Heart rate variability in gaming — methods and preliminary results

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Summary

Background: Both the civil and military authorities are introducing computer programs, similar to games, as educational tools and for medical treatment. Analyses of the users' psychophysiological responses have become a valuable tool within media research. The aim of this study was to evaluate a method for capturing HRV (heart rate variability) data related to war-like events in a computer game, reflecting autonomic influences of heart rate. *Methods and subjects:* Six participants (one female) 19–37 years of age played an action game tutorial three times each. The measured variables were various HRV parameters, obtained with the mobile POLAR 810i device. These values were analyzed in relation to events in the computer game, captured by video recordings. *Results:* The result indicates that the methods with the mobile POLAR 810i and video-recorders fulfil the basal requirements for capturing intended data. The HRV analyses, with the curves coupled to the video monitored game on the screen, showed features indicating a relation between game events and the HF (High Frequency) and LF (Low Frequency) power. There were great differences between subjects in absolute HRV values but the response pattern to game events was similar within subjects. The HF power was significantly reduced ($P \leqslant 0{,}001$) when computer gaming (428 ms^2) compared with resting in a supine position (1613 ms^2). The LF/HF-ratio was also significantly higher when gaming (340 ms^2) compared with resting (94 ms^2) indicating a depressed parasympathetic (vagal) drive which favours the sympathetic one. In media research the HF component of HRV is usually called RSA (Respiratory Sinus Arrhythmia). *Conclusion:* Psychophysiological responses appeared to be related to events in a war-like computer game. HRV seemed to be a useful and easily obtainable measure.

Key words: computer game, heart rate variability, HRV, psychophysiological responses, RSA.

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Introduction

Ordinary military exercises in physical surroundings and civil training concepts are successively being supplanted by game based ones with commercialized PC-games as training and exercise tools (Wulff, 2000; Dreborg & Svensson, 1990). Methods on how to evaluate the emotional presence and commitment in a training situation simulated on-site or virtually in a computer game, needs to be taken into consideration. Analyses of psychophysiological responses as heart rate variability (HRV) might be of use for making the training as efficient as possible and hence cost-effective. Also in treatment of various diseases, as for example battle stress, computer games with virtual realities have been used (Olin M. Reuters, 2005). In March 2005 San Diego Virtual Reality Medical Center (www.eurekalert.org) published the report on «Evaluating virtual reality therapy for treating acute post traumatic stress disorder» used for home-coming soldiers from the Iraque war[1]. The Swedish Defence College (FHS) and the Swedish Defence Research Agency (FOI) have made many reports on computer gaming or/and simulated environments discussing psychophysiological studies where especially heart rate (HR), blood pressure, eye-movements, cortisol-levels and skin conductance have been studied along with psychological tests (Magnusson, Berggren, Danielsson et al., 2001; Olofsson & Nilsson, 2004). Theorell (2001) has discussed stress markers where he asks for mobile devices in ordinary environments. Ekerstedt and Theorell (2002) are of the opinion that about 15 trials are enough for physiologic data analyses.

The Task Force of European Society of Cardiology and the North American Society of Pacing and Electrophysiology in 1996 stated their «Guidelines» entitled «Heart Rate Variability – Standards of measurement, physiological interpretation, and clinical use». This report is the base for analyses related to heart rate variability (HRV) worldwide ever since. The frequency band is divided into Very Low Frequency (VLF) Power 0,00–0,04 Hz, Low Frequency (LF) Power, 0,04–0,15 Hz and High Frequency (HF) Power, 0,15–0,40 Hz. The unit for power is ms^2. The LF/HF ratio is regarded as reflecting the SNS/PNS-balance (Sympathetic Nervous System/Parasympathetic Nervous System). This balance is measured during different conditions and SNS acts as a «throttle» and PNS as a «brake pedal» in the autonomous psychophysiological system. HRV analyses are mostly made in either the time domain or the frequency domain In media research the HF component of HRV is usually known as Respiratory Sinus Arrhythmia (RSA). Individually great differences may be present e.g. due to genetic variations in the choline transporter gene taking part in the parasympathetic response (Neuman, Lawrence et al., 2005). They found that relative to men women had significantly lower LF power, lower LF/HF ratio and marginally greater HF power at a certain genetic covariance. Autonomous nervous system dysregulation, particularly low parasympathetic activity, is associated with higher psychosocial risk factors as coronary heart disease and depression (Neuman, Lawrence et al., 2005).

Ravaja (2004) mentioned, referring to many different studies, that the attention and emotion created by a game is depending on the personality of that specific person but also in the manner the person is coping his/her life. Antonovsky (2001) made his research on coping related to a sense of coherence in a person's life. In «Context and Consciousness» (Nardi, 2001) the very important socio-cultural

[1] http://www.aftonbladet.se/atv/player.html?catID=10&clipID=411 (2005-03-27)

influences on Human Computer Interaction (HCI) are pointed out. An interesting report by Meehan (2001) is describing «Physiological Reaction as an objective Measure of Presence in Virtual Environments». The study shows how especially heart rate response to stress is varying instantly with increased rate and strength related to different events in a virtual environment. He also checked skin temperature and skin conductance along with questionnaires and stated that heart rate was the most reliable test for measuring the stress level, which he interpreted as a measure of presence. In the report on «Emotional Response Patterns and Sense of Presence during Video Games: Potential Criterion Variables for Game Design» Ravaja, Saari, Salminen et. al (2004) found compelling evidence for the suggestion that the reaction elicited by different games may vary as a function of the personality. In «Phasic Reactions to Video Game Event: A Psychophysiological Investigation» by the former authors they concluded that the valence of the emotional response varied as a function of the player's active participation (coping). They measured electrodermal activity and cardiac inter-beat intervals (R-R-intervals).

Apparently, gaming is not just for fun any more and the discussion on how to train personnel in management of various crises in an efficient way is very serious. By means of combining these two different worlds a new concept useful for civilian as well as for military personnel training might emerge. A new challenge comes up when action games are introduced in the education in crisis management and war strategy. In the reports «The New Role of Gaming» (Frank & Lindblad, 2002), «When War Games Meet Video Games» (Asaravala, 2004) and «Game Based Training and Education» (Rencrantz, 2003) the new possibilities provided by interactive media and games are described. It is important to make the games as realistic as possible and interviewed participants told about the realistic scenarios that gave the feeling that «the blood pressure goes up» (Asaravala, 2004).

Hjortskov, Rissén, Blangstedt et al. (2004) performed a study on «The effect of mental stress on heart rate variability and blood pressure during computer work». The results showed dissociation between HRV and blood pressure variables indicating that HRV is a more selective measure of stress. The blood pressure remained on a higher level more than eight minutes after the HRV was normalized. The HF component of HRV was significantly reduced in the stress session compared with the control session. In the stress session a memory test with cognitive aspects was included while in the control session the stress factors were eliminated as much as possible. The LF/HF ratio was significantly reduced during rest periods compared with work. Also of interest was the observation that there were no differences in the electromyography (EMG) activity from the trapezius muscle between the different sessions indicating that the changes in HRV were not related to variations in physical demands during the work task. The main finding in this study was that HRV indices of PNS activity are sensitive indicators of mental stress during computer work.

Many studies have been done exploring the responses to both pleasant and unpleasant stimuli where unpleasant pictures exhibit relatively more HR deceleration compared to pleasant once. Also an attention-related RSA deceleration during perception has been shown (Lacey & Lacey, 1970; Ravaja, 2004). RSA is affected by changes in demand for attention (Ravaja, 2004). In the reports by Castor, Nählinder& Lindström (2003) and Magnusson, Berggren, Danielsson & Svensson (2001), not only physiological responses as heart rate were measured but also eye-movement as indicators for mental workload in armoured vehicles respectively in simulated and real flights. The results showed increasing HR during high mental workload and HR, HRV and eye movement seemed to be correlated.

Lindley (2004 & 2005) is of the opinion that as game research is a very young discipline it is necessary to build up a multidisciplinary framework including research on design, programming, graphics, linguistics, semiotics, motions etc. Every sub-discipline would probably benefit of doing psychophysiological research as a part of the study design. Game research is an expanding area with great challenges and a lot of new knowledge is expected to be explored in a near future (Lindley, 2004 & 2005). Making research on HCI by means of psychophysiological analyzing methods is essential for creating a fundamental understanding of what is happening within subjects and between subjects while using artefacts as digital devices and computers, so called «functional organs» according to the activity theory (Kaptelinin, 2001). Complementary areas of interest for HRV analyses are «comparable» sessions with and without computer games, different screen sizes, habituation responses, social science aspects related to coherence and closely related to the activity theory, game addiction and other health aspects (Lazarus 1972 & 1999; Ravaja, 2004 & 2004a & 2004b; Ravaja, Kallinen et al, 2004). Empirical studies have been discussed above pointing out areas of specific interest. A lot of questions are unsolved related to the psychophysiological research and especially the HF factor has been in focus. The reason is increasing evidence that HF, almost synonymously with RSA, may be a highly applicable measure of attention in the research on new media technologies (Ravaja, 2004).

The main purpose of the analysis was to find out if relations between HRV and war-like events in a computer game could be demonstrated. The result was supposed to provide further information on the benefit from HRV in the interactive media research, useful for example in crisis management education and training and treatment of battle stress.

Material and methods of research

The experimental design was an empirical study where evaluation of methods for collecting HRV data during computer gaming was performed using mobile devices. Thereafter the data from gaming situations that could simulate war-like events were analysed.

Participants: The participants were more than 18 years old, selected from skilled male and female computer game players and invited from the nearby university and regiment. They were randomly picked out from the group who had shown their interest to participate. The participants were not paid. The study was conducted according to the principles of the Helsinki declaration.

Trial Procedure: Short information was sent on e-mail and a questionnaire on demographic information was added for fulfilment before the experiment took place. Informed signed consent was given by the participant before the start of the study. No smoking was allowed from two hours ahead until the experiment was finished. A mobile HR-device (POLAR 810i) was attached[2] around the chest with signals to a receiver designed as a wristwatch. The HR was converted into R–R-intervals which represent the distance between the heart ventricular contractions. The computer game study consisted of six subjects playing each three game sessions after each other where every session contained six

[2]Electrode gel was used for maximal dermal contact.

different sequences[3]. The used time varied according to the players' skilfulness. The used Counter-Strike tutorial is an action game where a terrorist group is competing against an antiterrorist-group. The subject acted as a first game player (FGP). The participants did not know in advance which game they were going to play or that they would play the same game three times. As every participant was interacting with the tutorial every video recorded game was slightly different. The computer game trial was performed on a DELL PC Latitude D 800 with 1680x1050 pixels on the screen. A Logitech Cordless Desktop Optical mouse was placed on the right hand PC side. A Canon 750i video-recorder was monitoring the participant from the right hand side with focus on the computer screen and a solitary big clock continuously showing the time-schedule.

Data analysis: A base-line with R-R-interval data was registered at five minutes supine rest before gaming. After that a less threatening game event (running) and a most threatening game event (shooting) were analysed. Power spectral density analysis was used with autoregressive modelling over selected areas of frequency bands of a normal or close to normal distribution. The first game of three was examined in all six trials. Error corrections were made of the R–R recorded information. All participants carried out the experiment and 18 passed games were analysed. VLF, LF, HF powers and LF/HF-ratio, the mean and SD were calculated for HRV. The two-way ANOVA test was used for analyzing HRV comparing rest and game sessions. Significance level was set at $P \leqslant 0{,}05$. The HR-recordings and video sequences had to be synchronized manually. Only two game sequences («shooting under fire» and «running through a corridor») have been analysed in detail for all participants. Only one gaming session has been examined in detail for all six training sequences in the tutorial.

Results of research

The participants were one female and five males with no stories of cardiovascular diseases or medications with a mean age of 27,16 (19–37) years, 50% were smokers. The mean game experience was 12,2 years (SD, 4,5). The experiment duration was between 50–140 minutes depending on the subject.

Method evaluation: One of the purposes of the present study was to evaluate the hardware and software for video monitored game analyses of collected R–R-interval data, synchronised with stimulus presentations in the action-game tutorial. The mobile devises for collecting data were easy to handle and so was the software. They did not interfere with the gamers activities. The manually synchronized procedure was extremely time-consuming and hard to handle with high precision. The electrode gel was quite necessary for continuous and correct R–R-interval registration.

HRV analyses: The POLAR 810i software was used to analyse the R–R-intervals in the time and frequency domain. Error corrections was made of the R–R-intervals (mean 3.9 % errors, SD 2.3). The HF power component (Tab. 1) in the 18 games during sequence II, «shooting under fire», was significantly reduced ($P \leqslant 0{,}001$) when computer gaming (428 ms^2) compared with resting in a supine position (1613 ms^2). The LF/HF-ratio was also significantly higher when gaming (340 ms^2) compared with resting (94 ms^2) (Tab. 1). No convincing habituation effects were noticed in this small material either between or within subjects. In the gaming session that was examined in detail for all six training sequences clearly related changes on the curve appeared to be influenced by the different activities belonging to each training area (Fig. 1). In the trial protocol the supervisor made notations that the HR changes were seen instantly. The training area II, «shooting under fire» and «running» were supplementary studied in details for both time and frequency domains for the same subject (Tab. 3). The participant was actively shooting with the gun while protecting under fire. These time domain data showed that the heart rate increased from rest to running and to shooting activities (64, 73 and 85 beats per minute, respectively). The HF component successively decreased as well as the LF/HF-ratio. HF power is increased at rest (1452 ms^2) and decreased as the mental workload increased during running and shooting conditions (169 ms^2 respective 320 ms^2). Before reaching each new training area, verbal information was given (within the game) with cognitive demands.

When analyzing all six subjects during their first shooting sequence in every game the staple diagram shows great differences in HF power between the subjects; at rest almost a difference of 10 times (Fig. 2). Within subjects the proportions have the same tendencies but for one subject. There seemed to be an increasing influence on HF power during running and shooting. However, the mean values were difficult to interpret since shooting has a slightly higher value than running when evaluating the mean values but when checking each participant separately all subjects but one had lower HF power value when shooting, compared to running.

Discussion of results

Methodology: There is a great need for synchronising abilities between R-R-interval registrations and screen captures on an automatic level for getting highest possible precision when interpreting the psychophysiological responses. The mobile

Tab. 1. Analyses of 18 games in sequence II «Shooting under fire» comparing to rest.

Trial 1–6	TOTAL POWER ms^2	VLF POWER ms^2	LF POWER ms^2	HF POWER (RSA) ms^2	LF/HF RATIO ms^2
GAME 1–18		(0,00–0,04 Hz)	(0,00–0,15 Hz)	(0,00–0,40 Hz)	
MEAN	43083	41619	1036	428	340
SD (Standard Dev.)	23467	23097	378	371	145
Rest 5 min					
MEAN	49200	44427	1639	1613	94
SD	32637	28788	1143	3133	61

In the frequency domain the LF/HF-ratio is said to reflect the SNS/PNS-balance. The experiment indicates that the game-players react on the game events as raising of the ratio stands for increased sympathetic and reduced parasympathetic drive.

[3] The following simulation training areas had to be passed: I. Meet and rescue a hostage, II. Shooting under fire, III. Shooting against targets, not under fire, IV. Grenade, V. Disarm a bomb (you are told to hurry on the way to the next area) and VI. Defuse a bomb.

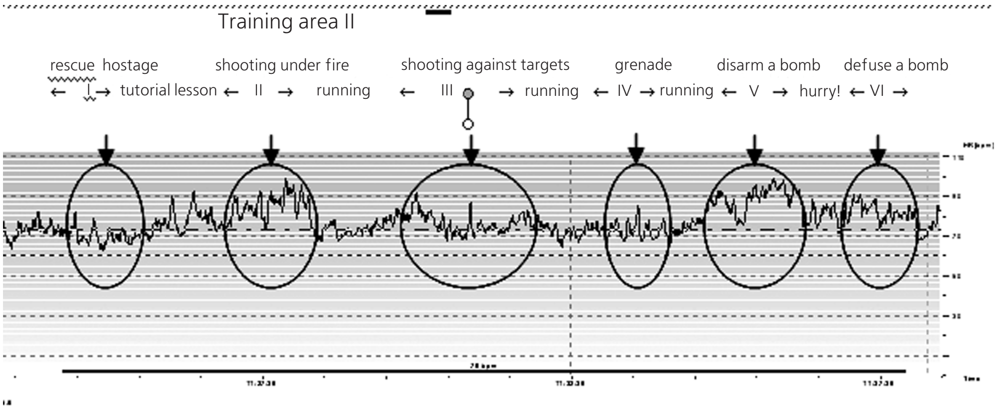

Fig. 1. Analyses of six sequences in the time domain for one session.

All six sequences in the session are marked with errors according to data inputs from both the HR (Heart Rate) device and the video recording. At any point of the curve information is registered according to the time domain with R–R-intervals which makes later analyses of different kinds possible.

Tab. 2. Comparison of data available in Time Domain respective Frequency Domain.

Subject in Trial 1, game 1(3)		Rest (no game)	Running	Sequence II: Shooting under fire
Data	Unit	Value	Value	Value
Duration		00:05:07	00:01:29	00:01:25
Sampling Rate		R–R Inter-vals	R–R Inter-vals	R–R Intervals
Time Domain				
Beats per min (bmp), HR	n	63,7	73	85,2
Number of Heart Beats	beat	325	108	121
Minimum R–R Interval	ms (84 bmp)	718	699	602
Average R–R Interval	ms (63 bmp)	945	827	706
Maximum R–R Interval	ms (53 bmp	1126	932	863
RLX baseline	ms	39	20	17
Standard Deviation, SD	ms	80,4	41,2	51,8
Max/min ratio		1,57	1,33	1,43
Weighted RR Average	ms	952	829	710
SD1	ms	48,3	20,3	17,9
SD2	ms	115,2	54	67,6
RMSSD	ms	54,9	29,1	25,5
pNN50	%	17,5	3,7	0,8
Frequency Domain				
Total power (0,00–0,40 Hz)	ms^2	33185,55	15703,93	35984,09
VLF (0,00–0,04 Hz)	ms^2 (89,4%)	29680,45	14339,12	34383,14
LF (0,04–0,15 Hz)	ms^2 (6,2%)	2053,13	1045,23	1431,81
HF (0,15–0,40 Hz), (RSA)	ms^2 (4,4%)	1451,97	319,59	169,13
LF/HF ratio	%	141,5	327,1	846,6

The table compares measures in time and frequency domains when resting, running and shooting. According to the Task Force time domain should be preferred for registration of very short periods. Anyway frequency domain seems to add interesting information with suppressed PNS activity comparing shooting and resting,

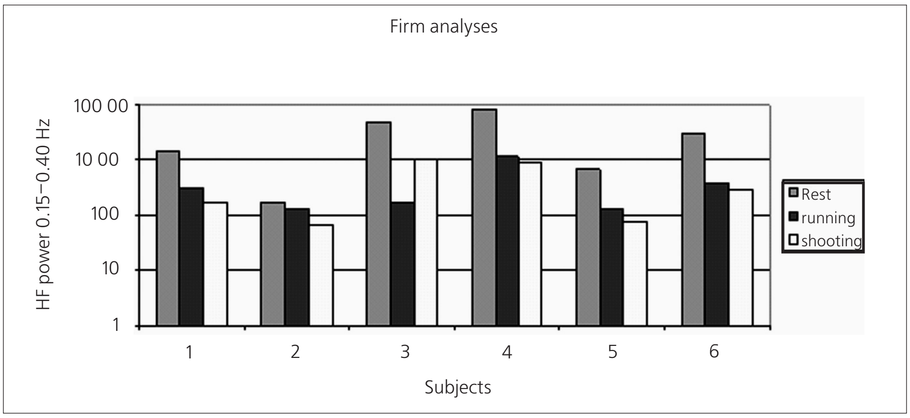

Fig. 2. HF–power analyses in six subjects while resting, running and shooting

There are differences within subjects and between subjects related to changed activities. There might be a possibility that the choline transporter gene plays a role but more research has to be done.

equipment was very useful for the game research. There is a need for software development.

HRV Discussions: In the present study HRV was recorded at rest in a supine position and during computer gaming. As expected, a considerable difference between the gaming and the resting periods was observed in all of the participants reflecting a change in body position but probably also influenced by the game activity which indicates a modulation of the parasympathetic system favouring the sympathetic one when gaming. However, large differences in absolute value differences between subjects were seen. The between subject differences might to certain extent be due to a genetic (Neumann, Lawrence, Jennings et al., 2005)) and socio-cultural reason (Lazarus, 1999; Antonovsky, 2001; Nardi, 2001; Theorell, 2001) as well as the interest for the specific game (Ravaja, Saari, Salminen et al., 2004). Trial one was the only experiment with a habituation tendency. There are reports on subjects listening to radio messages and looking on TV messages that did not habituate over time (Ravaja, 2004). He also notices that the issue of response habituation clearly deserves attention in media studies. Ravaja highlights the need to be cautious when interpreting RSA in media studies, since the increasing attentional engagement during perception not always leads to the expected HR deceleration. HR will decrease as an indicator of attention but only when hardly any cognitive functions are used (Ravaja, 2004). In the current study HR was increased while gaming compared to resting. The same tendency was seen in five of the six studied subjects, during a shooting event compared to a running event, although this difference was not statistically significant at group level, presumably because of the large difference between individual differences in absolute values. At the same time the HF power component was decreased indicating that the parasympathetic drive is suppressed which favours the sympathetic system (Ravaja, 2004). Computer gaming can probably be compared with computer work, characterized by high visual and cognitive demands, according to Hjortskov, Rissén, Blangsted et al (2004). Hjortskov et al. (2004) observed that mental stress during computer work had a marked influence of cardiovascular response, reflected in a reduction of the HF component of HRV and an increase in LF/HF-ratio in stress situation compared with the control session. His hypothesis is that the combination of cognitive and emotional stressors would induce mental stress. This mental stress will also influence the blood pressure. The preliminary observations in the current study, i.e. high level of HF power while resting and a lowering of HF power while gaming are in agreement with these findings. Only skilled players were participating in order to eliminate the cognitive effort needed for learning and understanding how to play and just playing the game is therefore thought to be reflected in the HRV analysis.

Castor et al. (2003) found similar HR reactions in real flight-missions compared to simulated ones, although the values were higher in the real-world setting. The participants in this study can not be assumed to experience a feeling of reality, due to the highly artificial experimental setup and the use of a tutorial of a standard computer game. Yet, a clear pattern of HRV reactions to events in the game emerged in five of the six participants. Meehan (2001) reported that HRV was the most reliable test for measuring stress levels, which may be regarded as a support for the observation in the current study.

In this study the elevated HR, the lowered HF power as well as the lowered LF/HF-ratio all indicates that the participants are exposed to a high level of perceptual stimuli which probably reflects increased emotional arousal. A perception related HR deceleration could not be confirmed as described by Lacey & Lacey (1970) and researchers thereafter. The HF-power was affected by changes in demand for attention but did not stay on a high baseline level as a sign of ability to maintain attention mentioned by Ravaja, (2004b). Further studies are still needed to examine if HF-power is a useful measure for media research as it seems to be highly sensitive to changes in attention but it is hard to tell how to interpret the findings. The parasympathetic activity causes the heart to slow down and is associated with attention and information intake. The sympathetic activity causes HR acceleration and emotional arousal and action. In the performed study the results indicate that the action game tutorial elicits sympathetic responses which differ between subjects and within subjects. High baseline level of RSA is associated with the ability to maintain attention and RSA should be suppressed during states of sustained attention. In media research related to attention a HR decrease is expected when attention increases which this study cannot confirm. Notable is that there is a HR increase parallel with a decrease in HF power.

Compared with Task Force (1996) with a mean total power at supine 5-min recording of 3466 ms^2 this study shows great differences with a much higher value of 37186 ms^2 while the HF-power values are almost the same (975 msl respective 1452 ms^2, Tab. 2). It seems to be an interesting observation which asks for further studies. Perhaps the small groups mentioned in Task Force (1996) and in this study are very different (age, health, medication, gender etc) and in Task Force there was a demand for studies in large normal populations.

It is probably important to have some restrictions in the intake of caffeine, alcohol and nicotine for a certain time period before a measure and Neumann, Lawrence et al. (2005) had restriction of caffeine and alcohol. In this study only nicotine use was asked for and in Trial 5 the curve shows a declining mean value probably because the participant was a heavy smoker and was smoking immediately before the test. As the nicotine drive vanished the HR slowly went down in spite of the ongoing test.

Conclusions

POLAR 810i HRV registrations, analysed in connection with video recordings of computer game sessions, appeared to be useful for evaluation of autonomic reactions to gaming events. The device is suitable as it does not interfere with gaming activities. For future analyses however an automatic synchronised procedure has to be used. A consistent pattern of reaction was observed in five of six tested subjects. The large differences between subjects in absolute values indicate that algorithms for evaluation of individual patterns of reactions rather than group mean values might be useful. Further research needs to be done in the field of measuring HRV as a possible indicator of mental workload and emotional response in simulated crises environments using VR and games, including gender aspects. Research of interest would probably also include differences between subjects depending on genetic presentations of the choline transporter gene. Psychophysiological research seems to be of use for the study of reactions to games in interactive media research.

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