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ABS-MindHeart: An agent based simulator of the influence of mindfulness programs on heart rate variability

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ABSTRACT

The heart rate variability is one of the most relevant health indicators. This indicator is related with the survival after myocardial infarction, the capacity of self-regulating emotions to positive states and the tolerance to stress. This work presents an agent-based simulator about the influences of different mindfulness programs on this indicator. The simulator is useful for (a) instructors as they can simulate the repercussion of new mindfulness programs, and for (b) practitioners since it can assist them in selecting an appropriate mindfulness program. The simulator is called ABS-MindHeart, and has been experienced with two different mindfulness programs. Its simulated outcomes are similar to the real ones according to the Paired *t*-test. This open-source simulator is distributed as an app and an online tool.

1. Introduction

Heart rate variability (HRV) is a relevant health indicator because of its proven relations with the survival after myocardial infarction [19], the mortality even in older people at very low cardiovascular risk [20], the outcomes of post-cardiac transplants [11], the conditions of congestive heart failure and diabetic neuropathy [39], and disorders such as fibromyalgia and the chronic fatigue syndrome [26]. From a psychological perspective, a reduced HRV is related with depression, the state of anxiety, emotional strain and an excessive daily worry, while a high HRV is usually related with the self-regulatory capacity [24] for guiding thoughts, feelings and behaviors to reach personal goals and positive emotional states. In general, the increments of HRV commonly alleviate the aforementioned health problems, and increase the corresponding health indicators.

The capacity of being aware moment-to-moment of the stream of consciousness, known as mindfulness, has proven to influence HRV [29,9] among other health and well-being features [4,17,34,16]. In particular, Delgado-Pastor et al. [9] measured the HRV of mindfulness experts, and showed that they increased their HRV when practicing mindfulness meditation. Other two works [21,27] analyzed the influence of certain mindfulness interventions on naive meditators, and both found significant differences of HRV during meditation between pre- and post-intervention measures.

Mindfulness can be trained with different approaches [5]. Some of these are based on Buddhist meditations like Vipassana and Zen meditations, while others use group-based interventions such as mindfulness-based stress reduction (MBSR) and mindfulness-based cognitive therapy or other interventions with a psychological background. There are different variations of the programs for applying these mindfulness-based approaches regarding the main techniques, aims and philosophical background. Experienced mindfulness instructors could define new mindfulness programs or amend some of the existing ones. However, to the best of our knowledge, their repercussions would be unknown until these programs are actually instructed for a group of practitioners.

In this context, the current approach presents a simulator of mindfulness programs taking HRV into account. This simulator is a twofold contribution, which (a) allows instructors to define new mindfulness programs and simulate their influence on a group of practitioners considering their HRV, and (b) allows practitioners to simulate the effects of certain mindfulness programs with different durations on their HRV. The simulator has been developed as a mobile application called ABS-MindHeart, in order to adhere

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to the trend of m-health [25] with all their surrounding advantages such as the anytime and anywhere access that reduces the costs of healthcare services [35], and the capability of changing the lifestyles of elder, disabled and chronically ill people [22]. ABS-MindHeart is also available from an online tool to reach to a wider range of users, who might not want to install the app. The current simulator has been modeled with the Ingenias language for multi-agent systems (MASs) [15] and implemented as an object-oriented application for obtaining a high performance following our process validated in the MAS community [12].

The remainder of this article is organized as follows. The next section introduces the related works and highlights the gap of the literature that is covered by the current approach. Section 3 describes the approach of the presented simulator. Section 4 presents the experimentation with two different mindfulness programs, comparing simulated and real results. Finally, Section 5 mentions the conclusions of this work and depicts some other ongoing lines of work in this context.

2. Related work

In order to contextualize the current research, the presentation of the most related works is divided into the applications for mindfulness in Section 2.1 and the simulators in cardiology in Section 2.2.

2.1. Applications for mindfulness

There are applications that support the practice of mindfulness, including both mobile applications and computer-based ones. These applications can be useful for practicing mindfulness individually, training in groups with certain mindfulness programs, and supporting mindfulness-based interventions in healthcare systems [10].

A large number of mobile applications have been developed to support mindfulness practice as two recent reviews reveal [30,23]. For instance, AEON is an app for practicing thought distancing in the context of mindfulness [6]. Practitioners write their thoughts in the app, and their thoughts are displayed with hand-writing appearance. Practitioners can touch the screen, and the app simulates waves of water that dissolve these thoughts with a smooth transition. This app increased the mindfulness and pleasantness of naive meditators in comparison to two traditional thought distancing techniques. This app was also evaluated in the large by distributing it in the main online stores [7]. The participants increased their level of mindfulness in a four-week period. AEON has been further evaluated in a recent work [8] by analyzing qualitative interviews of participants at the end of a five-week period. Some participants experienced decentering from their worries while using the app. Plaza et al. [31,28] developed a mobile application for supporting the practice of mindfulness. This is the first mindfulness app in Spanish. This app was proven to be useful for both naive and experienced users thanks to the great variety of mindfulness exercises, and for both individual home practice and mindfulness training in groups.

Several computer-based applications assist mindfulness training. Besides the e-learning systems for providing material for learning mindfulness, there are several interactive systems for practicing mindfulness. For instance, Mindfulness Sphere [40] allows mindfulness practitioners to focus their attention on their heartbeats. In particular, users only need to touch a sphere. This sphere changes its color or has soft vibrations when sensing their heartbeats. Yu et al. [44] present two systems that support the practice of mindful walking meditation. Users were asked to synchronize their footsteps with their breathing. Their walking-aware system (WAS) included a pair of shoes with sensors and was aimed at making users aware of their walk. Breathwalk-aware system (BAS) was aimed at allowing users to be aware of their respiration when walking. The users received feedback from the systems so that beginners improved their awareness of walking. They learned to (a) reduce the walking speed and to (b) better synchronize the footsteps with respiration. Sonic Cradle [43] facilitates users in practicing mindful breathing. This system allows practitioners to construct new sound patterns by breathing in different ways. When the system senses a breathing pattern, it constructs an associated sound pattern, and plays it through speakers. The user can hold breath, and the first sound pattern continues. Then, they breathe in a different way and the corresponding second sound pattern mixes with the first one. This can be done more than two times, constructing complex mixed sound patterns. This system is immersive as users have this experience in a chamber with complete darkness. In a later work [42], the participants assessed the experience of Sonic Cradle as relaxing, and mentioned that this approach was easier to be engaged than other meditation experiences. The application of Hudlicka [18] provides a virtual coach implemented as a conversational character. It can keep a natural language dialog, customizing the training plan for each user according to their responses.

All these mindfulness applications are aimed at supporting the practice of mindfulness. However, these applications neither allow users to evaluate and compare different mindfulness programs nor predict the health repercussions of these programs.

2.2. Simulators in cardiology

Several simulators have been useful for analyzing, understanding and/or simulating the heart activity, presenting advances in cardiology. There are two main groups of works in this line of research. The first group gathers the immersive simulators that allow users to experience different extreme situations, while their heart activity is recorded for being analyzed. The second group simulates the heart activity showing the variation in certain cardiac features.

In the first group, Tozman et al. [41] conducted a study with a driving simulator using different demand levels to induce from boredom to anxiety. They measured the HRV of the participants in order to relate it with different mental states. They concluded that virtual environments such as a driving simulator were useful for analyzing the relation of HRV with certain psychological aspects such as flow (i.e. immersion with full attention and enjoyment) or anxiety. Saus et al. [32] used a navigation simulator for the training and education of maritime personnel. In their experiments with first-year students, they showed that the subjects with high situation awareness were able to modulate their HRV.

In the second group, MioLab [36] is a simulator that graphically shows the influence of the calcium ion on cardiac electrical activity. This allows understanding complex processes of excitation–contraction–relaxation (ECR) cycle. In general, ECR cycle is the whole biological process that underlies a muscle contraction in mammalians. The main events of this cycle [38] are (1) the propagation of an action in the tabular system, (2) the detection of the depolarization signal and its propagation to the sarcoplasmic reticulum membrane, (3) release of a calcium ion, (4) rise of myoplasmic, (5) activation of the contractile apparatus, and (6) the returning back of the calcium ion. In the MioLab simulator, the different movements of the calcium ion were simulated for the ECR cycles of heartbeats. This simulator allowed doctors to analyze the effects of drugs on the treatment of cardiac arrhythmias. Aktaruzzaman and Sassi [1] implemented a simulation mechanism for estimating the sample entropy in HRV from short measurement periods. The advantage of their approach was that it