Technical Papers of ISA

Biomedical Sciences Instrumentation

Volume 43

Presented at:
Denver, Colorado
13-15 April 2007

Technical Papers
Composing the Proceedings of the
44th Annual Rocky Mountain Bioengineering Symposium
&
44th International ISA Biomedical Sciences
Instrumentation Symposium

ISA Volume 468

ISA
Research Triangle Park, North Carolina

Edited by: John S. Sollers, III, PhD and Julian F. Thayer, PhD

ISA
67 Alexander Drive
P.O. Box 12277
Research Triangle Park, NC 27709
PHONE (919) 549-8411
FAX (919) 549-8288
E-MAIL info@isa.org
www.isa.org

0067-8856(200704)43:1;1-U

ISA

Technical Papers of ISA

Biomedical Sciences Instrumentation

Volume 43

Presented at:
Denver, Colorado
13-15 April 2007

Technical Papers
Composing the Proceedings of the
44th Annual Rocky Mountain Bioengineering Symposium
&
44th International ISA Biomedical Sciences
Instrumentation Symposium

ISA Volume 468

ISA
Research Triangle Park, North Carolina
Edited by: John S. Sollers, III, PhD and Julian F. Thayer, PhD

ISA

Setting the Standard for Automation

ISA Volume 468
BIOMEDICAL SCIENCES INSTRUMENTATION Volume 43

ISSN: 0067-8856 2007 04 43 1

ISA
67 Alexander Drive
Research Triangle Park, North Carolina 27709
USA

Reprints of articles in this publication are available on a custom basis at reasonable prices in quantities of 100 or more.

FOREWORD

The Rocky Mountain Bioengineering Symposium (RMBS) has been held annually since 1964, making RMBS the oldest continually held biomedical engineering conference in North America. Originally considered a regional conference, contributors and attendees now come from all over the United States, Canada, and the world. In fact, at this year's symposium we have contributors from **26** states and **6** international countries. The conference was sponsored by the Instrument Society of America (ISA)

The 44th annual RMBS was held at the Sheraton Four Points, Denver, CO on April 13-15, 2007. This volume, published by the ISA, contains the proceedings of the 44th conference. Many papers (**65**) were presented at sessions covering topics such as Biochemical Engineering, Signal Processing, Modeling, Image Processing, Biomechanics, Cardiovascular Engineering, Trauma & Injury, and Information Systems.

One of the highlights of the conference for many attendees was the presentation of the RMBS Student Paper Awards. Many thanks to Elena Oggero and Guido Pagnacco, Co-Chairpersons of the student paper contest, and to all the many paper and presentation reviewers. The high quality of the student papers and the presentation skills displayed continue to impress the attendees and indicate the future of the field of bioengineering is in good hands.

The Conference and Program Chairpersons would like to offer their sincere thanks to all the 44th RMBS authors, attendees, session chairpersons, and members of the RMBS Board of Directors. The close interaction among all these individuals and groups is what makes the RMBS so successful.

On to RMBS 2008…

John J. Sollers III	Julian F. Thayer	Carolyn Sterling
Program Co-Chair	Program Co-Chair	Conference Chairperson

Rocky Mountain Bioengineering Symposium – Review Process

Manuscripts submitted to the Rocky Mountain Bioengineering Symposium (RMBS) are subject to a procedure that leads to the acceptance of manuscripts for publication or rejection. The manuscripts submitted to the RMBS are sorted into categories by an organizational committee. Upon receipt of the full-length manuscript, the Program Chair assigns at least two reviewers for each paper to evaluate the originality and novelty of the research (Scores: 1=Rejection, 2= conditional acceptance with modifications suggested by reviewers, 3 = Acceptable, 4= Very Good Paper, and 5 = Excellent Work). A third reviewer is also assigned to review the paper when scores vary by more than 1.

First authors of accepted papers are notified of acceptance by January 15th, and in some cases may receive comments from the reviewers. Authors receiving reviewer comments will typically elect to make voluntary corrections before the final submission deadline of January 30. Some manuscripts may be rejected after initial review, and some may be accepted conditionally, subject to recommended changes. For papers that are conditionally accepted, final notification of acceptance or rejection will occur within a week of final submission. The deadline for the final submission for all corrected manuscripts is January 30.

Accepted manuscripts are considered refereed papers under the umbrella of "accept or reject", meaning that in some cases, there may be no communications with the authors for corrections. Compiled manuscripts are subject to another screening process by ISA and subsequently indexed in the largest database in the world, Medline.

ISA- (The Instrumentation, Systems and Automation Society) fosters advancement in the theory, design, manufacture, and use of sensors, biomedical instruments, computers, and systems for measurement and control in a wide variety of applications. Founded in 1945 as a nonprofit, educational organization, ISA has expanded its technical and geographical reach to become a resource for 39,000 members and thousands of other professionals and practitioners in more than 110 countries around the world.

MEASUREMENT OF PUPIL DIAMETER VARIATIONS AS A PHYSIOLOGICAL INDICATOR OF THE AFFECTIVE STATE IN A COMPUTER USER

Armando Barreto[1,2], Jing Zhai[1], Naphtali Rishe[3] and Ying Gao[1]

[1]Department of Electrical and Computer Engineering
[2]Department of Biomedical Engineering
[3]School of Computer and Information Sciences
Florida International University, Miami FL, 33174

ABSTRACT

In this paper we explore the potential of analyzing pupil diameter measurements obtained using a desktop-mounted Eye Gaze Tracking (EGT) instrument to identify changes in the affective state of a computer user. In our experiment we induced intervals of relaxed and stressed affective states by asking the computer user to respond to sequences of congruent and incongruent Stroop word presentations. The recorded pupil diameter values verify our initial expectations by showing an increase in pupil diameter mean value as the subject transitions form a congruent Stroop sequence or segment to an incongruent Stroop segment. This mean pupil diameter value increase was found in all but one of the 96 transitions studied from 32 subjects. The statistical significance of these mean value increases was studied by means of a t-test for the comparison of means. All the pairs of mean pupil diameter values were found to be significantly different at a 0.05 significance level ($p < 0.05$). This seems to indicate that the real-time measurement of pupil diameter of the computer user holds a strong promise to become a non-intrusive way to make the computer aware of changes in the affective status of the user. However, it is clear that several implementation issues still must be resolved before this approach can be practical for use in the context of ordinary human-computer interaction, where, for example, the environmental illumination levels are not controlled, as they were during our experiments.

Keywords: Pupil Diameter, Affective State, Affective Computing, T-Test, Difference in means

INTRODUCTION

Since the mid 1990s there have been several research groups that have envisioned the advantages that could be achieved if machines (i.e., computers) could be aware of the affective states of their users. Rosalind Picard galvanized those visions in her 1997 book "Affective Computing" [1], which proposed that an affective computer would have the ability to respond intelligently to the emotional state of the user and help him/her relax. Hudlicka and others have described the importance of the emotional and affective factors in human-computer interaction [2]. The knowledge of a user's affect can provide useful feedback regarding the degree to which a user's goals are being met, enabling dynamic and intelligent adaptation. This capability could prove crucial for some areas of application of computers, such as computer-based training, where the type and pace of instructional materials presented by the computer could be chosen to always keep the stress or frustration of the user at low levels.

Implementation of the full promise of Affective Computing requires the development of a robust real-time mechanism for affective sensing, i.e., the establishment of means by which the machine could remain aware of the current affective state of the user at all times. Unfortunately, this has proven not to be a simple goal to achieve. Attempts have been made through the use of a variety of measurements available to computer systems, such as the identification of speech patterns, typing patterns, facial expressions, and body gesture recognition, for example. These approaches have not achieved levels of success that make their implementation practical. A different school of thought has pursued the well-known link that exists between the psyche of a human being and his/her physiological processes through the Sympathetic and Parasympathetic divisions of the Autonomic Nervous System (ANS). This approach seems particularly suitable when the goal of affective sensing is focused, for example, on the differentiation of states of relaxation, known to be associated with parasympathetic preponderance, from states of stress, identified with sympathetic activation.

In their pursuit of the identification of affective states through the monitoring of physiological changes, affective computing researchers have borrowed methods and instrumentation used in the context of "detection of deception" (otherwise known as "lie detector") work. Because of this, several groups in the affective computing community have focused their efforts on the processing of physiological signals traditionally associated with the polygraph, such as the Galvanic Skin Response (GSR), or electrodermal activity and the changes in the circulatory system reflected by modifications observed in the Blood Volume Pulse (BVP) signal. Other physiological signals that have been explored in this context include the respiration rate, the electrocardiogram (ECG), and the electromyogram (EMG). Interestingly, there has been relatively little emphasis on the measurement of changes in the pupil diameter of a subject as a means to differentiate his/her affective states, in spite of the knowledge available regarding the control of the Autonomic Nervous System over the two sets of muscles that determine the diameter of the pupil at a given time. The sympathetic ANS branch, mediated by posterior hypothalamic nuclei, produces enlargement of the pupil by direct stimulation of the *dilator muscles*. The contribution of the parasympathetic pathway is mediated by central inhibition of the Edinger–Westphal complex of the oculomotor nucleus (n. III) in the midbrain, which is the motor center for parasympathetic pathway. Inhibition of this complex results in relaxation of the *sphincter muscles* and, thus, dilation of the pupil [3]. The impact of affective stimulation over pupil diameter has been verified experimentally by Partala and Surakka, who found that using auditory emotional stimulation, the pupil size variation can be seen as an indication of affective processing [4]. More recently, Steinhauer et al. confirmed that pupil diameter is associated with the level of difficulty of a task performed by experimental subjects. Using pharmacological blockade of sympathetic and parasympathetic effects on the pupil they were able to characterize and differentiate the contributions of the two ANS divisions to the control of pupil diameter [3]. Our group has recorded simultaneous variations in pupil diameter and other physiological signals (e.g., BVP, GSR) in response to affective stimuli [5]. This paper highlights the potential of pupil diameter measurements to identify affective state changes in a computer user.

METHODS

A key element of the verification of any method to detect affective changes in a human subject is the design of an affective elicitation protocol that can be expected to produce predictable affective states in the user at pre-determined time intervals. We utilized a computer-based version of the "Paced Stroop Test" for this purpose. This stimulation mechanism is derived from the Stroop Color-Word Interference Test [6], which originally requires that the font color of a word designating a different color be named. For our experiment the Stroop Test was adapted into an interactive version in which the subject must click on the "on-screen button" labeled with the correct answer, instead of stating it verbally. Further, due to previous reports in the literature showing that the stress elicitation impact of the Stroop effect is increased by adding pacing to the protocol [7], each trial of our computer-based version was designed to only wait 3 seconds for a user response. If the subject could not make a decision within 3 seconds, the screen automatically changed to the next trial.

Figure 1 summarizes the timeline followed during each complete experimental session, for each participating subject. The complete experiment comprises three consecutive sections. In each section, we have four segments including: 1) 'IS' - the Introductory Segment to let the subject get used to the task environment, in order to establish an appropriate initial level for his/her psychological state, according to the law of initial values (LIV) [8]; 2) 'C' – is a Congruent segment, comprising 45 Stroop congruent word presentations (font color matches the meaning of the word), which are not expected to elicit significant stress in the subject; 3) 'I' – is an Incongruent segment of the Stroop Test in which the font color and the meaning of the 30 words presented differ, which is expected to induce stress in the subject; 4) 'RS' – is a Resting Segment to act as a buffer between the sections of the protocol.

The computer providing the Stroop stimuli and receiving the responses from the subject was also programmed to transmit distinct codes (shown in binary) at each of the segment transitions (i.e., between IS and C, between C and I, and between I and RS), within each protocol section, so that the pupil diameter data recorded by the instrument described below within each stimulus segment could be identified later.

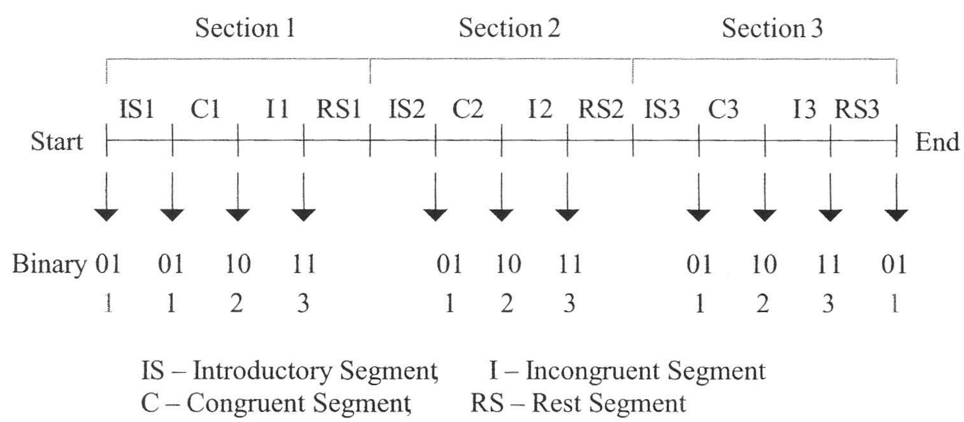


Figure 1. Timeline for the experimental protocol employed

The measurement of pupil diameter values throughout the protocol was performed by means of an eye gaze tracking system (Model ASL-504, Applied Science Laboratory, Bedford, MA.). This system is based on a pan/tilt module, which includes a collection of infrared light emitting diodes (LEDs) used to illuminate the face of the subject with infrared radiation. The module also includes a digital camera with an infrared filter that captures and analyzes 60 images of one of the subject's eyes every second (in our case the left eye was monitored). The infrared radiation, back-reflected by the retina, causes the pupil to appear bright in the infrared images captured by the camera. Real-time image processing performed in the control module of the ASL-504 eye gaze tracking system isolates the contour of the bright pupil and estimates its diameter, in camera pixels. (Ordinarily the center of the pupil and the corneal reflection are estimated and used to determine the line of gaze of the subject, but the emphasis in our experiment was in the monitoring of pupil diameter values through the experiment). The estimated pupil diameter (PD) values were up-sampled to 360 interpolated PD values per second and recorded digitally, along with the transition codes (e.g., from a 'C' segment to the ensuing 'I" segment) provided by the personal computer implementing the stimulus protocol shown in Figure 1. The environmental illumination in the room where the tests took place was kept constant throughout the protocol, and was the same for all the subjects. The screens of the stimulation program were designed to have the same amount of light radiated during the presentation of congruent and incongruent sequences of Stroop word stimuli. These efforts sought to minimize the potential impact of the pupillary light reflex in the pupil diameter variations to be measured in the subjects.

Thirty-two individuals (11 female and 21 male) volunteered to participate in the experiment. Their ages ranged from 21 to 42 years. They were from diverse professional and ethnic backgrounds. They were all fluent in English and familiar with personal computers. None of them needed to wear eyeglasses (which could potentially interfere with the operation of the eye gaze tracking system).

Figure 2 shows an example of the pupil diameter sequence of values obtained from one subject throughout the complete experimental protocol (top panel). The transition markers recorded at the beginning of each 'C' segment, in between 'C' and 'I' segments and at the end of each 'I' segment are shown as vertical lines. (Abrupt blinking artifacts in the PD data series were detected automatically and eliminated by interpolation). Our analysis focused on the difference of PD values collected during each 'C' segment (congruent Stroop stimulation, not expected to cause stress in the subject), and during the following 'I' segment (incongruent Stroop stimulation, expected to elicit stress in the subject). The change of PD values between each relaxed ('C') segment and the ensuing stressed ('I') segment is better appreciated in the lower panel of Figure 2, where the 'C' and 'I' data have been replaced by the PD mean value during the corresponding segments. Other segments (i.e., 'IS' and 'RS') are not represented.

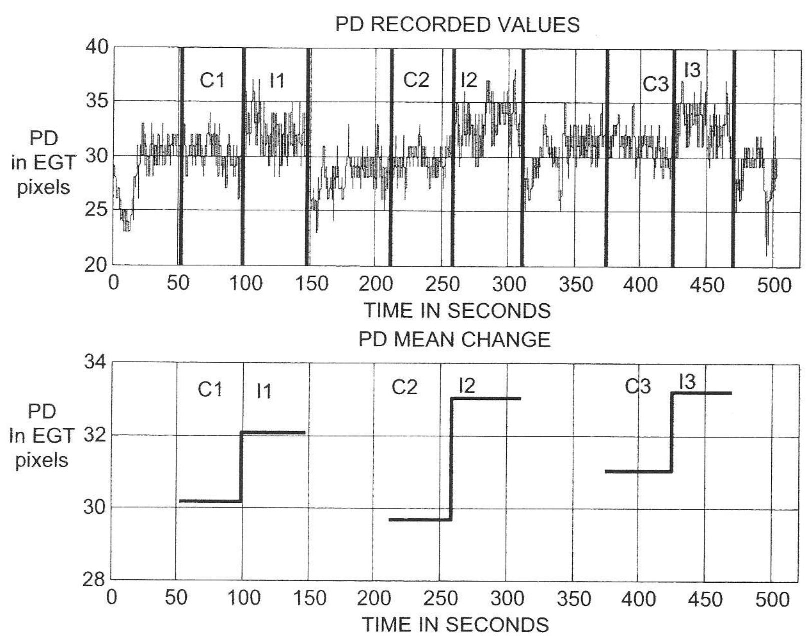


Figure 2. Example of pupil diameter signal recorded and the mean values corresponding to 'C' and 'I' segments.

While the three 'C to I' transitions shown in this particular record clearly indicate that an increase in pupil diameter is associated with the elicitation of stress in this subject, the goal of our analysis is to verify if this change in means ('C segment mean' and 'I segment mean') was consistently associated with a transition form a relaxed state to a stressed state.

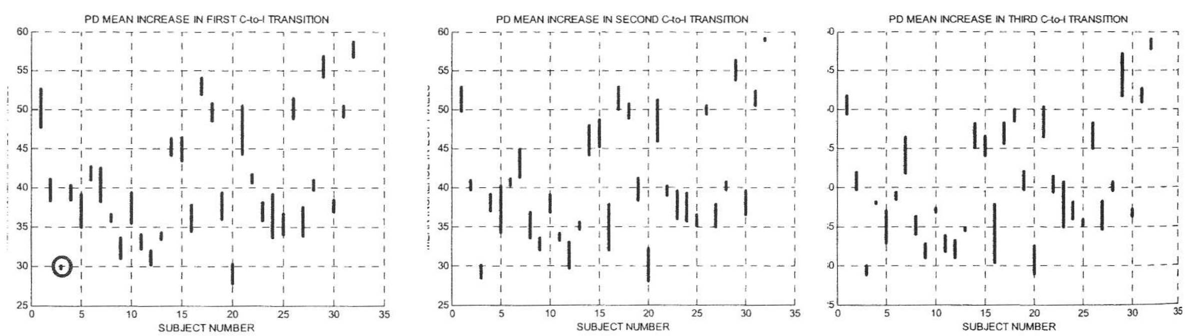
In order to determine if the increase of pupil diameter values recorded during each 'I' segment, with respect to the pupil diameter values recorded in the preceding 'C' segment was significant, a t test for difference in means was performed for each one of those transitions, for all subjects (3 transitions per subject). This test is based on the computation of the T statistic:

$$T = \frac{C_{mean} - I_{mean}}{\sigma\sqrt{\frac{1}{n} + \frac{1}{m}}} \qquad \text{(eq.1)}$$

where C_{mean} and I_{mean} are the mean values of the PD samples during the 'C' and 'I' segments under analysis, n and m are the number of samples available in the 'C' and 'I' segments and σ is the pooled sample standard deviation for these collections of pupil diameter values. The resulting T values were used to test if the means were different at a 0.05 significance level ($p < 0.05$).

RESULTS

Figure 3 below shows, by means of the thicker vertical bars, the mean PD value increments observed for the first (C1 to I1), second (C2 to I2) and third (C3 to I3) transitions from relaxed to stressed states in the protocol, for all 32 participating subjects. In all cases the mean for the 'I' segment was higher than that for the preceding 'C' segment, except for the C1 to I1 transition recorded from subject 3, where the C1 mean was 30.03 pixels and I1 mean was 29.69 pixels (case circled in the left panel of Figure 3). Interestingly, all the 96 t-tests for mean difference indicated that adjacent 'C' and 'I' means were statistically different, at a level of significance $p< 0.05$.



a) PD mean increase from C1 to I1 b) PD mean increase from C2 to I2 c) PD mean increase from C3 to I3

Figure 3. Increases from Cmean to Imean for the pupil diameter values recorded during the first (left), second (center) and third (right) transitions for all experimental subjects (32, shown in the horizontal axes).

DISCUSSION

The statistical significance of the difference between PD means in adjacent 'C' and 'I' segments confirms that (in all cases) a relevant change in the control of pupil diameter occurs through the transition from the congruent Stroop (relaxed) state to the incongruent Stroop (stressed) state. This observation seems to indicate that real-time pupil diameter measurements could be used in the course of human-computer interactions to provide valuable information about the affective shifts in the user, like those elicited by different types (congruent vs. incongruent) of Stroop stimulation during our experiment. It should be noted, however, that the practical implementation of this concept still poses significant challenges, as, for example, the 'C-to-I' PD mean increases displayed a consistent magnitude (C1 to I1: average = 2.60, std. dev. = 1.41; C2 to I2: average = 2.61, std. dev. = 1.45; C3 to I3: average = 2.48, std. dev. = 1.66) but clearly started from different 'Cmean' levels for different subjects. This may imply that affective sensing processes based on pupil diameter measurements will need to be calibrated according to individual users and/or sessions. Further, mechanisms will be required to separate pupil diameter variations produced by affective shifts from those caused by pupillary light reflex when the environmental light levels are unconstrained, as they may be in ordinary human-computer interactions.

CONCLUSIONS

This paper has explored the potential of real-time pupil diameter measurements as an important source of information about affective shifts in a computer user. In our experiment, contrasting affective states of relaxation and (mental) stress were elicited by repeated presentation of congruent and incongruent Stroop word stimuli, respectively. In all but one of the 96 'C-to-I' transitions studied an increase of the mean pupil diameter values measured was noted. By means of a t-test, it was verified that all the mean differences between adjacent congruent and incongruent segments were statistically significant ($p<0.05$). This seems to highlight the potential of real-time pupil diameter measurements as a mechanism to detect affective shifts in computer users, although a number of implementation requirements would still need to be addressed to make this a practical approach in the context of ordinary human-computer interactions.

ACKNOWLEDGMENTS

This work was sponsored by NSF grants IIS-0308155, CNS-0520811, HRD-0317692 and CNS-0426125. Ms. Ying Gao is the recipient of a Presidential Enhancement Assistantship from Florida International University.

REFERENCES

[1] R. W. Picard, 1997. Affective Computing. MIT Press, Cambridge, Mass.

[2] E. Hudlicka, 2003. "To feel or not to feel: The role of affect in human-computer interaction." *International Journal of Human-Computer Studies* 59:1-32.

[3] S. R. Steinhauer, G. J. Siegle, R. Condray and M. Pless, "Sympathetic and parasympathetic innervation of pupillary dilation during sustained processing", *International Journal of Psychophysiology* 52 (2004) 77–86.

[4] T. Partala and V. Surakka, 2003. "Pupil size variation as an indication of affective processing." *International Journal of Human-Computer Studies* 59:185-198.

[5] J. Zhai and A. Barreto, 2006. "Stress Detection in Computer Users Through Noninvasive Monitoring of Physiological Signals", *Biomedical Science Instrumentation*, vol. 42, pp. 495-500.

[6] J. R. Stroop, 1935. "Studies of interference in serial verbal reactions." *Journal of Experimental Psychology* 18:643-662.

[7] P. Renaud and J.-P. Blondin, "The stress of Stroop performance: physiological and emotional responses to color-word interference, task pacing, and pacing speed." *International Journal of Psychophysiology*, vol. 27, pp. 87-97, 1997.

[8] R.M. Stern, W.J. Ray and K.S. Quigley, 2001. Psychophysiological Recording. Oxford University Press.