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Affective computing vs. affective placebo: Study of a biofeedback-controlled game for relaxation training ☆

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ABSTRACT

Relaxation training is an application of affective computing with important implications for health and wellness. After detecting user's affective state through physiological sensors, a relaxation training application can provide the user with explicit feedback about his/her detected affective state. This process (biofeedback) can enable an individual to learn over time how to change his/her physiological activity for the purposes of improving health and performance. In this paper, we provide three contributions to the field of affective computing for health and wellness. First, we propose a novel application for relaxation training that combines ideas from affective computing and games. The game detects user's level of stress and uses it to influence the affective state and the behavior of a 3D virtual character as a form of embodied feedback. Second, we compare two algorithms for stress detection which follow two different approaches in the affective computing literature: a more practical and less costly approach that uses a single physiological sensor (skin conductance), and a potentially more accurate approach that uses four sensors (skin conductance, heart rate, muscle activity of corrugator supercilii and zygomaticus major). Third, as the central motivation of our research, we aim to improve the traditional methodology employed for comparisons in affective computing studies. To do so, we add to the study a *placebo* condition in which user's stress level, unbeknown to him/her, is determined pseudo-randomly instead of taking into account his/her physiological sensor readings. The obtained results show that only the feedback presented by the single-sensor algorithm was perceived as significantly more accurate than the placebo. If the placebo condition was not included in the study, the effectiveness of the two algorithms would have instead appeared similar. This outcome highlights the importance of using more thorough methodologies in future affective computing studies.

1. Introduction

Affective computing systems aim at detecting user's affective state and change their behavior based on that information (Picard, 1997). Relaxation training is one of the applications of affective computing which have important implications for health and wellness. After detecting user's affective state using physiological sensors, the application can provide the user with explicit feedback about his/her detected affective state. This process (*biofeedback*) can enable an individual to learn over time how to change his/her physiological activity for the purposes of improving health and performance (Association for Applied Psychophysiology and Biofeedback, 2011).

More specifically, biofeedback applications measure users' physiological signals like *electrodermal activity* (EDA) and *heart rate* (HR), and "feed back" this information to the user who, over time, can learn to consciously control his/her physiological processes and support the desired physiological changes. Biofeedback is employed to improve individual well-being in the treatment of medical and medical-related conditions, such as pain (Jensen et al., 2009), incontinence (Enck, 1993), migraine (Fentress et al., 1986). Moreover, it can be used to reduce stress-related symptoms (Bouchard et al., 2012) and enhance personal well-being (Chandler et al., 2001).

Many biofeedback systems in the literature still employ very simple acoustic or visual cues to provide users with information about their stress level, e.g., alarm sounds that are activated when a physiological signal reaches a certain threshold or virtual thermometers whose level is directly related to user's arousal. However, in recent years, some authors started to employ richer stimuli such as virtual reality and video games to convey biofeedback to users, e.g., Bersak et al. (2001), Bouchard et al. (2012). An advantage of this approach is that immersive and realistic *virtual environments* (VEs) draw more of the users' attention and can make the feedback more effective (Bersak et al., 2001).

The goal of this paper is threefold. First, we propose a novel biofeedback application for relaxation training that combines ideas from affective computing and games. We employ a 3D VE

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to present users with real-life simulated scenarios in which they have to focus on maintaining relaxation when faced with stressors. The level of stress detected through physiological signals determines the facial expressions as well as the behavior of a virtual character that represents the player in the VE. This relation between user's affective state and the virtual character provides users with an embodied visual and acoustic feedback about their state of relaxation. To detect users' level of stress, the game can employ up to four physiological sensors: EDA, HR, and two *electromyography* (EMG) sensors, which respectively measure the activity of *corrugator supercilii* and *zygomaticus major* muscles.

Second, we compare the perceived quality of the feedback provided by two versions of the game, which differ only in the stress detection algorithm they use. To relate our research to well-known approaches proposed in the affective computing literature, one of the stress detection algorithms we implemented is inspired by Healey and Picard (1998) while the other follows Mandryk and Atkins (2007). In particular, the first approach exploits only the EDA sensor while the second considers all the four physiological sensors mentioned above to compute the stress index for the biofeedback application. We are interested in comparing these two approaches in the context of biofeedback-based relaxation training because they may have different advantages: a single-sensor approach is more practical and less costly, but the use of multiple physiological sensors may improve the accuracy of stress detection by taking into account different bodily responses.

Third, as the central motivation of our research, we aim to improve the traditional methodology employed for comparisons in affective computing studies. To do so, we add to the study a *placebo* condition in which user's stress level, unbeknown to him/her, is determined pseudo-randomly instead of taking into account his/her physiological sensor readings. In medical studies, placebo conditions (i.e., conditions in which a sham instead of a real treatment is administered to participants) are commonly employed because factors such as participants' suggestibility could lead to improvements even with sham treatments. The purpose of the placebo condition is therefore to experimentally evaluate if the proposed treatment (e.g., a pill containing a new drug) is really superior to the sham treatment (e.g., a pill that looks like the real drug but does not actually contain it). In affective computing studies, one cannot rule out the possibility that the suggestibility of participants could alter their perception of the feedback provided by the application, leading them to believe that a real biofeedback system is in place although the provided feedback is actually sham. The use of a placebo condition is common in the biofeedback literature for the evaluation of the long-term efficacy of biofeedback therapy based on simple stimuli, often with interesting results, e.g., Hunyor et al. (1997). In studies of affective computing systems, it could be interesting to include placebo conditions in long-term evaluations as well as in evaluations of the immediate perceived accuracy of the rich feedback provided by the application to determine if the – often complex and costly – affective computing techniques are actually playing a significant role in the effectiveness of the feedback. However, to the best of our knowledge, the affective computing literature has not yet explored this way of evaluating systems.

The paper is organized as follows. In Section 2, we review the literature on biofeedback applications and evaluation of affective computing systems. Section 3 describes in detail the proposed biofeedback game. Then, Sections 4 and 5 describe in detail our experiment and its results, while Section 6 critically discusses the results. Finally, Section 7 presents conclusions and future work.

2. Related work

Three professional biofeedback organizations, the Association for Applied Psychophysiology and Biofeedback (AAPB), the Biofeedback Certification International Alliance (BCIA), and the International Society for Neurofeedback and Research (ISNR), define biofeedback as follows.

> Biofeedback is a process that enables an individual to learn how to change physiological activity for the purposes of improving health and performance. Precise instruments measure physiological activity such as brainwaves, heart function, breathing, muscle activity, and skin temperature. These instruments rapidly and accurately “feed back” information to the user. The presentation of this information – often in conjunction with changes in thinking, emotions, and behavior – supports desired physiological changes. Over time, these changes can endure without continued use of an instrument. (Association for Applied Psychophysiology and Biofeedback, 2011)

The use of biofeedback in relaxation training and stress treatment is widely described in the literature. It aims to improve trainees' health and wellness by increasing their ability to relax, and to make them learn how to better cope with stress. Indeed, high levels of arousal are often hallmarks of anxiety disorders and stress (Chandler et al., 2001), which can threaten well-being, safety and security (Carr, 2006). Interventions such as biofeedback-assisted relaxation training could reduce stress-related symptoms (Chandler et al., 2001), improve quality of life (Pistoia et al., 2013) and increase feelings of well-being (Chandler et al., 2001; Critchley et al., 2001; Pistoia et al., 2013).

Biofeedback-based relaxation training is also used in the treatment of some medical conditions such as chronic pain (Jensen et al., 2009), fibromyalgia (Buckelew et al., 1998), migraine (Fentress et al., 1986; Pistoia et al., 2013; Vasudeva et al., 2003), and hypertension (Hunyor et al., 1997). In these cases, biofeedback leads to positive effects on patients' health and wellness that, in some cases, are at least comparable to traditional therapies (Buckelew et al., 1998; Jensen et al., 2009; Vasudeva et al., 2003). To further improve the efficacy of the intervention, the integration of biofeedback with traditional therapies is often considered, e.g., Pistoia et al. (2013). The fact that biofeedback-based treatments, while effective, do not provide in some cases significant advantages over classic therapies led some authors, e.g., Fentress et al. (1986) to question whether the cost of biofeedback equipment is justifiable when simpler and less expensive alternatives are available. For example, *relaxation response* (Benson, 1975), i.e., a set of coordinated physiological changes related to a state of increasing relaxation, can be brought forth when a person focuses attention on a repetitive mental activity (e.g., repeating a word or a phrase) and passively ignores distracting thoughts (Fentress et al., 1986).

Jensen et al. (2009) underline a common limitation of many biofeedback-based therapy studies in the literature, which often focus only on the short-term effects of the therapy on patients' medical conditions, without paying much attention to longer-term effects. For example, this issue is apparent in studies that apply biofeedback to the treatment of gastrointestinal and pelvic floor disorders. The reviews by Enck (1993) and Bassotti and Whitehead (1997) report how the application of biofeedback seems to provide short term improvements in numerous functional disorders of the gastrointestinal tract, especially those related to the lower part of the gut (Bassotti and Whitehead, 1997), but more research is instead needed about the long-term effects of biofeedback-based treatments (Enck, 1993).

Attention deficit-hyperactivity disorder (ADHD) is another common target for biofeedback-based treatments, as originally proposed by Lubar and Shouse (1976). The review by Lubar (1991) shows that biofeedback training, although time consuming, can lead to significant improvements in ADHD, while the meta-analysis by Arns et al. (2009) confirms that it can be regarded as

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