Design and Evaluation of an Ambient Lighting Interface of HRV Biofeedback System in Home Setting

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Abstract. Chronic stress puts individuals at an increasing risk of numerous health problems. In this study, we present an ambient lighting interface of a biofeedback system that helps users to self-regulate their breathing pattern in a home environment. To evaluate the usability and functionality of the ambient lighting interface, an experiment was conducted with 12 participants. The results suggest that users would be able to use ambient lighting biofeedback to regulate their breathing with the purpose of improving heart rate variability. Moreover, the lighting interface designed in the study is more acceptable than a traditional graphic interface for home use. We discuss these results as well as design implications for the interface of future biofeedback systems.

Keywords: Stress, Ambient intelligence, Pervasive healthcare, Biofeedback.

1 Introduction

Chronic stress has a number of negative effects on individual health and well-being. Without relief between stresses in everyday life, such stress would increase the risk of diseases such as depression, heart attacks and even cancer [1]. Biofeedback techniques have demonstrated efficacy in coping with stress [2]. Heart rate variability (HRV), the variation between heart-beat intervals, represents one of the most promising markers of the autonomic nervous system (ANS). Due to the chronic stress, the autonomic nervous system tends to be thrown out of balance. Heart rate variability (HRV) biofeedback is a powerful tool for coping with chronic stress. During HRV biofeedback training, individuals will be able to restore overall autonomic balance by following the feedback information and using breathing and relaxation techniques[3].

Pervasive healthcare enables individuals to increase awareness about their health condition through bio-sensing. By integrating computer interfaces into the real environment, a user can obtain health information from the surrounding environment and interact with it. The combination of decorative and informative aspects makes intelligent lighting both pleasant and helpful for users. Based on this hypothesis, we believe that ambient lighting could be a ubiquitous interface in biofeedback systems. In clinical settings, most of biofeedback systems utilize numeric or graphic interfaces as shown in figure 1(b), which may not apply to the average people for home use. Therefore, in this study, we designed a HRV biofeedback system which integrates ambient lighting, assisting users in regulating breathing patterns for stress reduction at

R. Hervás et al. (Eds.): UCAmI 2014, LNCS 8867, pp. 88–91, 2014.

home. In our system, heart-beat data are recorded by a pulse sensor in a bio-sensing unit and transmitted to a data processing unit; then, heart rate variability value is calculated and fed back to users through the changes of ambient light. The feasibility of ambient lighting interface in presenting biofeedback information was evaluated in an experiment with 12 participants. Based on the results, we discuss our findings for the design of future biofeedback system interfaces in the context of pervasive healthcare.

2 System Design

In this study, we designed an ambient lighting interface for a HRV biofeedback system of home use. Users do not have to sit in front of a computer and stare at the screen, but they can perform biofeedback training in the living room, the bedroom or even the bathroom. The intensity and color of light are selected to represent two variables of heart-beats: beat-to-beat intervals and real-time heart rate variability, as shown in Figure 1(a). Light intensity is controlled directly by beat-to-beat intervals while light color is controlled by heart rate variability in real-time.

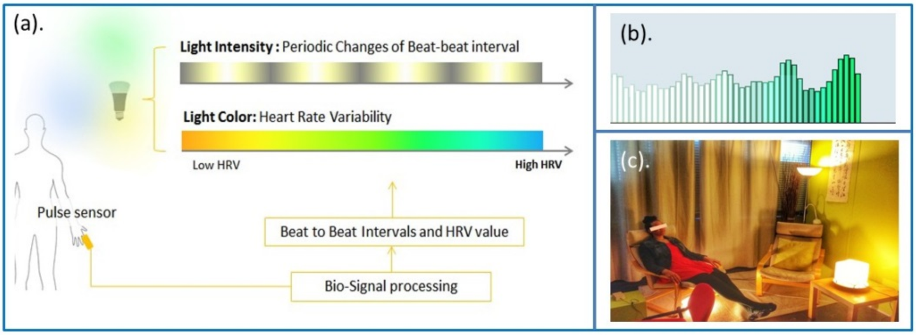

Fig. 1. (a). Ambient lighting responses to HRV (b). Traditional graphic interface

In HRV biofeedback training, the individual can learn to consciously influence the HRV with changing ambient lighting. Firstly, beat-to-beat intervals guide users to adjust their breath to fit in their resonant breathing frequency for example; secondly, actual HRV value would make users be aware of the training effects, which helps to enhance their confidence in a training process. With the user's breathing becoming slow and deep, the beat-beat intervals change in an approximate sinusoidal pattern, and accordingly, the light changes from dark to bright and back to the dark periodically. Depending on the improvement of HRV, the light color changes from warm tone (orange) to calming tone (blue), indicating the degree of users' training effects. The system consists of three parts: a bio-sensing unit, a data processing unit, and a "Hue" intelligent light (*Phillips, the Netherlands*). The heart beat data is measured by a PPG sensor placed on the left index finger. In the signal acquisition unit, the beat-to-beat interval data is calculated and transmitted to the PC's data processing program through a USB serial port. The Hue's intensity and color is controlled by the beat-to-beat interval and heart rate variability via a Wi-Fi wireless connection.

3 Experiment

12 volunteers employed in research positions in Eindhoven University of Technology were involved in the experiment. Subjects' physiological data (pulse and respiration) were collected by a bio-signal acquisition device designed at TU/e and a set of the ANT system (*ANT, the Netherlands*) respectively. All participants complete two biofeedback tests: one with a traditional graphic interface and the other one with the lighting interface, see figure 1(c). Before the experiment, the instructions were given to all participants. In the graphic biofeedback test, the instructions were: "*the waveform represents beat-to-beat intervals, which is related to your breathing. Try to make the waveform in a smooth sinusoidal form by adjusting your breath slowed-down and deeper.*" In the lighting biofeedback test, the instructions were: "*the intensity of light represents beat-to-beat intervals, which is related to your breathing. Try to make the light change from dark to bright and then to dark periodically by regulating your breath. You breathe more slowly and deeply, the changes of light become more smooth and regular. The colors of light indicate the heart rate variability, when it turns from orange into blue, which means your heart rate variability is being improved.*"

After finishing the tutorial, we fitted participants with bio-sensors and instructed them to relax for 10 minutes with eyes closed. This pre-test resting period is intended to normalize users' average HRV value and breathing pattern in resting state. Next, participants performed two biofeedback tests in a random order and they were given a 10-minute break between each test to answer a questionnaire and relax. During the tests, pulse signal was recorded throughout this period. The participants' perceptions were collected using a questionnaire survey. The questionnaire consisted of 21 questions, which were partly adopted from Lund's USE Questionnaire [4]. One-way ANOVA was then used to analyze whether there were any significant differences in HRV and participant's perceptions between the lighting interface and the graphic interface.

4 Results and Discussion

There were twelve participants in this study; however two participants, who did not finish the biofeedback tests, were eliminated. The final effective sample size was thus ten, with five males and five females. In Table 1, the result of questionnaire survey showed that there was no significant difference on user evaluation between ambient lighting and graphic interfaces. In the satisfaction dimension, the feedback of lighting biofeedback test (M=0.53) was positive compared to graphic test (M=0.03). We received more detailed feedback from the open-ended questions. Specifically, more than 80% participants were interested in ambient lighting interface and emphasized that the ambient lighting was very convenient due to fewer restrictions on place of use. Moreover, they found ambient lighting made them feel more comfortable and relaxed during the training. The improvement of HRV throughout graphic and lighting biofeedback tests was calculated as shown in Table 2. Compared to the value before the tests, the average HRV were improved in both tests. The improvement was significant in the graphic test (M= 37%, $F=9.11$, $p < 0.05$). In the lighting test, average HRV was also improved by 30%. There was no significant difference on improvement of HRV between the lighting and graphic biofeedback tests.

Table 1. Mean scores of participant's perceptions between graphic and lighting interface

Dimensions	Graphic interface (n=10)		Lighting interface (n=10)		ANOVA	
	M	SD	M	SD	F	P
Ease of use	0.85	1.08	0.74	0.87	0.07	0.797
Ease of learning	1.34	1.00	1.11	0.76	0.39	0.540
Satisfaction	0.03	1.24	0.53	0.92	1.05	0.319

Table 2. The improvement of heart rate variability in the graphic and lighting biofeedback tests

HRV Improvement (%)	Graphic interface (n=10)		Lighting interface (n=10)		ANOVA	
	M	SD	M	SD	F	P
	37*	0.39	30	0.52	0.14	0.72

* $p<0.05$ HRV improvement: Graphic bio-test vs. Pre-test

Based on these results, we think that ambient lighting interfaces could be a new ubiquitous interface of biofeedback system. In future work, we are interested in involving audio or haptic interface in biofeedback system, which enable users to perform training sessions with eyes closed. In our view, the timeliness, accuracy and stability of feedback interface is crucial to provide a pleasant user experience during biofeedback training. We will reconsider the mapping from physiological information and the properties of ambient lighting, making it clearer and easier to learn. Combining these results with qualitative feedback from participants, we concluded that ambient lighting holds a promise for becoming a good interface to present biofeedback information to users in home settings; specifically for the purpose of relaxation, ambient lighting also has a great potential in setting the ambiance.

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LNCS 8867

Ubiquitous Computing and Ambient Intelligence

Personalisation and User Adapted Services

8th International Conference, UCAmI 2014
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Proceedings

Springer

Lecture Notes in Computer Science 8867

Commenced Publication in 1973
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ISSN 0302-9743 e-ISSN 1611-3349
ISBN 978-3-319-13101-6 e-ISBN 978-3-319-13102-3
DOI 10.1007/978-3-319-13102-3
Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014953288

LNCS Sublibrary: SL 3 – Information Systems and Application, incl. Internet/Web and HCI

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Ambient intelligence promotes environments surrounded by intelligent interfaces and ubiquitous communication embedded into everyday objects to support human activities and achieve a better quality of life. Ambient Intelligence (AmI), since the initial vision of ISTAG in 2002, has been evolving in recent years while still maintaining a holistic view: AmI focuses on users, beyond the technology. This year we celebrated a joint event for the 8th International Conference on Ubiquitous Computing and Ambient Intelligence (UCAmI 2014) and the 6th International Work-conference on Ambient Assisted Living (IWAAL 2014) in Belfast, UK. The UCAmI conference, since its inception, has evolved adapting its topics to consider new trends in AmI in addition to the inclusion of workshops targeting the most specific areas. Furthermore, in an effort to increase the visibility of the contributions of UCAmI, selected papers will be invited for submission as extended versions in the journals: *Sensors, Journal of Medical Systems, Medical Informatics and Decision Making* and the *Journal of Cognitive Computation*. As such we would like to thank the distinguished editors of these journals for providing us with these opportunities.

The program of this joint event includes the UCAmI Workshops on Ambient Intelligence for Urban Areas (AmIUA), Internet of Things Everywhere: Towards Smart Objects Everywhere (IoTE), End-User Service Provision for Ambient Intelligence (EUSPAI) and Video Soft Sensing (VSS). This year's event included keynotes from internationally recognized researchers in their fields: Dr. Michael J. McGrath from Intel Labs, Dr. Riitta Hellman from Karde AS, and Prof. Jesse Hoey from the Computational Health Informatics Laboratory (CHIL). We would like to thank our distinguish keynote speakers for their participation and contribution to this joint event.

We received an over whelming response from researchers who submitted their contributions for consideration to UCAmI 2014, with a 50% increase in manuscripts submitted compared to last year's edition of UCAmI (UCAmI 2013). In this eighth edition of UCAmI, we received 70 submissions involving 238 authors from 20 different countries. Following the review process we had an acceptance rate for long papers of 40%. A total number of 168 reviews were undertaken by 106 reviewers from 29 countries. We would like to thank all the authors who submitted their work for consideration and also the reviewers for providing their detailed and con-structive reviews in a timely manner.

Finally, we would like to express our deepest thanks to our colleagues for assisting in organizing this event, particularly Professor Chris Nugent from the

University of Ulster and Professor Jose Bravo from Castilla-La Mancha University. We would also like to thank all the Program Committee members for their time and contributions.

December 2014

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