This is a preprint of the article to be published in *the AACE Journal of Interactive Learning Research*. The final version is available in the Learning and Technology Library: http://www.editlib.org/j/JILR. The paper was originally presented at the 29th EdMedia World Conference on Educational Media and Technology, held in Washington D.C. USA, on 20–23 June 2017.

Conceptual Framework for Therapeutic Training with Biofeedback in Virtual Reality: First Evaluation of a Relaxation Simulator

Mikhail Fominykh
Molde University College, Norway; Volga State University of Technology, Russia
mikhail.fominykh@himolde.no; FominykhMA@volgatech.net

Ekaterina Prasolova-Førland
Department of Education and Lifelong Learning, Norwegian University of Science and Technology, Norway
ekaterip@ntnu.no

Tore C. Stiles
Department of Psychology, Norwegian University of Science and Technology, Norway
tore.stiles@ntnu.no

Anne Berit Krogh
Department of Public Health and Nursing, Norwegian University of Science and Technology, Norway
anne-berit.krogh@ntnu.no

Mattias Linde
Department of Neuromedicine and Movement Science, Norwegian University of Science and Technology, Norway
mattias.linde@ntnu.no

Abstract. This paper presents a concept for designing low-cost therapeutic training with biofeedback and virtual reality. We completed the first evaluation of a prototype - a mobile learning application for relaxation training, primarily for adolescents suffering from tension-type headaches. The system delivers visual experience on a head-mounted display. A wirelessly connected wristband is used to measure user's pulse and adjust the training scenario based on the heart rate data. Repeating the exercise can make the user able to go through the scenario without using the app, learn how to relax, and ultimately combat tension-type headache. The prototype has been evaluated with 25 participants. The results demonstrate that the application provides a relaxing experience and the implementation of biofeedback is useful for therapeutic training. The results are discussed to evaluate the technological, therapeutic and educational potential of the prototype and to improve the conceptual framework.

1. Introduction

Virtual Reality (VR) technologies provide fresh perspectives to health care and great potential supported by several examples of documented positive effect (Li et al. 2011; Kipping et al. 2012; de Ribaupierre et al. 2014) but still with room for improvement (Cook et al. 2013). The realism of VR-based systems has improved significantly due to advanced graphics. Modern desktop-free human-computer interfaces increase the value and transferability of virtual experience, as the human mind is closely connected to the sensory-motor experience (Barsalou 2008). The theory of Embodied Cognition suggests and stipulates that human mind is defined by the body and specific context (Gallagher 2005). Therefore, embodied experience of activities in VR is closer to the real-world experience and it supports immersive and believable delivery of multi-perspective and contextualized experience (Slater 2009; Yuen et al. 2013).

In 2015 and 2016, several leading information technology companies entered the global competition in VR hardware and software. Simultaneously, there is an ongoing wave of Wearable Technology (WT) devices, wireless body sensors which can measure, for example, heart rate with reasonable accuracy and precision (El-Amrawy et al. 2015; Chatzipavlou et al. 2016). The WT sees, hears and perceives the user's physical state.

Examples of diagnostic and therapeutic software applications developed with VR, WT and Mobile technologies can be found (Hoffman et al. 2011; Harvie et al. 2015; Sarig Bahat et al.). However, despite of the rapid development and acceptance of both software and enabling hardware (smartphones, VR glasses and wearable sensors), there is a lack of literature exploring the delivery of behavioral interventions using these technologies for headache (Minen et al. 2016).

The prevalence of headache is increasing among children and adolescents in northern Europe (Sillanpaa and Anttila 1996; Laurell et al. 2004). Especially chronic tension-type headache (CTTH) causes a high burden on the young sufferers. It was recently found that 1.2% of teenagers in Norway suffered from CTTH. Its consequences included substantial impairment of social interaction and deterioration of functioning in school (Krogh et al. 2015). In addition, anxiety and depression was associated with tension-type headache among adolescents (Blaauw et al. 2014).

There is no available prophylactic medication for CTTH in this age group (Termine et al. 2011), but biofeedback, a behavioral treatment without known side effects, seems to be effective. Unfortunately, this is today a highly-specialized therapy unavailable to most people in need.

European treatment guidelines conclude that biofeedback has a documented effect for tension-type headache patients as a group (Bendtsen et al. 2010). Furthermore, specifically in the pediatric subgroup, biofeedback is generally claimed to be efficacious (Blume et al. 2012), even with a larger effect in children and adolescents than in adults (Nestoriuc et al. 2008).

Our research focuses on applying innovative low-cost technologies in healthcare, aiming at developing and evaluating a new method and an application for therapy training in real settings. The objectives of the project include:

1. Develop a conceptual framework for therapeutic training with biofeedback in VR
2. Design an educational method for therapeutic training
3. Design and develop a prototype (a VR simulator) for training patients in developing psychological skills, incorporating the theoretical background of Cognitive-Behavioral Therapy (CBT) and technology-enhanced learning to maximize learning effect
4. Conduct training sessions for patients at the clinic and outside the clinic to test and evaluate the VR simulator with target-group volunteers, measuring the psychological, technological, and educational aspects

2. Background and Related Work

2.1 Learning to Control Body Reactions: Psychological Treatment with Biofeedback

Psychological treatments are designed to alter processes underlying or contributing to pain, distress, and/or disability (Eccleston et al. 2014). Such treatments can be an alternative where there are no effective prophylactic medications, for example, in treatment of CTTH among adolescents (Termine et al. 2011). Psychological treatments were originally developed for delivery in the clinic in a format in which the patient and therapist work face-to-face (Bussone et al. 1998; Andrasik et al. 2003). This requires trained personnel with special resources in multidisciplinary settings which are unavailable to the most of persons in need. Hence, there is a need for self-administered and easily accessible technology.

Mobile Health applications (mHealth apps) handle various medical or health issues using mobile devices (Chatzipavlou et al. 2016). This is a new innovative field, and its greatest potential is in chronic diseases that are highly prevalent, because the mHealth apps improve access to health care and can deliver therapy procedures that would be inaccessible otherwise. In addition, there are now several wireless, wearable body sensors which can measure, bodily functions.

Biofeedback has been used in healthcare since the late fifties and gained popularity in recent years with the availability of bio sensors and mobile technology (Schwartz and Andrasik 2017). It improves psychological treatments, allowing patients to learn how to voluntarily modify their bodily reactions through the feedback from their own physiological processes. The most frequently used modalities are electromyographic activity, heart rate, and peripheral skin temperature (Blume et al. 2012). It is generally considered that biofeedback reduces the excitability within central nervous system networks and renders individuals more resilient to effects of environmental stressors (Siniatchkin et al. 2000; Lehrer and Eddie 2013).

European treatment guidelines conclude that biofeedback has a documented effect for tension-type headache patients as a group (Bendtsen et al. 2010). Biofeedback is generally claimed to be efficacious (Blume et al. 2012), with a larger effect in children and adolescents than in adults (Nestoriuc et al. 2008).

2.2 Perception and Sensing: Virtual Reality and Wearable Technologies

VR simulates spaces, objects, humans, and activities that can reproduce a precise image of the reality and simulate required settings (Steuer 1992). Although, VR systems offer different interaction modes, the recent popularity and attention has been generated by VR glasses, after Oculus Rift released their first device in 2013. VR glasses is a type of WT devices that is worn on the head and has a display in front of the user's eyes (Cakmakci and Rolland 2006; van Krevelen and Poelman 2010). Most of these devices contain a tracking system, which allows much greater immersion, as the user can control the direction of the view in a virtual environment in the same way as in the physical world – by turning the head. The displays of VR goggles have larger field of view compared to desktop applications and provide a stereoscopic image, making the experience more believable. Modern desktop-free human-computer interfaces increase the value and transferability of virtual experience.

Other types of WT devices include wireless body sensors. A sensor is “a source of information” (Dasarathy 1997), which can be active, passive, or mixed active/passive. Sensors cover a wide range of application areas and can be classified based on measurands, technological aspects, detection means, conversion phenomena, sensor materials, and fields of application (White 1987). Body sensors perceive the user’s physical state. They can, for example, measure heart rate with reasonable accuracy and precision (El-Amrawy et al. 2015; Chatzipavlou et al. 2016). Wearable sensors bear potential to capture the key aspects of human performance during a learning activity. This can allow analysis and reflection upon the activity, individually or collaboratively (Fominykh et al. 2015; Limbu et al. 2017). Capturing human’s psycho-physiological states using bio-signals and physiological phenomena is at the core of perceptual technologies (Stiefelhagen 2009).

Both VR and wearable sensors contribute to increasing immersion of the user.

3. Conceptual Framework for Therapeutic Training with Biofeedback in Virtual Reality

We are developing a conceptual framework to facilitate future development of VR applications for therapeutic purposes. Therapeutic training is a large field that includes methods such as exposure therapy for the treatment of traumatic stress syndrome, phobias, depression and more. Therefore, we start with the area of pain coping and relief that includes training how to cope with pain.

We have identified the following major pain coping mechanisms and therapeutic procedures that can be applied in VR: distraction, relaxation, illusion, visualization and physiotherapy:

- **Distraction**: drawing attention from the patient’s mental pain processing with immersive and interactive VR experiences, for example, SnowWorld for burn victims (Hoffman et al. 2011).
- **Relaxation**: immersing users in relaxing simulated virtual situations and places, suitable for meditation and mindfulness, for example, Guided Meditation VR (https://guidedmeditationvr.com/).
- **Illusion**: manipulating sensory brain input (visual, haptic etc.) in order to manipulate experience of pain, for example, providing false visual feedback of head movements to people with neck pain alters onset of movement-evoked pain (Harvie et al. 2015).
- **Visualization**: controlling pain by manipulating a visual representation of pain experience (in 3D/VR), often with bio- or neurofeedback, for example: manipulating stereoscopic geometric shapes (with mouse), each of them corresponding to a certain type and intensity of pain.
- **Physiotherapy**: enhancing traditional training in a variety of physiotherapeutic situations with VR, for example, VR training for patients with neck injuries (Sarig Bahat et al.).

CBT for chronic pain management identifies a number of therapy goals/subgoals and situations (see e.g. (Murphy et al. 2016)). A treatment plan could be simply presented as a sequence of such goals and subgoals:

- Relaxation: muscular relaxation, guided imagery with or without feedback
- Pleasant activities: mindfulness games, active distraction, games
- Cognitive coping: coping with negative thoughts, learning imagery skills for pain management
- Sleep strategies

The framework matches the presented VR mechanisms for pain coping and relief with therapy goals (such as relaxation, sleep strategies, coping). For example, the therapy sub-goal ‘Guided imagery with biofeedback’ is matched with the ‘Relaxation’ VR pain coping mechanism, while it is natural to associate the ‘Learning imagery skills for pain management’ sub-goal with the Visualization mechanism. Still, this correspondence is not one-to-one and should be seen in the context of a concrete therapy situation.

We have previously characterized educational desktop-based VR environments along the dimensions of User, Place and Artifact (inspired by the Activity theory, see e.g. (Prasolova-Førland and Divitini 2003)). Similarly, for therapy purposes, we have identified VR features along the dimensions of User/Patient, Virtual therapy place and Therapy artifacts. In addition, we include Scenario features and User Interfaces into the framework, to take into account the variety of equipment available to the patients today and the importance of storytelling elements for an immersive and enjoyable patient experience. As the framework aims to guide the development of VR applications, it matches existing VR pain coping mechanisms and therapeutic procedures (distraction, relaxation, illusion, visualization, physiotherapy), corresponding VR features (Table 1), scenario features (Table 2) and user interfaces (Table 3). An "X" symbol in the three tables below indicates what features are important to support the corresponding mechanisms and procedures. The absence of "X" means that the corresponding features are optional but might be added for an enhanced user experience.

Table 1. VR features for pain coping and relief therapy

VR features		**Mechanisms for pain coping and relief in VR**				
		Distraction	Relaxation	Illusion	Visualization	Physiotherapy
User / Patient	Embodiment			X	X	X
	Sense of presence and immersion	X	X	X	X	X
	Identity				X	
Virtual place	Visual appearance	X	X		X	
	Place structure and navigation	X	X			X
	Multisensory: sound, touch, movement	X	X	X	X	X
Therapy artefacts	Objects and interactions with objects	X		X	X	X
	Bio- and neurofeedback associated with objects		X		X	

Table 2. Scenario features for pain coping and relief therapy

Scenario features	**Mechanisms for pain coping and relief in VR**				
	Distraction	Relaxation	Illusion	Visualization	Physiotherapy
Linear narrative	X	X	X	X	X
Branching and levels	X	X		X	X
Role playing	X			X	
Progression through tasks	X	X	X	X	X
Inter-platform transitions	X	X		X	X

Table 3. User interfaces and technology platforms for pain coping and relief therapy

User interfaces and tech. platforms		**Mechanisms for pain coping and relief in VR**				
		Distraction	Relaxation	Illusion	Visualization	Physiotherapy
Output	Visualization devices (HMD, PC, smart phone)	X	X	X	X	X
	Sound devices (stereo, 3d sound)	X	X			X
Input	Biosensors (heart rate, EEG, skin conductivity)		X		X	
	Body tracking (head movement, gestures, motion capture)	X		X	X	X
	Controls, haptic, treadmill	X		X		X

The design concepts and scenarios for specific therapeutic goals and subgoals in the context of CBT (Murphy et al. 2016) and biofeedback can be developed by selecting VR features, scenario features and user interfaces associated with the required VR mechanisms for pain coping and relief. The relaxation simulator prototype provides such an example (see Section 4).

4. Prototype design

Developing the relaxation simulator prototype presented in this paper, we address a single CBT therapy sub-goal Guided imagery with biofeedback. The objectives of the prototype are (a) to design a platform for therapeutic training in VR and (b) to implement a single therapy sub-goal module. While only one such module has been created at the current stage, the platform supports design and seamless integration of additional modules for other therapeutic goals, such as for developing different types of relaxation, imagery and coping skills, and for engaging in 'pleasant activities' such as mindfulness games.

An overview of the design features used to support the given sub-goal is presented below (Table 4).

Table 4. Conceptual design features of the prototype

Features		**Selection for Relaxation mechanism for guided imagery with biofeedback sub-goal**
VR features	Embodiment	First-person view, neutral avatar in a fixed sitting position (optional)
	Sense of presence and immersion	Realistic virtual environment, possibility for looking around naturally
	Identity	No distinct identity apart from simple user identification/guest mode associated with game performance
	Visual appearance	Tropical beach, calm relaxing atmosphere
	Place structure and navigation	Visual borders limiting navigation, small land area and shoreline
	Multisensory	Visual + sound (voice, music, sound of waves and birds)
	Objects and interactions with objects	Several objects that are part of the scenery, contributing to the overall atmosphere: trees, birds, rocks; Direct interaction with objects is not implemented
	Bio- and neurofeedback associated with objects	Interactive dynamic elements of the VR environment that indicate changes in heart rate and provide biofeedback (waves, sky/clouds, wind, floating bird)
Scenario features	Linear narrative	Simple narrative created by the therapist's voice
	Branching and levels	Environment appearance and the choice of voice instructions reflect changing levels of relaxation (up or down)
	Role playing	Not implemented
	Progression through tasks	Progression through the simple task of lowering the heart rate
	Inter-platform transitions	From advanced / stationary to simple / mobile versions
User interfaces	Visualization devices (VR glasses, PC, smartphone)	Versions for multiple devices (cardboard, desktop PC / projector, GearVR, Oculus Rift)
	Sound devices (stereo, 3d sound)	Stereo sound (Standard headphones)
	Biosensors (heart rate, EEG, skin conductivity)	Heart rate sensor (Mio Link or Mio Alpha)
	Body tracking (head movement, gestures, motion capture)	Not directly supporting relaxation mechanism: Head movement tracking (Gyroscope in VR glasses / smartphone)
	Controls, haptic, treadmill	Not directly supporting relaxation mechanism: Controls (Gamepad in the version for Oculus Rift)

The selection of features for the prototype presented in the table above was guided by a list of functional and non-functional requirements imposed by the study design (Section 5.1):

- The users should be able to use simulator both in the clinic (stationary) and outside the clinic (mobile).
- The stationary version should deliver the best possible experience without limitations for the required equipment.
- The mobile version should deliver acceptable experience and be able to run on the majority of smartphones.
- The device to measure heart rate should be mobile and available for sale locally.

The current version of the prototype has a simple modular hardware / software architecture (Fig. 1). The following provides short descriptions of the architecture elements.

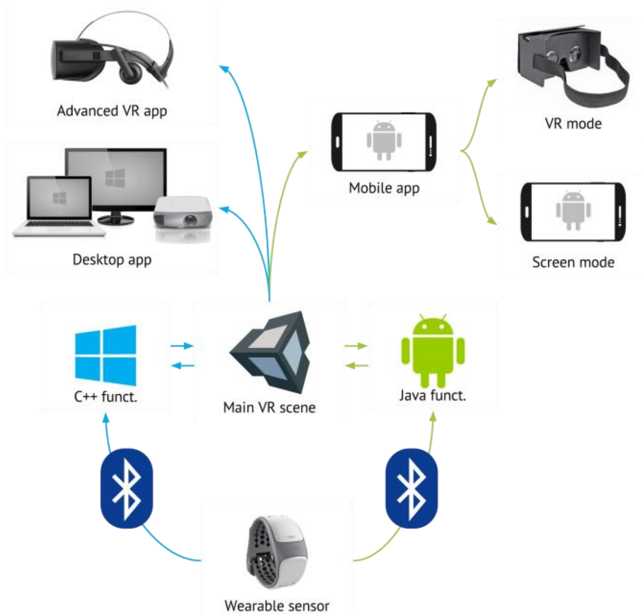

Figure 1. Hardware / software architecture of the prototype

- *Main VR scene*. This module displays the main virtual reality scene and plays the sounds based on the heart rate data received in real time from the wearable sensor. The scene is assembled in Unity 3D.
- *C++ functions*. This module contains a set of functions to search, connect and communicate with the wireless device in applications built on Windows operating system. These functions are called from the Main VR scene, communicate with the wearable sensor via a Bluetooth connection, and return the heart rate values to the Main VR scene.
- *Java functions*. This module contains a set of functions to search, connect and communicate with the wireless device in applications built on Android operating system. The data flow is similar to the C++ functions module.
- *Wearable sensor*. This is a device that is worn by the user and measures his/her heart rate. The device we currently use is MIO Link (also compatible with MIO Alpha) Heart Rate Wristband. It uses an optical sensor to measure EKG-accurate heart rate and can transmit data using Bluetooth Smart (4.0) and ANT+ technologies.
- *Desktop app* delivers the VR experience to the end user via the 2D screen of a regular PC that runs Windows operating system. The mouse can be used in this app to look around in the 3D virtual environment. Searching and pairing the wearable sensor device is done in windows prior to running the app.
- *Advanced VR app* delivers the VR experience to the end user via the head-mounted display Oculus Rift. Head movement of the user is tracked to allow to look around the virtual environment naturally. Oculus rift is installed and configured prior to running the app. Searching and pairing the wearable sensor device is done in windows prior to running the app.

- *Mobile app* delivers the VR experience to the end user via a smartphone. The user interface of the app allows to choose the VR mode or the Screen mode. It runs on Android operating system and the majority of the smart phones. Searching and connecting the wearable sensor service is done in the app.
- *VR mode* of the mobile app delivers an immersive/stereo VR experience to the end user. This mode is intended for simple 3D glasses that can be used with a smartphone, such as Google cardboard. This was further extended to support Gear VR, more advanced VR glasses.
- *Screen mode* of the mobile app delivers a 2D VR experience to the end user. This mode is intended for a smartphone alone, where a 3D environment of the simulator renders on a flat 2D screen of the smartphone.
- *Blue arrows* show the data flow of the Windows-based apps and connect the enabled modules.
- *Green arrows* show the data flow of the Android-based apps and connect the enabled modules.

In the prototype, the user only has access to a single test-module that implements a beach scene and a relaxation training scenario. In the development of a virtual environment, we wanted to make sure that the environment would support the modular approach to allow further extension and integration of additional sub-modules (as additional virtual scenes).

The 'size' of the environment of the test module is limited. The user is able to see a patch of white sand surrounded by a tropical forest, a shoreline with some rocks and waves, the sky and some clouds. The user is only able to observe a small patch of the 'land', limited by the tropical forest and the shoreline. The scene design and complexity was adjusted in accordance with the availability of pre-made elements and computational power of smartphones. In addition to the visual stimuli, the user is getting audio input: sound of waves and relaxation instructions from the therapist.

The virtual environment contains two types of elements: static and interactive. The static elements are decorations that are added to create the right atmosphere defined by the scenario. The interactive elements change depending on the user behavior: heart rate and gaze direction. Sea waves gradually become higher when the heart rate of the user increases and vice versa (Fig. 2). The sky and clouds become darker and a wind sound is added when the heart rate is higher than in the beginning of the session. A set of 26 sound instructions is included in the simulator to guide the user. The instructions are not given linearly one after another, but triggered depending on the user's progression in the scenario. In the very beginning of the session, the user is instructed by the therapist voice to face the waves and try to control their amplitude by controlling his/her relaxation status/heart rate.

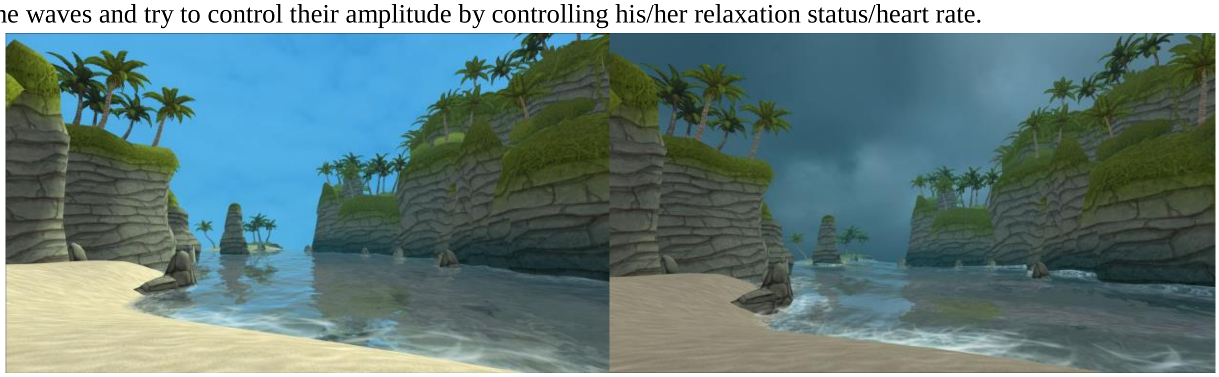

Figure 2. Environment changes: low heart rate (left) and increased heart rate (right)

The sea waves is the main interactive element of the simulator. Their height is updated in real time based on the user's pulse. The starting wave amplitude in the simulator is pre-defined. It is the same every session (every run of the app) for every new or 'guest' user. The application can adjust to the owner of the device. The wave amplitude is normalized if the same user runs the app several times on the same device. The data from previous runs are stored locally. The starting heart rate is used as a baseline that represents a normal wave height and a normal weather. When the session starts, this amplitude is 'matched' with the user's current heart rate of the user. Further increase/reduction in the heart rate is seen relative to the baseline and is represented with increased/decreased wave amplitude.

The goal of the exercise is to make the sea as 'calm' as possible, where the threshold value for a 'calm' sea is adjusted/calculated individually from the baseline heart rate value. The following biofeedback mechanism is working in real time:

- The user perceives the VR environment at a certain state and tries to control his/her heart rate (Fig. 3, left).
- User's pulse is measured by a wearable sensor and sent to a wirelessly connected PC or a mobile device (Fig. 3, bottom).

- The VR application installed on the device reads the pulse data and compares it to the previous values to understand the dynamics. Based on the updated data, the application updates the interactive elements of the VR environment and the therapeutic instructions accordingly (Fig. 3 right).
- The HMD receives an updated image and displays it to the user, completing the loop (Fig. 3, top).

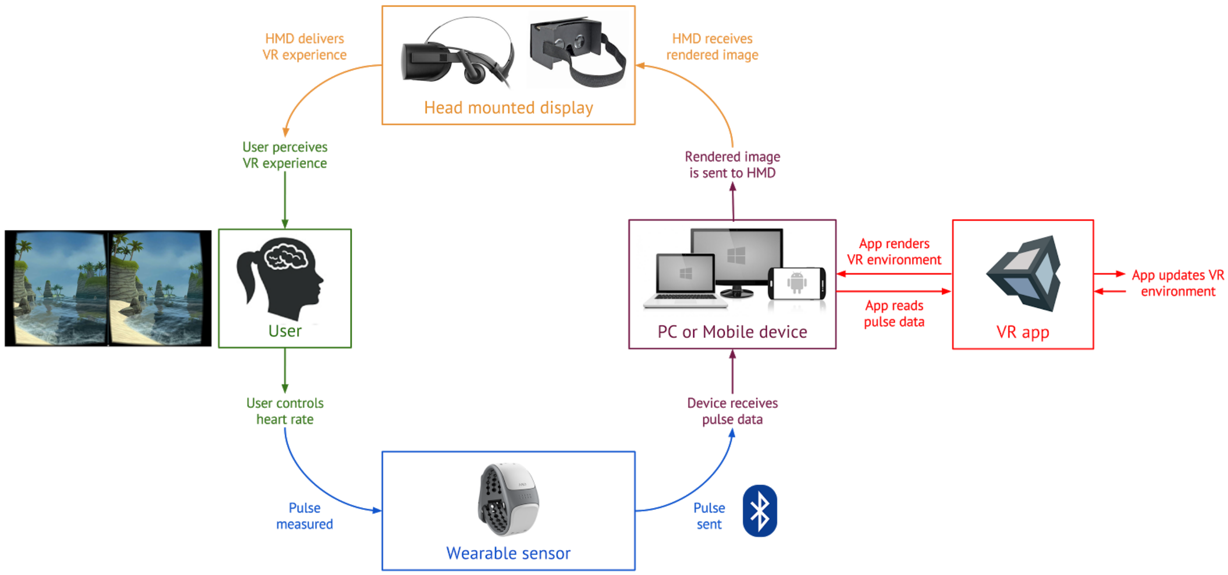

Figure 3. Biofeedback concept for therapeutic training in VR

The session ends when one of the following conditions is met:

- The threshold value for the ‘calm sea’ has been met (the heart rate is 20% lower than the baseline value)
- The absolute heart rate value is lower than 30
- The threshold value for the ‘stormy sea’ has been met (the heart rate is 75% higher than the baseline value)
- The absolute heart rate value is higher than 120
- The maximum time of the session has elapsed (10 minutes)
- The user chooses to end the session

5. Study Design

5.1 Full study design

The full study design consists of three major phases and a feasibility study (pre-phase). The present paper presents the feasibility study (section 5.2) that aims to test the technical solutions and polish them before proceeding to the evaluation with patients.

In phase 1 of the treatment program/pilot, the user accesses the Advanced VR version of the simulator at the clinic. Before starting the session, the user is provided with basic instructions and receives assistance if necessary. After the end of the session, the user will receive a questionnaire and perform a short interview with the researcher. The user’s activities during the session will be video-recorded. The physiological parameters (heart rate) pre/post will be recorded either manually or by the simulator. The simulator will record the data of the user and store the log locally for evaluation purpose only. A corresponding consent form is to be signed.

In phase 2, the user accesses both Advanced VR and the Mobile versions, both in and outside the clinic. The user installs the developed app during the clinic visit and checks that it works properly with the wearable device as well as receives some basic instructions. For simplicity, the user might perform the test/one of the tests in the clinic, right after testing the desktop version. The user will be encouraged to complete a simple online questionnaire right after each session, or complete questionnaires/answer interview questions during the next appointment at the clinic.

In phase 3, the user is asked to try out relaxations techniques he/she acquired before in the phases 1 and 2., but without VR equipment. While wearing the sensor and monitoring own heart rate, the user will close his/her eyes and attempt to imagine the visuals from the previous phases, trying to control the imagery waves and in this way control own heart rate. At the end of the trial period, the user visits the clinic to return the equipment and answer additional questionnaire/interview questions. Ideally, by the end of the trial and the full therapeutic training course, the user should have learned the basic relaxation techniques and is capable of performing relaxation sessions on his/her own.

5.2 Technical Feasibility Study Design

We started the technical feasibility study - pre-phase of the evaluation has been conducted with 25 volunteer subjects. In November 2016, 13 individual sessions were conducted and published (Fominykh et al. 2017). Based on the collected data minor improvements have been made (mostly, new instructions that better explain the purpose of the app). In April 2017, 12 additional individual sessions were conducted. The following procedure was used with each participant:

1. The evaluator briefly introduces the subject to the study and hardware devices, but not to the logic in the simulator.
2. The subject tries to use one of the prototype apps (VR app or VR mode first, when available).
3. The subject tells the evaluator what he or she understood and felt while using the simulator.
4. The evaluator explains to the subject the logic and the rationale behind the simulator features.
5. In some cases, the subject tries to use the prototype app(s) again (the same or different app and/or mode). All the subjects tried at least one prototype app, while some tried two or three apps or modes.
6. The subject fills in the questionnaire.
7. The evaluator interviews the subject using open questions, filling in short notes.

As the evaluation sessions were conducted in different locations (local events and meetups), different apps of the prototype were used. Some subjects tried the advanced VR app and the mobile app in the VR mode, others tried the desktop app and the mobile app in the screen mode, and, in some cases, combinations.

The questionnaire contained four background questions, three general Likert scale questions, seven design-and-functionality Likert scale questions, and nine relaxation-and-biofeedback Likert scale questions. The semi-structured interview contained six open questions.

Questionnaire data were analyzed without using statistical methods because the aim was to reveal general impressions. In addition, the number of subjects was small. The interviews were not recorded for full transcription, but instead captured in notes. The notes were then grouped by questions and qualitatively analyzed.

6. Evaluation Results

The technical feasibility study provided detailed feedback on specific components of the prototype simulator. The target group consisted of 25 subjects who were older than the target end users of the simulator. Their age varied 22 to 46 (average 29,04). Even though the target group of the study was older than the proposed target group of the application, it allowed us to collect feedback on different aspects of the simulator. Among the participants 12 were male and 13 female, all with different professional backgrounds. Only three participants had some previous experience with VR. Such diversity of the participants resulted in rich feedback and suggestions on technical, psychological, and pedagogical aspects of the simulator.

6.1 Design and functionality

The general feedback questions indicated that it was generally easy to use the simulator. All the answers distributed between fully disagree (1 participant), unsure (2), agree (13) and fully agree (11). Answering if it was physically uncomfortable to use the simulator, two participants agreed, one was neutral, and the rest disagreed or fully disagreed.

Three Likert-scale questions evaluated the general attitude towards fun to use, appearance of the virtual environment and sound instructions (Fig. 4). The participants definitely liked how the virtual beach looked (21 participants agreed). The majority (17 participants answered agree and two - fully agree) also answered that it was fun to use the simulator, while the remaining 6 were unsure (two of them explicitly said that relaxation cannot be fun, but rather comforting). The feedback given to the sound instructions varied mostly because of four reasons given later in the interviews: (a) language difficulties for participants with immigrant background, (b) difficulty to understand how each instruction is connected to the others and to the progression of the user, (c) incomplete information on the features and aims of the simulator, and (d) annoyance by the repeated instruction (when the user is holding the same level of the heart rate).

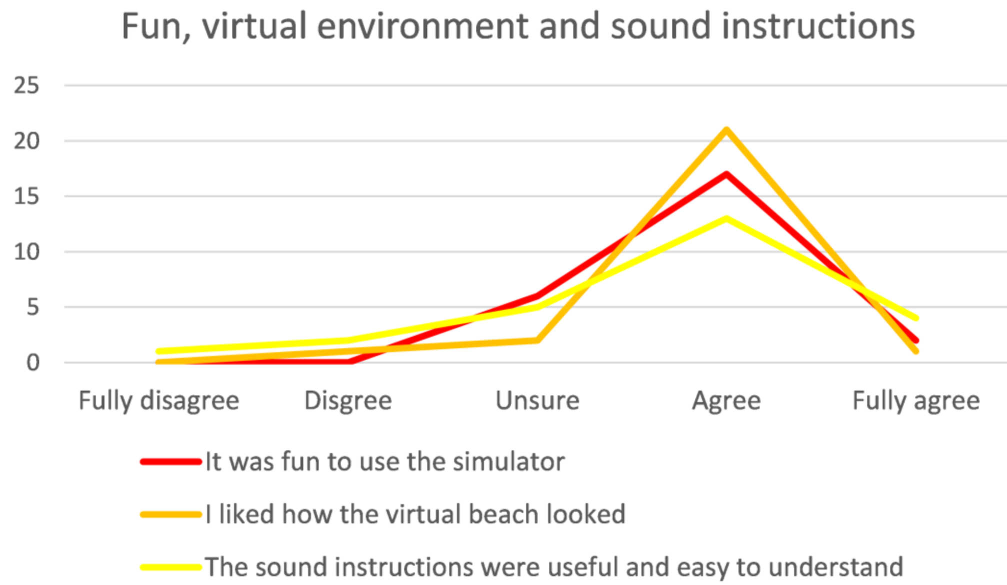

Figure 4. Results for fun, virtual environment and sound instructions

The design and functionality Likert scale questions revealed only a few clear trends but provided ideas for the suggestions expressed in the interviews. Most of the participants (13) reported that they felt present at the virtual beach (using both Advanced VR and Mobile versions), while the rest of the answers distributed between disagree (5), unsure (5) and fully agree (2). A positive trend was also identified in the ease of exploring the virtual beach environment by looking around. The majority of the participants answered agree (13) and fully agree (5) to the question if it was easy to look around in the virtual beach. The answers of the other participants distributed between the options disagree (2) and unsure (5).

6.2 Relaxation and biofeedback

When evaluating their relaxation experience and biofeedback in questionnaires, the participants were often unsure (Fig. 5 red and orange). The majority of the participants were unsure if the changes in the waves reflected the changes in their pulse and that the size of the waves well corresponded to their general stress level. In the individual interviews, the participants highlighted some of the reasons, including (a) the fact that it is difficult to see the difference in the wave size if the heart rate changes only slightly and (b) difficulty in assessing own stress / excitement level.

The largest number of unsure answers were given to the question if it was easy to make waves help me to relax (Fig. 5, yellow). During the interviews, some of the participants provided additional feedback, mostly discussing (a) if showing larger waves when pulse increases is appropriate and (b) how additional elements, such as sound, could complement the waves.

Most of the participants felt more relaxed after using the app (Fig. 5, green). The majority answered agree (12) and fully agree (4). The other answered disagree (4) and unsure (4). Some of the reasons on why the experience was not relaxing were provided during the interviews. A large number of them was related to physical experience, such as: uncomfortable VR glasses (5), uncomfortable chair (3), uncomfortable surrounding environment (2), and experience is tiring for eyes. Another recurring reason for the experience not being relaxing was feeling stressed trying to control the virtual environment (e.g., waves). Some of the participants answered agree (5) that they felt more stressed when they had to control the waves in the app (Fig. 5, blue). During the interviews, two of them clearly highlighted that they felt very stressed when trying and managing (or not managing) to calm down the sea.

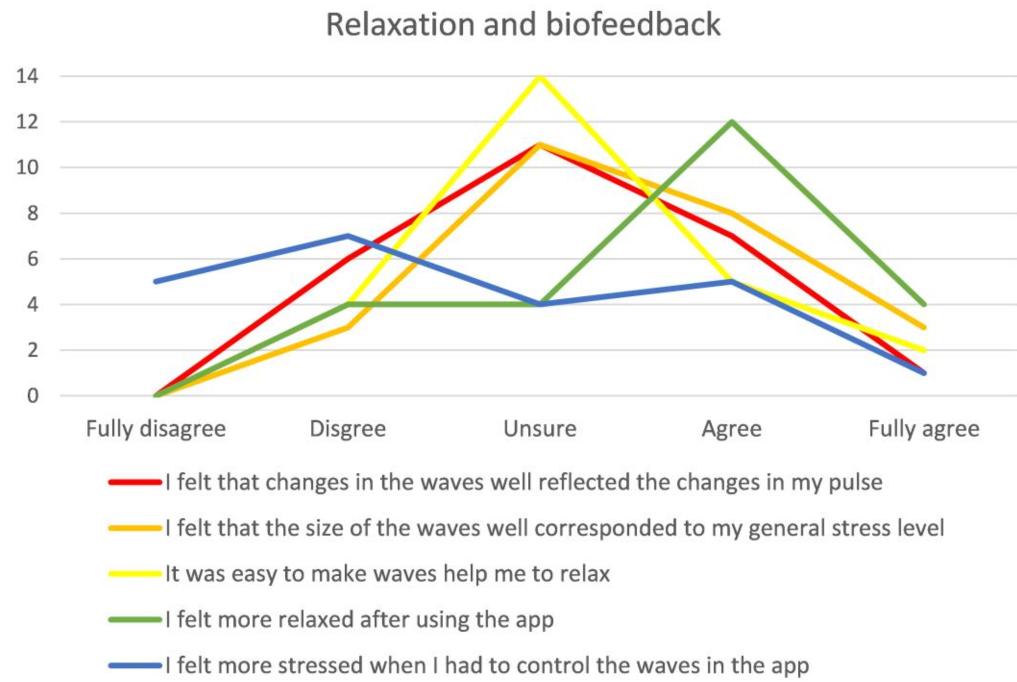

Figure 5. Results related to relaxation and stress

6.3 Suggestions for future work

Three Likert scale questions aimed to evaluate how much potential the participants saw in the relaxation application and the therapeutic training concept (Fig. 6). When answering if it would be possible to use such an app in the future for relaxation, most of the participants answered unsure (8), agree (8), and fully agree (7). The participants were even more positive when evaluating statements "I think it is possible to use such an app as part of training" (Fig. 6, orange) and "I could recommend such an app to my friends" (Fig. 6, yellow).

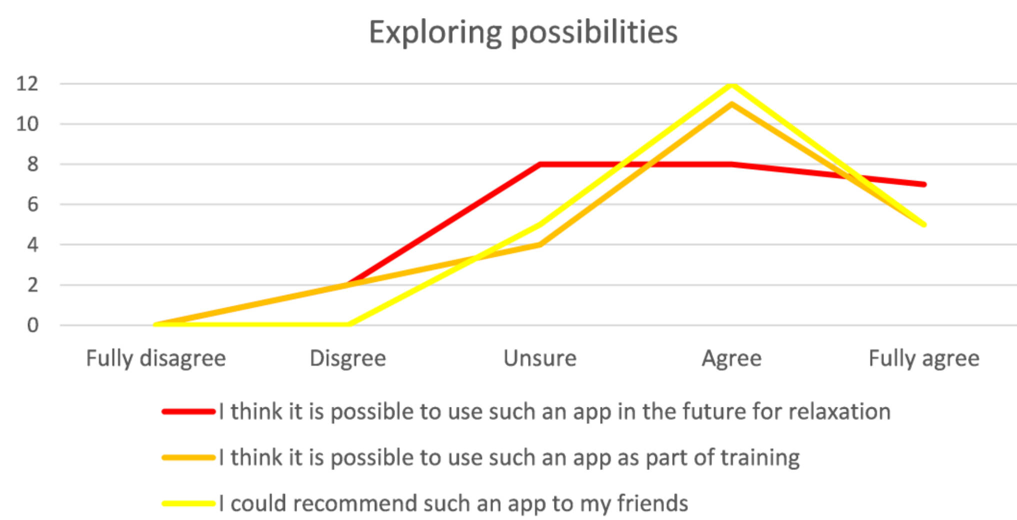

Figure 6. Results for exploring possibilities

During the interviews, the participants gave many suggestions on how to improve the application, how to improve biofeedback-based therapeutic training, and what could be other application domains for such a concept.

The most popular suggestions on improving user-friendliness of the application and making it more fun included: more stimulating, varied, interactive and dynamic virtual environment (from 7 participants), adding game elements (4), and improvement of therapeutic component and training (3).

Fifteen suggestions of other virtual locations that are good for relaxation were given. The most popular included: forest (10), mountains with a view (7), outer space (3), non-tropical seaside (3), underwater (2), river bank (2) and flight / sky (2).

Discussing how such an application could provide a better therapeutic effect, the participants gave suggestions that fell into the categories: more / other interactive virtual environment (7), more / other interactive elements as indicators of heart rate (3), better environment sound (3), more relaxing virtual environment / landscape (3), better guidance and training scenario (2), remove game elements (2), see yourself (2), add realism (2), and improve physical environment (2).

Finally, we asked the participants if they see any other usage domains for future applications build using biofeedback and VR. The most popular answers included: stress management and stress management training (3), phobia management and exposure therapy (3), meditation (3), medical treatment (2), assistance at work (2), and situation and attention training (2).

7. Discussion

The evaluation of the prototype aimed to test the VR simulator, measuring the technological, psychological, and educational aspects. The primary objectives of the first evaluation round we have completed were (1) to evaluate the design and functionality of the prototype and (2) based on the results, further develop the VR, scenario and user interface features of the prototype as well as the conceptual framework behind.

The *design and functionality* results (presented in Section 6.1) demonstrate that the simulator is relatively easy and comfortable to use. This also provides indication that the approach of using VR-based simulation with biofeedback is feasible, including how comfortable it is to wear various VR glasses and the wristband. Several directions for improvement were identified by the volunteer participants (which are very likely to be important for the main target group). These mostly included suggestions for VR features (Visual appearance and Bio- and neurofeedback associated with objects) and scenario features (Linear narrative, Branching and levels and Progression through tasks).

The *relaxation and biofeedback* results (presented in Section 6.2) showed that the application fulfills one of its purposes, providing a relaxation experience without adding too much stress by the need to complete tasks. At the same time, some of the VR and the scenario features did not function as intended and therefore need improvement. The VR feature Bio- and neurofeedback associated with objects was evaluated as functioning, but not effective enough (e.g., it was difficult to spot the changes of the waves). The visual feedback from waves/weather might be supplemented by a more 'traditional' measurement of heart-rate activity (e.g., a bar in the corner).

The voice instructions that aimed to guide the participant through the relaxation training scenario functioned well if the changes in the heart rate were significant. However, if the heart rate of the participant did not change much, the scenario and the sound instructions were quickly losing sense and became annoying with too many repetitions. Therefore, the scenario features Linear narrative and Branching will need to be improved. These features will need to be better connected to the Progression through tasks.

The relaxation and biofeedback results presented in this paper provide only a limited indication of the therapeutic aspects of the application due to testing it with volunteers not from the target group.

The *suggestion for future work results* (presented in Section 6.3) indicated the positive attitude of the participants towards the concept of therapeutic training with VR and biofeedback. These results provide only provisional and limited evaluation of the educational aspects of the application due to testing it with single sessions instead of the proposed continuous training. It was therefore not possible to assess whether the participants acquired any relaxation skills.

8. Conclusions and Future Work

This paper presents an outline for a conceptual framework for therapeutic training with biofeedback in VR and the first evaluation results of a relaxation simulator prototype. We are progressing towards reaching the objectives of the project, described in the Introduction.

1. We developed a conceptual framework for an area of therapeutic training (pain coping and relief) with biofeedback in VR
2. We have not yet started the phase in the project where we could measure skills acquisition and the educational method for therapeutic training, but only collected feedback on the possibility to use such a method for training
3. We designed and developed a prototype for training patients in developing relaxation skills
4. We have not yet conducted training sessions for patients – the actual target group, but tested and evaluated the VR simulator with other volunteers, assessing the psychological, technological, and educational aspects

Further exploration and systematization of therapeutic training mechanisms and development of the framework will be an important direction for future work, providing a modular and research-based methodology for developing VR-based therapeutic applications. We will work on further refinement of the framework presented in Section 3. The future work should include the extension of the framework to cover other areas of therapeutic training (in addition to pain coping and relief), such as treatment of post-traumatic stress syndrome, phobias, and depression.

Further in this project, we plan to incorporate clinical outcome measures into the biofeedback-app, run a pilot-study of its tolerability and effectiveness in adolescents with chronic headache, and eventually evaluate it in a randomized controlled trial. This will be done with extensive support and supervision from a multidisciplinary group of experts in neurology, psychology, and technology-enhanced learning.

References

Andrasik, F., Grazzi, L., Usai, S., D'Amico, D., Leone, M. and Bussone, G. (2003). "Brief neurologist-administered behavioral treatment of pediatric episodic tension-type headache." *Neurology* 60(7): 1215–1216.

Barsalou, L. W. (2008). "Grounded cognition." *Annual Review of Psychology* 59(0): 617–645.

Bendtsen, L., Evers, S., Linde, M., Mitsikostas, D. D., Sandrini, G., Schoenen, J. and Efns (2010). "EFNS guideline on the treatment of tension-type headache - report of an EFNS task force." *Eur J Neurol* 17(11): 1318–1325.

Blaauw, B. A., Dyb, G., Hagen, K., Holmen, T. L., Linde, M., Wentzel-Larsen, T. and Zwart, J. A. (2014). "Anxiety, depression and behavioral problems among adolescents with recurrent headache: the Young-HUNT study." *J Headache Pain* 15: 38.

Blume, H. K., Brockman, L. N. and Breuner, C. C. (2012). "Biofeedback therapy for pediatric headache: factors associated with response." *Headache* 52(9): 1377–1386.

Bussone, G., Grazzi, L., D'Amico, D., Leone, M. and Andrasik, F. (1998). "Biofeedback-assisted relaxation training for young adolescents with tension-type headache: a controlled study." *Cephalalgia* 18(7): 463–467.

Cakmakci, O. and Rolland, J. (2006). "Head-worn displays: a review." *Display Technology, Journal of* 2(3): 199–216.

Chatzipavlou, I. A., Christoforidou, S. A. and Vlachopoulou, M. (2016). "A recommended guideline for the development of mHealth Apps." *mHealth* 2(21): 1–7.

Cook, D. A., Brydges, R., Zendejas, B., Hamstra, S. J. and Hatala, R. (2013). "Technology-Enhanced Simulation to Assess Health Professionals: A Systematic Review of Validity Evidence, Research Methods, and Reporting Quality." *Academic Medicine* 88(6): 872–883.

Dasarathy, B. V. (1997). "Sensor fusion potential exploitation-innovative architectures and illustrative applications." *Proceedings of the IEEE* 85(1): 24–38.

de Ribaupierre, S., Kapralos, B., Haji, F., Stroulia, E., Dubrowski, A. and Eagleson, R. (2014). Healthcare Training Enhancement Through Virtual Reality and Serious Games. *Virtual, Augmented Reality and Serious Games for Healthcare 1*. M. Ma, L. C. Jain and P. Anderson. Berlin, Heidelberg, Springer Berlin Heidelberg**:** 9–27.

Eccleston, C., Palermo, T. M., Williams, A. C., Lewandowski Holley, A., Morley, S., Fisher, E. and Law, E. (2014). "Psychological therapies for the management of chronic and recurrent pain in children and adolescents." *Cochrane Database Syst Rev* 5: CD003968.

El-Amrawy, F., Pharm, B. and Nounou, M. I. (2015). "Are currently available wearable devices for cctivity tracking and heart rate monitoring accurate, precise, and medically beneficial?" *Health Informatics Research* 21(4): 315-320.

Fominykh, M., Prasolova-Førland, E., Stiles, T. C., Borchgrevink, P., Krogh, A. B. and Linde, M. (2017). Relaxation Training with Biofeedback in Virtual Reality: Discussion of Wearability. *3rd Annual International Conference of the Immersive Learning Research Network*, Coimbra, Portugal, in press.

Fominykh, M., Wild, F., Smith, C., Alvarez, V. and Morozov, M. (2015). An Overview of Capturing Live Experience with Virtual and Augmented Reality. *1st Immersive Learning Research Network Conference (iLRN)*, Prague, Czech Republic, IOS Press, 298–305.

Gallagher, S. (2005). *How the body shapes the mind*. Oxford, UK, Clarendon Press.

Harvie, D. S., Broecker, M., Smith, R. T., Meulders, A., Madden, V. J. and Moseley, G. L. (2015). "Bogus Visual Feedback Alters Onset of Movement-Evoked Pain in People With Neck Pain." *Psychological Science* 26(4): 385–392.

Hoffman, H. G., Chambers, G. T., Meyer, W. J., Arceneaux, L. L., Russell, W. J., Seibel, E. J., Richards, T. L., Sharar, S. R. and Patterson, D. R. (2011). "Virtual Reality as an Adjunctive Non-pharmacologic Analgesic for Acute Burn Pain During Medical Procedures." *Annals of Behavioral Medicine* 41(2): 183–191.

Kipping, B., Rodger, S., Miller, K. and Kimble, R. M. (2012). "Virtual reality for acute pain reduction in adolescents undergoing burn wound care: A prospective randomized controlled trial." *Burns* 38(5): 650–657.

Krogh, A.-B., Larsson, B. and Linde, M. (2015). "Prevalence and disability of headache among Norwegian adolescents: A cross-sectional school-based study." *Cephalalgia* 35(13): 1181–1191.

Laurell, K., Larsson, B. and Eeg-Olofsson, O. (2004). "Prevalence of headache in Swedish schoolchildren, with a focus on tension-type headache." *Cephalalgia* 24(5): 380-8.

Lehrer, P. and Eddie, D. (2013). "Dynamic processes in regulation and some implications for biofeedback and biobehavioral interventions." *Appl Psychophysiol Biofeedback* 38(2): 143-55.

Li, A., Montano, Z., Chen, V. J. and Gold, J. I. (2011). "Virtual reality and pain management: current trends and future directions." *Pain Manag* 1(2): 147–157.

Limbu, B., Fominykh, M., Klemke, R., Specht, M. and Wild, F. (2017). Supporting Training of Expertise with Wearable Technologies: The WEKIT Reference Framework. *The International Handbook of Mobile and Ubiquitous Learning*. S. Yu, M. Ally and A. Tsinakos. New York, Springer, in press.

Minen, M. T., Torous, J., Raynowska, J., Piazza, A., Grudzen, C., Powers, S., Lipton, R. and Sevick, M. A. (2016). "Electronic behavioral interventions for headache: a systematic review." *J Headache Pain* 17: 51.

Murphy, J. L., McKellar, J. D., Raffa, S. D., Clark, M. E., Kerns, R. D. and Karlin, B. E. (2016). Cognitive Behavioral Therapy for Chronic Pain among veterans: Therapist Manual Washington, DC, Department of Veterans Affairs.

Nestoriuc, Y., Rief, W. and Martin, A. (2008). "Meta-analysis of biofeedback for tension-type headache: efficacy, specificity, and treatment moderators." *J Consult Clin Psychol* 76(3): 379-96.

Prasolova-Førland, E. and Divitini, M. (2003). Collaborative virtual environments for supporting learning communities: an experience of use. *12th International Conference on Supporting Group Work*, New York, NY, USA, ACM, 58–67.

Sarig Bahat, H., Takasaki, H., Chen, X., Bet-Or, Y. and Treleaven, J. (2015). "Cervical kinematic training with and without interactive VR training for chronic neck pain - a randomized clinical trial." *Manual Therapy* 20(1): 68–78.

Schwartz, M. S. and Andrasik, F., Eds. (2017). *Biofeedback: A Practitioner's Guide*. New York, NY, Guilford Press.

Sillanpaa, M. and Anttila, P. (1996). "Increasing prevalence of headache in 7-year-old schoolchildren." *Headache* 36(8): 466-70.

Siniatchkin, M., Hierundar, A., Kropp, P., Kuhnert, R., Gerber, W. D. and Stephani, U. (2000). "Self-regulation of slow cortical potentials in children with migraine: an exploratory study." *Appl Psychophysiol Biofeedback* 25(1): 13-32.

Slater, M. (2009). "Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments." *Philosophical Transactions of the Royal Society of London* 364(1535): 3549–3557.

Steuer, J. (1992). "Defining Virtual Reality: Dimensions Determining Telepresence." *Journal of Communication* 42(4): 73–93.

Stiefelhagen, R. (2009). Perceptual Technologies: Analyzing the Who, What, Where of Human Interaction. *Computers in the Human Interaction Loop*. A. Waibel and R. Stiefelhagen, Springer London**:** 9–10.

Termine, C., Ozge, A., Antonaci, F., Natriashvili, S., Guidetti, V. and Wober-Bingol, C. (2011). "Overview of diagnosis and management of paediatric headache. Part II: therapeutic management." *J Headache Pain* 12(1): 25-34.

van Krevelen, D. W. F. and Poelman, R. (2010). "A Survey of Augmented Reality Technologies, Applications and Limitations." *The International Journal of Virtual Reality* 9(2): 1–20.

White, R. M. (1987). "A Sensor Classification Scheme." *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* 34(2): 124–126.

Yuen, S.-Y., Yaoyuneyong, G. and Johnson, E. (2013). Augmented Reality and Education: Applications and Potentials. *Reshaping Learning*. R. Huang and J. M. Spector, Springer Berlin Heidelberg**:** 385–414.