FeedBreath: Designing Complementary Treatment Wearable Biofeedback System for Teenagers with anxiety disorder

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Abstract. Nowadays, mental health disorders have increased, particularly anxiety disorders. It is especially problematic because it affects adolescents, causing emotional and physical problems. The treatments available today do not focus on this specific target and its developmental phase. In this context, exploring complementary therapies like biofeedback training has recently increased and is considered a powerful tool. The most common biofeedback signal for anxiety disorder is breathing. However, today's classic breathing training methods have a limited target group and low retention rates, making them unattractive to teenage users. This project proposes the design of a wearable based complementary biofeedback system for teenagers to promote breathing training, treatment engagement, and behavior change. The concept uses breathing as input to control the game displayed in augmented reality, and different game modalities are investigated through user testing. The project explores how biofeedback and gamification can improve user experience, promote active participation, and improve engagement in the treatment.

Keywords: Wearable, Biofeedback, Augmented Reality, Anxiety Disorder, Gamification, Teenagers

1 Introduction

Mental health disorders have been central to several discussions worldwide in the last few years. Inside this spectrum, anxiety disorders are one of the prevalent categories of psychopathology in children and adolescents [1]. Unfortunately, the number of adolescents with anxiety disorder has increased in the last few years. It is estimated that nearly 1 in 3 adolescents aged 13 to 18 will experience an anxiety disorder [2]. Since most adult disorders are an extension of juvenile disorders,

adolescents have become a priority prevention target for reducing psychiatric disorders in the adult population. An anxiety disorder may lead to severe physical, emotional, and mental impairment and disability. The physical symptoms can cause teenagers to avoid public situations because of the concern of triggering these reactions leading to further social. Nowadays, the treatment options for anxiety in teenagers are psychotherapy, medication, and a combination of the two [3]. However, these treatments can encounter challenges in dealing with teenagers as they were thought to be practiced in adults.
As seen in the last few years, to increase access and support for mental health problems, digital tools have been hugely used and, in several studies, have been shown to provide benefits for young people [4]. Moreover, the increased use of mobile technologies has created new interaction opportunities for adolescents, and emerging technologies such as Augmented reality have enormous potential to improve patient motivation and promote active participation during medical treatments [5]. Complementary therapies (CAM) to treat anxiety in teenagers are non-invasive and engaging and give teenagers control over their own health. Biofeedback-based system has gained much interest in providing sensory information to help teenagers self-regulate their physical symptoms [6-7]. FeedBreath aims to design a complementary system for teenagers to cope with and control their anxiety-related physical symptoms following the integrated behavior change model [8] to promote behavior change. A system that can create motivation and engagement during the treatment using the AR scenario together with the teenager's biophysical feedback to control the experience. The system supports traditional treatment methods attending to the target group's specific needs.
The project investigates:

- *To what extent does **biofeedback** help teenagers with anxiety disorder **self-regulate and cope with their physical symptoms?***
- What *are the **benefits of multisensorial stimulus** in a biofeedback system compared with a single stimulus, and **how it influences the experience of the user**?*
- *Does **gamification** in an augmented reality environment and **biofeedback increase motivation and engagement** in treating anxiety in teenagers?*

2. Breathing training

In the long term, regular slow breathing practice can facilitate people to acquire a good breathing habit that sustains their autonomic balance and strengthens their resilience against anxiety [9]. Several systems have been developed for facilitating slow breathing training in the last few years [10]. The most found signals to aid novice users in slow breathing practice are two: feedforward guidance and bio-feedback. Today's breathing guides are straightforward, simply guiding the user at a fixed six-pace [11]. However, despite the use of mobile apps and sensors, this classic breathing training has a limited target group, and retention rates are meager. The exercises are repetitive and boring and not attractive to the younger population. So, another approach that has been gaining attention is the biofeedback-based system that can provide sensory information during breathing training [12]. The biofeedback breathing training game Breeze [13] uses biofeedback visualization to foster long-term engagement and increase experiential value to expand their target audience and enhance adherence by motivating individuals. The study found that participants enjoyed more gameful breathing training than the traditional one. With the emergence of new and alternative technologies in the last years (e.g., virtual reality, Internet of Things (IoT) devices such as smartwatches, sporting sensors, and more), the approach used to breathe training has changed. AR applications are already available in education [5-14] and medicine [15] and have emerged as a helpful treatment in several areas in the field of health. However, in clinical psychology, the use of AR is still in the early stage, with just a few studies demonstrating the utility of AR for treating animal phobias [16]. This concept in which an AR scenario utilizes the patient biophysical feedback to control the experience could further improve patient motivation and active participation. Providing real-time feedback on the procedure instead of using pre-recorded sequences during the sessions can increase trust and understanding. In the last few years, some attempts to create more engagement in health treatments have been made using the gamification approach [17-18]. Unlike in conventional games, advancement to different levels or steps in serious games is not based on the player's cognitive skills but on achieving therapeutic goals. Serious games deepen digital interventions and engagement as they provide an alternative world where exploration, learning, and agency are encouraged. Further methods for mental disorders' digital interventions already exist and have been explored more broadly. One of these is computerized cognitive behavior therapy (CBT), which has shown evidence of a successful effect in treating anxiety and depression among teenagers [19].

3. FEEDBREATH

The FeedBreath system was developed based on the integrated behavior change model [8] and behavioral change theories [20]. Here Feedbreath's main features are described, including how the system supports active participation in treatment and self-regulation of physical symptoms and reflects the increase in engagement through biofeedback and gamification narrative. An iterative user-centered design process was used to shape the storyline, the interface's style, and game elements and understand some aspects of the anxiety that should be addressed. In addition to helping gather feedback on design concepts, these studies also investigated people's basic expectations for a biofeedback-based system, assessed their willingness to practice breathing training to cope with physical anxiety symptoms, and collected data about multisensory and breathing training programs. A small group in person and slightly bigger samples online were engaged in this process. The initial design requirements, storyboarding, and personas were constructed from 30 surveys and 6 interviews. The following are the outcomes that contributed directly or indirectly to the project's key features and design.

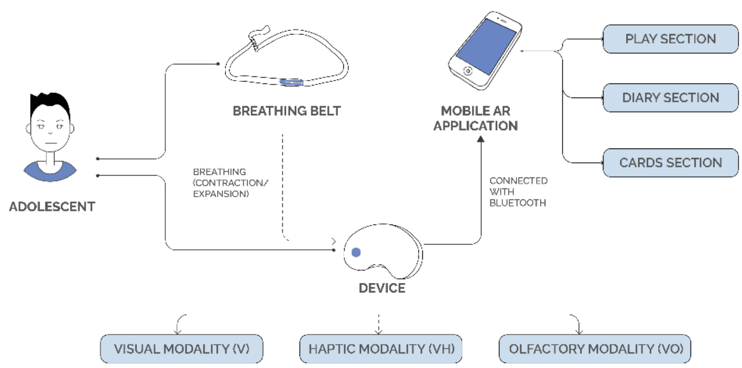

Fig. 1. FeedBreath System Architecture

The FeedBreath system is composed of a wearable breathing belt and a device that will allow the different modalities of the game. The belt will collect the breathing pattern data and transmit it to the device that will elaborate it and send the data to the mobile via Bluetooth to be used as input for the game. All the information on the system can be shared with doctors and therapists. In the prototype, all information is saved within the phone and must be manually shared with the physician. In the final version, the data will be saved on the cloud protected by encryption and passwords to comply with all GDPR security and privacy criteria. The game's story was used as an instrument to explain a little bit about the breathing process to the teenager and create a narrative that could progress with the game. For this reason, Alvi, the main character, was inspired by the pulmonary alveolus. The other two characters, the good particles, and the harmful particles were inspired by the oxygen particles and carbon dioxide particles. There are no other elements in the game itself not to distract the teenagers from their primary purpose, which is breathing training. The application is divided into four main sections: Play, Diary, Cards, and Achievements. The play section is where the game will be played and where the users can choose the modality they want to play. The cards section was inspired by the anxiety deck cards [21] available today in the market. It was created to allow teenagers to process their thoughts and feelings more relaxed and playfully. It combines visualization techniques, mindfulness, and creative thinking. The users can draw a “card of the day” that will inspire some action, thoughts, or feelings every day.

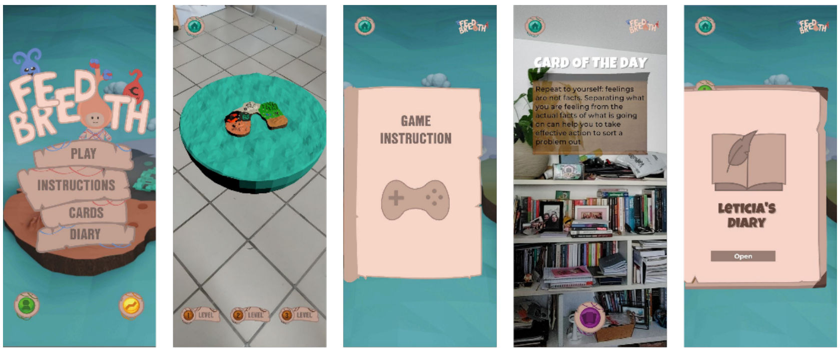

Fig. 2. FeedBreath app sections

The diary section is where teenagers can enter information about their anxiety attacks. It will allow them to keep track of their attacks and better understand the triggers that made them happen. It will also provide more information to the therapist and the parents.

The achievement section will provide an overview of their rewards, breathing sections, and progress to encourage and incentivize the continuation of breathing training and the use of the application.
The game can be played in 3 different modalities: visual, olfactory, and haptic mode, based on the user's choice. In all three ways, the character starts the game running automatically without needing the users' input, while the height will be controlled by the breathing input provided by the player. When the user breathes in (inhales), the character starts to jump; when they hold, it remains at the same height, and when they breathe out (exhale), the character goes down. The different modalities are related to feedforward. In the visual mode (V), the main character relies solely on visual cues with oxygen particles guiding them to inhale and exhale based on their position in the game. The vibration modality (VH) can have both haptic and visual cues to jump, hold, and go down, having a multisensory experience while playing the game. Different waveforms create vibration cues with different meanings to indicate to the users which action to take. The same goes for the olfactory modality (VO), which has both visual and olfactory cues to guide the player in the game. The score point system of the game is based on collecting oxygen particles that add points to the users and avoiding the carbon dioxide particles that subtract points from the score. As a reward system, every time the player collects 200 oxygen particles, they will unblock a character's new dance so that the player can learn and record dancing with the character. To collect the user's breathing pattern, a wearable sensor taking the form of a conductive knitted stretch was developed. It was designed to be wrapped around the user's chest/stomach, and when the chest/stomach expands and contracts, the sensor will follow the movement. The electrical conductivity will be altered, allowing for the identification of these two movements. Compared with other breathing stretching sensors available today, the smart textile should be more comfortable, easy to use, and less invasive, not perceived as a medical device but as just a piece of clothing. A wearable pulse sensor is implemented in the prototype in order to measure heart rate variability. From the sensor, it was possible to extract the heart rate, inter-beats intervals, and HRV which is widely considered one of the best objective metrics to determine the body's performance [22]. The increase or decrease of the heart rate variability can indicate success or failure in altering the breathing pattern. It can become a performance indicator to evaluate the

application's efficiency and breathing exercises objectively. For the vibration game modality, the haptic motor driver was used to control the mini-vibration motor, allowing the creation of different waveforms for the feedforward. The haptic controller is activated by the mobile application with the vibration button. A fogger transducer mist maker made with a piezoelectric, a humidifier atomization module, a small recipient with the fragrance (which can be selected by the user), and a cotton stick were used to create an aromatic mist for the olfactory display. As for the haptic model, the humidifier is also activated by the mobile application. A device form was idealized to hide the elements and create a more comfortable and practical component that the users can hold while playing. The shape was considered easy to hold, sustain, and comfortable in the hands. The material used was "felt," which is soft and malleable, allowing the curves of the prototype.

4. **Prototype's test**

The tests were executed individually and in a private room where all the equipment was set to create a calm and undisturbed environment. The FeedBreath software was installed on an Android cellphone and placed on a tripod for the commodity of the participants. The FeedBreath hardware was given to the participants, where they could wrap the belt around their chest and hold the device. A total of 20 teenagers participated in the usability test and the game evaluation (14 females and 6 males) aged from 12 to 16 (M = 14.05, SD = 1.099). All participants had already experienced an anxiety attack in their lifetime, but not all had been diagnosed with anxiety disorder. The participants were chosen randomly from the first questionnaire, where they answered positively to test the application in the future. The participants had no experience with breathing biofeedback techniques or any other biofeedback practice. All participants and their legal responsible gave written informed consent. The experiment was conducted on three consecutive days, so the participants experienced one of the three modalities each day. For each breathing training modality, the participants performed the exercises for 3-minutes. Before the experiment, the participant explored the application and watched the video instructions to understand the game's mechanism. At the beginning of the experiment session on the first day, the HRV of each participant was collected for 1 minute; the procedure was repeated on the last day following the exercise. The number of oxygen particles (participant' performance data) was collected during the training. After completing the activity, the participant filled out a game evaluation form. When the participant had completed all three experimental sessions, a follow-up interview was conducted in person. Qualitative and quantitative data were collected during the experiment with the aim to: evaluate the physiological benefits of the breathing training; evaluate the impact of the multisensory approach during the breathing training (number of O2 particles collected during each game modalities and the participant's expressed their opinions and preferences about the different modalities); evaluate the user experience in terms of engagement, motivation, and game experience (40 questions across five categories). Moreover, a SUS questionnaire was also performed to evaluate the application's usability.

3 RESULTS

The changes in HRV generated by the application were used as a performance indicator to evaluate breathing training efficiency. HRV before and after had a significant change, $p < 0.001$. The comparison showed that the HRV after ($M = 593$, $SD = 88$, $SE = 19.7$) was significantly better than the HRV before ($M = 420$, $SD = 71.6$, $SE = 16$) which proves the efficiency of the breathing training. In some users, the changes in HRV could be perceived more than others which can be explained by a range of factors that include not performing the breathing exercise correctly, having outside factors changing the HRV, and the nervous aspect of performing the test and being recorded.
The particles of oxygen collected for each of the three modalities show that participants' performance increased in the haptic modality, which indicates that the addition of the vibration increased the performance in the breathing training. The questionnaire can further confirm the results, where 50% of participants choose the haptic modality as the preferred modality. The multisensory approach helped the teenagers to achieve a higher score and have a better experience. However, not all multisensory approaches have the same effect, as shown by the insignificant difference between the olfactory and visual modalities. Even though the performance was slightly better in the olfactory modality compared with the visual modality, the results do not suggest a significant change.

3.1 Subjective Engagement

During the interviews, the participants expressed their opinion on the system more subjectively. These insights collected are reported below.

Biofeedback system to promote self-regulation. The participants of the experience expressed their positive experience with the biofeedback system during the exercises mainly because it made them focus on the breathing training as their data directly influenced their performance on the game. – e.g., *"I liked the biofeedback because it makes me interact more with the game and concentrate on what I am doing"*. The biofeedback added a new layer to breathing training and created a sense of ownership in the individuals recognizing their control over their health and disease and allowing them to practice self-regulation. One participant mentioned, "*I think it would be helpful not only for those who suffer from anxiety, but everyone as breathing is an essential aspect of our lives."*. One of the participants commented that biofeedback played an essential role in her involvement in the game because she could see the *"effect of her breathing and the changes it could provoke in the game's character.* It gave her a real-time cause-and-effect instrument where she could actively check if she were breathing correctly.

Gamification for engagement. Participants appreciated the game mechanism and elements, and *"innovative and funny way to deal with anxiety"*. Beyond engagement with the game mechanism, participants' engagement with the storytelling was also perceived. Participants were interested in exploring other levels and worlds and seeing the development of the character, although it was not so visible in the prototype – e.g., "*I would love to see Alvi change based on the changes I see in myself. That would reflect my improvements and give me the motivation to continue"*. Most participants appreciated receiving positive feedback when completing sessions and achieving specific goals. The reward system, such as the characters' new dance used as a celebration for their progress and time of playing, was found to be encouraging. The lack of negative feedback, as FeedBreath avoids punishment, considering findings that in a serious game, positive reinforcement is more motivational, were not perceived as lacking in progress or intention. Finally, participants demonstrated a strong interest in the multisensory features of the game as *"stimulating and different from any other game I have ever played"*. The different modalities allowed the participants to test other senses, understand which type of interaction works better for them, and provide their performance. The olfactory element was perceived as unusual and “produced a calm effect during the game”

Integration with traditional treatments. During the interviews, users found the diary section a critical feature and valuable for their anxiety treatment. The diary was seen as an opportunity to share more about their episodes and create a bridge between the two types of treatment. 80% of the participants demonstrated a strong interest in the game, while the remaining 20% showed some interest. Also, 60% would like to play with a high frequency while 30% would play at a regular frequency, and just 10% would not play a lot, but none said they would never play again. Moreover, 90% appreciated the graphic style and illustrations, especially the instructions video and the island. They revealed that the game could have more elements like more characters, more environmental aspects, and more rewards. Furthermore, an average score of 80.5 was given to the application using the SUS evaluation, which is considered good, especially considering the missing elements of a complete game. The score reveals that the game was understood and appreciated as a concept but still needs improvement in the graphics and variety of game elements.

4 Discussion and Results

This article presents the design and evaluation of FeedBreath, a wearable device-based biofeedback system that supports the self-regulation of physical symptoms for Anxious Teenagers. A user experiment was conducted to evaluate the effectiveness of FeedBreath in supporting breathing exercises and to investigate the role of system interactivity in enhancing motivation and engagement in treatment, user experience, and providing psychological benefits. Three breathing training modalities of FeedBreath were created and used in a within-subject experiment with 20 participants. The interactivity of FeedBreath is provided in three ways:

1. FeedBreath provides users with real-time biofeedback on their breathing performance through the character’s animation and playing.
2. It allows different playing modalities with additional stimuli.

3. FeedBreath offers users a virtual reward (in the form of dance character animations to learn and record) to enhance motivation for doing the exercise.

The results demonstrated that FeedBreath could effectively facilitate breathing training exercises and self-regulation, particularly increasing adhesion rates and enjoyable to practice. These outcomes are likely to be associated with the interactive exercises and the real-time biofeedback performance, which creates more focus on the activity. Participants stated that exercising with FeedBreath considerably enhanced their user experience due to perceived competence, increased enjoyment and motivation, and the multisensory experience. The results suggested that the multisensorial stimulus created the best user performance and experience. The user responses also supported this affirmation during the questionnaire, in which 14/20 participants stated that the VH modality was their preferred modality and the most health-beneficial modality for breathing exercises. Furthermore, they defined their experience as "exciting," "challenging," and "fun." The quantitative results analyzed above, and qualitative results from the interview helped generate insights about the interactive system design.

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