

Prediction of Players' Motivational States using Electrophysiological Measures during Serious Game Play

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Abstract—This study investigated players' motivation during serious game play. It is based on a theoretical model of motivation. Statistical analysis showed a significant increase of motivation during the game. This study tried to dissect predictors of Players' Motivational States. Multiple linear regression showed statistical significance of specific electrophysiological data. The theta wave in the frontal regions and motivation were positively correlated. High-beta wave in the left-center region was also a significant predictor for high level of motivation. Skin conductance was also a significant predictor for motivation. However, we could not find a significant correlation between players' motivation and their heart rate responses.

Keywords- Motivation; Learning; Serious game; Multiple linear regression; Power spectral EEG; Skin conductance; Heart rate

I. INTRODUCTION

Motivation has long been considered as an important step in learning. According to Chan and Ahern, "when people are intrinsically motivated to learn, they not only learn more, they also have a more positive experience [1]."

Recently, games appeared as the most appropriate tool to motivate people [2, 3]. Besides, millions are captivated by games. They spend their time and money to play. Therefore, the potential for the integration of games and learning becomes ever more significant. Many experimental studies state that computer games, and especially some features, can provide new ways of learning [4, 5, 6]. In fact, they have shown that educational games (or serious games) are capable of helping players to learn.

Additionally, game experience is a psychological and physiological process. During the video game, specific physiological and neurological reactions take place in players. Some researchers have examined players' reactions using electrophysiological responses such as the galvanic skin response [7], the heart rate response [8], the electroencephalography activity [9, 10].

In this paper, we study players' motivation during different parts of serious game play using electrophysiological measures (electroencephalography EEG, skin conductance SC, and heart rate HR). More

precisely, we examine the increase of motivation and knowledge improvements. This study is based on a theoretical model of motivation (John Keller's ARCS model of motivation). The questions we address here are the following: Does a serious game motivate players and enhance their knowledge? Can electrophysiological measures provide objective indicators for high motivation? What are the significant predictor variables for the players' motivation?

The rest of paper is organised as follow: the next section presents previous work realized in relation to the motivation phenomena in serious games and education. This leads us to specify John Keller's ARCS Model of Motivation. Then, we describe the materials used and the procedure of the experiment. Finally, the experimental results are presented and discussed.

II. PREVIOUS WORK

Serious games are computer applications that combine a serious intent, learning and training using video environment or computer simulation. They have become an important social trend. Indeed, game environments have great potential to support immersive learning experiences. Several researches have shown that serious games can provide a suitable context via interactive, engaging and immersive tasks [11, 12, 13]. For instance, Tactical Language and Culture Training System (TLCTS) helps people quickly acquire functional skills in foreign languages and cultures [13]. It includes interactive lessons that focus on particular communicative skills and interactive games that apply those skills.

Researchers believe serious games have become an important teaching tool. In fact, serious games have the capacity to provide intrinsic motivation. The latter arises from many sources in a school setting: engaging and meaningful tasks and materials, giving and receiving constructive feedback, actively exploring a variety of resources and working persistently to reach a deeper understanding [14].

For over 20 years, Malone and Lepper used computer games as a platform for studying intrinsic motivations for learning [11]. They argued that the key features responsible for the positive affect created by computer games were challenge, curiosity, control and fantasy. Self-

determination theory SDT [15] has shown the value of video games and the virtual worlds in providing motivation and satisfaction [16]. The motivational pull of video games is attributed to the combination of optimal challenge and informational feedback. Prensky, for instance, developed a set of key criteria that encourage engagement with the game. He argues that games are defined by a set of key characteristics: goals/objectives, conflict/competition/challenge/opposition, interaction, outcomes/feedback, rules, and representation/story [12]. According to Garris et al., fantasy, rules/goals, sensory stimuli, challenge, mystery and control are the six features that characterize games [17]. They state that the key aspect of effective learning is motivation. Players who are highly motivated persist longer and perform better at a particular activity.

III. ARCS LEARNING MOTIVATIONAL MODEL

John Keller used existing research on psychological motivation to identify four components of motivation: Attention, Relevance, Confidence, and Satisfaction. These components are the ARCS model of motivation [18].

- **Attention:** to attract learners' attention at the beginning and during the process of learning. Diverse activities should be considered to maintain students' feelings of novelty, thus the attention can be sustained.
- **Relevance:** to inform learners of the importance of learning and explain how to make the learning meaningful and beneficial.
- **Confidence:** to allow learners to know the goal and to believe that the goal can be achieved, if enough effort (physical and/or intellectual) has been made.
- **Satisfaction:** to provide feedback on performance and allow learners to know how they are able to perform well and apply what is learned in real life situations.

In our study, we adopted the Keller's ARCS Learning Motivational Model. We used this model to assess learner's motivation during video game play. For this purpose, we based on a motivational measurement instrument called Instructional Materials Motivation Survey IMMS [19]. There are 36 statements (items) in the original IMMS form. We used the ARCS questionnaire for five times during the experiment. Because of this time constraint, Keller advised us to use a short IMMS form which contained 16 items.

IV. METHOD

A. Participants

This study involved thirty three volunteer participants (11 female), who ranged from 19 to 42 years of age. These participants were recruited at Université de Montréal, Polytechnique Montréal, and HEC Montréal in return for some fixed remuneration. Four participants (2 female)

were excluded from EEG analysis because of technical problems at the time of recording.

B. Materials

In the present study, EEG electrodes were managed by the Thought Technology ProComp Infinity Encoder¹. Data were collected and then extracted using Thought Technology Ltd Software. We used the serious game called FoodForce² which is an initiative of the World Food Program of the United Nations intended to educate about the problem of world hunger. The player is placed on Sheylan, a fictitious island in the Indian Ocean. He must succeed to feed as many people as possible. For this, a budget of 30 cents per person is allotted. The game's missions are intended to show the different stages of food aid.

C. Procedure

The average time that participants spent playing the game was around 45 minutes. Each participant was placed in front of two computers: one computer is used for playing serious game and the other one is used to answer a number of questionnaires. Two cameras were also used: one to record movements of the participant's face and one to record screenshots of the participant's interactions with the game. After a brief description of the experiment, the participant filled out a written informed consent form. Electrophysiological data were recorded during the whole of the experiment. The galvanic skin response (GSR) electrodes and the blood volume pulse (BVP) sensor were attached to the fingers of participant's non-dominant hands, leaving the other hand free for the experimental task. EEG electrodes were then attached to the participant's head using EEG gel injected into each electrode site.

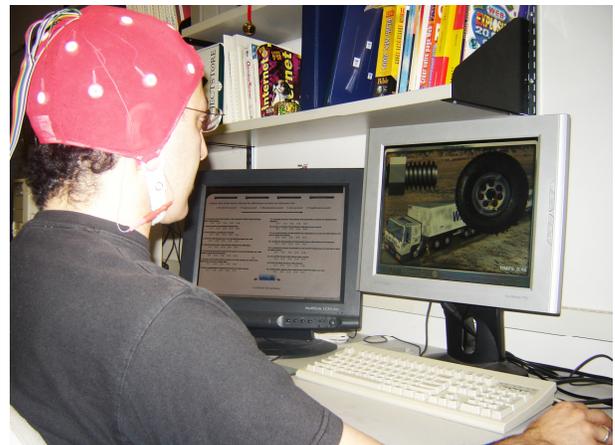


Figure 1. Experimental setup

After a baseline period (60 seconds for eyes-closed rest), the participant filled out knowledge pre-test and started playing the different missions of the game. Note

¹ <http://www.thoughttechnology.com/>

² <http://www.food-force.com/>

that the participant also filled out the short form ARCS questionnaire after finishing each mission. Finally, he answered knowledge post-test. When the experiment is finished, the electrodes were removed and the participant was cleaned and paid.

D. EEG recordings

EEG was recorded by using an electrode cap with a linked-mastoids reference. The electrodes were placed on four selected sites (F3, Fz, C3 and Pz) according to the international 10-20 system (Fig. 1).

The reference electrode was located at Cz and the ground electrode at Fpz point. Impedance at each electrode site was maintained below 5 K Ω . The EEG was sampled at a rate of 256 Hz. According to standard EEG definitions, the Fast Fourier Transformation (FFT) divided the EEG into common frequencies: delta (1 - 4 Hz), theta (4 - 8 Hz), alpha (8 - 12 Hz), low-beta (12-20 Hz), high-beta (20-32 Hz) and gamma (33-42 Hz). To reduce artefact sources, participants were asked to minimize eye blinks and muscle movements during recording.

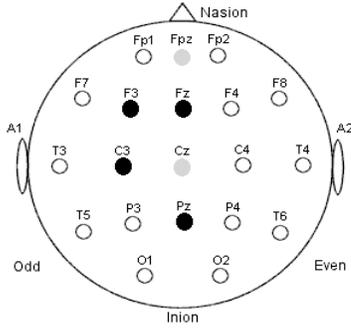


Figure 2. International electrode positioning system over the scalp (10-20 system)

V. DATA ANALYSIS

We resorted to a power spectral analysis of EEG measures to dissect the EEG patterns correlated with the high motivation of participants during the game. Power spectral techniques can involve parametric or non-parametric approaches. The Welch’s method [20] is one of the most popular classical methods to estimate the power spectral density (PSD) for different EEG waves. It is carried out by dividing the time signal into successive blocks, and averaging squared-magnitude FFT of the signal blocks. 60-second period of EEG recording was performed during each mission. A natural log transformation (\ln) was used to normalize the distributions of power values [21].

Again, normalization of physiological data was necessary to statistical analysis. A z-score transformation was performed. It does not change physiological patterns for individual participants but establishes a common metric between the participants. Indeed, SC measures of each participant were subtracted from baseline SC measures and divided by SC standard deviation. Similarly, we calculated z-score for HR measures. This normalization

procedure was performed for physiological data extracted during all played missions.

The prediction model was based on a multiple regression. The latter is a technique that allows the analysis separately of many factors so that the effect of each can be estimated. It is valuable for quantifying the impact of various simultaneous influences upon a single dependent variable. In our study, we used a multiple regression to predict players’ motivation (criterion variable) from different electrophysiological measures (predictor variables) during all played missions. For automatically selecting significant predictor variables, we performed stepwise regression and more precisely we used stepwise selection method which is the most sophisticated of statistical methods [22]. Normalized average PSD for each wave, normalized SC, and normalized HR were used through our prediction model.

VI. RESULTS

A. Motivation and learning improvements

We evaluated differences between motivation scores obtained by ARCS model during the game. By applying a paired sample t-test [22] between motivation scores of participants, we noticed a significant increase of motivation during the experiment ($t(32)=-2.650$, 2-tailed $p=0.012<0.05$). More specially, significant effects were found for “Attention” component ($t(32)=-4.950$, 2-tailed $p=0.000<0.05$) and for “Confidence” component ($t(32)=-2.677$, 2-tailed $p=0.012<0.05$) of the Keller’s ARCS model of motivation. Table 1 reports results of paired samples t-test analysis.

Similarly, all participants showed learning improvement into post-test scores in comparison to their pre-test scores. By using again a paired sample t-test, we can statistically conclude that there is a difference between pairs of pre-test and post-test scores ($t(32)= -11.563$, 2-tailed $p=0.000<0.05$).

TABLE I. RESULTS OF PAIRED SAMPLES T-TEST FOR ARCS MODEL

Paired components	Mean	t	df	Sig. (2tailed)
Attention: Initial – Final	-2.46970	-4.950(**)	32	0.000
Relevance: Initial – Final	-0.03030	-0.090	32	0.929
Confidence: Initial – Final	-1.25253	-2.677(*)	32	0.012
Satisfaction: Initial – Final	0.29798	1.030	32	0.311
Motivation: Initial – Final	-3.45455	-2.650(*)	32	0.012

** Difference is significant at the 0.01 level (2-tailed)

* Difference is significant at the 0.05 level (2-tailed)

B. Prediction models

During the experiment, each participant was asked to fill out a series of ARCS questionnaires of motivation after finishing each mission of the serious game (participant plays only the first five missions of the game). By using ARCS questionnaires results, we defined initial and final motivation scores. Initial motivation was calculated by averaging scores of ARCS motivation during initial missions (missions 1 and 2) of the game. Final motivation was also calculated by averaging scores of ARCS motivation during the remaining missions (missions 3, 4, and 5).

1) Initial players' motivation

We applied a multiple linear regression [22] to predict initial players' motivation. Our prediction model used three predictor variables: normalized average PSD for each wave, normalized SC, and normalized HR. Note that we used values of variables during initial missions.

Using the stepwise method, results of the regression showed a significant effect of four predictors: SC, alpha (Fz), low-beta (Fz), and high-beta (C3). Our model for initial players' motivation accounted for 70.8% of the variance in the criterion variable ($R^2=0.708$, $F(4, 24)=14.535$, $p=0.000<0.05$). Table 2 reports results of regression analysis.

TABLE II. PREDICTION MODEL FOR INITIAL MOTIVATION

Predictor	Beta	t	Sig.
SC	0.240	2.085	0.048
alpha (Fz)	0.808	5.397	0.000
low-beta (Fz)	-0.533	-3.494	0.002
high-beta (C3)	0.410	3.408	0.002

2) Final players' motivation

We used again the same predictor variables (EEG, SC, and HR) to predict final players' motivation. Using values of variables during final missions, a multiple linear regression showed that showed a significant effect of four predictors: SC, theta (F3), theta (Fz), and high-beta (C3).

Our model for initial players' motivation accounted for 73.6% of the variance in the criterion variable ($R^2=0.736$, $F(4, 24)=16.706$, $p=0.000<0.05$). Table 3 reports results of regression analysis.

TABLE III. PREDICTION MODEL FOR FINAL MOTIVATION

Predictor	Beta	t	Sig.
SC	0.285	2.251	0.034
theta (F3)	0.333	2.926	0.007
theta (Fz)	-0.425	-3.884	0.001
high-beta (C3)	0.541	4.055	0.000

VII. DISCUSSION OF THE RESULTS

We are interested in the study of motivation in learning by game environment. Studying the impact of this environment on improving players' motivation was firstly investigated by our experiment. The study results revealed that the increase of motivation during the serious game is especially related of the increase of players' attention and

confidence. According to Keller's ARCS motivation theory, the learner's motivation is gained possibly by "novel, surprising, or incongruous events..." called perceptual arousal. Serious game (Food Force) played by participants closes this category of arousal. For instance, we mention unexpected situations like the companion involvement or alarm trigger through the different missions. Furthermore, Keller's ARCS motivation theory tells us that the learner's motivation is also aroused by the mean of "solving a problem or resolving an open issue..." called inquiry arousal. Food Force closes mental tasks that require concentration and attention: drop food from the air without risking human lives (mission 3) and guide a convoy of trucks safely to a feeding centre while overcoming challenges from clearing land mines to rebuilding bridges and negotiating with local rebel forces (mission 5), etc.

This study also investigated players' physiological responses to determine the relationship to their initial and final motivations. Specifically, normalized SC and normalized HR were used through our prediction model. We conducted multiple regressions to predict players' motivation. Skin conductance showed statistical significance for initial and final motivation. However, the present study failed to find a significant correlation between players' motivation and their heart rate measures.

Previous studies showed that brain activity has a close relation with alpha and theta changes during video game playing [23]. Indeed, when participants are more motivation and attention, alpha wave's power tends to be suppressed by attention and theta wave's power increases. We used normalized average PSD for each wave through our prediction model. When participants are more motivation especially during final missions, the correlation between motivation and theta wave in the frontal regions (F3 and Fz) was more significant. Moreover, high-beta wave in the C3 region was a significant predictor for high level of motivation.

In the present study, the results of our prediction model confirm some previous indications; for instance, the frontal midline theta rhythm is found to be associated with clearly changes during video game playing [23]. However, our finding is not also consistent with some other studies; for instance, variations were significantly observed in heart responses of participants during different stages of an immersive virtual environment experiment [8].

VIII. CONCLUSION AND FUTURE WORKS

The present study was intended to analyze the players' motivational state during serious game play. We firstly evaluated differences between motivation and knowledge scores along the game. Players increase their motivation and learning process takes place. The aim of our statistical analysis was then designed to dissect the electrophysiological characteristics to predict players' motivation. By applying multiple linear regression, results showed that skin conductance, theta wave in the frontal region and high-beta wave in the left central region provide significant predictors for players' motivation.

For future works, the addition of others variables to our model can improve its prediction quality. Indeed, some personal characteristics (age, gender, player style, etc.) heart rate variability, etc.), hours spent playing video games, and others variables can be additional predictors for players' motivation. Furthermore, brain activity can also be more analysis in the future to study players' reactions in specific situations during serious game play. For this purpose, others EEG analysis methods (Event-related potentials ERPs for instance) can be used to test whether different events in serious game evoke differential EEG responses.

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