DOI: https://doi.org/10.3217/978-3-85125-530-0-41

# Relaxation Training with Biofeedback in Virtual Reality: Discussion of Wearability

Mikhail Fominykh[1], Ekaterina Prasolova-Førland[2], Tore C. Stiles[3], Petter Chr. Borchgrevink[4], Anne Berit Krogh[5], and Mattias Linde[6]

[1] Independent Researcher,
[2] Department of Education and Lifelong Learning, NTNU Trondheim
[3] Department of Psychology, NTNU Trondheim
[4] Department of circulation and medical imaging, NTNU Trondheim
[5] Department of Public Health and Nursing, NTNU Trondheim
[6] Department of Neuromedicine and Movement Science, NTNU Trondheim
mihail.fominyh@gmail.com, {ekaterip, tore.stiles, mattias.linde, petter.borchgrevink, anne-berit.krogh}@ntnu.no

**Keywords:** Biofeedback, virtual reality, wearable technologies, psychological treatment, relaxation, technology-enhanced learning

**Abstract.** This paper describes a mobile learning app aimed to be used for relaxation training, primarily for adolescents suffering from tension-type headaches. Combining expertise from neuromedicine, psychology, and technology-enhanced learning, we have developed a concept and a working prototype for low-cost biofeedback training applications. The system uses virtual reality technology for delivering visual experience on both low-cost and advanced virtual reality glasses. A wirelessly connected wristband is used to measure user's pulse and adjust the training scenario and the virtual environment based on the heart rate data. The app simulates an immersive environment of a tropical beach with several interactive visual and audio elements. The main goal of the simulation is to make the weather as calm as possible by reducing own heart rate. The progression through the scenario is guided by a therapist's voice with some degree of self-exploration. Repeating the exercise would 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 is currently being evaluated in a feasibility study with a small group of participants that answer a questionnaire and interview questions after trying the app. The first evaluation results are presented in the paper. The results are discussed with a focus on wearability – suitable for wearing – of virtual reality glasses and of the wristband.

## 1 Introduction

Virtual Reality (VR) has been applied to learning and training providing flexible alternatives with immersive simulations of places and activities. This technology can benefit educational process due to low cost, high safety and a sense of presence [1, 2]. Wearable Technologies (WT), such as head-mounted displays and on-body biological sensors,

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

can be used as part of VR systems to create additional modes of interaction and feedback.

In this paper, we explore the combination of VR and biological wearable sensors for creating educational experiences. We developed a conceptual framework for designing low-cost training applications that use this combination of technologies. The framework is demonstrated on an example of a prototype app for relaxation training. Relaxation is used in psychological treatment when medication is not an option [3]. Being able to relax quickly is an important skill that is not easy to acquire. Training how to relax is the learning objective of the prototype presented in this paper, while the ultimate purpose is to help adolescence combat tension-type headache, as a part of the bigger project 'Cognitive behaviour therapy treatment of chronic tension-type headache in adolescents in virtual reality', coordinated by the Norwegian University of Science and Technology (NTNU) and St. Olavs hospital, Trondheim, Norway.

Tension-type headache is the second most prevalent of all health disorders among adolescents. Especially chronic headache causes a high burden on the young sufferers. There is no available prophylactic medication in this age group, but biofeedback, a behavioural treatment without known side effects, seems to be effective. Biofeedback is a "process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance" [4]. Presently, this is a highly-specialized therapy unavailable to most people in need. Despite of the rapid development and acceptance of smartphones, VR, WT, and mobile health, there is a lack of literature exploring the delivery of behavioral interventions using these technologies for headache [5].

Our research focuses on an innovative technology in healthcare, aiming at developing and evaluating in real settings a new method for technology-enhanced psychological treatment. The overall hypothesis is that biofeedback in VR is effective and tolerable for the prophylaxis of chronic tension-type headache in adolescents, and that it can be self-administered by patients at home. The hypothesis has not yet been verified. The prototype we have developed is being evaluated in stages. In this paper, we describe the system design and present the concept behind it. We also present and discuss the first evaluation results related to the wearability aspect.

## 2 Background

### 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 [3]. Such treatments can be an alternative where there are no effective prophylactic medications, for example, in treatment of chronic tension-type headache among adolescents [6]. Psychological treatments were originally developed for delivery in the clinic in a format in which the patient and therapist work face-to-face [7, 8]. This requires trained personnel with special resources in multidisciplinary settings which are unavailable to the absolute majority of persons in need. Hence, there is a need for self-administered and easily accessible technology.

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

Mobile Health applications (mHealth apps) handle various medical or health issues using mobile devices [9]. 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 experience that would be impossible to create otherwise. In addition, there are now several wireless, wearable body sensors which can measure, bodily functions with reasonable accuracy and precision [9, 10].

Biofeedback method has been used in healthcare since late fifties and gained popularity in the recent years with the availability of bio sensors and mobile technology [11]. 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 [12]. It is generally considered that this reduces the excitability within central nervous system networks and renders individuals more resilient to effects of environmental stressors [13, 14].

European treatment guidelines conclude that biofeedback has a documented effect for tension-type headache patients as a group [15]. Biofeedback is generally claimed to be efficacious [12], with a larger effect in children and adolescents than in adults [16].

**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 [17]. VR technologies provide fresh perspectives to healthcare and great potential supported by several examples of documented positive effect [18-20] but still with room for improvement [21].

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 [22, 23]. 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 exactly the same way as in the physical world – by turning the head. Modern desktop-free human-computer interfaces increase the value and transferability of virtual experience.

Other types of WT devices include wireless body sensors that can measure, for example, heart rate with reasonable accuracy and precision [9, 10]. The WT sees, hears and perceives the user’s physical state. 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 [24, 25]. Capturing human’s psycho-physiological states using bio-signals and physiological phenomena is at the core of perceptual technologies [26].

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

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

## 3 Training with Virtual Reality and Biofeedback: Concept Design

We are designing an overarching conceptual framework to facilitate future development of VR applications for therapeutic purposes, especially in pain coping and relief. We have identified the following major VR mechanisms for pain coping and relief:

- **Distraction**: drawing attention from the patient's mental pain processing with immersive and interactive VR experiences, for example, SnowWorld for burn victims [27].
- **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 movement to people with neck pain alters onset of movement-evoked pain [28].
- **Imagery skills for pain control**: 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 [29].

We have also developed a VR characterization framework with features and elements along the dimensions of User/Patient, Virtual Therapy Place, Therapy artifacts and Interface. The design concepts and scenarios for specific therapeutic goals and situations in the context of Cognitive Behavioral Therapy and biofeedback goals, such as relaxation, sleep strategies, and coping, [30] are developed by matching the VR pain mechanisms with corresponding VR features and elements.

Biofeedback and wearable interaction [31] are the central concepts of the framework (Fig. 1). The user (on the left) wears 3D glasses and a headset to perceive the VR experience and a wearable sensor that measures pulse. The user exercises relaxation and tries to control his/her heart rate. The wearable sensor (bottom) measures the pulse of the user and sends it via Bluetooth to the wirelessly connected PC or mobile device at the constant requests coming from the VR app. The VR app (right) receives the pulse data in real time, updates the features of the VR environment based on these data, and renders the VR environment accordingly. The head-mounted display (top) receives the images and sounds and delivers the VR experience back to the user.

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

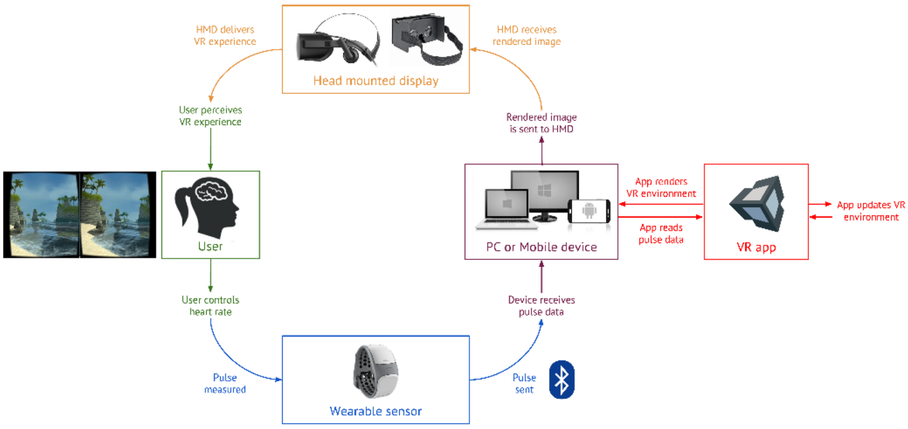


**Fig. 1.** Conceptual design and biofeedback

The framework is designed to support mobility of the users. It should be possible to create applications that can be used in treatment programs in and outside of a clinic. This is reflected in the hardware setup. The applications should run on the advanced VR glasses, stationary PCs, and read data from highly accurate sensors. At the same time, the applications should also run on smartphones, cardboards, and consumer wrist-band sensors. In addition, the domain of scenarios we focus on (relaxation, coping, imagery skills) assumes that the user is comfortable while experiencing the simulation. Therefore, the wearability aspect is addressed in the design and evaluation.

In our technological setup, both the heart-rate sensor and the VR glasses are wearable devices. Wearability plays an important role in the users' comfort and quality of experience, but often is not been taken into consideration in studies [32]. The discomfort may be caused, as defined in [32], by low wearability (e.g., device gets in the user's way of activity) and strange appearance (e.g., devices attached to the body with a band, tape, cap, or wig). Several additional factors that affect wearability include functionality, application task, system management, maintenance, economic sustainability, interoperability, style, fashion, and branding. These factors can be applied to the design, selection, and placement of devices.

## 4 Prototype Design

### Scenario

In the current version of the prototype, the user only has access to a single test-module of the virtual environment that implements a tropical beach scene and a relaxation training scenario. The virtual environment contains two types of elements: static and interactive. The static elements are decorations that are added to create the right atmosphere

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

defined by the scenario. The interactive elements change depending on the user behavior, heart rate and gaze direction. For example, sea waves gradually become higher when the heart rate of the user increases and vice versa (Fig. 2). 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.

**Fig. 2.** Environment changes: lowest heart rate (left) and highest heart rate (right)

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 starting / baseline heart-rate value. The session ends when one of the following conditions is met:

- The threshold value for the 'calm sea' has been met (baseline value - 20%)
- The absolute heart rate is lower than 30
- The threshold value for the 'stormy sea' has been met (baseline value + 75%)
- 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

**Architecture**

The current version of the prototype has a simple modular hardware / software architecture (Fig. 3). Main VR scene is a central software element that is present is three different user applications: advance VR app (version for Oculus Rift and version Gear VR), desktop app, and a mobile app (with two modes: for a regular screen and for Google Cardboard or similar). Depending on the platform, the main VR scene uses Java or C++ modules to read the pulse data from the wearable sensor and update the 3D environment and the scenario.

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

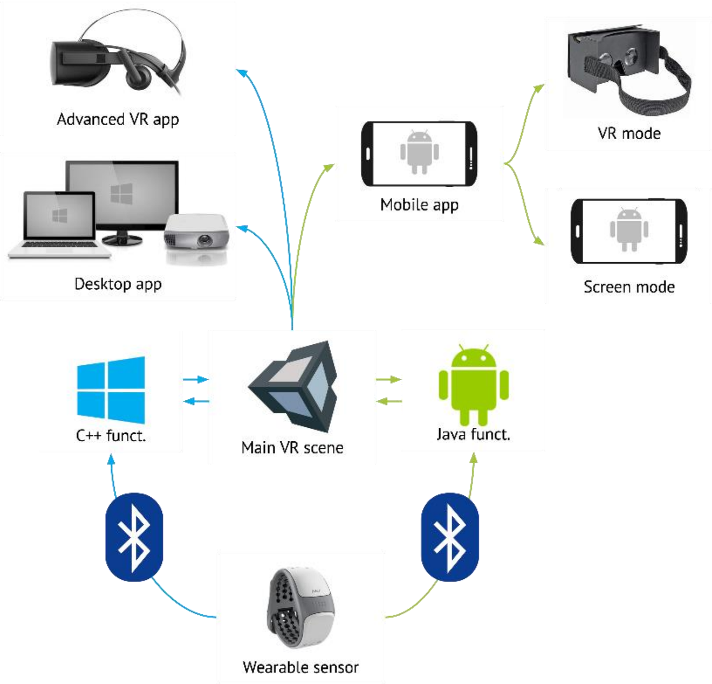


**Fig. 3.** Hardware / software architecture of the prototype

## 5 Evaluation

### Settings

We started the technical feasibility study by demonstrating the prototype to a group of 84 last-year high school students (with a few older people in the group) in September 2016. All of them volunteered to test the simulator. A special version of the Mobile app gave each participant one minute to relax immersed in the virtual environment and displayed the results. We tested the overall impression of the target group participants, comfort of using a wearable sensor and 3D glasses, and the observed general trends in their heart rates. We did not collect any personal data (e.g., name, age, photo), but asked briefly about the general impressions. The app also recorded four heart values for each participant: at the start of the session, at the end, maximum, and minimum.

Next, a more detailed evaluation has been conducted with 13 volunteer subjects in 13 individual test sessions conducted in November 2016. 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).

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

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. The subject tries out 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, some other tried the desktop app and the mobile app in the screen mode, and in other 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 was analyzed without using statistical methods because of the aim to reveal general impressions and the small number of subjects. The interviews were not recorded for full transcription, but instead captured in notes. The notes were then grouped by questions and qualitatively analyzed. In this paper, we present the results that are related to the comfort of use, biofeedback and wearability.

The main project ‘Cognitive behaviour therapy treatment of chronic tension-type headache in adolescents in virtual reality’ has been submitted for approval to the Regional Committees for Medical and Health Research Ethics. According to the Ethics Committee, the feasibility study part of the project does not fall under medical and health research and hence does not need specific approval. Since no personal information has been collected (such as names of the participants), it was not required to seek approval from the Norwegian Centre of Research Data, either.

## Results

The results of the test conducted with 84 participants in September 2016 demonstrated that the target group subjects are generally very interested in both VR simulators and WT devices. All the participants agreed to wear the sensor on their wrists and all understood how to use the cardboard 3D glasses. Not everybody gave an explicit feedback, but those who did overall enjoyed the experience. The great majority of the subjects 83 out of 84 did not have any difficulties preparing to and going through the relaxation session. Only one participant could not complete it because of a difficulty wearing the cardboard.

The logs collected by the app allowed us to better understand how quickly the heart rate of the participants of this age group can change. The diagram below features the pulse change as measured by the wearable device. On the horizontal axis, the values for each participant are given sorted by how much they relaxed (Fig. 4). The values vary from the pulse values decreasing for 37.3% (Fig. 4, left) to increasing for 57.4%

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

(Fig. 4, right). The number of participants who managed to relax (heart rate in the end of the session is lower than in the beginning) was 61 out of 84.

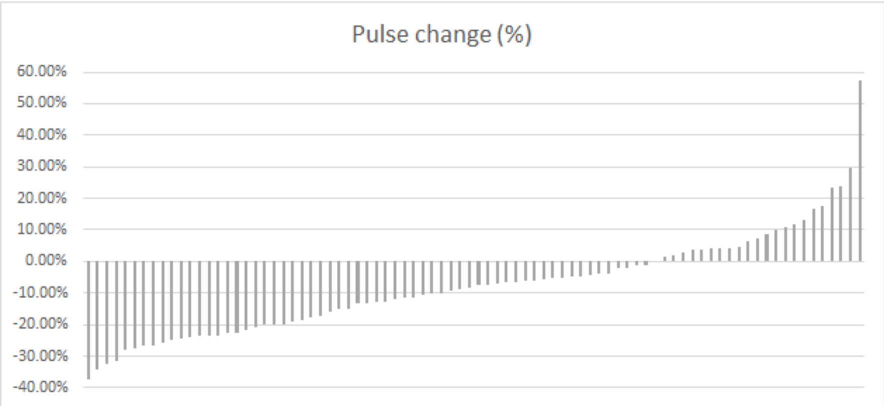


**Fig. 4.** Pulse change from the start to the end of the session

The technical feasibility study provided more detailed feedback on specific components of the simulator. The target group consisted of 13 subjects who were older than the target end users of the simulator. Their age varied 22 to 46 (average 28,9). Even though the feedback data was affected by the age, it allowed us to conduct detailed interviews, try different versions and different devices and discuss different aspects of the simulator.

The questionnaire contained a specific question if it was physically uncomfortable to use the simulator application. All who rated the advanced VR version (with Oculus Rift) responded that it was comfortable to use the simulator. The majority of those who evaluated the cardboard version were also comfortable, but two participants responded that it was uncomfortable and very uncomfortable. The interview data gives a much deeper insight to the issue.

The interview did not contain specific questions about wearability or comfort of use, but several questions where these aspects could be brought up as issues. Five out of 13 participants pointed out wearability and comfort as important aspects, and for three of them these issues were the most important factors affecting the experience.

When describing their general impressions, three participants reported that it was physically uncomfortable to wear 3D glasses. All these three participants tried the cardboard version. The issues discussed included the difficulty setting up and adjusting the 3D glasses and the cardboard being generally to wear for a period of time. Another issue was related to the extreme focus on the VR simulation that cuts off the peripheral vision, which could negatively affect relaxation. One participant discussed distraction of the relaxation process caused by virtual elements. As many people slightly bend down their head when trying to relax, they would gaze at the waves in the simulator, not seeing the horizon and the sky, while the reflections on water might look too distracting. Moreover, some elements of the virtual environment, such as the therapeutic

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

instructions, are asking the user to pay attention to certain elements of the virtual environment, which requires to look up.

Interview note: "*I saw reflections on the waves, they distracted me. It was difficult to control the balloons, because I needed to change my position and look up.*"

When discussing how the simulator can help users to relax better and then how to make it more user-friendly, two participants suggested to take care of the comfortable physical environment. The user should be instructed and should have access to a comfortable place to sit (e.g., an armchair), and the wearable devices should not prevent the user to be in unnatural positions. For example, the 3D glasses should not be held in hands, but adjusted with a strap, and it should be possible to adjust the lenses. One negative consequence was identified in testing with two participants, when the wearable sensor could not measure pulse for some time (while the participants were moving actively trying to find a comfortable position). This led to scenario development not corresponding the actual heart rate of the user. For better relaxation, one participant mentioned that the simulator should give an option to close eyes to use imagination for further visualization of the scenario.

## 6 Discussion and Conclusions

The results demonstrate that wearability and comfort are indeed very important for the users. The issues of low wearability were considered more important for relaxation with VR than strange appearance [32]. Utilizing the main functions of the wearable devices without being obstructed was the most important factor in the presented evaluation. The wristband measuring pulse was found easy to wear and comfortable, but possible malfunctioning (failure to read pulse) was sometimes difficult to spot immediately. 3D glasses caused several issues, especially the cardboard. At the same time, the function of 3D glasses was critically important, and the advanced VR glasses (Oculus Rift) did not cause as much discomfort.

The evaluation of the first prototype demonstrated that wearability and comfort are not only important for some users but should be considered as central design features for relaxation and psychological treatment simulations. As the VR environment affects the user in the physical world (by visual cues or sound instructions), it changes posture and the hear movement of the user, and therefore affects the heart rate. Therefore, it should be considered when designing a scenario and the interactive elements.

The instructions and user guidelines should include the setup of the physical environment (comfortable chair) and describe the correct posture. The importance of such instructions increases in individual use outside of the clinic setting.

An important aspect that was not evaluated in this paper is the use of the simulation by a person that is experiencing headache. As our main target group include young people with relatively frequent headaches, special instructions should be given for such situations.

The major contribution that we anticipate in this project is in using VR and WT to direct patient's attention and help to control his/her psychological state during therapy in ways that support stimulated recall of experiential learning.

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

## References


1. Warburton S.: Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. British Journal of Educational Technology 40 (3), 414–426 (2009)
2. Mckerlich R., Riis M., Anderson T., Eastman B.: Student Perceptions of Teaching Presence, Social Presence, and Cognitive Presence in a Virtual World. Journal of Online Learning and Teaching 7 (3), 324–336 (2011)
3. Eccleston C., Palermo T.M., Williams A.C., Lewandowski Holley A., Morley S., Fisher E., Law E.: Psychological therapies for the management of chronic and recurrent pain in children and adolescents. Cochrane Database Syst Rev 5, CD003968 (2014)
4. AAPB: What is Biofeedback. Association for Applied Psychophysiology and Biofeedback (2008), http://www.aapb.org/i4a/pages/index.cfm?pageid=1
5. Minen M.T., Torous J., Raynowska J., Piazza A., Grudzen C., Powers S., Lipton R., Sevick M.A.: Electronic behavioral interventions for headache: a systematic review. J Headache Pain 17, 51 (2016)
6. Termine C., Ozge A., Antonaci F., Natriashvili S., Guidetti V., Wober-Bingol C.: Overview of diagnosis and management of paediatric headache. Part II: therapeutic management. J Headache Pain 12 (1), 25-34 (2011)
7. Bussone G., Grazzi L., D'Amico D., Leone M., Andrasik F.: Biofeedback-assisted relaxation training for young adolescents with tension-type headache: a controlled study. Cephalalgia 18 (7), 463-467 (1998)
8. Andrasik F., Grazzi L., Usai S., D'Amico D., Leone M., Bussone G.: Brief neurologist-administered behavioral treatment of pediatric episodic tension-type headache. Neurology 60 (7), 1215-1216 (2003)
9. Chatzipavlou I.A., Christoforidou S.A., Vlachopoulou M.: A recommended guideline for the development of mHealth Apps. mHealth 2 (21), 1-7 (2016)
10. El-Amrawy F., Pharm B., Nounou M.I.: Are currently available wearable devices for cctivity tracking and heart rate monitoring accurate, precise, and medically beneficial? Health Informatics Research 21 (4), 315-320 (2015)
11. Schwartz M.S., Andrasik F. (eds.): Biofeedback: A Practitioner's Guide. Guilford Press, New York, NY (2017)
12. Blume H.K., Brockman L.N., Breuner C.C.: Biofeedback therapy for pediatric headache: factors associated with response. Headache 52 (9), 1377-1386 (2012)
13. Lehrer P., Eddie D.: Dynamic processes in regulation and some implications for biofeedback and biobehavioral interventions. Appl Psychophysiol Biofeedback 38 (2), 143-155 (2013)
14. Siniatchkin M., Hierundar A., Kropp P., Kuhnert R., Gerber W.D., Stephani U.: Self-regulation of slow cortical potentials in children with migraine: an exploratory study. Appl Psychophysiol Biofeedback 25 (1), 13-32 (2000)
15. Bendtsen L., Evers S., Linde M., Mitsikostas D.D., Sandrini G., Schoenen J., Efns: EFNS guideline on the treatment of tension-type headache - report of an EFNS task force. Eur J Neurol 17 (11), 1318-1325 (2010)
16. Nestoriuc Y., Rief W., Martin A.: Meta-analysis of biofeedback for tension-type headache: efficacy, specificity, and treatment moderators. J Consult Clin Psychol 76 (3), 379-396 (2008)
17. Steuer J.: Defining Virtual Reality: Dimensions Determining Telepresence. Journal of Communication 42 (4), 73–93 (1992)
18. Li A., Montano Z., Chen V.J., Gold J.I.: Virtual reality and pain management: current trends and future directions. Pain management 1 (2), 147–157 (2011)

DOI: https://doi.org/10.3217/978-3-85125-530-0-41

19. de Ribaupierre S., Kapralos B., Haji F., Stroulia E., Dubrowski A., Eagleson R.: Healthcare Training Enhancement Through Virtual Reality and Serious Games. In: Ma M, Jain LC, Anderson P (eds.) Virtual, Augmented Reality and Serious Games for Healthcare 1. pp. 9-27. Springer Berlin Heidelberg, Berlin, Heidelberg (2014)
20. Kipping B., Rodger S., Miller K., Kimble R.M.: Virtual reality for acute pain reduction in adolescents undergoing burn wound care: A prospective randomized controlled trial. Burns 38 (5), 650-657 (2012)
21. Cook D.A., Brydges R., Zendejas B., Hamstra S.J., Hatala R.: Technology-Enhanced Simulation to Assess Health Professionals: A Systematic Review of Validity Evidence, Research Methods, and Reporting Quality. Academic Medicine 88 (6), 872-883 (2013)
22. Cakmakci O., Rolland J.: Head-worn displays: a review. Display Technology, Journal of 2 (3), 199–216 (2006)
23. van Krevelen D.W.F., Poelman R.: A Survey of Augmented Reality Technologies, Applications and Limitations. The International Journal of Virtual Reality 9 (2), 1–20 (2010)
24. Fominykh M., Wild F., Smith C., Alvarez V., Morozov M.: An Overview of Capturing Live Experience with Virtual and Augmented Reality. In: Preuveneers D (ed.) 1st Immersive Learning Research Network Conference (iLRN), Prague, Czech Republic, July 13–14, Ambient Intelligence and Smart Environments, vol Workshop Proceedings of the 11th International Conference on Intelligent Environments, pp. 298–305. IOS Press, Amsterdam, Netherlands (2015)
25. Limbu B., Fominykh M., Klemke R., Specht M., Wild F.: Supporting Training of Expertise with Wearable Technologies: The WEKIT Reference Framework. In: Yu S, Ally M, Tsinakos A (eds.) The International Handbook of Mobile and Ubiquitous Learning. Springer, New York (2017), in press
26. Stiefelhagen R.: Perceptual Technologies: Analyzing the Who, What, Where of Human Interaction. In: Waibel A, Stiefelhagen R (eds.) Computers in the Human Interaction Loop. Human–Computer Interaction Series, pp. 9–10. Springer London (2009)
27. Hoffman H.G., Chambers G.T., Meyer W.J., Arceneaux L.L., Russell W.J., Seibel E.J., Richards T.L., Sharar S.R., Patterson D.R.: Virtual Reality as an Adjunctive Non-pharmacologic Analgesic for Acute Burn Pain During Medical Procedures. Annals of Behavioral Medicine 41 (2), 183–191 (2011)
28. Harvie D.S., Broecker M., Smith R.T., Meulders A., Madden V.J., Moseley G.L.: Bogus Visual Feedback Alters Onset of Movement-Evoked Pain in People With Neck Pain. Psychological Science 26 (4), 385–392 (2015)
29. Sarig Bahat H., Takasaki H., Chen X., Bet-Or Y., Treleaven J.: Cervical kinematic training with and without interactive VR training for chronic neck pain – a randomized clinical trial. Manual Therapy 20 (1), 68–78
30. Murphy J.L., McKellar J.D., Raffa S.D., Clark M.E., Kerns R.D., Karlin B.E.: Cognitive Behavioral Therapy for Chronic Pain among veterans: Therapist Manual Department of Veterans Affairs, Washington, DC, (2016),
31. Xu Q., Yi X., Pan Y.: A structured interaction model of wearable system. In: Proceedings of HCI Korea, Seoul, Republic of Korea, pp. 71-75. Hanbit Media, Inc., 2729497 (2014)
32. Murao K., Mogari H., Terada T., Tsukamoto M.: Evaluation function of sensor position for activity recognition considering wearability. In: Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication, Zurich, Switzerland, pp. 623-632. ACM, 2495983 (2013)