Mining physiological data for automated educational feedback in virtual learning environments

Zdena Lustigova [1], Aude Dufresne [2], Fethi Guerdelli [3]

[1]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
[2]Department of Communication, University of Montreal, Montreal, Canada
[3]Department of Communication, University of Montreal, Montreal, Canada

Key words: *physiological data mining, real time monitoring, educational feedback, automated learning response, virtual learning environments*

Abstract:

The authors present, on the base of their own research activities and recent studies, dealing with neurology, educational psychology, cognitive brain science, etc., the great potential of data, obtained from noninvasive physiological measurement, for immediate and individualized reaction on the learning process of the learning subject. They emphasized electrodermal activities (e.g. galvanic skin response) measurements, eyes tracking, blink rate and blink speed measurements, and heart rate (esp. EEG), for their potential to reflect decreasing attention, increasing visual or cognitive information load, task difficulty, tension, arousal, stress and fatigue of the learning subject. The present paper highlights the advantages and constraints of different physiological monitoring approaches, their advantages as well as constraints, done by (1) the hardware and software limits, (2) by the necessity of individual setup (often continuous), (3) by the problems with real time data processing, including wrong data recognition and elimination, etc. Analyzing data of GSR, EEG and eye tracking studies employing a wide range of cognitive tasks, authors give some recommendations, which are till now rarely used for educational data mining and/or real time monitoring for automated feedback in virtual learning environments.

1 Introduction

Within the progress of information technologies for education, and the progress of physiological measuring tools, the chance to reflect real and immediate learning and emotional needs of a subject, who learns, has emerged in a inconceivable way. Generally, computer supported inquiry based learning environments are developing along the lines of integrated learning and combining multiple approaches; but till now, they have rarely included immediate and individualized reaction on the decreasing attention, increasing visual or cognitive information load, task difficulty, tension, arousal, stress, achievement of the learning subject.

Simple, noninvasive, low cost measurements of eyes blinks, galvanic skin response (GSR) or heart rate are easily available and with the progress and miniaturization in technologies, transferable to the „out of laboratory“ conditions – into the real learning environments – home, classroom, internet coffees, etc.

2 Eye tracking and blinking patterns

Among many different data, obtained from eye tracking systems, the changes in spontaneous blink rate seem to be the most easily detected significant factor for cognitive and visual information load and thus easily used for real time automated educational feedback.

2.1 Advantages:

1/ Significant reflection of information load
According (Holland, 1974), blinking occurs between visual fixations and may be timed so as not to interfere with significant visual input. Blink rate is low when information memory is operating, and cognitive processes utilizing display areas accessible to visual input are disrupted during the blackout period of a blink. Blinking is thus suspended during certain cognitive activities to avoid disrupting these processes. (Wong, 2002)
As an example Wong, Wan and Kaye (Wong, 2002), research among surgeons could serve. They found the significant reduction in the average blink rate between two conditions (casual conversation and operating, using the microscope) -16.69/min and 4.75/min, p= 0.0002 paired *t* test, on average a three and a half fold decrease occurred while operating.
It was also noted that the onset of conversation such as the request for an instrument or demonstration of an intraocular structure, was associated with the onset of a blink response.

Table. 1 Average blink rates (No/min) for ophthalmic surgeons during periods of casual conversation and while operating using the microscope. Br J Ophthalmol. 2002 April; 86(4): 479

Surgeon	1	2	3	4	5	6	7	8	9	Mean (SD)
Casual	17.29	17.75	7.75	17.60	27.44	24.67	11.50	13.86	12.33	16.69
Operating	9.71	9.00	0.29	7.40	1.68	8.67	1.59	3.86	0.54	4.75
p Value	0.000002	0.002	0.002	0.002	0.0001	0.0001	0.00003	0.0004	0.0002	0.0003

2/ Stability in time
Blinking rate personal pattern are stable in time. Barbato et al, 2000 investigated daily pattern of spontaneous eye-blink rate at 24 healthy subjects. It showed a stable personal pattern in morning, midday and afternoon hours. A significant increase was found at the evening time point (20.30 h). The researchers suggested the connection to a late evening increase of central dopamine activity. An increased level of subjective sleepiness was also found at the same evening point. Similar research results are confirming this fact.
3/ Possible detection of the level of fatigue
According some researchers (e.g. Bittner et al, 2001) blink rate and especially blink speed might reflect (be affected by) the level of fatigue, which might be also an important factor for the automated feedback of virtual learning environment. Some studies (Ebert, 1996) suggested that significant BR increase (caused by the sleep deprivation) occurs mainly among people with depressions, while others (Barbato et al, 2000) proved general BR increase among people with sleep deprivation. The most recent studies, especially among drivers (e.g Bittner et al, 2001) investigated probably even more significant factors of fatigue then BR, the **speed of blinks;** drowsy person (with demand on visual concentration) blinks more slowly than an alert.

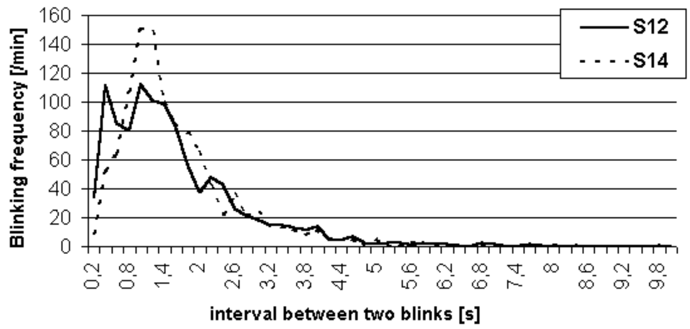

Fig: 1 Frequency polygon of time intervals of consecutive eye blinks in an alert (s12) and a drowsy (s14) driver (adopted from Bittner et al., 2001)

4/ Easy to detect (economic issues)
Blinking rate is easy to detect comparing to other eyes features detection (saccades, fixations, gaze position, etc). Pupil size and movements (saccades, gaze) both need eye tracking systems, including high resolution and high speed cameras, and sophisticated (and thus expensive) SW for data processing. Especially real time data processing, necessary for real time feedback of an automatic agent, is demanding task and might be hard to manage it for distance/online education purposes in larger rate. Thus detection of saccades, gaze, etc. seems to be more expensive and usually less comfortable for both, user and researcher/automatic agent.

2.2 Constraints:

1/ Cognitive versus visual information load
Wong and his co-researchers (Wong et al, 2002), they also found the connection between the need of good contrast acuity and the blinking rate. Blink rates and blink amplitude vary according to vision related behavior and a reduction in the blink rate occurs with tasks of increasing visual difficulty. In other words, students maintaining good contrast acuity, blink less frequently. According (Wong, 2002) based on (Patel at al, 1991) observations visual tasks requiring concentration, result in a decrease in average blink rate from 18.4/mm to 3.6 blinks/min.
2/ Baseline conditions
Other researchers (Cho et al, 2007) hesitate about BR results, measured under different (baseline) conditions. According them, it produced different results so it is important for investigators to describe the baseline condition very clearly in studies where BBR are measured. Their results also indicated that mean blink rate was affected by the position of gaze and not only by the level of task difficulty. According Wong 2002, from ophthalmologic point of view (production of tears, tear film stability and thickness) is good to ensure video display unit screens be kept below eye level. A reduction in the blink rate such as, for example, a pause between blinks of 15 seconds has been associated with a change in the shape of the profile of the corneal tear film and up to a 6% reduction in visual acuity
Setting display screen bellow user's eye level can ensure both, better visual comfort for the user (more healthy conditions for his/her eyes) and stable baseline conditions for real time data processing and thus better automated feedback.
3/ Individual blink rate patterns

3 Galvanic skin response - skin conductivity

Mental, physical or emotional excitation affects the skin of the tested person. During this excitation, in accordance with the sympathetic response, sweat glands in the skin fill with

sweat, a weak electrolyte and good conductor. This results in many low-resistance parallel pathways, thereby increasing the conductivity of the skin (Malmivuo, 1995).
GSR - galvanic skin response is one of the several electrodermal responses/activities (EDR/EDA).
GSR generally consists of two components: tonic and phasic. The tonic component is a low frequency baseline conductivity level, which can oscillate over the course of days. Each person has a different tonic conductivity, measured in micro Siemens, generally in between 2 and 20 MicroSiemens. The phasic component rides on top of the tonic component, is of higher frequency, and generally increases (in frequency and amplitude) when a person is aroused.

3.1 Advantages:

1/ Tonic skin response rise in anticipation of performing a variety of tasks and during the performance of these tasks (mental arithmetic, attention tasks, discussing social issues are often used to demonstrate this phenomenon).
2/ Phasic skin response is supposed to reflect the level of stress as well as the level of social empathy and other „social emotions".
3/ An interesting alternative to GSR is the sympathetic skin response (SSR), which is easily recorded using ECG, but it is not so easily obtained (contacts, electrodes,) noninvasive, low costs and easy to use in naturalistic settings (economical and human issues)

3.2 Constraints:

1/ Baseline individual differences and instability in time
The low frequency baseline conductivity level (tonic component), which can oscillate over the course of days and generally slowly increases with the level of the person's arousal, is characterized by large individual differences. See Fig. 2

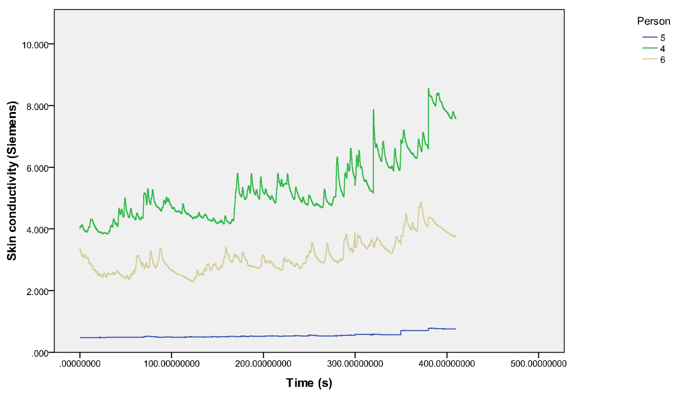

Fig. 2 The individual differences in both phasic and tonic components of the skin conductance (micro Siemens) during the exposition to the same web side content. The person 4 is more aroused then person 6. Phasic component of the person 5 is within this scale (0-10) unrecognizable. Data obtained by authors.

2/ Data processing and interpretation
The signal of the phasic component is usually evaluated on the base of amplitude and latent period. For the evaluation of the relative amplitude of the phasic reaction in percent relative to the tonic level is often used. The signals of both, the tonic and phasic component, are not periodic; their spectra are continuous and overlap. But the possibility for their frequency separation exists – the bulk of the energy of the tonic component is in the frequency band 0-0.05 Hz, while the energy bulk of the phasic component is within the frequency band 0,05-1-2 Hz. (Ishchenko, 1989).

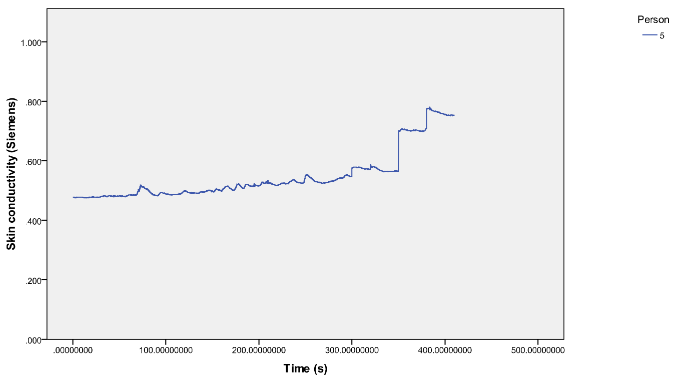

Fig.3 Problems with the data interpretation - phasic component of the person 5, (see fig.2) scaled 0-1 micro Siemens. Phasic component is still hardly visible, tonic component seems very low. The person might be badly connected, or not excited with the web content at all. Data obtained by authors.

For phasic component data interpretation signal processing methods are rarely used, although some methods, e.g. FFT (Fast Fourier Transformation), seem to bring new information (Ishchenko, 1989).

Usually the amplitude in microSiemens, latitude, rise time and half recovery time (all in sec, typical values in the same order are 3s, 1-3s, 2-10s), are measured (Ishchenko,1989).

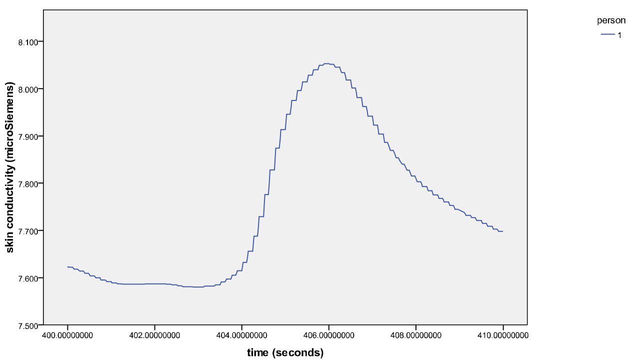

Fig 4: Typical response, illustrating the time parameters for rise time and half recovery time. Data obtained by authors.

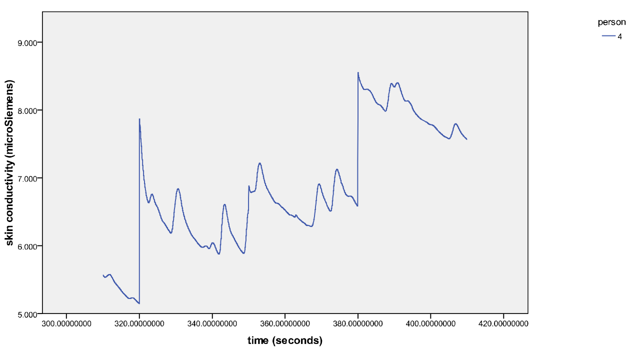

Fig 5: GSR during long time interval (120 s). Responses with arise time shorter then 0,25 s are supposed not to be valid and should be eliminated. Data obtained by authors.

According some authors (e.g. Rani et al, 2004) the slope of the rise to the peak should be greater than 0.05 Micro-Siemens/minute, the amplitude should be greater than 0.05 Micro-Siemens and the rise time should be greater than 0.25 sec.

3/ Dependence on the skin path

Tonic skin conductance (measured in units of siemens) depends on the skin path length between the two electrodes contacts, even for subjects with identical skin conductivity (measured in units of siemens/meter).

4 Heart rate + EEG

While GSR changes are mostly connected with emotional arousal and the level of person's involvement, and BR is highly influenced by the level of fatigue and visual acuity, the heart rate and EEG measurements undoubtedly reflect mainly mental activities.
Most of the EEG studies reported had used alpha power measures for exploring differences in intelligence. Evidence, since the beginning of 20th century, indicates that alpha power is inversely related to mental. Amplitude decrease in the alpha rhythm, called "alpha blocking," or "alpha desynchronization " has been reported for several cognitive tasks such as mental arithmetic, tasks taken from IQ tests, and creative problems (e.g. Butler, 1976; Donchin et al, 1977; Martindale, 1999; Nunez, 1995). An interesting description of alpha blocking was provided in an early study by Penfield and Jasper (1954) for Einstein (Jausevic, 2005).

4.1 Advantages:

1/ Large spectrum of valid research results, often connected with learning and educational activities
Neurologist and cognitive brain researchers use parameters like spectral power and coherence, different Alfa frequency bands (the lower α_1 = 7.9-10.0 Hz, and upper α_2 =10.1 -12.9 Hz, some authors use 8-10 and 10-12 Hz, while others start at 5,6 Hz (Fink, 2005)) and event related desynchronization (ERD) between different frequency bands.
They presented lot of evidence that the correlations between lower and upper alpha band ERD systematically decline as task demands increase (Fink et al, 2005).
Research results also suggest that creativity and intelligence are different abilities that also differ in the neurological activity displayed by individuals while solving open or closed problems. They also proved EEG differences in cognitive processes between gifted, intelligent, creative, and average individuals (Jausevic, 2005) and many others results, highly relevant for automated educational feedback in virtual learning environments.

4.2 Constraints:

1/ Data processing
Data processing and data interpretation is not simple, uses different statistical methods, signal processing, etc. For virtual learning automated educational feedback purposes real time frequency analyses seems necessary.
2/ Individual differences:
Due to individual differences in alpha activity, it is suggested to adjust alpha frequency bands individually for each research participant.
3/ Laboratory conditions
Generally the heart rate measurements are provided mainly in laboratory conditions and the possibilities for large scale out of laboratory use seem to be very limited, till nowadays.

5 Conclusions

In virtual learning environments, where feedback or automated educational response is partially supported by real time physiological data monitoring and processing, especially with eye pupil positioning and blink rates frequency, students have to use high resolution displays. Both, virtual learning environments' developers and content designers, have to ensure the highest contrast acuity of „onscreen" activities - educational tasks (e.g. reading graphs, controlling simulations of phenomena and/or operating simulated technical equipment,

solving equations, etc.) . Otherwise low blinking rate doesn't reflect the cognition activities (like cognitive information load) but more visual information load.
Researchers (educators) have also to ensure (for the significant feedback) that the students' monitors are setup below the eye level and do not change the vertical position during the study unit.

For immediate reflection of emotional arousal (both positive and negative), person's involvement estimation and attention during the learning process, GSR measurement, which dates from the turn of the 19th century, is still one the most exciting and economically rationalized way. With the progress in technologies and miniaturization, the wearable wireless Bluetooth skin conductance sensors with high sampling frequency became easily available and very comfortable feedback tool for both – users and SW designers. Despite this fact, GSR is rarely used for large scale, "out of laboratory" educational experiments and practically never used for automated feedback in virtual learning environments. The reason might be in lasting skin "contacts" problems, huge individual differences, ineffective elimination of wrong data sets, together with inadequate data processing methods, negatively influenced both reliability and validity of GSR measurements and lead into a large variety of inconsistent research results. Fast Fourier Transformation and other relevant methods for GSR phasic component data processing and interpretation are rarely used, although some of them seem to bring new views (needs further evaluation and research).

EEG and Heart rate measurements, although bringing a lot of information highly valid for automated educational feedback in virtual learning environments, seems to be, due to different reasons (economic, safety, real time signal processing, necessity of individual setup, etc.), still the most expensive and most complicated solution.

References:

[1] Barbato, G., Ficca, G., Muscettola,G., Fichele, M., Beatrice, M., Rinaldi, F.: Diurnal variation in spontaneous eye-blink rate, Psychiatry Research, Volume 93, Issue 2, Pp. 145-151, ISSN 0165-1781. 2000.

[2] Bittner, R, Smrcka, P, Pavelka, M, Vysoky, P. and Pousek, L, :Fatigue Indicators of Drowsy Drivers Based on Analysis of Physiological Signals . Springer. Berlin / Heidelberg. ISSN: 0302-9743 (Print) 1611-3349 (Online), Volume 2199/2001, p. 62-68.

[3] Butler, S. R., & Glass, A.: EEG correlates of cerebral dominance. In A. H. Reisen & R. F. Thompson (Eds.), Advances in psychology (Vol. 3, pp. 219-384). New York. Wiley.1976.

[4] Donchin, E., Kutas, M., McCarthy, G.: Electrocortical indices of hemispheric specialization. In S.Doty, R. W. Doty, L. Goldstein, J. Jaynes, & G. Krauthamer (Eds.), Lateralization in the nervous system (pp. 339-384). New York: Academic Press. 1997.

[5] Ebert, D., Albert,R., Hammon,G., Strasser,B., May, A., Merz,E.: Eye-blink rates and depression: Is the antidepressant effect of sleep deprivation mediated by thedopamine system?, Neuropsychopharmacology, Volume 15, Issue 4, October 1996, Pages 332-339, ISSN 0893-133X

[6] Fink, A., Grabner, R.H., Neuper, C., Neubauer, A.C. : EEG alpha band dissociation with increasing task demands Cognitive Brain Research 24 (2005) 252–259

[7] Fink, A.: Event-related desynchronization in the EEG during emotional and cognitive information processing: Differential effects of extraversion. Biological Psychology 70 (2005). pp. 152–160

[8] Ishchenko, A. N. , Shev'ev, P. P. : Automated complex for multiparameter analysis of the galvanic skin response signal. Biomedical Engineering. Springer New York. 0006-3398 (Print) 1573-8256 (Online). Volume 23. Number 3. May. 1989

[9] Jausovec, N: Differences in Cognitive Processes between Gifted, Intelligent, Creative, and Average Individuals While Solvin Formatting Instructions.
[10] Malmivuo, J. , Plonsey, R.: Bioelectromagnetism. The Electrodermal Response. Oxford University Press: New York. 1995.
[11] MacIntosh, B.J., Mraz, R., McIlroy, W.E., Graham, J.S.: Brain activity during a motor learning task: An fMRI and skin conductance study. Human Brain Mapping. Volume 28 Issue 12, Pages 1359 – 1367. Published Online: 22 Feb 2007. 2009 Wiley-Liss, Inc., A Wiley Company
[12] Martindale, C.: Biological bases of creativity. In R. J. Sternberg (Ed.), Handbook of creativity (pp. 137-152). New York: Cambridge Univ. Press.1999.
[13] Nunez, P. L. : Mind, brain, and electroencephalography. In P. L. Nunez (Ed.), Neocortical dynamics and human EEG rhythms (pp. 133-194). New York: Oxford Univ. Press. 2005.
[14] Patel, S., Henderson, R., Bradley, L., *et al*. Effect of visual display unit use on blink rate and tear stability. Optom Vis Sci. 1991. 68:888–92.
[15] Rani, P., Sarkar, N., Smith,C.A., Kirby, L.D.: Anxiety detecting robotic system – towards implicit human-robot collaboration. Robotica (2004) volume 22, pp. 85–95. 2004 Cambridge University Press
[16] Stern, J.A., Boye, D., Schroeder, D.: Blink rate – a possible measure of fatigue. Department of Psychology. Washington University. St. Louis, MO 63130.
Holland MK, Tarlow G. Blinking and thinking. *Percept Mot Skills* 1975;41:505–6.
[17] Wong, K.K. Wan, W.Y. , Kaye,S.B.: Blinking and operating: cognition versus vision. 2002. British Journal of Ophthalmology. April; 86(4): 479.

Authors:

Zdena Lustigova [1], Aude Dufresne [2]
[1]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic
[2]Department of Communication, University of Montreal, Montreal, Canada
lustigo@plk.mff.cuni.cz, aude.dufresne@umontreal.ca