Biofeedback Sensors in Game Telemetry Research

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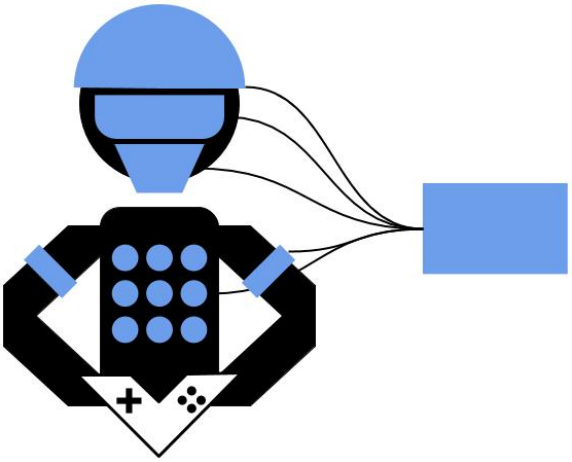

Figure 1: User data acquisition schema in Game Analytics.

ABSTRACT

Game Analytics is one of the new research trends in digital games' industry. It consists of analyzing the variables collected during a game session in order to improve game designing and collaborate with gamer behavior research as well. These data may be acquired from the game itself, such as level progression, session duration and the user's overall performance; or from the users, like heartbeat, brain activity, gaze movement or any indication of attention, fun or boredom. The automatic process used to capture such data is called game telemetry. Several studies have been proposing different ways to apply measurement techniques and to employ specific sensors to collect user data. This study aims to survey the uses of biofeedback sensors in recent research, in the context of game data telemetry. The devices will be described and their reliability aspects will be outlined to better summarize the survey. The results shown here intend to assist researchers interested in obtaining information on sensors and methods applied in game telemetry.

Keywords: Game analytics, user data telemetry, biofeedback sensors.

1 INTRODUCTION

Game development was, during the early years of game history, a process of experimenting and trying out new game concepts [4]. Since then, many design theories have been created and studied in this area, based on new games and genres that rose in the following decades. When new games have become a success, they made the industry grow from that new concept or genre recently introduced. These cases, however, did not always give useful information neither a recipe on how to systematically develop a remarkable game, as user behavior and acceptance of the game were not predictable in a simple way.

In order to improve the development process and to analyze player behavior, game design has been moving towards a new approach in recent years. For modern designers, it has become clear that more information on the user experience was needed, to identify and analyze the aspects that produce a notable game. Several studies point that a data-driven game design is not only beneficial to the industry but also necessary, given the game market diversification, in both companies and consumer spheres [15].

Game Analytics, then, emerged as a new way to proceed when designing a game. The application of analytics in game data serves as a powerful tool when thinking about user preferences and expected reaction to the game [15]. Recently, games are being developed with not only the designer's experience, but also based on actual data derived directly from the game and its users. Level proceed rate, average play session time and other game-related variables are being collected and stored in order to evaluate game progression and replayability. In addition, users are also supplying useful data, as their excitement level is being analyzed to determine which moments in the game are thrilling or boring, for example.

Game Telemetry, as it is called the process of measuring game data from a distant source [15], is a key step in game analytics to gather user and game information. While game data is obtained directly from inner computational methods and sent via network, for instance, user data is acquired from sensors and supervisor systems physically linked to them, and also from questionnaires given after a game session. The devices employed usually sense biofeedback data, i.e. data derived from the physiological and motor systems of the human body [17], so gamer behavior can be studied directly

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from his/her body reactions.

This study will present some of the recent research efforts in acquiring game user data [7] [13] [25] [32] [43] [50]. They have different goals and application environments, as some focus on new sensor usage methods, others propose better hardware applications and also statistical methods that may improve game data analysis. On the other hand, all of them similarly present the data acquisition scenario, and a way of evaluating the results, compared to a theoretical basis. In addition, user data obtainment process is surrounded by a number of challenges like hardware limitations, invasive sensors and noise interference. These hurdles will be highlighted for each type of sensor described here.

The main goal of this study is to give a better understanding on the methods used in recent Game Telemetry research. More precisely, how physiological gamer data are collected and analyzed, pointing out the findings with respect to the sensors employed.

The rest of this article is organized as follows. In Section 2 a brief explanation on some basic concepts used in this research is given. A brief introduction on the biofeedback sensors considered in the study is presented in Section 3. Section 4 is devoted to present a survey on the main works that employ the sensors presented in Section 3, as well as give a classification according to their purpose of use. Finally, Section 5 gives some final remarks and future work.

2 Fundamental Concepts

2.1 Game Analytics

Game Analytics is the employment of analysis techniques in game industry [15]. It aims to assist game development process in all its phases: conception, design, development, testing and releasing. It is also used in other fields of game industry, such as design, programming and business model. The analysis is made from data arising from variables and metrics related to the game, user experience or physiological reaction.

Each company and research facility has its own way of evaluating game data, and each investigation leads to a new discovery about the game and user's behavior. Thus, researchers are able to develop a system to assist game designers to, eventually, ajust, balance and improve the game, based on such feedback information.

2.2 Game Telemetry

Game Telemetry is the process of collecting game data over a distance [15]. It supports Game Analytics and includes receiving data from online servers, or from a set of sensors installed in a nearby game station, for example. A general scenario sees an installed game client transmitting data about user-game interaction to a server, where the data are transformed and stored in an accessible format, supporting analysis and further reporting. There are many applications of telemetry in games, including remote monitoring and analysis of game servers, mobile devices and user behavior.

The source of telemetry best represented in this paper is *user telemetry*, i.e. data on the player behavior, such as, interactions in the game, physiological behavior, physical motion, purchasing habits, or interaction with other users, groups or applications [14].

Usually, the information is collected and stored, and big sets of equivalent variables are grouped to make the analysis simpler and objective.

Game data obtainment is employed to aid research initiatives in many areas. In the game industry, it can be used to study ways to analyze player's affective state after certain events or to induce specific reactions over them during a game session, with the purpose of providing the best gaming experience. This field is called Affective Gaming [52]. In Health Sciences, it may be a way to perform several kinds of treatment to different disorders and disabilities, using games as a way to provide a playful experience to patients and using telemetry to collect their progression [11]. In Psychology, it is a tool of analyzing human behavior during a human-machine interaction, considering game events as a cognitive stimuli [48].

2.3 Biofeedback

The method of obtaining human biological variables in response of stimuli in real time is called Biofeedback [17]. It is divided in two main categories: biomechanical and physiological. The first is related to movement and motor capabilities, while the other corresponds to the variables generated by the human organism, like temperature or heart beat (Figure 2).

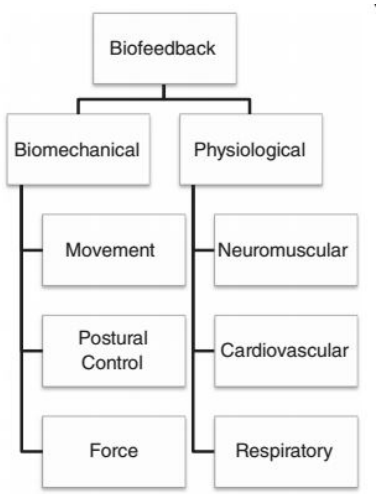

Figure 2: Some biofeedback categories [17].

Biofeedback is employed in medical sciences, mainly when leading physical treatment to traumas and disabilities. Also, it plays in important role in the field of games studies supporting user data acquisition for further utilization in Game Analytics.

2.4 Human-Computer Interaction

Human-Computer Interaction is a broad research field concerned with user experience in computer usage. The main concept related to the user-centered approach is usability, which consists of "the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments" [46]. However, when evaluating a game experience, the ISO 9241-11 standard is not sufficient [42]. In this sense, "playability" concept is proposed to describe requisites of systems in which the goal is entertainment, instead of productivity [6].

As a consequence, gameplay experience has been measured in terms of emotional and cognitive constructs, such as engagement, immersion, presence, enjoyment and flow [10]. Most studies reviewed used questionnaires to assess the player experience, however, some used objective measures, such as eye movement, physiological responses and touch pressure, in order to test their effectiveness and/or compare them to the subject measures. Jennett et al. [22] showed that immersion can be measured through eye movement, which is characterized by a reduction on the number of eye fixation and the increase of each fixation duration over time. However, the assessment of emotions in gameplay was done mostly through physiological responses (i.e., heart rate, skin conductivity, brain activity, etc.). In the following sections, these measures will be described in more details.

3 Biofeedback Data Acquisition Sensors

Game data acquisition process consists of obtaining the electric and digital signals emitted by sensors, and using statistic methods to

prepare this information to be analyzed. In this effort, a main role is played by the sensors and the way the data are transformed into signals. Biofeedback sensors represent the devices that measure biomechanical and physiological variables from a person [17] (Figure 3).

Figure 3: Examples of biofeedback sensors [24].

In this section the main sensors used to acquire biofeedback user data in Game Telemetry will be described. Their usages, obtainable physiological variables, advantages and drawbacks are pointed out as well.

3.1 Heart Rate (HR) Monitor

A Heart Rate Monitor is a sensor widely used in Game Telemetry [34] [1] [51] [5] [7] [26] [36] [44]. It detects human heartbeats and emits signals in an equivalent rate, that can be used to determine a person's heart rate over time. It is also very simple and not expensive to build [8].

Its most common implementations include a band with a pulse sensor attached to the user's wrist, or a light detector aligned to a LED (Light Emitting Diode), where the user's finger is placed in between (Figure 4) [7]. Both ways provide similar results and the same level of invasion.

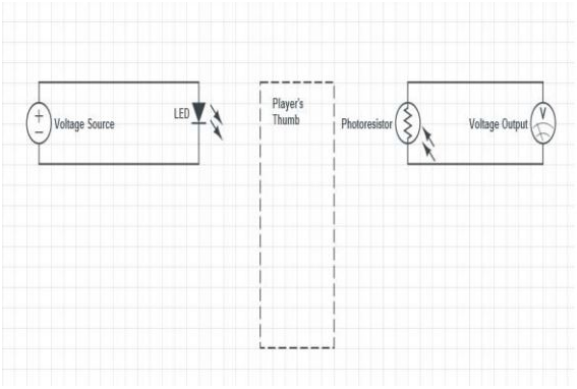

Figure 4: A heart rate monitor electronic diagram [8].

As it is a considerably basic sensor, it is noisy and not reliable, when used in many applications. However, there are some techniques used to overcome these drawbacks, such as noise reduction and more precise heart beat peak detection [28]. Besides, compared to an electrocardiography data, shown in Section 3.2, a heart rate analysis is very simplistic.

When considering a game environment, heart rate is often related to excitement or boredom level, and it is indeed a good indicative to express these stress levels [18]. Therefore, it is usually used to detect intense moments in the game, like scary scenes or action-filled sequences [1].

3.2 Electrocardiography (ECG)

Electrocardiography is the generation of a heart beat electrical waveform into a graph, called electrocardiogram (Figure 5) [16]. This tool gives more ways to analyze heart response to stimuli than the heart rate monitor itself.

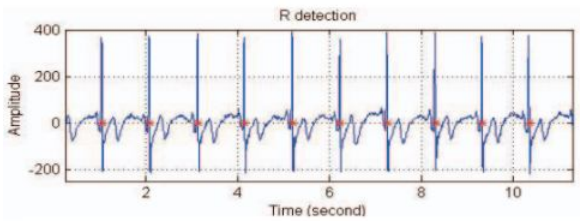

Figure 5: An ECG graph [48].

The electrical activity of the heart is obtained from electrodes placed on the user's chest. A pattern of the collected data is drawn into a graph, representing the heart electric pulses during the exam's session. Each peak and valley drawn represents a different pulse in the heart beat routine (Figure 6) [20].

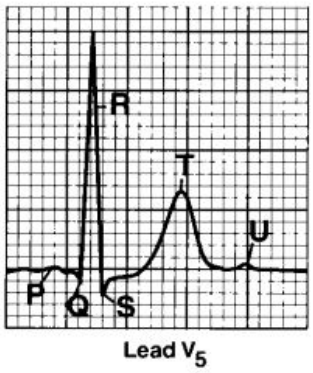

Figure 6: A normal ECG waveform [20].

From the ECG, there are many indicatives of excitement or boredom, obtained from heart rate and wave amplitude, for example. However, it is possible to extract more information, by applying some signal processing into the generated result. The intensity of sympathetic and parasympathetic activities, for example, may be derived from the ECG waveform [48].

Meanwhile, as the ECG uses several electrodes attached to the user's chest, it is considered an invasive sensor, therefore, it may interfere with the game experience during the data acquirement process. Another disadvantage is that the signals generated require some manipulation before being analyzed, thus it may impose some limitations in experiments that require a real-time response.

3.3 Electrodermal Activity (EDA) Sensor

Electrodermal activity is the variation of the electrical aspects of the skin, usually related to some kind of sympathetic reaction, indicating a change in the level of excitement [9]. It is generated by the activity of sweat glands beneath the skin.

The sensor is composed of electrodes that detect conductivity changes in the skin, and it is as invasive as a heart rate monitor, requiring some wires and plugs on the user's hand (Figure 7). It may,

then, disturb the player, if they have to use their hands to handle a controller or mouse/keyboard, for example.

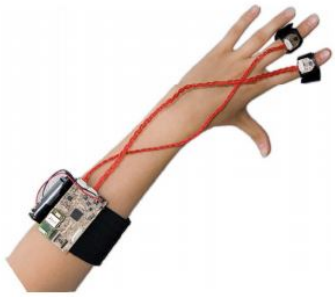

Figure 7: Emotion Board, an EDA Sensor [45].

In games, EDA sensors are used to identify the excitement variation caused by some events in a play session. Unfortunately, they have some flaws related to the different skin types found in humans, generating distinct electrodermal characteristics from person to person [3].

3.4 Electromiography (EMG)

Electromiography is the process of monitoring electrical signals from muscles [2]. The signal is generated by neurons when the muscle flexes or relaxes and is detected by electrodes placed on the user's skin. By putting the electrodes in the correct position, it is possible to identify body movement arising from a specific muscle (Figure 8).

To obtain a complete measure of a certain body region, several electrodes are placed and each one is responsible for collecting the electrical signals generated from a single muscle of that region. By combining these signals, the specific body part movement can be analyzed.

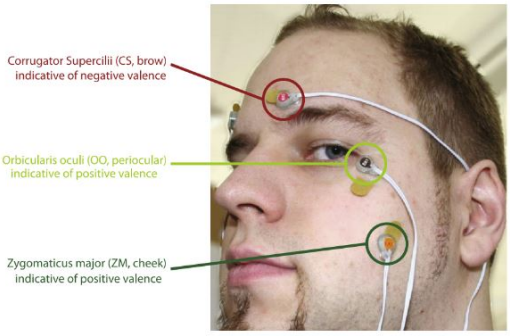

Figure 8: Example of EMG sensor. Each electrode is collecting data from a facial muscle and is used to detect emotions. [38].

In medical sciences, EMG is widely used in rehabilitation treatments, as it can be used to analyze the patient's progression and response during the exercise sessions [11][47]. In the game industry, EMG is being studied as a kind of input in the game, to control a character's movement, for example [43]; and also as a way to acquire information on the user's emotional state [38].

EMG has limitations in terms of signal reliability, as the signals generated in inner muscles may interfere with the measurement. Fat layers or thick skin may also place some difficulty in a more precise data acquisition.

3.5 Electroencephalography (EEG)

Electroencephalography is the procedure of recording electrical activity from the brain [40]. Several electrodes are placed on the user's scalp and detect the electrical voltage variation generated by neurons in the brain. Each group of electrodes measures the electrical signal coming from a different region of the brain (Figure 9), which is responsible for a specific brain activity, such as movement control, emotion or memory.

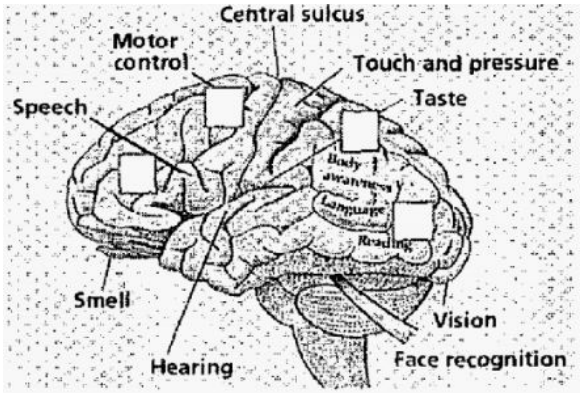

Figure 9: Some brain regions and their functions [35].

Usually, the EEG sensor is a sort of cap, that is put over the user's head. Data are collected and mapped to represent the different brain sectors (Figure 10). Then, the sensor plots the signals for each region over time. The main uses of the EEG in games are in Affective Gaming, to obtain an estimate on the user's affective state based on their brain activity [38][35] and also as an input, serving as a game controller [32].

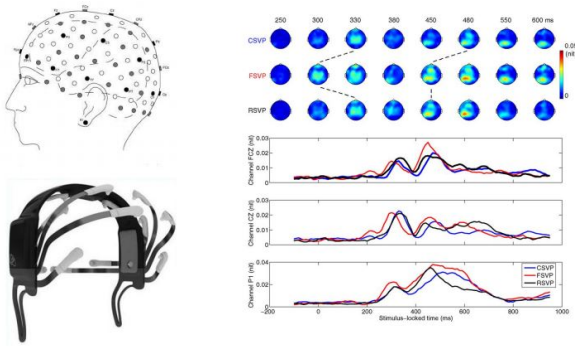

Figure 10: An EEG sensor schema [3].

An EEG is one of the most useful sensors in game data analysis, as it can provide a view on the excitement and valence aspects of the human behavior. However, it is expensive and subject to noise, as its sensibility level must be set at the highest in order to obtain the electrical signals generated by neurons [3].

3.6 Respiration Sensor (RESP)

A respiration sensor is a device that captures the user breathing rate and inhalation intensity [25]. It consists of a belt that is worn around the belly, and detects the movement made when breathing in and out (Figure 11).

It is commonly used to identify excitement changes, usually related to a variation in the breathing rate. In game analytics, its main usage is to perceive sudden excitement shifts caused by certain events in the game.

Figure 11: A player wearing a Respiration Sensor belt [25].

The respiration sensor signals are imprecise when trying to determine time-strict events, as it may detect a delayed reaction. Also, it might be somewhat uncomfortable to wear while playing.

3.7 Motion Sensors

Motion sensors are responsible for capturing the user's position, orientation and movement. Each sensor has its own peculiarities and parameters, as well as a specific usage. Some well-known motion sensors that emerged in the games market are:

- Nintendo Wii Remote[1];
- Nintendo Wii Balance Board[1];
- Sony Playstation Move[2];
- Microsoft Kinect [3] (Figure 12);
- Motion Tracking Gloves, like the 5DT Glove [4].

Their usage goes beyond serving merely as an input controller, as they are present in researches on behavior analysis and muscle rehabilitation as well. The Kinect sensor is remarkable in this area because it does not require the user to wear or hold any kind of apparel or device in order to capture movement and position.

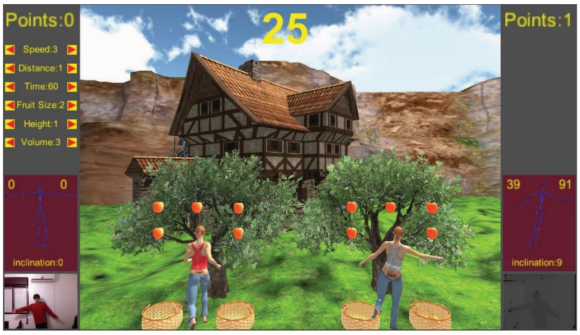

Figure 12: Example of a biofeedback game with the Kinect sensor [13].

Despite their usefulness, motion capture sensors are not very precise and usually provide little feedback on the user emotional state. Moreover, they need computer vision techniques or posture recognition to become more helpful in Game Analytics.

[1] http://www.nintendo.com/wiiu/accessories
[2] https://www.playstation.com/en-gb/explore/ps3/accessories/
[3] https://developer.microsoft.com/en-us/windows/kinect
[4] http://www.5dt.com/?page_id=34

4 Biofeedback Sensors Survey

Here, a survey on the research initiatives that use the biofeedback sensors listed in Section 3 will be presented. The selection of the relevant articles for this survey was based on the following requirements:

1. The study must be related to games;
2. It must deal with at least one biofeedback sensor;
3. It should have a practical application of the sensor;
4. The sensor must be employed in the study as a game input mechanism or as a means of analyzing player behavior;
5. The study must show some result related to the sensor used.

The main database for this survey was the IEEE Xplore Digital Library [21], a major scientific publisher in Computer Science field. The terms "biofeedback", "game analytics", "game sensor" and "affective gaming" were used as keywords in the search for relevant works.

For simplification purposes, from now on, the following abbreviations will be used:
HR - Heart Rate,
ECG - Electrocardiography,
EDA - Electrodermal Activity,
EMG - Electromiography,
EEG - Electroencephalography,
RSP - Respiration Sensor and
MV - Motion Sensor.

Considering the requirements established above, Table 1 shows a list of this survey articles, pointing out the respective biofeedback sensors employed.

Concerning the approach when employing the biofeedback sensor systems, the studies could be divided in two categories: the ones that used sensors as merely an input to the game (INPUT), and those that used them as a way to analyze the user affective state (AFFECTIVE). Table 2 lists the articles according to this separation.

By crossing the information given in Tables 1 and 2, it is possible to create a single table for each sensor, listing the articles that deal with that sensor and classifying them the according to the specific usage. Thus, the following subsections are dedicated to present such information for the Biofeedback sensors considered in this work. Also, for each sensor, relevant conclusions and observations extracted from the analyzed papers will be highlighted.

4.1 Heart Rate Sensor Analysis

Table 3 lists the articles that employ HR sensors divided according to its specific usage. The following conclusions excerpted from these works are considered relevant to mention:

- In [26], heart rate measurement was not significant enough to be related to emotional response.
- In [44], authors mentioned that the HR signal fluctuated significantly across participants and game sessions, and that a normalization was necessary to use this data in game adaptation.
- Abe et al. [1] found a correlation between player HR and the game score, but stated that additional analysis is needed to confirm it.

Paper	HR	ECG	EDA	EMG	EEG	RSP	MV
[1]	✓						
[5]	✓						
[7]	✓						
[11]				✓			
[12]				✓		✓	✓
[13]							✓
[19]				✓			
[25]			✓			✓	
[26]	✓		✓	✓		✓	
[29]		✓	✓				
[32]					✓		
[33]				✓			
[34]	✓		✓				
[36]	✓		✓				
[38]			✓	✓			
[39]			✓				
[41]		✓				✓	
[43]				✓			
[44]	✓		✓			✓	
[47]				✓			
[48]		✓					
[49]					✓		
[50]		✓			✓		
[51]	✓		✓				
Total							
24	8	4	9	8	3	5	2

Table 1: A list of the surveyed articles and the respective biofeedback sensors employed.

INPUT	AFFECTIVE
[11]	[1]
[12]	[5]
[13]	[7]
[19]	[25]
[32]	[26]
[33]	[29]
[34]	[36]
[43]	[38]
[47]	[39]
[49]	[41]
[51]	[44]
	[48]
	[50]
Total	
11	13
46%	54%

Table 2: Studies grouped according to the sensor usage approach.

INPUT	AFFECTIVE
[34]	[1]
[51]	[5]
	[7]
	[26]
	[36]
	[44]
Total	
2	6

Table 3: Studies using HR sensor, grouped according to sensor usage.

4.2 Electrocardiography Analysis

Table 4 shows that all the considered articles regarding the ECG used this sensor to analyze user behavior. From these works, some fruitful outcomes on the ECG usage in games were also observed:

- In [48] the features extracted from the ECG described mental stress in terms of sympathetic and parasympathetic activity. From this information, authors concluded that the mental stress was much higher during game session, when comparing to rest time.
- In [50] the results showed that the ECG signal was satisfactory in predicting the affect changes in a horror game. Also, when compared to the EEG sensor, the ECG presented better results. The EEG may, however, be better suited for different game environments.

4.3 Electrodermal Activity Sensor Analysis

The different purposes of use of the EDA sensor are shown in Table 5. Relevant findings on EDA sensor research are:

- In [26], the EDA sensor showed a correlation between electrodermal activity and events occurring in the game. This correlation was present in 15 out of 32 cases analysed, that is, 46.9% of the total.
- During the game analysed in [36], sound effects caused significant changes in the user's EDA response. This supported the authors' hypothesis that this sensor may be used to detect the impact of game aspects on player affect.
- Parnandi et al. [44] observed that EDA is a physiological variable which may be difficult for a person to control, compared to HR or respiration, for instance. Thus, for stress management learning, where a person should control their own emotional state, EDA is not recommended to be used as an input.

4.4 Elecromiography Analysis

Each work that used the EMG, had its purpose of use in one of the two different categories, INPUT or AFFECTIVE, as shown in Table 6. Below are listed some discussions about the EMG sensor data acquisition process:

- During the study described in [11], participants performed various stretches and strengthening exercises, and several muscles were used. However, the EMG sensor was only able to detect muscular activity from the surface muscles.
- The disadvantages of the EMG mentioned in [43] are: the EMG is a signal that may vary significantly, depending on the participant or the skin condition. It also requires a stable contact between the electrode and the skin, which may cause problems during the muscle's movement. However, authors noticed that a calibration process is able to overcome many of the problems with this sensor.

4.5 Electroencephalography Analysis

Table 7 displays the usage division of the EEG. Selected conclusions on this sensor are the following:

INPUT	AFFECTIVE
	[29]
	[41]
	[48]
	[50]
Total	
0	4

Table 4: Studies using ECG, grouped according to sensor usage.

INPUT	AFFECTIVE
[34]	[25]
[51]	[26]
	[29]
	[36]
	[38]
	[39]
	[44]
Total	
2	7

Table 5: Studies using EDA, grouped according to sensor usage.

- Vachiratamporn et al. [50] stated that although the EEG showed worse results than the ECG, it still has potential to analyze mental stress in horror games.
- In [49], the EEG based neurofeedback training was considered as a promising candidate for boosting the cognitive skills of healthy as well as disabled people.

4.6 Respiration Sensor Analysis

Table 8 categorizes the five analyzed articles that employed Respiration Sensors. In these works, the following points were considered pertinent:

- The research accomplished in [44] showed that, although respiration is an indication of stress, this variable is not decisive enough on its own. More breathing related indicators should be used, such as tidal volume and end-tidal CO2.
- Kuikkaniemi et al. [25] observed that normalizing the respiration signal is not completely trivial. There is a lot of difference in breathing rhythm and amplitude, which makes normalized signals ultimately insensitive in long-term studies.

4.7 Motion Sensor Analysis

Among the investigated papers, two of them use Motion Sensors as a game input mechanism (Table 9). The next relevant information were summarized from these works:

- Silva et al. [12] used a Tracker Glove in their research. It is a glove with embedded sensors which can continuously monitor the state of the wearer's fingers. According to the authors it is a preferable alternative to computer vision based techniques, as the glove does not need to be visible to a camera, nor the person needs to be in a specific position for the measuring to occur.
- In [13], the Kinect sensor was used and pointed out as a reasonable alternative for obtaining data relevant to the analysis, due to its ability to map the body's joints up to two players. It was possible to use the Kinect to analyze the optimal position of the upper and limbs of the patient, as well as the joints position and muscle extension or flexion.

INPUT	AFFECTIVE
[11]	[26]
[12]	[38]
[19]	
[33]	
[43]	
[47]	
Total	
6	2

Table 6: Studies using EMG, grouped according to sensor usage.

INPUT	AFFECTIVE
[32]	[50]
[49]	
Total	
2	1

Table 7: Studies using EEG, grouped according to sensor usage.

5 Final Remarks

In this work, several studies were shown to provide a comprehensive view on the biofeedback sensors usages. This overview aims to support professionals and researchers in the fields of Game Telemetry and Analytics, as well as Game Design, by summarizing the information on sensors used in players' emotions assessment. Besides using the sensors as a mechanism to analyze the user's affective state, it was observed that some articles also discuss their usage as game input. As this is not an exhaustive survey, some sensors may have been wrongly disregarded. In each analyzed article, different methods and devices were applied, making it impossible to obtain a general quantitative evaluation for each sensor.

Regarding the physiological emotion detection, due to the complex structure of the human affective system and the difference found by competing assessment methods [30], the sensors are commonly used in a combined manner to increase the results' reliability. For example, to measure anxiety levels in a human-computer interaction task, Liu et al. [31] employed several physiological parameters related to (1) cardiac activity, (2) heart sound, (3) bioimpedance, (4) electrodermal activity, (5) electromyographic activity and (6) temperature. Accordingly, several sensors can be used simultaneously, as HRV, facial EMG, GSR, blood pulse volume, and peripheral temperature to properly infer the anxiety level of the user. Likewise, similar parameters were considered in a significant number of studies on media consumers and players' emotions (e.g., HR, GSR, along with Blood Volume Pressure [27]; ECG, Breathing Rate, EDA, EMG, and Skin Temperature [30]; HR, Skin Conductance Level, and Cortisol level [37]; Interbeat Interval and EDA [23]).

Furthermore, the present study revealed that the same sensor applied to measure the user affective state can also be used as an input to the system, promoting a diverse gaming experience to the player. Nevermind [5], for example, is a horror game which uses physiological biofeedback to enhance the player's experience. The game dynamically responds to variations in both psychological stress level (through HR) and emotional states (face expressions through eye tracking) to change gameplay. In this sense, games that have biofeedback systems are fed back structures in which the user becomes the regulator of his/her own affective system as a new way to play.

Ultimately, it was perceived that the studies considering the application of determined sensors as an input or as a measure of

[5] http://nevermindgame.com.

INPUT	AFFECTIVE
[12]	[25]
	[26]
	[41]
	[44]
Total	
1	4

Table 8: Studies using Respiration Sensors, grouped according to sensor usage.

INPUT	AFFECTIVE
[12]	
[13]	
Total	
2	0

Table 9: Studies using Motion Sensors, grouped according to sensor usage.

the user affective state are heterogeneous. Therefore, it is recommended for future research to magnify the focus of the investigation for potential applications to the same technologies. As an extension of the present work, the authors intend to use this survey as a base to implement a practical study employing the sensors presented here in a Game Analytics context and conducting experiments in order to accomplish an accurate comparative study.

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