A Mathematical Model for Personalized Relaxation for Stress Management

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***Abstract*— Several researchers have highlighted the importance of studying stress and exploring methods to effectively reduce its harmful effects on human wellbeing. Biofeedback is an emerging technology being used as a legitimate preventive health care technique for achieving higher levels of well-being and can also be used for stress management. In this paper, we propose a mathematical model for personalizing relaxation techniques for stress management. The model considers both physiological reactions to various relaxation techniques and contextual information to optimize relaxation effectiveness. The long term objective is to teach users about what actually works best for them among several relaxation techniques. A case study for ubiquitous stress management application is presented to demonstrate the effectiveness of the model. The simulation results demonstrate the ability of the proposed model to provide users with feedback about what relaxation techniques work best for them as well as adapt to various environmental conditions.**

***Index Terms*—Stress management, biofeedback, relaxation techniques, personalization, mathematical modeling.**

I. Introduction

The concept of health is no longer limited to the treatment or cure of diseases; rather, there has been a shift towards preventive or avoidance health care techniques that are aimed at improving the quality of life [1-2]. A large proportion of health concerns are attributed to stress-related disturbances, including both mental and physical stress [3]. For instance, the American Institute for Stress lists fifty common signs/symptoms of stress ranging from headaches to more serious illnesses such as obesity and heart palpitations [4]. Awareness of stress and the ability to control and manage stress levels are essential for maintaining a high level of mental and physical well-being [5].

Relaxation techniques include a number of practices such as progressive relaxation, guided imagery, biofeedback, self-hypnosis, controlled breathing, meditation and visualization to release tension and/or counteract the ill effects of stress [6]. Several researchers (such as [7]) have classified stress management interventions as primary, secondary, and tertiary. The goal of primary prevention is to deal with stressors before subjects experience stress symptoms or disease. Secondary prevention equips subjects with tools and skills to handle stress. Tertiary level interventions aim to treat, compensate, or rehabilitate subjects who suffer from stress symptoms or related diseases. Relaxation belongs to the secondary or tertiary intervention category.

Traditional relaxation techniques are usually time-consuming and costly and thus are accessible to only a few of the general public and usually unavailable where and when stress strikes [8]. Computer-based biofeedback is a promising technology that can help monitoring the health condition of users without intervening in their daily living [9]. Computer-based biofeedback is the process of capturing physiological and psychological information about a human subject, using wearable health related sensors, and displaying the information to the user in a comprehendible form (via visual and/or auditory displays) [10]. By viewing these parameters the subject can learn self-regulation schemes and optimize the body-mind system performance.

Biofeedback-assisted relaxation teaches a user how to consciously produce the relaxation response. Biofeedback is more effective when combined with relaxation techniques, self-hypnotism and psychotherapy [11]. Of particular interest, relaxation can have numerous health benefits, many of which relate to the benefits of biofeedback, such as stress relief, lowering one's blood pressure, reducing muscle tension, improving concentration or reducing frustration. The ultimate objective is to familiarize users with biofeedback relaxation techniques so that they use them correctly, and make them an active, ongoing part of their lives.

Effects of relaxation have been assessed with different physiological and psychological measures. Examples of psychological techniques include user questionnaires such as State-Trait Anxiety Inventory (STAI), Perceived Stress Scale (PSS) and General Health Questionnaire (GHQ) [12]. Physiological techniques include blood pressure and Heart Rate Variability (HRV) measurements [13], among others. Heart Rate Variability (HRV) and especially its High Frequency band (HF) are documented to reflect parasympathetic tone of the cardiac system, which is considered to be a sign of relaxation. In this paper, we use HRV analysis to measure the stress index and produce a personalized relaxation depending on the user preferences

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and/or environmental conditions.

The transition to applying biofeedback-assisted relaxation practices and skills in everyday life as well as and personalizing such responses according to individual needs and preferences remain major challenges (researchers have confirmed that the effectiveness of relaxation is user and context dependent [14]). In this paper, we propose a mathematical model for personalized biofeedback-assisted relaxation that adapts to the user preferences and relaxation responses. The proposed model is adaptive to physiological reactions and can learn what best works for each user by continuously measuring the effectiveness of relaxation techniques.

The rest of the paper is organized as follows: Section II reviews the related researches in biofeedback-assisted stress management, in particular relaxation techniques. In section III, we propose the mathematical model for dynamically adapting relaxation responses according to user needs and reactions. Section IV presents simulation analysis to evaluate the proposed model and demonstrate its merits. Finally, section V provides a summary of our finding and provides perspectives for future work.

II. Related Work

Several researchers investigated biofeedback-assisted stress management by measuring the body's physiological responses in real-time using wearable electronic devices and developing tools to learn to control them. A European project, named INTERSTRESS, aims at designing and developing advanced simulation and sensing technologies for the assessment and treatment of psychological stress [15]. A new concept of treatment by means of INTERREALITY is proposed in [16], which consists of developing mixed reality experience to merge the physical and virtual world. The focus of this work is however the design and evaluation of a filtering technique which allows reliable and real-time evaluation of psychological stress.

A rule-based expert system is introduced in [17] to support diagnosis and recommendation to provide virtual consultancy for stress management. The system uses personality test to determine the user's interests and behavior in order to optimize relaxation procedure. The approach is however not computer-based as the user has to fill in questionnaire during the personality test.

A portable sensor stress management system that can measure stress level during everyday situations (such a home or office) using Case-Based Reasoning (CBR) is presented and evaluated in [14]. CBR approach is based on learning from the past and solving new problems based on previously solved cases and is utilized to measure stress using figure temperature sensor. However, this approach requires calibration phase and is not applicable to relaxation responses.

In another study, the authors focused on evaluating a mobile phone application (named SelfRelax) for voice guided relaxation techniques as user want [18]. Results showed that with SelfRelax people can decrease their stress better than with their own techniques; however statistical difference was not significant. Furthermore, the proposed guided relaxation does not take into consideration history of relaxation responses, neither environmental condition.

Personalization is about matching and satisfying user needs in a specific context [19]. The authors in [20] have developed an automated wellness system with which individuals can manage their personalized fitness program over the Internet. Based on customer's health and wellness concerns, the system is able to recommend suitable wellness therapies to fulfill user's wellness needs. In a similar work, a Hybrid Case-Based Reasoning (HCBR) is proposed for wellness therapy recommendation [21].

Unlike existing work, we propose a mathematical model for personalized stress management that adapts relaxation techniques to the user's physiological conditions as well as the environmental context, so that optimized relaxation is provided to the user.

III. Mathematical Model For Personalized Relaxation

In this section, we present the mathematical model for personalized relaxation and detail how the model works.

A. Proposed Mathematical Model

The mathematical model aims to personalize the relaxation process as the system learns of what is working better for a particular user. The objective of this model is to track the user's reactions to various relaxation techniques by monitoring physiological reactions and eventually determine what best matches the user's needs.

Let X be the initial preferences for the relaxation techniques where: $0 \leq x_i \leq 1$. This means that out of "n" relaxation techniques, each element of X corresponds to the preference allotted by the user to that particular technique, with 1 being the highest preference and 0 being the lowest one. Note that these weights might not be necessarily accurate as sometimes the user might not be aware of what works best of them.

$$X = [x_1 \quad x_2 \quad x_3 \quad \dots \quad x_n]^T \tag{1}$$

W is the actual relaxations techniques preferences. These preferences will evolve as the relaxation process is run and data is collected regarding the efficiency of different techniques. Initially, W is equal to X. The values of W are updated to reflect how effective particular relaxation responses were in the last relaxation iteration. Therefore, as W evolves, the relaxation procedure becomes more personalized according to the physiological feedback obtained from the user.

$$W = [w_1 \quad w_2 \quad w_3 \quad \dots \quad w_n]^T \tag{2}$$

For Relaxation technique "i":

- Variable "t" represents the number of times the relaxation process has been run.

- U represents the efficiency of different relaxation techniques the last time they ran. U is initialized to unity matrix at t=0. Element "i" of U represents how efficient that corresponding technique was at time "t". The U matrix is determined based on the physiological responses after a relaxation is applied.

$$\mathrm{U} = [u_1 \quad u_2 \quad u_3 \quad \dots \quad u_n]^T \tag{3}$$

$$w_i(t) = \begin{cases} x_i, \; t = 1 \\ \sum_{j=0}^{n} \propto_{i,j} \times u_j(t-1) \times w_j(t-1), \; t > 1 \end{cases} \tag{4}$$

Many relaxation techniques are similar. α is called the correlation matrix (an n×n matrix) as it describes the relationship between any two relaxation techniques. For instance, napping and watching funny videos have no relationship and thus the correlation factor between the two is zero.

Matrix O combines the actual preference W with the environmental factors matrix E. Matrix E (environmental factors) holds elements that describe how appropriate each relaxation technique for different environmental setting. For instance, it would not be appropriate to observe relaxing images while the user is driving. Assuming that (m) contexts are defined for the system (such as work, car, home, etc.), E would be an (mxn) matrix capturing relationship between the (m) contexts and the (n) relaxation techniques. Therefore, the following equations can be derived:

$$\mathrm{O} = [o_1 \quad o_2 \quad o_3 \quad \dots \quad o_n]^T \tag{5}$$

$$o_i = e_{i,k} \times w_i(t) \tag{6}$$

$$s = \sum_{i=0}^{n} o_i(t) \tag{7}$$

$$F(r) = \left[\frac{o_1}{s} \quad \frac{o_2}{s} \quad \frac{o_3}{s} \quad \dots \quad \frac{o}{s}\right]^T \tag{8}$$

Where F(r), named the personalization matrix, is a probability mass function with the random variable "r" being the index of the relaxation technique. The relaxation technique with maximum probability is the best match for the user needs. The personalization matrix F(r) can be simply displayed to the user to show how their actual reactions of various relaxation techniques are indeed so the user is aware of what works best for them. It can also be used to dynamically control the relaxation techniques recommended to the user to provide maximum efficiency of relaxation.

B. Procedure

Step 1: When the user starts the application for the first time, she/he ranks the available relaxation techniques according to their personal preferences (starting from the highest preference to the lowest preference). This information defines the initial preference matrix (X) as shown in equation (1).

Step 2: Context for each relaxation techniques is captured and the matrix (E) is updated accordingly. Examples of contexts are location, time, weather condition, etc.

Step 3: Whenever the user is stressed and a relaxation response is executed, the physiological responses (such as ECG, EEG, muscles activities, respiratory responses) are captured to evaluate the effectiveness of the relaxation technique. The metrics (U) and (W) are updated accordingly.

Step 4: The personalization function F(r) is then updated according to equations (5) to (8) (which reflects the actual user personalization).

IV. Case Study: Personalized Relaxation for Ubiquitous Stress Management

The case study application is presented in this section to demonstrate how the proposed mathematical model can be materialized and deployed.

A. Measuring Stress

The application prototype is shown in Figure 1 whereas the stress monitor interface is shown in Figure 2. The application monitors stress levels for individuals anywhere, anytime, and presents feedback and initiates a response to aid the user in the relaxation process.

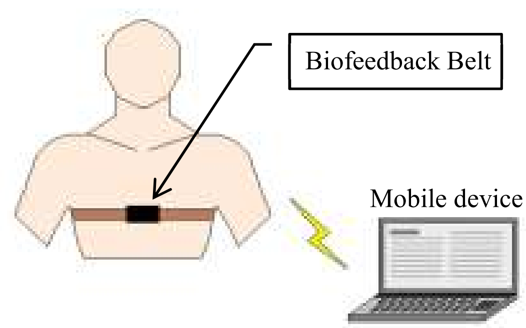

Figure 1: Personalized stress management system setup.

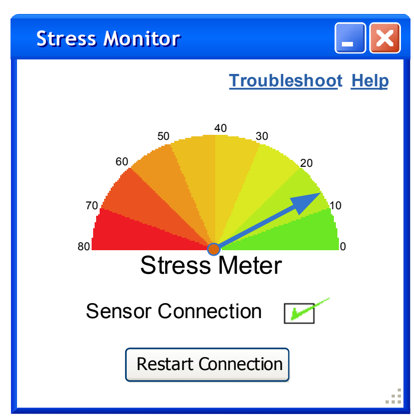

Figure 2: Stress monitor interface.

The system relies on continuous electrocardiography (ECG) measures to extract an HRV signal; such signal is used to extract HRV parameters that express useful information regarding the state of the autonomous nervous system. In particular, the system relies on frequency domain measurements obtained, especially HF and LF/HF. The calculated parameters are used to assess the stress level of the individual and derive a stress index. For instance, a decrease in HF or an increase in LF/HF indicates a stress build up. The algorithm presented in Figure 3 is implemented so that it runs continuously as follows:

1. Collect 3 to 5 minutes of ECG information
2. Calculate HRV parameters
3. Assess stress level
4. Display stress level
5. Initiate relaxation procedure when stress level surpasses a predefined procedure

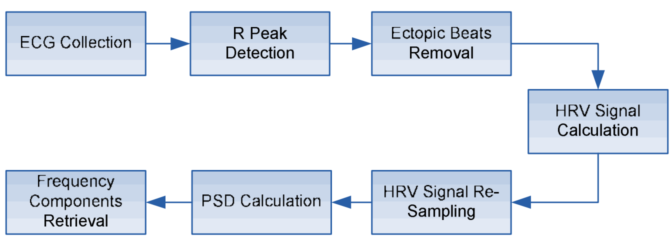

Figure 3: Frequency Components Retrieval from HRV Signal.

B. Relaxation Response

In this study, we intend to reduce stress through a personalized process that aims to disrupt the onset of a stressful event while conducting daily living. The personalization process works as follows:

1. Complete a form to rank relaxation techniques that the user prefers or perceives as more efficient from a list of ones. Examples of relaxation options include controlled breathing, listening to music, watching entertaining videos, physical exercise, etc… The idea is to distract the attention from the stressful situation so that it can be approached later with a more relaxed mind set.
2. Continuously monitor the stress level.
3. When stressful situations arise, initiate the pre-customized stress response to reduce the stressful thoughts. The response can be in the form of a humorous video, relaxing song, instructions to perform controlled breathing etc… Depending on the user physiological reactions to the selected response technique, the mathematical model will automatically update the prioritization of the available responses.

In this case study, we included the following relaxation techniques (based on a survey of relaxation techniques in biofeedback systems):

1. Relaxing music
2. Relaxing images
3. Relaxing images and music
4. Peaceful sounds
5. Relaxing images and peaceful sounds
6. Visualization meditation
7. Deep breathing meditation
8. Body scan meditation
9. Progressive muscle relaxation
10. Breathing exercise
11. Massage
12. Funny videos
13. Eating
14. Napping
15. Exercising

Accordingly, α becomes a 15x15 matrix describing the correlation between any of the relaxation techniques. For instance the element at row 2 and column 3 describe the correlation between relaxation technique 2 (relaxing images) and technique 3 (relaxing images and music). Since they both share images slideshow component, they have a high correlation of 0.75. Therefore, the matrix α would look like the following:

$$\alpha = \begin{bmatrix}
1 & 0 & 0.75 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0.75 & 0 & 0.75 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.75 & 0.75 & 1 & 0.5 & 0.75 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.5 & 0 & 0.5 & 1 & 0.75 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.5 & 0.75 & 0.75 & 0.75 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0.75 & 0.75 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.75 & 1 & 0.75 & 0.5 & 0.75 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.75 & 0.75 & 1 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.5 & 0.5 & 0.5 & 1 & 0.5 & 0.25 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.5 & 0.75 & 0.5 & 0.5 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.25 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}$$

Different relaxation technique is appropriate for different settings. For instance, napping is not a valid relaxation technique when the user is at work (in most cases at least!). Here we consider a list of predefined settings where context is defined by the physical location:

1. Work
2. Home
3. Car
4. Class
5. Gym
6. Spa

Therefore, (E) becomes a 6x15 matrix to describe the correlation between context (location of user) and the relaxation technique. For instance the element at row 1 and column 13 allocates a weight of 0.5 to eating at work. While row 3 and column 2 allocates a weight of 0 to watching relaxing images while driving. An example value for the (E) matrix is:

$$E = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0.5 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.25 & 0 & 0 & 0.25 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0.25 & 0.25 & 0.25 & 0.25 & 0.25 & 0 & 0 & 0 & 0 & 1 \\ 0.75 & 0.75 & 0.75 & 0.75 & 0.75 & 0.25 & 0.25 & 0.25 & 0.5 & 0.5 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

V. Performance Evaluation

The objective of the performance evaluation is to measure the ability of the proposed model to adapt relaxation techniques preferences according to the user's physiological responses as well as to the environmental conditions.

A. Experimental Setup

Five relaxation responses are considered (shown in Table 1). The user relaxation preferences are set in increasing preference order with relaxing music having least preference and relaxing images and peaceful sounds having highest preference. The following matrices can be defined:

$$\mathrm{X} = [0.1 \quad 0.3 \quad 0.5 \quad 0.7 \quad 0.9]$$

$$\mathrm{W} = [0.1 \quad 0.3 \quad 0.5 \quad 0.7 \quad 0.9]$$

$$\alpha = \begin{bmatrix} 1 & 0 & 0.75 & 0.5 & 0.5 \\ 0 & 1 & 0.75 & 0 & 0.75 \\ 0.75 & 0.75 & 1 & 0.5 & 0.75 \\ 0.5 & 0 & 0.5 & 1 & 0.75 \\ 0.5 & 0.75 & 0.75 & 0.75 & 1 \end{bmatrix}$$

Table 1: Relaxation techniques preference index notation

Relaxation technique	Preference Index
Relaxing music	W_m
Relaxing images	W_i
Relaxing images and music	W_{im}
Peaceful sounds	W_s
Relaxing images and peaceful sounds	W_{ims}

Assume that the environment context is defined by five physical locations: Work, Home, Car, Class, and Gym. The corresponding *E* matrix becomes:

$$E = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0.75 & 0.75 & 0.75 & 0.75 & 0.75 \end{bmatrix}$$

B. Adaptability to Physiological Responses

When a relaxation technique is found effective for the user relaxation, it should be used more often, given the same context. As shown in Figure 4, the model has adapted the relaxation technique preferences matrix (W) in accordance with the user's physiological reactions. At iteration 5, relaxing images and peaceful sound response (represented by $\mathrm{W_{ims}}$) was applied and proved not effective, therefore the proposed model has increased the weight of the peaceful sounds relaxation technique (represented by the index $\mathrm{W_s}$) until it bypassed the $\mathrm{W_{ims}}$ index (at iteration 8). Hence the relaxation response of peaceful sounds has highest preference index and thus will be suggested to the user for the next iteration. The proposed model tracks the user's physiological responses and personalizes relaxation response techniques preferences based on the actual needs of the user and thus provides more effective relaxation.

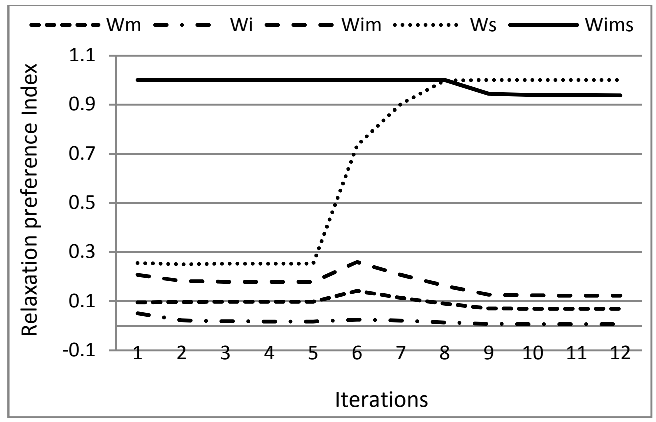

Figure 4: Adaptability to physiological responses

C. Adaptability to Environment Conditions

The second distinguished feature of the proposed model is its ability to adapt to changes in the ambient environment (for example, location). Here we demonstrate how the actual relaxation techniques preference matrix changes according to changes in the location context. As shown in Figure 5, the relaxation techniques preference indices have changed when the user moved from a work environment to a car environment (at iteration 4).

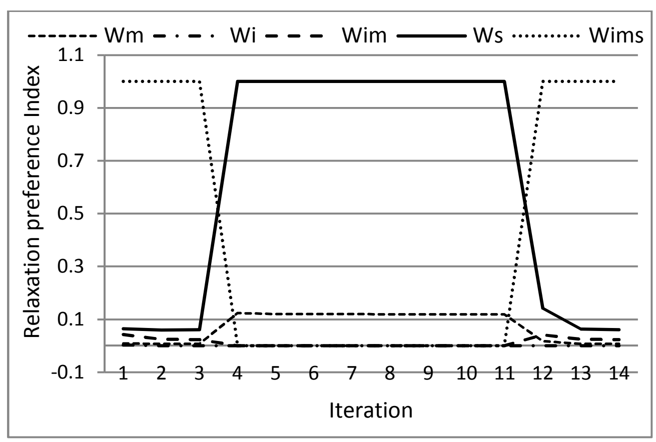

Figure 5: Adaptability to environment context

Note that watching relaxing images in car (when the user is driving) is not appropriate and thus the preference for relaxation techniques having image display (W_i and W_{ims}) have dropped to 0 whereas sound-only relaxation techniques are promoted (by increasing the W_s and W_m indices); as shown in Figure 5. At iteration 12, and as the context changed back to work environment, the relaxation techniques preferences restored their initial values.

D. General Performance

In this experiment, we evaluate the performance of the model when physiological responses and environment context are combined. Figure 6 shows that W_{ims} value changed to 0 at iteration 4 when the environment context has changed to gym (where it is typically hard to play peaceful sounds in gym due to high ambient noises). However, when the context changed again to home (at iteration 8), it became possible to play peaceful music and thus the W_{ims} value increased. After few iteration (and due to positive physiological responses from the user), W_{ims} continued to increase until it became the maximum value (at iteration 13). Therefore, the two types of feedback (physiological responses and environment context) can be combined to provide a more efficient and practical personalization of relaxation techniques.

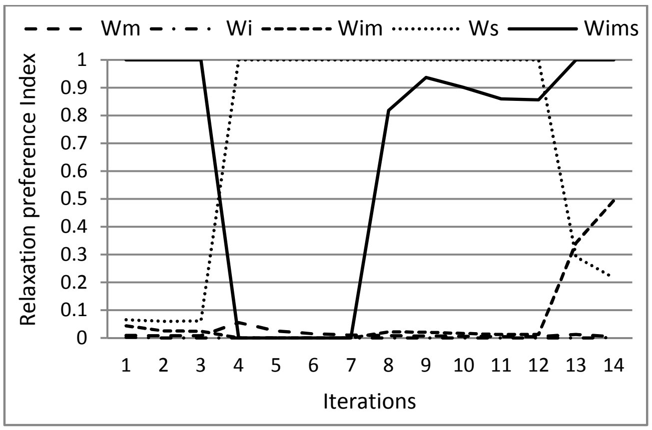

Figure 6: general performance (Physiological Responses and environment context).

VI. Conclusion and Future Work

In this paper, we present a mathematical model that enables dynamic personalization of relaxation techniques in accordance with the user's physiological reactions and the environment context. The objective here is to build a system that can be used to educate people about stressors and their physiological reactions to various relaxation techniques. The system also teaches users about what relaxation techniques work best of them under various circumstances (environmental context).

After simulation, our immediate next step is to implement and test the model with users and evaluate the effectiveness of the proposed model in real life situations. Furthermore, we will conduct usability testing debriefing (and possibly questionnaires) to evaluate the user satisfaction about the system. Another potential future work is to extend the environment context to support other parameters such as time, weather condition, etc.

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