752>
- Critchley, H. D., Eccles, J., & Garfinkel, S. N. (2013). Interaction between cognition, emotion, and the autonomic nervous system. In R. M. Buijs & D. F. Swaab (Eds.), *Handbook of Clinical Neurology* (pp. 59–77). Elsevier B.V. <https://doi.org/10.1016/B978-0-444-53491-0.00006-7>
- Crucian, G. P., Hughes, J. D., Barrett, A. M., Williamson, D. J. G., Bauer, R. M., Bowers, D., & Heilman, K. M. (2000). Emotional and physiological responses to false feedback. *Cortex, 36*(1), 1–11. [https://doi.org/10.1016/S0010-0285\(00\)00006-7](https://doi.org/10.1016/S0010-0285(00)00006-7)

36, 623–647. [https://doi.org/10.1016/S0010-9452\(08\)70542-2](https://doi.org/10.1016/S0010-9452(08)70542-2)

Cuijpers, P., & Schuurmans, J. (2007). Self-help interventions for anxiety disorders: An overview. *Current Psychiatry Reports*, 9, 284–290. <https://doi.org/10.1007/s11920-007-0034-6>

Demos, J. N. (2005). *Getting started with neurofeedback*. New York: W. W. Norton.

Deterding, S., O’Hara, K., Sicart, M., Dixon, D., & Nacke, L. (2011). Gamification: Using game design elements in non-game contexts. In *Proceedings of the 2011 Annual Conference on Human Factors in Computing Systems* (pp. 1–4). <https://doi.org/10.1145/1979742.1979575>

Dillon, A., Kelly, M., Robertson, I. H., & Robertson, D. A. (2016). Smartphone applications utilizing biofeedback can aid stress reduction. *Frontiers in Psychology*, 7, 832. <https://doi.org/10.3389/fpsyg.2016.00832>

Fleming, T. M., Bavin, L., Stasiak, K., Hermansson-Webb, E., Merry, S. N., Cheek, C., ... Hetrick, S. (2016). Serious games and gamification for mental health: Current status and promising directions. *Frontiers in Psychiatry*, 7, 215. <https://doi.org/10.3389/fpsyt.2016.00215>

Friedman, B. H. (2007). An autonomic flexibility-neurovisceral integration model of anxiety and cardiac vagal tone. *Biological Psychology*, 74(2), 185–199. <https://doi.org/10.1016/j.biopsycho.2005.08.009>

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>

Grassi, M., Caldirola, D., Valentina, N., Chiaro, D., Riva, A., Daccò, S., ... Perna, G. (2014). Are respiratory abnormalities specific for panic disorder? A meta-analysis. *Neuropsychobiology*,

70, 52–60. <https://doi.org/10.1159/000364830>

- Gray, S. N. (2017). An overview of the use of neurofeedback biofeedback for the treatment of symptoms of traumatic brain injury in military and civilian populations. *Medical Acupuncture, 29*(4), 215–219. <https://doi.org/10.1089/acu.2017.1220>
- Janka, A., Adler, C., Brunner, B., Oppenrieder, S., & Duschek, S. (2017). Biofeedback training in crisis managers: A randomized controlled trial. *Applied Psychophysiology and Biofeedback, 42*(2), 117–125. <https://doi.org/10.1007/s10484-017-9360-6>
- Jester, D. J., Rozek, E. K., & McKelley, R. A. (2018). Heart rate variability biofeedback: Implications for cognitive and psychiatric effects in older adults. *Aging & Mental Health, in press*, 1–7. <https://doi.org/10.1080/13607863.2018.1432031>
- Jorm, A., Patten, S. B., Brugha, T. S., & Mojtabai, R. (2017). Has increased provision of treatment reduced the prevalence of common mental disorders? Review of the evidence from four countries. *World Psychiatry, 16*(1), 90–99. <https://doi.org/10.1002/wps.20388>
- Kleen, M., & Reitsma, B. (2011). Appliance of heart rate variability biofeedback in acceptance and commitment therapy: A pilot study. *Journal of Neurotherapy, 15*(2), 170–181. <https://doi.org/10.1080/10874208.2011.570695>
- Kopřivová, J., Congedo, M., Raszka, M., Praško, J., Brunovský, M., & Horáček, J. (2013). Prediction of treatment response and the effect of independent component neurofeedback in obsessive-compulsive disorder: A randomized, sham-controlled, double-blind study. *Neuropsychobiology, 67*(4), 210–223. <https://doi.org/10.1159/000347087>
- Larsen, P. D., & Galletly, D. C. (2006). The sound of silence is music to the heart. *Heart, 92*(4), 433–434. <https://doi.org/10.1136/hrt.2005.071902>
- Laxman, K., Krishnan, S. B., & Dhillon, J. S. (2015). Barriers to adoption of consumer health

- informatics applications for health self management. *Health Science Journal*, 9(5), 1–7.
- Lehrer, P. M., & Gevirtz, R. (2014). Heart rate variability biofeedback: How and why does it work? *Frontiers in Psychology*, 5, 756. <https://doi.org/10.3389/fpsyg.2014.00756>
- Lehrer, P. M., Vaschillo, E., Vaschillo, B., Lu, S. E., Eckberg, D. L., Edelberg, R., ... Hamer, R. M. (2003). Heart rate variability biofeedback increases baroreflex gain and peak expiratory flow. *Psychosomatic Medicine*, 65(5), 796–805. <https://doi.org/10.1097/01.PSY.0000089200.81962.19>
- Ley, R. (1999). The modification of breathing behavior. *Behavior Modification*, 23(3), 441–479. <https://doi.org/10.1177/0145445599233006>
- Lui, J. H. L., Marcus, D. K., & Barry, C. T. (2017). Evidence-based apps? A review of mental health mobile applications in a psychotherapy context. *Professional Psychology: Research and Practice*, 48(3), 199–210. <https://doi.org/10.1037/pro0000122>
- Lustyk, M. K. B., Chawla, N., Nolan, R. S., & Marlatt, G. A. (2009). Mindfulness meditation research: Issues of participant screening, safety procedures, and researcher training. *Advances in Mind-Body Medicine*, 24(1), 20–30.
- Mallorquí-Bagué, N., Bulbena, A., Pailhez, G., Garfinkel, S. N., & Critchley, H. D. (2016). Mind-body interactions in anxiety and somatic symptoms. *Harvard Review of Psychiatry*, 24(1), 53–60. <https://doi.org/10.1097/HRP.0000000000000085>
- Manzoni, G. M., Pagnini, F., Castelnuovo, G., & Molinari, E. (2008). Relaxation training for anxiety: A ten-years systematic review with meta-analysis. *BMC Psychiatry*, 8, 1–12. <https://doi.org/10.1186/1471-244X-8-41>
- McEvoy, P. M., Grove, R., & Slade, T. (2011). Epidemiology of anxiety disorders in the Australian general population: Findings of the 2007 Australian National Survey of Mental

- Health and Wellbeing. *Australian and New Zealand Journal of Psychiatry*, 45(11), 957–967.  
<https://doi.org/10.3109/00048674.2011.624083>
- Meuret, A. E., Wilhelm, F. H., & Roth, W. T. (2004). Respiratory feedback for treating panic disorder. *Journal of Clinical Psychology*, 60(2), 197–207.  
<https://doi.org/10.1002/jclp.10245>
- Mojtabai, R., Olfson, M., Sampson, N. a, Druss, B., Wang, P. S., Wells, K. B., ... Kessler, R. C. (2012). Barriers to mental health treatment: Results from the national comorbidity survey replication (NCS-R). *Psychological Medicine*, 41(8), 1751–1761.  
<https://doi.org/10.1017/S0033291710002291.Barriers>
- Moraveji, N. (2012). *Augmented self-regulation*. Stanford University.
- Moraveji, N., Santoro, E., Smith, E., Kane, A., Crum, A., & Susi, M. (2017). *Using a wearable health tracker to improve health and wellbeing under stress*. Retrieved from <http://assets.spire.io/Spire-Stanford-LinkedIn-Workplace-Stress-Study.pdf>
- Morris, M. E., & Aguilera, A. (2012). Mobile, social, and wearable computing and the evolution of psychological practice. *Professional Psychology: Research and Practice*, 43(6), 622–626.  
<https://doi.org/10.1037/a0029041>
- Nasir, S., & Yurder, Y. (2015). Consumers' and physicians' perceptions about high tech wearable health products. *Procedia - Social and Behavioral Sciences*, 195, 1261–1267.  
<https://doi.org/10.1016/j.sbspro.2015.06.279>
- Neary, M., & Schueller, S. M. (2018). State of the field of mental health apps. *Cognitive and Behavioral Practice*, in press. <https://doi.org/10.1016/j.cbpra.2018.01.002>
- O'Connor, M., Munnely, A., Whelan, R., & McHugh, L. (2017). The efficacy and acceptability of third-wave behavioral and cognitive eHealth treatments: A systematic review and meta-

analysis of randomized controlled trials. *Behavior Therapy, in press.*

<https://doi.org/10.1016/j.beth.2017.07.007>

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>

Pascoe, M. C., Thompson, D. R., Jenkins, Z. M., & Ski, C. F. (2017). Mindfulness mediates the physiological markers of stress: Systematic review and meta-analysis. *Journal of Psychiatric Research, 95*, 156–178. <https://doi.org/10.1016/j.jpsychires.2017.08.004>

Piwek, L., Ellis, D. A., Andrews, S., & Joinson, A. (2016). The rise of consumer health wearables: Promises and barriers. *PLoS Medicine, 13*(2), 1–9. <https://doi.org/10.1371/journal.pmed.1001953>

Plarre, K., Rajj, A., Hossain, S. M., Ali, A. A., Nakajima, M., Absi, M., ... Wittmers, L. E. (2011). Continuous inference of psychological stress from sensory measurements collected in the natural environment. In *10th International Conference on Information Processing in Sensor Networks* (pp. 97–108).

Plews, D. J., Scott, B., Altini, M., Wood, M., Kilding, A. E., & Laursen, P. B. (2017). Comparison of heart-rate-variability recording with smartphone photoplethysmography, Polar H7 chest strap, and electrocardiography. *International Journal of Sports Physiology and Performance, 12*(10), 1324–1328. <https://doi.org/10.1123/ijsp.2016-0668>

Prinsloo, G. E., Rauch, H. G. L., Karpul, D., & Derman, W. E. (2013). The effect of a single session of short duration heart rate variability biofeedback on EEG: A pilot study. *Applied Psychophysiology and Biofeedback, 38*(1), 45–56. <https://doi.org/10.1007/s10484-012-9207-0>

- Richards, P., Simpson, S., Bastiampillai, T., Pietrabissa, G., & Castelnuovo, G. (2016). The impact of technology on therapeutic alliance and engagement in psychotherapy: The therapist's perspective. *Clinical Psychologist*. <https://doi.org/10.1111/cp.12102>
- Riley, W. T. (2017). Behavioral and social sciences at the National Institutes of Health: Adoption of research findings in health research and practice as a scientific priority. *Translational Behavioral Medicine*, 7, 380–384. <https://doi.org/10.1007/s13142-017-0474-4z>
- Ross, J. M., & Balasubramaniam, R. (2014). Physical and neural entrainment to rhythm: Human sensorimotor coordination across tasks and effector systems. *Frontiers in Human Neuroscience*, 8, 1–6. <https://doi.org/10.3389/fnhum.2014.00576>
- Salafi, T., & Kah, J. (2015). Design of unobtrusive wearable mental stress monitoring device using physiological sensor. In J. Goh & C. Lim (Eds.), *7th WACBE World Congress on Bioengineering 2015, IFMBE Proceedings*. Springer. [https://doi.org/10.1007/978-3-319-19452-3\\_4](https://doi.org/10.1007/978-3-319-19452-3_4)
- Schmidt, J., & Martin, A. (2017). Heart rate variability in clinical practice. *Psychotherapeut*, 62(6), 498–506. <https://doi.org/10.1007/s00278-017-0236-2>
- 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>
- Singh, S. K., & Gorey, K. M. (2017). Relative effectiveness of mindfulness and cognitive behavioral interventions for anxiety disorders: Meta-analytic review. *Social Work in Mental Health*, 16(2), 1–14. <https://doi.org/10.1080/15332985.2017.1373266>
- 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>

Stoyanov, S. R., Hides, L., Kavanagh, D. J., Zelenko, O., Tjondronegoro, D., & Mani, M. (2015).

Mobile app rating scale: A new tool for assessing the quality of health mobile apps. *JMIR MHealth and UHealth*, 3(1), 1–9. <https://doi.org/10.2196/mhealth.3422>

Torous, J. B., Chan, S. R., Gipson, S. Y.-M. T., Kim, J. W., Nguyen, T.-Q., Luo, J., & Wang, P.

(2018). A hierarchical framework for evaluation and informed decision making regarding smartphone apps for clinical care. *Psychiatric Services*, 69(5), 498–500.

<https://doi.org/10.1176/appi.ps.201700423>

Torous, J., Levin, M. E., Ahern, D. K., & Oser, M. L. (2017). Cognitive behavioral mobile

applications: Clinical studies, marketplace overview, and research agenda. *Cognitive and Behavioral Practice*, 24(2), 215–225. <https://doi.org/10.1016/j.cbpra.2016.05.007>

Torous, J., & Roberts, L. W. (2017). The ethical use of mobile health technology in clinical

psychiatry. *Journal of Nervous and Mental Disease*, 205(1), 4–8.

<https://doi.org/10.1097/NMD.0000000000000596>

van der Zwan, J. E., de Vente, W., Huizink, A. C., Bögels, S. M., & de Bruin, E. I. (2015).

Physical activity, mindfulness meditation, or heart rate variability biofeedback for stress reduction: A randomized controlled trial. *Applied Psychophysiology and Biofeedback*, 40(4),

257–268. <https://doi.org/10.1007/s10484-015-9293-x>

van Lutterveld, R., Houlihan, S. D., Pal, P., Sacchet, M. D., McFarlane-Blake, C., Patel, P. R., ...

Brewer, J. A. (2017). Source-space EEG neurofeedback links subjective experience with brain activity during effortless awareness meditation. *NeuroImage*, 151, 117–127.

<https://doi.org/10.1016/j.neuroimage.2016.02.047>

Visnovcova, Z., Mestanik, M., Gala, M., Mestanikova, A., & Tonhajzerova, I. (2016). The

complexity of electrodermal activity is altered in mental cognitive stressors. *Computers in Biology and Medicine*, 79, 123–129. <https://doi.org/10.1016/J.COMPBIOMED.2016.10.014>

Wheat, A. L., & Larkin, K. T. (2010). Biofeedback of heart rate variability and related physiology: A critical review. *Applied Psychophysiology and Biofeedback*, 35(3), 229–242. <https://doi.org/10.1007/s10484-010-9133-y>

Figures

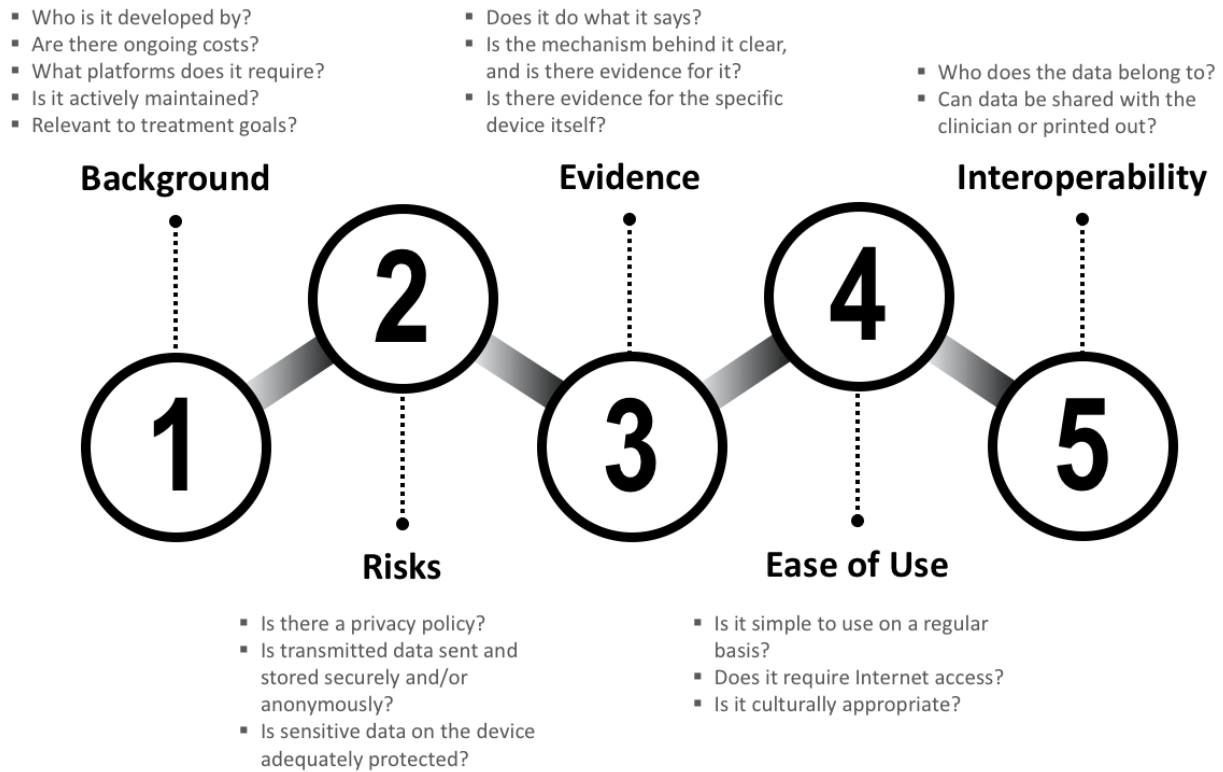


Figure 1: Wearable device evaluation process, after American Psychiatric Association (2017)

## Tables

Table 1

*Summary of wearable devices with potential benefit for anxiety symptoms*

Modality	Device	Website	Comments	Approx. Cost
EDA	Pip (2014) <i>Galvanic Ltd</i>	thepip.com	Held between thumb and forefinger like a guitar plectrum; developer currently in liquidation.	\$245 AUD
EEG	Brainlink (2014) <i>Macrotellect Ltd</i>	o.macrotellect.com	1 channel dry sensor headband	€149 EUR
	Insight (2015) <i>Emotiv, Inc.</i>	emotiv.com	5 channel hybrid sensor headband (requires minimal priming with saline)	\$299 USD
	Lowdown Focus (2017) <i>SmithOptics, Inc.</i>	smithoptics.com	EEG sunglasses based on Interaxon Muse technology (described below)	\$349 USD
	Mindwave (2011) <i>Neurosky, Inc.</i>	neurosky.com	1 channel dry sensor headband	\$79 USD
	Muse (v2, 2016) <i>Interaxon, Inc.</i>	choosemuse.com	4 channel dry sensor headband; primarily offers aided meditation but third-party apps can be used also	\$249 USD
	Myndband (2016) <i>Myndplay Ltd</i>	myndplay.com	1 channel dry sensor headband	£179 GBP
	SenzeBand (2016) <i>Neeuro Pte Ltd</i>	neuro.com	4 channel dry sensor headband	\$299 USD
Entrainment	Doppel (2018) <i>Team Turquoise Ltd</i>	feeldoppel.com	Worn on inside of wrist where the pulse is normally felt; provides a regular heartbeat-like tactile sensation	\$179 USD
HRV <sup>†</sup>	emWave 2 (2011) <i>HeartMath, Inc.</i>	heartmath.com	Standalone feedback device or used with apps on Mac or Windows (no smartphone support)	\$199 USD

Modality	Device	Website	Comments	Approx. Cost
	Blaze, Charge 2, Ionic, Versa <i>FitBit, Inc.</i>	fitbit.com	'Relax' app guides breathing based on HRV patterns	\$119-\$249 USD
	Inner Balance (2013) <i>HeartMath, Inc.</i>	heartmath.com	Bluetooth or wired sensor worn on the earlobe during biofeedback sessions	\$159 USD
	Sona (2015) <i>Caeden, Inc.</i>	caeden.com	Wristband; monitors HRV through the day and offers HRV biofeedback sessions	\$199 USD
Respiration	Stone (2014) <i>Spire, Inc.</i>	spire.io	Sensor worn on belt or bra; feedback on elevated and calm states in realtime; also short biofeedback sessions	\$149 USD

Note: † The products listed here are integrated software and hardware HRV solutions. However, a range of smartphone apps can also be linked to low-cost generic sensor devices (chest strap, ear clip, finger clip and a limited range of smart watch devices) to provide session-based HRV biofeedback.