Deducing User States of Engagement in Real Time by Using a Purpose Built Unobtrusive Physiological Measurement Device: An Empirical Study and HCI Design Challenges

Anthony Psaltis[1], Charalampos Rizopoulos[1,2],
Zacharias Lekkas[1], and Constantinos Mourlas[1]

[1] Department of Communication and Media Studies,
National and Kapodistrian University of Athens, Greece
`{apsaltis,c_rizopoulos,mourlas}@media.uoa.gr`,
`zlekkas@gmail.com`
[2] Department of Communication and Internet Studies,
Cyprus University of Technology, Limassol, Cyprus
`c.rizopoulos@cut.ac.cy`

Abstract. Human emotion is a psycho-physiological state in most cases not obvious to the subject. Different permutations of emotional constituents sometimes cause similar outward expressions; therefore facial expression methods cannot achieve reliable estimates. Sensing physiological manifestations of hormonal and neural stimulations instigated by emotion and affect is widely accepted as a credible method of detecting psycho-physiological states. A major impediment in interactive environments employing physiological sensing affecting the credibility of measurements is the physical and psychological impairment caused by electrodes and wiring used for the acquisition of signals. In the system described in this paper, the above obstacle has been overcome. Physiological signals acquired via an in-house developed computer mouse and coinciding physiological patterns were investigated as reactions to emotion raising events. A classification algorithm analyzed herein produced a real time allocation model of states of engagement. Experiments have revealed strong correlations between events and respective emotional states.

Keywords: HCI, Biofeedback Measurements, Affective Interactions, User Evaluation, Stress Loading.

1 Introduction

User Engagement (UE) is an important component of user experience in a variety of applications – e.g. educational software, computer games etc. The aspects of UE evaluated in this study are essentially user centered and include focused attention and felt involvement [1-2]. Detection of engagement is not an easy task as it is a non-instantaneous subjective experience; often, self-report techniques are inadequate for

D.D. Schmorrow and C.M. Fidopiastis (Eds.): AC 2014, LNAI 8534, pp. 55–66, 2014.

the real-time detection of user engagement. Facial expression assessment methods also cannot predict the loading of emotional expression due to social, cultural and other factors causing a disparity error. Additionally, interruptions in user engagement during the process of assessment via a self-report instrument may negatively affect the validity of the measurement. Also, the self-reported state of engagement is more error-prone on account of the subjective nature of the user's perception. To that end, it is necessary to adopt a more objective method for measuring user engagement. Prior research on emotion from the areas of psychology [3-7], clinical physiology [8-12], affective computing and neuroscience [13-14], HCI [15-17], and game studies (e.g. [18-19]) have shown that emotionally induced physiological reactions of the autonomic nervous system are instant, can be identified, measured and quantified by using functional Magnetic Resonance Imaging (fMRI), Electro Encephalography (EEG), Electro Dermal Activity (EDA), Electro Cardiography (ECG), or a mix of the above.

A purpose-built electronic device that has been designed specifically for the detection and quantification of the users' state of engagement senses two of the above quantities; the Skin Conductance (SC) used for measuring electro-dermal activity as an expression of stressful reactions and the Heart Rate (HR) used for detecting variability as well as short and long term excitement [20]. The measurements obtained via the aforementioned instruments are mapped onto a two-dimensional concept space representing four distinct states of user engagement (labeled "Active involvement", "Contentment", "Perceived difficulty", and "Apathy / non-involvement"). These states are identified on the basis of the real-time characteristics of simultaneous augmentation of SC and HR measurements (hereafter referred to as "gradients"). Quantified data obtained were visualized onto the above concept space and the correlation of events and responses was assessed in real time.

Our endeavor to assess concurrent excitation of two physiological quantities in a specifically designed interface manifesting predetermined emotional stimulation has attempted to answer the following questions:

- Can a change of a psychosomatic state of a human subject be detected reliably by assessing simultaneously increasing or decreasing heart rate and stress levels?
- When both the above conditions are met, could a behavioral interpretation of the psychosomatic state of the subject be proven?
- Is there an inference between events that occur during the interaction with the system and the aforementioned quantities?
- Could an acceptable allocation pattern of the measured quantities in response to certain emotional event groups be deduced?
- Could this system be validated as an effective HCI tool for inferring a psychosomatic condition that would ideally represent clusters of emotional constructs?
- Is there a correlation between the emotional representation produced by the system and an established model of affect, namely Russell's [21, 22] circumplex model?

This paper is structured as follows: a reference to the basic physiological functions of the human body involved in reactions to emotion is provided. Then, a brief description of typical measurement practices and biofeedback principles is followed by our purpose built electronic device and our system setup, expanding into experiment design methodologies adopted and the development of the aforementioned system. Analysis of data derived from the experiments is presented later. Presumptions, limitations, and predictions before and after the experiments are clarified in detail in the psychosomatic analysis section and conclusive interpretation of our experimental data follows. Finally, we stress our views on the findings, reason specific results and make suggestions as to how the system may be used in broader areas of HCI.

2 Physiological Expression of Emotion

Theorists from a variety of orientations tend to agree on two emotional processing systems with considerable conceptual overlap: a schematic, associative and implicit system that has connections with bodily response systems and involves fast and automatic processes, and an abstract propositional 'rational' system that is analytical, reflective, logical, and relies on high-level executive functions. The former system is susceptible to biological mechanisms and is often manifested in the form of anxiety and stress. The latter system relies on logic and rationality. Recent neuroscientific findings are consistent with these multi-level conceptualizations. LeDoux [23] has reviewed evidence suggesting that emotion networks have direct anatomical connections. The aforementioned terms describe properties of behavior that concern the individual's typical ways of coping with life events. This paper emphasizes on the physiological aspect of the emotional experience and investigates how complex processes may alter emotional states and induce emotional responses like stress.

Stress is an unpleasant combination of emotions that includes fear, worry and uneasiness and is often accompanied by physical reactions such as increased heart rate and other body signals [24]. Prolonged stress can lead to long-term exhaustion, diminished motivation and lack of engagement in all levels of human activity.

Psychological stress is manifested in the human body as a physiological response of the sympathetic nervous system inducing vasodilatation of the skin's sweat glands. Water content alterations in the outer skin yield measurable changes in electrical skin conductance and skin temperature that subsequently create quantifiable indicators of stress levels. Under intense stress, the human body stimulated by brain hormonal secretion and neurotransmitters, experiences cardiac elevation and arrhythmias, abnormal respiration, and involuntary muscular contractions of the intestinal tract. An all-encompassing term used for the above conditions occurring together is reputably known as anxiety. The parasympathetic system reacts to the above condition, thus reinstating the human homeostatic equilibrium.

3 Acquisition of Signals and Implementation

3.1 Acquisition of Signals

The two physiological quantities mentioned above were considered as the most influential indicators for detecting psychosomatic state and therefore were chosen for the assessment of states of engagement. HR and SC were assessed together, as an indicator of the response of the sympathetic nervous system of the subject. The bodily condition described as “fight or flight effect” attempts to compensate for immediate corrective measures taken by the brain via the autonomic nervous system and was assumed to occur when HR and SC were both increasing. HR and SC in the opposite condition was supposing to indicate the effect of the counteractions taken (rest and digest phase) as a response from the parasympathetic nervous system.

HR was acquired based on the principle of Infrared Spectroscopy, effectively using as sensing elements two self-deflecting infrared sensors acquiring HR pulses simultaneously, for optimized error cancellation and a more reliable reading. Stress level was identified by two silver-silver chloride contact rings measuring skin conductance, placed on the sides of a computer mouse and at the points where the thumb and ring fingers are resting during the typical use of the mouse by a user. The two HR sensors were situated in the center of the SC rings. The mouse, including a signal preconditioning circuit, was connected to a Personal Computer via an in-house developed electronic interfacing circuit that included filters and conditioning of the above primary signals and fed them to a computer via the two channel audio input. A purpose-built software suite was developed using MATLAB, comprised by the appropriate components required for a system configuration console including automatic detection and identification of peripheral devices, connectivity and communication protocol as well as optional choices for recording and speed setting attributes. Finally the signal acquisition, raw signals processing, recording and visualization algorithms were incorporated into the above software. The use of this console was essential as the automatic detection of peripheral devices provided the flexibility to explore hardware specific attributes ensuring timely acquisition, selection of physiological signals as well as data storage configuration. The console provided also capabilities for the selection of raw data display in a variety of formats and options for use in combination with cameras for future incorporation of an eye pupil size detection subsystem.

Hardware redundancy was embedded in the electronic interfacing system with high precision circuitry and provision for handling external noise or other sources of error such as USB noise, current leakages, optical mouse interferences etc. In case of complete loss of contact, the system preserved the trait values measured up to the last valid measurement until the next valid measurement was detected. Since each particular measurement was evaluating the present event and it was only performed when a valid measurement had been acquired, discontinuities did not essentially affect the quality of assessment. Minute losses of contact with the sensors or erratic movement of the fingers onto the mouse could produce an error in HR reading interpreted effectively in the scale of milliseconds between pulse readings, while the SC measurement was unaffected. Such errors were typically corrected by software predictive algorithms implementing curve fitting, signal smoothing, periodic pulse error detection and correction, as well as typical missing pulse and ectopic beat detection and correction. Considering that the system in question is not required to take into account detailed pulse shape and cardiac arrhythmias, but is instead designed for detecting heart pulse interval and effectively HR and heart rate variability (HRV), this error was within acceptable margins of tolerance of the system, as it produced a negligible signal attenuation of ±0.018 of a pulse per reading in the worst case scenario.

3.2 Implementation

An SC auto-calibration algorithm was adopted, effectively providing a relative baseline for each subject independent of the actual stress levels of individuals. Since the main interest was not the quantity of stress that the user was experiencing but rather the state of stress in relation to the previous stress reading, a method for auto calibration was devised, envisaging a reference point ("baseline") at the mid distance between highest and lowest measured stress value weighed by the trait values. Each measured value was compared to the previous reading, thus resulting in a gradient with the following tendencies:

- Increasing (+), when the latest value was greater than the previous,
- Decreasing (-), when the latest value was less than the previous
- Neutral (0), when the two values were equal.

Subsequently, each SC value was compared to the baseline providing information about stress loading in relation to the trait value of this particular user. The baseline was continuously updated based on the measurements and the deviation from the mean value of SC ("tonic level"). By using this auto-update concept measured stress values were always included in the value set that was then projected onto the appropriate state area even if a new value was exceeding all previous measurements. Also the baseline value was important primarily because it eliminated problems like the need for initial calibration and similarly removed continuation inconsistencies during measurements once the user released the mouse for some reason. Moreover, as an additional threshold, the baseline provided a method of distinguishing additional details in the attributes of our measurements, effectively indicating the zero point of transition during instantaneous reactions of the users ("phasic response"). HR was compared to its previous reading deriving the HR gradient as raising (+) when the latest value was greater than the previous, dropping (-) when the latest value was less than the previous and (0) if they were both equal. The two gradients constrained the projected value within a quadrant as described in figure 1 below.

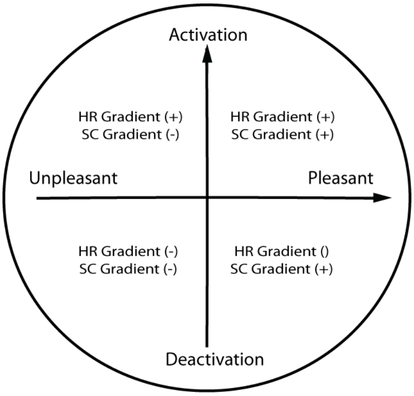

Fig. 1. Mapping of HR and SC gradients in terms of activation and valence

The indices in the axes (pleasant – unpleasant, activation – deactivation) represent an interpretation in compliance with common emotional models although none of the quantities (i.e. HR or SC) were directly associated to those meanings.

4 Assessment Study

4.1 General Description and Hypotheses

The first objective of our research was to assess the conditions where a certain measurement was representing a strong emotional stimulus. In our system, given that we had two important quantities such as HR and SC, a reasonable assumption was to examine conditions where both physiological quantities measured showed a common tendency compared to their previous measurement and also follow the same directional pattern, i.e. both either increasing or decreasing at the same time. Relevant findings derived from extensive research representing experimentally verified observations on HR and SC tendencies acquired when testing basic emotions (see [25]) have also shown that a correlation between HR, SC and basic emotion is present.

In order to validate the accuracy of the measurements, a study was conducted in which emotion-eliciting stimuli were presented to the users in the form of a video and a game. In the first part of the study, a puzzle game was used aiming to elicit stress loading caused by the mental effort of the user while tried to formulate the actions required for progressing through to the next levels and also positive affect as a result of the users' successful completion of game levels. During the second part of the study the subjects attended a video of traffic accidents, including some narrowly avoided ones. The video was intended to elicit negative affect (primarily stress and fear). Some of the accidents happened (or were narrowly avoided) at a distance, whereas in some other instances the camera was located within the vehicle that was actively involved in the accident. Thus, two different perceived threat levels were registered by the users weighted correspondingly during assessment. A comparison of the data obtained via physiological measurement with data obtained via self-report revealed that the former are accurate depictions of the users' state of engagement.

Apparently a detailed assessment of an exhaustive range of psychosomatic states of a human subject was not our aim and furthermore this was beyond the capabilities of our or any other system available to date. In our attempt to design an effective system primarily we set our objectives to develop an HCI tool that would be able to derive reliable indices of basic emotional manifestations as they were composed by the user. Therefore we classified four areas of dominant emotional states corresponding to our HCI behavioral patterns adopted in our experimental platform as follows:

1. State of Pleasant Attention where we expected the user to be pleased that has fulfilled the computer task in a state expressed by positive arousal and valence.
2. State of Tentative Attention, where we allocated inabilities to fulfill a task and some kind of frustration but with the component of Attention still prevailing.
3. State of Monotonous Involvement, where Attention and personal effort to focus on a task were diminishing and

4. State of Negative Interest, where we expected to find a really uninterested and inattentive person performing a task in negative state of valence and arousal levels.

These patterns of interpretation were deliberately chosen so as not to coincide with existing emotional allocation models. We reached this decision because the above states corresponded to an exact interpretation of the stimuli produced in HCI experimental procedures and that would have given us a good reference point for assessing the correlations between the system responses and emotional conditions. Otherwise, the number of emotional states and combinations derived from them would have made the assessment much more complex and difficult. Effectively we classified emotional groups into four states of attention in order to achieve a more realistic and simplified interpretation.

5 Evaluation Methodology

5.1 Description of Interface

Evaluating the design of a user environment that would benefit from the capabilities of the system to perform emotional assessment in a thorough and convincing manner and optimally explore the latest concepts of emotion inducing techniques in user interaction we faced the task to create a visual environment, in which stimulation events, measured user responses as well as processed data allocation had to be captured and projected on screen in real time. Representation had to include all processing parameters in an easy to follow, understandable and comprehensive manner. Generic data recordings as well as factors and parameters used for data transformation had to also be included. As the major advantage of the system was its capability to minimally affect the psychological loading on the users, they were inclined to use material from usual sources found in regular visiting pages of the Internet. Thus we reached the conclusion to include a simplified environment featuring a puzzle game and a video playback while the system was evaluating user responses to events evaluated within a corresponding weighted range. Each session of the experiment included two parts with total duration of twenty minutes. The creative game experience in the first part and the observation of emotion creating video was then adopted. One measurement was taken every 1.82 seconds.

5.2 Experiments

The emotion-inducing environment as well as the representation model adopted was chosen based on the authority of each scenario to absorb the user as much as possible. A game was chosen for the first part, where an unknown environment was presented to the user. Initially the level of difficulty was reasonably low, while was still keeping the user effort high as they tried to learn how to identify ways to overcome obstacles in order to progress to more demanding and difficult levels. This task was assessed in

10 minute sessions with no prior instructions or guidance. As a result the users had to adapt to this unfamiliar setup, increase their concentration and try to improvise in order to complete up to twelve progressively more difficult levels. The time limit did not allow to all participants to complete all levels as their pace of progress was different. Also due to those differences in progress levels, assessment process had to be individually evaluated for different number of events accordingly. The second part included a film capture that produced captivating and at the same time aversive and fearsome events for the purpose of causing substantial emotional and psychological responses. The content in this task consisted of a compilation of specifically chosen captions of traffic events including predictable as well as suddenly occurring road accidents. Portrayed events were filmed from the position of the driver of the vehicle that was affected minimally by the accident, instigating apprehension and stressful emotions to the viewer in a more realistic manner than if seen from a distance. Additional information regarding user profiling, preferences on personalization or psychological profiles was neither requested nor taken into account in this study.

Fifteen subjects (9 women and 6 men)[1] ranging from 18 to 47 years of age (mean age: 26.2 years) participated in the experiments with our customized experimental platform. Although the participants were aware that they were to take part in an experimental procedure, they had no prior knowledge of our experiment setup, had no restrictions declining from normal use of a personal computer task, and also retained the option to withdraw or refuse to complete any part during the experiments.

6 Data Analysis and Interpretation of Results

Data analysis included three stages. First the context of the exercises was weighed and scaled according to its significance as an emotion causing event. The actual response measured by the system was then assessed for the particular event according to its time stamp. Finally the deviation of data derived from our experiments from an optimal emotional curve of the expected emotional intensity was observed. Data from all subjects were combined to formulate a table effectively providing a more extensive indication of the convergence or divergence of emotional patterns derived from our system, thus shaping its performance rate.

Data post-processing algorithms were incorporated in the system producing results in their final form ready for analysis. In other words instead of having results of each experiment in form of raw data that then had to be transformed into a meaningful form, the work of processing and presenting data was done in real time. Naturally raw data recording allowed for further exploration and tracing as required. Data obtained from all 15 subjects are presented in fig. 2, presenting a clearly high degree of coincidence as explained below.

---

[1] Although the initial sample consisted of 17 subjects, two of them were not included in the final assessment: one female user due to inconsistent performance and one male participant due to being very talkative and thus exhibiting unnecessary respiration arrhythmias.

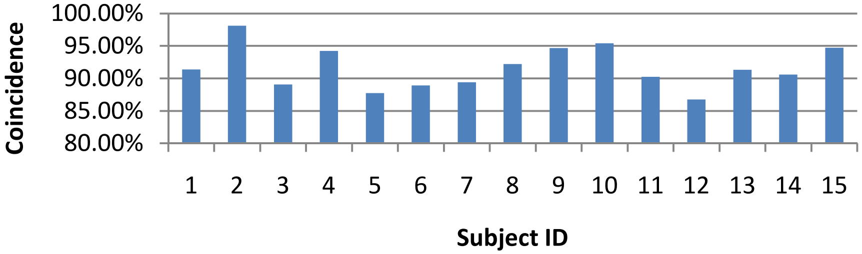

Fig. 2. Engagement validity rate

During the experiments, participants indicated that they perceived the environment as comfortable and characterized their estimate of psychosomatic condition mostly as 'Pleasant' except for two (experienced gamers) that characterized their condition as 'Neutral'. State of Pleasant and Tentative Attention was classified by our system indicating user positive involvement during the experiments and was the most important component in our interest. For this state the experiments have produced data indicating a high degree of validity (94-98%). State of '*Contentment'* was declining as found significantly higher than predicted. Examining this discrepancy from the view of physiological behavior of the SC signal, it was observed that the decay of the curve of a typical SC response is much slower than that of the stimulus, as illustrated in fig. 3.

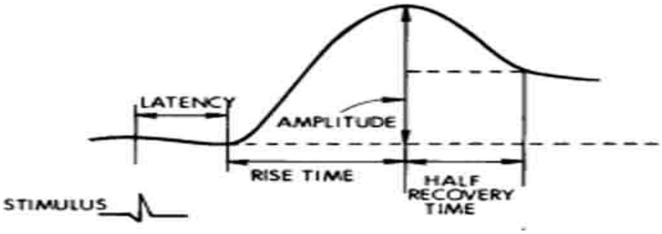

Fig. 3. Skin Conductance response overshoot

This slow decay of SC for a given stimulus eliciting positive affect caused the values to be projected in the quadrant representing the state of '*Contentment'* while the gradient of HR was still rising as the gradient of SC although still high was appearing to be negative. A corrective algorithm was implemented sustaining the state of '*Focused Involvement / Engagement'* until a threshold value of the SC was reached and for as long as the HR gradient was positive. Reprocessed data after the implementation of the correction algorithm have produced an improvement by 12% in erroneously projected events, thus improving even more the validity of the system. States of engagement representing reduced involvement by the user (e.g. when users were waiting for the next event or changing scenarios) had also a high degree of coincidence compared to the weighed evaluation values. Concluding results classified all subjects in the above four states of engagement as follows: Pleasant Attention, 0.442,

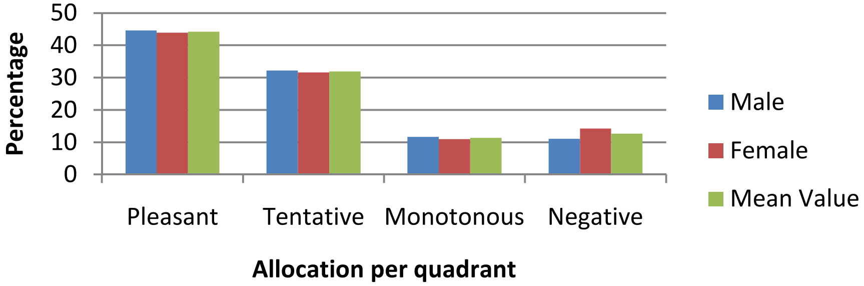

Fig. 4. Percentage allocation per quadrant

(corrected 0,496), Tentative Attention, 0.319, (corrected 0,265), Monotonous Involvement, 0.126 and Negative Interest at 0.113 of the time of the experiment respectively. Allocation per quadrant and gender in percentages is shown in fig. 4.

It can be seen from the results that there is no significant difference in responses between male and female participants (<1%) and event to response coincidence was found between 98% for male and 88% for female users. Coincidences in gaming were similar for both male and female participants while most differences occurred while attending the visual content. In our view this small difference has its origins in the profiles of male participants being affected more by aversive driving experiences (age of 32-47 with driving experience) than female participants (age 18-27 with little or no driving experience whatsoever). Differences in both male and female participants between gaming and visual observation sessions indicated less accurately event/response matching during the gaming session data than that during visual observation where the latter was by 4.1% more accurate. This is explained by the fact that during the gaming session users had more irregular positioning of their fingers on the mouse although during the video session the contact of their fingers with the sensing elements of the mouse was less erratic producing better quality of acquisition.

7 Discussion and Future Work

A reasonable outcome of this research concerning the validation of our system would have been to detect reliably a user's state of engagement. This goal was attained to a high degree. In a preliminary test conducted with 9 participants requested to look away from the computer and divert their concentration completely, we observed that the projection was consistently changing to states of Monotonous Involvement (22%) and Negative Interest (76.1%) with an overall accuracy of 98.1%. As soon as the participant redirected their sight back to the computer, the system was mapping them in the quadrant representing Pleasant / Tentative Attention. Witnessed from the above test, as well as the concluding results of the experiments we have indications that the correlation of common gradients of HR and SC can be used as an indicator in determining positive and negative states of attention, hence states of engagement.

Assessing the results we have produced a correction algorithm that has improved system accuracy.

Although experimental results point at the existence of a correlation, the precise emotion experienced by the user and captured by the system is unclear due to the inherent complexity of the way emotions are experienced, as well as their underlying psychological manifestation. For instance, underlying cognitive processes may be detected by the system as states of engagement due to the similarity of their physiological indices, although they may represent a different psychological state that is perceived by the user; however, as the prediction of the subjects' state of engagement was adequately accurate, further experimentation with specific emotional states such as frustration, sadness, depression etc, may result in improved capabilities of the system to identify states of emotion in greater detail.

Additionally, future research will expand into other domains, e.g. e-learning, educational applications, games, virtual environments, affective computing, and other areas. Further consideration and analysis of parameters and contexts such as users' cognitive and mental capabilities, socio-psychological factors, emotional states and attention grabbing strategies is needed. The above characteristics could improve the reliability and efficiency of customizing user requirements and, along with the 'traditional' user characteristics (i.e. name, age, education, experience, profession etc.), constitute a comprehensive user profile that serves as a strong basis for effective and efficient adaptation methodologies in HCI.

References

1. O'Brien, H.L., Toms, E.G.: What is user engagement? A Conceptual Framework for Defining User Engagement with Technology. Journal of the American Society for Information Science & Technology 59, 938–955 (2008)
2. O'Brien, H.L., Toms, E.G.: The development and evaluation of a survey to measure user engagement in e-commerce environments. Journal of the American Society for Information Science & Technology 61, 50–69 (2010)
3. Eysenck, M.: Attention and Arousal. Springer, New York (1982)
4. Eysenck, M.W.: Fundamentals of Cognition. Psychology Press, Hove & New York (2006)
5. Frijda, N.H.: The Emotions. Cambridge University Press, Cambridge (1986)
6. Scherer, K.R.: What Are Emotions? And How Can They Be Measured? Social Science Information 44, 695–729 (2005)
7. Strongman, K.T.: The Psychology of Emotion: From Everyday Life to Theory, 5th edn. John Wiley & Sons, Chichester (2003)
8. Lykken, D.T., Venables, P.H.: Direct Measurement of Skin Conductance: A Proposal for Standardization. Psychophysiology 8, 656–672 (1971)
9. Hassett, J.: A Primer of Psychophysiology. W. H. Freeman, San Francisco (1978)
10. Venables, P.H., Christie, M.J.: Electrodermal activity. In: Martin, I., Venables, P.H. (eds.) Techniques in Psychophysiology, pp. 2–67. John Wiley & Sons, New York (1980)
11. Damasio, A.R.: Descartes' Error: Emotion, Reason, and the Human Brain. Vintage, London (1994/2006)
12. Tsatsou, K.: A Study of Electrodermal Response to Bodily Evoked Potentials. Masters Dissertation, University of Patras, Greece (2006) (in Greek)

13. Fairclough, S.H.: Fundamentals of Physiological Computing. International Journal of Human-Computer Interaction 21, 133–145 (2009)
14. Picard, R.W.: Affective Computing. MIT Press, Cambridge (1997)
15. Brave, S., Nass, C.: Emotion in Human-Computer Interaction. In: Sears, A., Jacko, J.A. (eds.) The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications, 2nd edn., pp. 77–92. Lawrence Erlbaum Associates, New York and London (2008)
16. Kuniavsky, M.: Smart Things: Ubiquitous Computing User Experience Design. Morgan Kaufmann, Burlington (2010)
17. Norman, D.A.: Emotional Design: Why We Love (or Hate) Everyday Things. Basic Books, New York (2004)
18. Calleja, G.: In-game: From Immersion to Incorporation. MIT Press, Cambridge (2011)
19. Law, E.L.C., Sun, X.: Evaluating User Experience of Adaptive Digital Educational Games With Activity Theory. International Journal of Human-Computer Studies 70, 478–497 (2012)
20. Psaltis, A., Mourlas, C.: A Real Time Attachment Free, Psycho Physiological Stress and Heart Rate Measurement System. International Journal of Measurement Technologies and Instrumentation Engineering 1, 1–13 (2011)
21. Russell, J.A.: A Circumplex Model of Affect. Journal of Personality and Social Psychology 39, 1161–1178 (1980)
22. Russell, J.A.: Core Affect and the Psychological Construction of Emotion. Psychological Review 110, 145–172 (2003)
23. LeDoux, J.: The Emotional Brain. Simon & Schuster, New York (1996)
24. Kim, J., Gorman, J.: The psychobiology of anxiety. Clinical Neuroscience Research 4, 335–347 (2005)
25. Peter, C., Herbon, A.: Emotion representation and physiology assignments in digital systems. Interacting With Computers 18, 139–170 (2006)