Developing a Social Biofeedback Training System for Stress Management Training

Tanja Schneeberger, Naomi Sauerwein, Manuel S. Anglet, and Patrick Gebhard
firstname.lastname@dfki.de
German Research Center for Artificial Intelligence
Saarland Informatics Campus, Saarbrücken, Germany

ABSTRACT

Mental stress is the psychological and physiological response to a high frequency of or continuous stressors. If prolonged and not regulated successfully, it has a negative impact on health. Developing stress coping techniques, as an emotion regulation strategy, is a crucial part of most therapeutic interventions. Interactive biofeedback agents can be employed as a digital health tool for therapists to let patients train and develop stress-coping strategies. This paper presents an interactive stress management training system using biofeedback derived from the heart rate variability (HRV), with an Interactive Social Agent as an autonomous biofeedback trainer. First evaluations have shown promising results.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**.

KEYWORDS

Social Agents; Stress Management Training; Biofeedback; Heart Rate Variability

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1 INTRODUCTION

Persistent mental stress is a massive problem in today's society. Repeated, excessive, or prolonged stress reactivity can increase health risks. Many mental and physical diseases are caused by persistent mental stress [7]. The World Health Organization [27] considers stress to be one of the most significant health risks of our time and expects that by the end of 2020 more than one in two sick days will be caused by stress.

In meta-analyses, stress management training, in general, was found to have positive effects, e.g., on a healthy population [5], in the work context [29], or on students [20]. One application of stress management training is biofeedback training, in which immediate and continuous feedback for variations in physiological activity is provided to the trainee. Usually, guided by a therapist, the goal is to raise awareness for physiological functions and to reach voluntary control of them [32].

With the advanced simulation of social skills (e.g., active listening, mimicry, gestures, emotion models) [2, 12, 14, 15] for interactive agents, these are becoming able to emulate social relationship. Since this ability is essential to tackle mental grievances [8] like stress, such agents could theoretically be used to improve technologically supported stress management by emulating the interaction and tasks of a human biofeedback coach.

This paper presents a novel virtual stress management training with the interactive social agent Gloria (Fig. 1). Within this scenario, we implemented a training consisting of two stages: 1) Visual Feedback and Gloria; and 2) Gloria only. In the first one, both a biofeedback monitor, displaying information about physiological functions, and Gloria are presented. Gloria gives background information and feedback on proper sensor handling. In the second one, the biofeedback monitor is removed and its information is replaced by guidance of Gloria. She verbally gives encouraging feedback if the physiological functions develop in a non-optimal direction. The purpose of the two-stage training was to fade out the biofeedback as technically-supported awareness, and foster transfer to social situations without it; Gloria trains the transition to the social situations. The unique feature of the presented approach is that the biofeedback training instructions are given entirely by a social agent instead of a human coach.

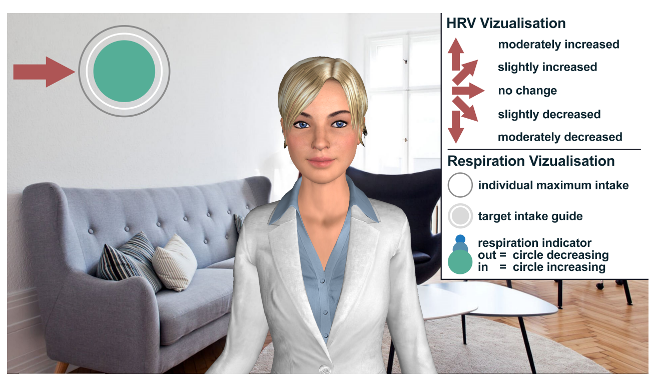

Figure 1: Biofeedback training system: user interface with the interactive social agent Gloria and the vizualisation of the physiological parameters.

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2 BACKGROUND ON STRESS AND BIOFEEDBACK TRAINING

In response to a stressor, the sympathetic nervous system is activated. In addition to the release of the neurotransmitters, adrenalin and noradrenalin, the sympathetic nervous system's impulses primarily cause physiological reactions in order to prepare the body for a quick reaction to the stressful situation [9]. This includes an increase in heart rate [36], respiratory rate [26], and a decrease in heart rate variability (HRV) [36]. A high frequency or continuity of stressors results in prolonged mental stress that has a negative long-term impact on psychological and physiological health. One reason for that is that the body cannot reach its homeostasis [7], which can cause psychiatric disorders such as depression [1]. As a physiological reaction, prolonged mental stress significantly reduces variability and chaotic behaviour of HRV [4].

As an instrument of stress management training, biofeedback is a widely used method for teaching voluntary control of various physiological functions by providing immediate and continuous feedback for variations in physiological activity [32]. Feedback usually is given in the form of visual and/or auditory signals derived from physiological recording devices. Physiological functions chosen for biofeedback training can include muscle tension, finger temperature, heart rate, blood pressure, or HRV [22].

HRV represents the beat to beat changes in the inter-beat interval (time between two successive R-waves). HRV training aims to increase the HRV amplitude that promotes vegetative nervous system balance. This balance is associated with improved physiological functioning as well as psychological benefits. Most individuals can learn to increase their HRV amplitude quickly, which involves slowing the breathing rate (around six breaths/min) to each individual's resonant frequency at which the amplitude of HRV is maximized [35]. HRV training has been meta-analytically evaluated to significantly reduce self-reported stress and anxiety for both community and clinical settings [13]. In recent years, it has been increasingly applied in healthy populations, especially in highly stressful work environments [28, 35].

In this paper, a HRV-based biofeedback training is presented. It uses a three-channel (two sensors just below the left and right collarbone, one at the center of the abdomen, Fig. 2) to record the heart rate as an output signal for heart rate variability. As an initial influencing process, the respiratory rate is recorded with a sensor-equipped chest strap and feed-backed to the user.

3 RELATED WORK

The health context, as a use case for interactive social agents, has been getting attention in research for about 15 years.

The Fit Track with the relational agent Laura is one of the first systems [2]. Laura has the role of an exercise advisor that interacts with patients daily for one month to motivate them to exercise more. Laura was equipped with different communication skills (i.a., empathy, social dialogue, nonverbal immediacy behaviors) to build and maintain good working relationships over multiple interactions. A study showed that the use of those social behaviors significantly increases the working alliance and the desire to continue working with the system.

Lucas and colleagues [23] showed positive effects of autonomous social agents in a health-care setting on overcoming the barrier to receive truthful patient information. They compared two different interviewers in a health-screening interview. Participants interacted with a virtual human and were led to believe that either a human or automation controlled the virtual human. Participants who believed they were interacting with a computer, reported lower fear of self-disclosure and were rated by observers as more willing to disclose.

The potential use of virtual humans as counselors in psychotherapeutic situations was investigated by Kang and Gratch [18]. Examining self-disclosure of patients in psychotherapy, they examined with which conversational partner participants disclose more private information measured with self as well as with external assessment. Their study reveals that a virtual human can elicit more self-disclosure in a hypothetical conversational scenario than a human in a raw or degraded video.

Regarding the design of stress management agents, Martin and colleagues [25] discuss underlying requirements and challenges, including the critical need to support both personalization and conversation. In a computer-aided interactive test designed for stress management education, the presence of a virtual agent positively affected enjoyment and learning outcomes [17].

A system for PTSD patients [37], in which patients can recollect their memories in a digital diary and recreate them in a 3D WorldBuilder, is using a virtual agent to inform and guide patients through the sessions. The agent employs an ontology-based question module for recollecting traumatic memories to elicit a detailed memory recollection further. In their study, the authors found hints that these questions were useful for memory recollection and conclude that their system can be a valuable addition to the spectrum of PTSD treatments, offering a novel type of home therapy assisted by a virtual agent.

Zhang et al. developed a virtual conversational agent that provides cardiovascular health counseling to hospitalized geriatrics patients [39]. The agent counsels patients on several health-related aspects such as decreasing stress and motivating them to be more involved and proactive in their self-care.

An embodied conversational agent in the role of a virtual intelligent university student advisor [19] was realized and piloted to support undergraduate students in stress management during their exams. In their study, the authors focus on gender effects of the advisor's perceived pleasantness, credibility, clarity, dynamism, and competence. Voices of male advisors were assessed as more pleasant and credible than female advisors', voices of female advisors were considered as more clear, dynamic and competent.

Shamekhi et al. [33] developed a virtual coach system for patients with a spinal cord injury that need training and support for self-care management after hospital discharge. The virtual coach educated the patients about managing their health and motivated them to healthy behavior. In their exploratory study, the authors found that patients were highly receptive and evaluated the virtual coach as an effective medium to promote self-care.

There also are other approaches, in which 3D virtual agents are used for biofeedback training. Chittaro and Sioni [6], e. g., employ them to reflect the user's level of stress. Based on the detection of the user's current stress level, the virtual agent's affective state and behavior are adapted as a form of embodied feedback. This work focuses on a comparison of single and multi-sensor stress detection algorithms. It uses the embodied feedback given by the virtual agent as a mediator for the perceived quality (in terms of accurateness) of biofeedback.

Generally, it seems that the exploitation of social agents in healthcare might have unique possibilities and even advantages to support the health-care system to overcome existing challenges. However, none of the existing systems provides an interactive social agent that is giving biofeedback training instructions.

4 REALIZATION

The interactive biofeedback environment extends the existing *Parley* [31] system with biosignal interpretation, biofeedback monitor, and image display components. The environment features the interactive social agent Gloria as the main user interface. Gloria interactively gives biofeedback training instructions and comments, as a human biofeedback coach would do.

Hardware-wise, the system runs on a desktop PC running MS Windows 10™ (Intel Core i7 CPU@3.5GHZ, 16GB Memory, NVIDIA RTX 2080 graphics cards) connected to a computer monitor (40 inches), showing Gloria at a realistic size.
The interaction with the system is realized with wireless biosignal sensors that measure the physiological parameters respiration rate and heart rate. To measure the physiological parameters, we rely on the *Plux* wireless biosignal toolkit[1]. These sensors were explicitly developed for research purposes and have already been successfully used in various studies [3, 16, 30]. To derive the heart rate, we use an electrocardiogram local differential triode. The three electrodes are placed just below both trainees' collarbones and centrally under the costal arch. To derive the respiratory rate and depth, we use a piezoelectric respiration sensor-equipped chest strap that is placed over the clothing. Both sensors are connected to a wireless 4-channel hub. To reduce data noise, the hub is placed on the table on the left in front of the trainee and the trainee is instructed to sit as still as possible. Also, Bluetooth should be switched off on all devices in the room.

Software-wise, the interactive biofeedback environment (Fig. 2) is realized with five main software components: 1. real-time signal interpretation, 2. content, behavior and interaction management, 3. biofeedback monitor, 4. character rendering, and 5. image display. All components are implemented as software agents and are asynchronously coordinated with events exchanged by a UDP network architecture. The last three components produce graphical output that is displayed in separate sections on the computer monitor (Fig. 2, a - c).

Signal interpretation. To process raw electrocardiogram data we employ the open-source *Social Signal Interpretation* framework (*SSI*) [38]. SSI has a pipeline concept that allows parallel processing of multiple sensor streams in real-time. In an electrocardiogram, the HRV describes the difference between two successive heartbeats. To assess the HRV, we use the Root Mean Square of the Successive Differences (RMSSD), one of the most commonly used measures derived from interval differences [24]. RMSSD is particularly suitable in the short-term range and permits an error-free analysis of the

[1]plux.info

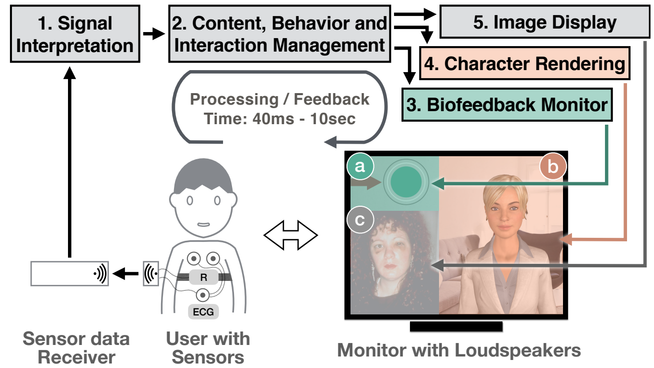

Figure 2: Biofeedback training system architecture.

HRV [34]. For the visual and verbal feedback of the training, the RMSSD values from ten heartbeats are calculated. For this purpose, absolute timestamps are assigned to the ten data points, which are subsequently sorted to exclude first-in-first-out errors. To avoid sorting errors, two additional values are added as buffers before and after, which are not included in the HRV calculation.

Content, behavior and interaction management. Central to the realization is the open-source *VisualSceneMaker* (VSM) toolkit [11], which is used to coordinate all software agents. VSM comes with a real-time execution and authoring component for modeling verbal and non-verbal behavior of virtual agents as well as system actions. Their execution (e.g., which scene to play when, or what process to run in the background) is determined by a finite-state automaton called the *sceneflow*. What happens in the scene (the agent's utterances or animations, or system commands) is described with a *scene script*, which is a human-readable text file.

Biofeedback monitor. To display the HRV and the respiratory rate and depth, we realized a biofeedback monitor in *Unity*[2]. A bordeaux colored arrow visualizes the HRV. Every ten seconds, it gives feedback in five steps (Fig. 1 up right) on how the HRV developed regarding the previous value. The respiration is visualized with three circles (Fig. 1 up left): 1. the grey one indicates the individual adaptive maximum intake that defines the deepest inhalation as a new maximum 2. the white one that moved continuously from the center to the grey circle and functions as the target intake guide (three seconds inhalation, four seconds exhalation), 3. the green to blue one that gives the actual feedback (approximately 40ms delay) of the trainee's respiration.

Character rendering. Gloria is a high-quality agent with a natural human appearance and verbal as well as nonverbal dialogue skills. Gloria is capable of performing social cue-based interaction with the user. She performs lip-sync speech output using the state-of-the-art CereProc[3] Text-To-Speech system. For a more advanced animation control, Gloria allows the direct manipulation of skeleton model joints (e.g., the neck joint or the spine joint). She comes with 36 conversational motion-captured gestures, which can be modified during run-time in some aspects (e.g., overall speed, extension).

[2]unity3d.com
[3]cereproc.com

Besides, the agent comes with a catalog of 14 facial expressions, which contains, among others, the six basic emotional expressions defined by Ekman [10].
Gloria is rendered by the commercial Charamel rendering engine that is free to use for any research purposes[4].

Image display. During the training sessions, stress inducing material in form of pictures or videos can be displayed in the image display. This enables the trainee to practice stress management strategies in various induced situations.

Apart from the biosignal sensors, all software components are already available for mobile devices. With the development of wearables that are able to measure physiological parameters (e.g., Apple Watch Series 5), it is possible to realize the complete biofeedback training system as a mobile version, which is being worked on.

5 FIRST EVALUATIONS

5.1 Expert Evaluation

To get a first feedback, we conducted a subject-matter expert (SME) interview with a biofeedback coach. After showing the system and explaining the purpose, we asked several questions regarding the usefulness, potential, and applicability. Overall, the SME rated the social biofeedback trainer agent as very valuable with extraordinary potential.

Notably, the image display that allows to show stress-inducing material was seen as a great additional benefit compared to state of the art biofeedback training. One of the most common biofeedback training critiques is that the stress regulation is not practiced during a stressful situation, but rather in a protected calm space. With the image display, it is possible to induce stress in the trainees with images or videos. This highly increases the possibility of stress management transfer to more natural situations. Optimally, the control about the respiration should be so well trained, such that it gets automatized. This automatizing can happen easier when the training is as close as possible to everyday life situations.

Regarding the applicability of the system, the SME can imagine that the PC driven training is used not only by therapists but also in companies as a preventive program for the employees. That a private person would buy the equipment needed for the PC driven training, was assessed as rather improbable. However, our SME sees great potential for the planned mobile version of the biofeedback trainer regarding the private use-case. With the help of smartphones and smartwatches tracking being able to monitor the heart rate, such a mobile trainer could be "anytime and anywhere available" for users.

5.2 Trainee Evaluation

To get a first feedback from trainees, we evaluated our biofeedback trainer with 35 student participants. After a two-session intervention with the biofeedback training, trainees rated the user experience with the UEQ [21] on six scales from 1 (*low*) to 5 (*high*): Attractiveness ($M = 3.61$, $SD = 0.71$), Stimulation ($M = 3.44$, $SD = 0.79$), Novelty ($M = 3.94$, $SD = 0.86$), Efficiency ($M = 3.61$, $SD = 0.60$), Perspicuity ($M = 3.79$, $SD = 0.79$), and Dependability ($M = 3.40$, $SD = 0.62$). Overall, the training was rated positively regarding the usability aspects. Especially the high values on the Novelty scale show that trainees assessed the training as inventive, leading-edge, and creative.

[4]charamel.com

6 CONCLUSION AND FUTURE WORK

The current level of interactive social agent technology allows sophisticated modeling of an interactive social agent in various scenarios. The presented biofeedback training components are freely available for scientific purposes. Some of them even have open-source licenses. Especially the content and interactive behavior modeling, provided by the VSM tool, can be easily adapted by non-computer science experts.

This work shows, once more, that technology can be employed to emulate human experts in the health context. We developed a technology-driven stress management training with a social agent as a coach. The field of application of such a system ranges from clinical to healthy user groups. It could complement state of the art therapies for mental diseases where stress management is already a crucial component, e.g., sleeping disorders, burnout or attention deficit hyperactivity disorder. Moreover, it can be used as a stress prevention program in healthy populations. In future work, we want to evaluate the developed system and compare it against state-of-the-art stress management training methods. Especially interesting is, if the virtual biofeedback trainer can emulate a human biofeedback trainer naturally and convincingly. Moreover, we want to finish the realization of a mobile version of the biofeedback training system to improve the accessibility for users.

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