# Design of an Upper Limbs Rehabilitation Videogame with sEMG and Biocybernetic Adaptation*

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## ABSTRACT

Motor rehabilitation is known to have several difficulties regarding patient's engagement and therapy adherence. Since advances in physiological computing technologies have had an exponential grown in the last decade, its use in novel therapies for motor rehabilitation is being popularized. Serious games, for instance, have been applied as a complementary therapy for neuromuscular disorders, being the game design process a key factor to influence both the attractiveness and effectiveness of the game. In this paper, we expose a design methodology used for the creation of a serious videogame for motor rehabilitation of upper limbs using surface electromyography (sEMG) as the human-computer interface to control the game and monitor the players' fatigue levels. By using an adaptation mechanism from the physiological computing field, called biocybernetic adaptation; the videogame can adapt the game difficulty based on measured fatigue levels. The game design was also informed with therapeutic recommendations and followed an iterative design process. We hope this paper can reveal important insights for both engineers and game designers to create more physiologically intelligent solutions for motor rehabilitation.

## CCS CONCEPTS

• Human Computer Interaction • Virtual Reality • Interaction design

## KEYWORDS

Motor rehabilitation, serious games, electromyography, physiological computing, biocybernetic adaptation, fatigue.

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## 1 Introduction

People suffering from motor disorders and those who need physical therapy are approximate as 15 % of the global population [1]. The recovery process often includes motor rehabilitation with the main goal of regaining the previous motor function or maintaining its current state with the ultimate goal to return/keep a person to a state of optimal functioning [2]. During the rehabilitation process, many patients found the difficulty sustaining their motivation which leads to treatment dropouts. Recent advances in technologies for well-being have revealed the use of serious games as a complement to conventional therapy that can overcome the usual obstacles in the monotonous rehabilitation process. Serious games are defined as games that rather of entertainment have an instrumental purpose such as education, social problems politics, and health [3]. The introduction of serious games into research in computer sciences and bioengineering had created a big revolution in health applications due to the large consumer wellness component [4]. Specifically, the use of serious games in motor rehabilitation provides a solution for the lack of motivation, a typical disadvantage of traditional therapy. The serious engineering application of immersive technologies such as virtual reality (VR) had only recently captured the research interest of healthcare laboratories and governments [5]. The aim of VR is to immerse patients in a virtual environment putting them in various situations that will help them to improve their performance during motor tasks [2].

The major advances in the VR field were made by the industry of entertainment, which have made available several devices easier, cheaper, wireless, and infused with multitudes of low-cost sensors, that turned to be useful for clinical purposes [4], [6]. For instance, some serious games for health use sensors to look for physiological biomarkers that might help at proving the game effectiveness and reflect the player's psychophysiological states [7]. The sEMG is one of the most studied signals by researchers looking for markers of fatigue and muscular stress while players are interacting with game[8]. Furthermore, the sEMG signal can be easily used as a feedback mechanism (biofeedback), which in rehabilitation have proved an important impact on the patients' skills recovery[7], [9]. In a more advanced fashion, biocybernetic adaptation can actively use specific human states detected (e.g. fatigue) and create modulations in the game difficulty in real time with the goal of reducing patient's fatigue while keeping them inside exertion levels that are therapeutically desired [8]. This paper documents the design aspects considered to develop a serious game applied for motor rehabilitation. The feedback management, iterative design process, and final screenshots of the game are presented. The game has integrated an adaptive layer that uses a biocybernetic loop mechanism able to detect fatigue levels by using a wearable sEMG armband.

# 2 Game Design Process

Due to the complexity of the pathologies, the rehabilitation is not performed by a single therapist. In order to have a holistic approach of a particular patient, a team of clinicians is needed to provide different points of view of a single pathology [2]. The development of serious games requires a similar healthcare team, often a physiotherapist or a physiatrist, complemented with game designers and developers. The physiatrist and exercise therapists provide the information related to the clinical aspects to consider while the game design team made the gamification of the medical intervention. Our process was developed with the main goal of defining how the mechanics, technology, story, and aesthetics of a game work together to create a player experience capable to entertain patients while providing an effective rehabilitation process [3]. In this section, we present our design process from the elicitation of therapeutic requirements to the final design of the balancing layer for physiological adaptation.

## 2.1 Therapeutic requirements

The main control signal to interact with the videogame was chosen to be the sEMG signals since the therapeutic goal was based on the stimulation of muscle contractions [10]. A physiatrist medical expert and two exercise therapists were included in early stages to clearly define the system requirements in terms of therapeutic benefits; they are listed as follows:

*2.1.1 Alternative instead of complementary.* The proposed system was thought of as a complementary intervention to conventional physical therapies [6]. Due to the complexity of the therapeutic intervention, the rehabilitation videogame is developed to be used at the start of the conventional therapy where patients can interact with it for a period of 10 minutes, the common time used to constantly exercise a single muscle, in our case, the biceps [11].

*2.1.2 The relevance of fatigue in rehabilitation processes.* Healthcare professionals were very persistent in highlighting the importance of muscular fatigue in motor rehabilitation processes. Although physicians should be alert to signs of fatigue, this is not always possible since conventional sEMG sensors are very cumbersome for clinical settings. Fatigue can lead to damages of exercised muscles or lead to an injury. The rehabilitation process should be aware of fatigue levels [11].

*2.1.3 Isometric instead of isotonic contractions.* Isometric exercise is a valuable rehabilitation method when joint movement is uncomfortable or contraindicated after an injury or a surgery. These isometric contractions are exerted at sub-maximum levels between 30% and 70% of the maximum voluntary contraction (MVC) with a duration between 20 to 30 seconds, and the same time to rest, following the recommendation for first stages of physical rehabilitation [11].

*2.1.4 Therapy quantification and calibration stage.* A quantitative evaluation of the therapy progress is needed. Both subjective and objective metrics should be considered to accurately quantify the possible benefits of the serious game designed. Finally, a calibration stage should be defined where individual capacities can be considered before the game starts.

## 2.2 Iterative Game Design

By using a mixed model, we include several widely used methodologies for the game design process.

*2.2.1 State of the art.* An extended revision of the literature was performed searching for previous work related to sEMG controlled videogames, videogames for motor rehabilitation, and exercise type of task to control videogames. The main common feature that was found was the simplicity of the proposed interaction to control the game elements [12]–[15]. Although daily life activities have been widely used, we believe transporting players to magical words and monster-like enemies can be beneficial to improve patient's engagement and motivation. All in all, we wanted to design a game more than a simulation. Moreover, the simplicity of activity is need due to in early stages of physical therapy the contractions required to gain muscle force are isometric ones, and those contractions do not require much joint movement.

*2.2.2 Brain Storming sessions.* Working together with a senior researcher in videogames for health, a physiatrist medical expert and two exercise therapists, we concluded that the interaction in the virtual environments should be based on simple actions such as throw, catch, defend, hit or shoot [16]. The main game mechanic proposed was a power-up that will reward users' desired muscular physical intensities

*2.2.3 Elemental tetrad.* Proposed by Schell [17] is a game design methodology which proposes synergies between four game elements called game mechanics, aesthetics, story and technology. Our game design process was strongly influenced in a clear definition of those elements as well as their interconnected interactions inside the game. The tetrad elements are defined as follows:

*2.2.3.1 Game Mechanics.* Defined based on the therapeutic requirements and the use of power-ups. In this element of the tetrad we defined:

1. Space: where the actions will take place, in our case an abstract circular space with two small circles that represented the spaces for the main player and his enemy was envisioned.
2. Time: A dimension to define the duration of games scenes and states, for instance, how many times will the enemies attack, how much time will take the character to die. In our case, the muscle contraction duration and the rest duration were the key factors to have in mind.

3. Objects: the elements which will mediate the interaction, in our game the characters, the powers of the characters and the control signal were the main objects to consider.
4. Actions: the verbs that defined the game mechanics, for instance, to attack, to defend, to win, to die.
5. Rules: the rules establish the consequences of game actions. The rules in our case were chosen following Parlett's rule analysis [17]. This model considers fundamental rules; for instance, the game can only be played if a calibration stage has been made; operational rules such as the constant muscle contractions required to users; and behavioral rules, for instance, reduce the user's life if the muscle contractions are not performed.

*2.2.3.2 Aesthetics.* We decided to check the freely available scenarios, modeling tools, and graphical assets in the game engine stores, due to the time limitation to model the virtual environments. An extra-planetary environment with mountains and lakes was chosen to recreate our virtual environment and characters.

*2.2.3.3 Story.* Initially, the game was defined in a fictional world where the main character is trapped in the middle of a lake and must defend him/herself of a monster who is constantly attacking, and the way to do it is through creating a force shield that will allow counterattacks.

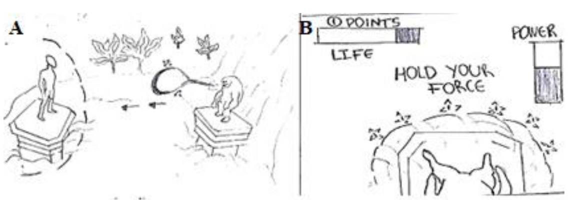


**Figure 1: Storyboard of the videogame. A) The monster shooting the main character. B) Elements in the screen: points, life, power.**

*2.2.3.4 Technology.* After analyzing different game platforms and wearable sensors for interfacing the EMG signals, the Myo Armband was chosen as a physiological sensor and Unity3D as the game engine. The Myo Armband [18], [19] is a wearable bracelet that includes 8 dry electrodes to record sEMG signals at 200 Hz sampling frequency. Moreover, Unity3D is free, has a very active developer community, has a plugin for the myo connection and allows the use of C# as a programming language.

*2.2.4 Storyboarding.* It is a pre-planning of the storytelling made by sketches [20]. A sequence of sketches was built considering the different scenes where the user should interact with the game objects. According to the concept found in [20], the storyboard for the muscular controlled videogame was developed following a sequence that can be seen in figure 1.

## 2.3 Dual flow model and physiological adaptation

Several studies suggest that repetitions while giving feedback and motivating the patients during the training process, can have an important effect on the patients' skills recovery [7]. Research has shown that a psychological status called flow reflects the enjoyment that game playing produces and it has a positive influence on motivation and learning [3]. By following the classic flow theory, Sinclar et al. [21] developed an extended model for Exergaming that encompasses an additional flow dimension called effectiveness which balances player's fitness levels with the Exergame intensity. We used this dual flow model in the game design process as a mechanism to control the challenge through the biocybernetic adaptation technique [22].

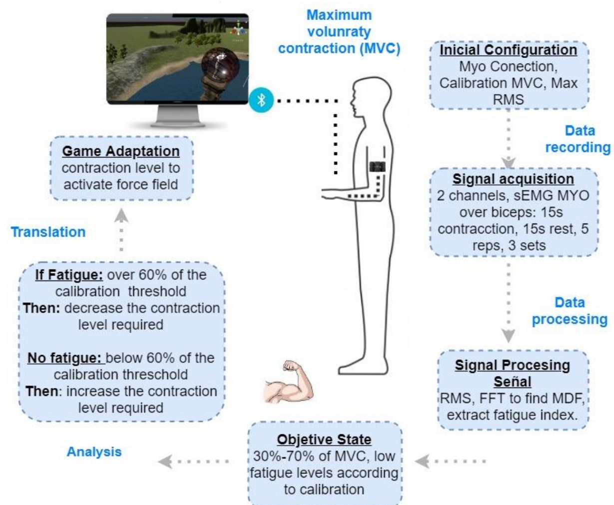


**Figure 2: Model of the biocybernetic loop created for the physiological adaptative videogame. MVC: maximum voluntary contraction. RMS: Root Mean Square value. FFT: Fast Fourier Transform. MDF: Median frequency of the power spectrum.**

Therefore, the biocybernetic adaptation was designed to control the intensity of the muscle exercise according to the clinical recommendations; this is exerting at the desired levels of MVC (30% - 70%). Figure 2 describes the biocybernetic loop design for videogame physiological adaptation. The different internal stages that are shown, emphasis into the signal processing to make decisions in the game difficulty implemented.

# 3 Force Defense Game: Final Implementation

Force Defense is a rehabilitation videogame created to provide interactive sessions of physical rehabilitation in upper limbs. The game uses a wearable bracelet as an interface to encourage players to perform multiple controlled isometric contractions while detecting the player's fatigue levels and adapting accordingly. The goal of the game is to survive the attacks of an enemy monster that is constantly shooting to the player with acid balls. While creating a protection field through controlled isometric contractions, players can reject their enemy attacks and attack back as a response.

- The videogame starts with *a short animation* that visualizes the scene details such as mountains, the lake, the platform where the monster is stood, and the platform where players are positioned (Figure 3A).

- A *calibration stage* is used to define initial parameters that will define the thresholds of the biocybernetic system. Particularly, the game requires players to hold a biceps' contraction for 15 seconds (Figure 3C). The maximum contraction level reached in this stage will moderate the contraction level in the main scene.
- The *user interface* elements are over-imposed in a first-person view of the game including i) a life bar that will decrease every time players receive a shoot (Figure 3D), ii) a power bar that will increase or decrease proportionally to the strength of the contraction, iii) a point-coin counter that will increase every time players can activate the power-up (Figure 3E), and iv) a countdown of 15 seconds that indicates the periods where the players have to perform contractions or rest. During the resting period, the monster will not attack, and players are allowed to relax their muscles while is waiting for the next attacks.
- The *game ends* if the player is killed by the monster, or when players manage to defeat the monster. Data logging features were added to record game events and sEMG signals. These signals are kept into an array to be used in diverse statistical states for monitoring the subject´s perseverance into the intervention with serious videogames.

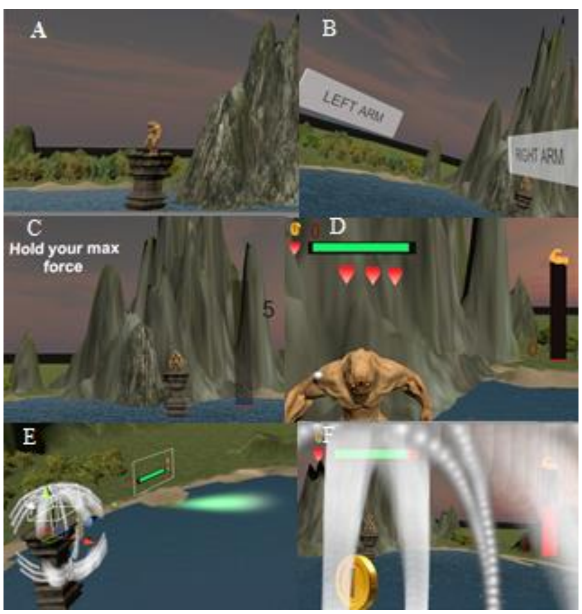


**Figure 3: Force Defense designed in Unity 3D. A) introducing scene. B-C) calibration scene. D) first-person view of the screen elements: points, life bar, and power bar. E-F) creation of the force field.**

## 4 Conclusions

In this work, we have presented a methodology to the design of a serious videogame for motor rehabilitation. We used a combination of well-known methodologies and frameworks from Exergame design and included valuable feedback from therapists. To understand how to do the gamification of repetitive isometric muscle contractions was the key to our design. Finally, the dual flow model aided the creation of the physiologically adaptive loop to modulate the difficulty of the game.

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