



Exergaming and rehabilitation: A methodology for the design of effective and safe therapeutic exergames [☆]



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ABSTRACT

We present here a comprehensive definition of therapeutic exergames from which a methodology to create safe exergames for real therapy pathways is derived. Three main steps are identified. (I) A clear identification of all the exercise requirements, not only in terms of goals of the therapy, but also in terms of additional constraints. Characteristic parameters for determining the challenge level and to assess progression are also defined in this phase. (II) The exercise is transformed into a Virtual Exercise, in which all the exercise elements are implemented inside a simple virtual environment. In this step the discussion between clinical and ICT teams allows maximizing the effectiveness of exergames implementation. (III) The final exergame is realized by introducing on top of the exercise all the game elements suggested by good game design to maximize entertainment. A clear line between exercises and games is drawn here. We illustrate the methodology with exergames designed for (1) balance and posture and (2) neglect rehabilitation, implemented and tested with post-stroke patients training autonomously at home. The methodology can have a broader impact as it can be applied also in other gaming fields in which the requirements go beyond entertainment.

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1. Introduction

Physical rehabilitation is nowadays ubiquitous and keeps expanding as the elderly population increases in industrialized countries. Stroke and traumatic brain injuries (TBI) represent the leading medical conditions that require intensive rehabilitation [1]. In the traditional healthcare model, rehabilitation consists of daily sessions of exercises carried out with a therapist supervising the patient in real-time [2]. This represents a large and ever-increasing cost for healthcare providers that cannot be sustained in the long term, hence why new solutions to administer rehabilitation are needed. In this context, a lot of research has recently been directed toward video games, and *exergames* in particular. Exergames let patients exercise while playing games that hide the burden of the therapeutic repetitive tasks under the hood of a compelling fantasy, thus providing effective treatment while leveraging the motivational power of games to increase adherence.

Exergames have become widespread in the well-being field, even finding commercial success, like the Wii Fit game.² An increasing number of recent studies have introduced exergames in rehabilitation [3,4]; these demonstrate that exergame-based therapy is effective and that motivational benefits do exist. However, current approaches require the presence of a therapist, at least remotely, for safety and efficacy reasons. This has limited so far the adoption of this approach in real settings as the gain appears small.

A few attempts were made in using commercial exergames for autonomous rehabilitation at home [5]. However, adverse effects were reported, such as occurrences of knee or back pain, and too little validation data are available as of now to conclude on their beneficial properties. Similar problems were reported also for the use of the Wii for fitness purposes [6].

Indeed, commercial exergames, made for entertainment and fitness, cannot address the whole range of requirements of a rehabilitation therapy. In fact, commercial exergames integrate into their gameplay the *primary* goals of an exercise, which are translated into game actions, but they do not address what we call here the *secondary* goals of an exercise, i.e. the specification of how an exercise should be carried out. This is important, for instance, in reha-

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² Available at <http://wiifit.com/>.

bilitation, where therapists not only assign exercises, but also **supervise, advise, and correct** the patient while exercising. Without this supervision activity, exercising could possibly do more harm than good due to maladaptation, wrong postures, and joint overloading [5,6].

Exergames can represent the key to provide autonomous rehabilitation at-home, but they should combine motivational content with supervision to guarantee therapy efficacy and safety. This raises a question: how can we design such exergames to guarantee this? Some initial work in this direction was carried out by Flores et al. [7] which pointed out the lack of common guidelines and made some initial proposals, but a shared view of which features a therapeutic exergame should possess is still missing. The discussion is also made difficult by confusion about terminology, a confusion that must be lifted if we want to create effective therapeutic exergames. In this paper, we aim to fill this gap. We clearly define what exergames and therapeutic exergames are, and, based on this, we outline a methodology for the design of exergames of therapeutic validity. We also show examples of use, and discuss the consequences of our approach applied to the rehabilitation domain.

2. Materials and methods

2.1. Defining exergames and therapeutic exergames

Although the term exergame has become widespread, its definition is still fuzzy. An exergame has a dual nature: it is both an exercise and a game, but it is hard to separate the two aspects. However, by drawing a line between these two aspects, the task of designing the exercise, its graphical appearance, or the gaming elements can be better approached by the respective field experts. Recently, Oh and Yang reviewed the use and definition of *exergame* in research, addressing the characteristics of the exercise aspects and proposing their own all-encompassing definition: “*an experiential activity in which playing an exergame or a video game requires physical exertion or movements that are more than sedentary activities and also include strength, balance, and flexibility activities*” [8].

However, neither this definition analyses the interplay between the game and the exercise aspects nor does it neatly separate the two. Moreover, current exergames are focused on **what** a user should do (primary goals) and totally disregard **how** user actions should be carried out (secondary goals). In addition, previous definitions do not give any insight on how to design exergames. Based on these observations, we provide here a novel comprehensive definition of exergames and we also make a clear distinction with exergames that can be applied in real clinical settings, referred to as therapeutic exergames.

We start from the definition of exercise. The concept of exercising is well known and leaves little doubt to its interpretation. We borrow its definition from a medical dictionary [9]:

1. “*Exercise is physical activity that is planned, structured, and repetitive for the purpose of conditioning any part of the body.*”

From this definition, it is clear that exergames can be fully considered exercises. Finding a suitable definition of game is harder, as even if many authors have endeavored to find an all-encompassing definition of what a game is, a consensus has not been reached yet. Dictionaries tend to define a game as “*a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participants*” [10]. However, different interpretations of the term do exist depending on the author’s focus, and the fact that the term game has many different uses makes a common definition even harder to achieve. Salen and Zimmermann [11] performed a throughout comparison of the definitions in the literature and

provided a popular definition that includes most of the commonly accepted elements:

2. “*A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.*”

These definitions have a point in common: an exercise is *structured*, while a game is *defined by rules*. The two concepts can be assimilated. Of the two, especially while treating therapeutic exergames, the exercise’s structure must clearly have priority, as our main goal must be to provide valid exercises, and only then to provide entertaining games. By defining how the exercise and the game are linked through this common point, we will come up with a suitable definition of exergame. Given a game, the person that interacts with it is said to be playing. Much like *game, play* is a term that has many different meanings. We borrow, again from [11], a quite general definition of play:

3. “*Play is free movement within a more rigid structure.*”

This definition better clarifies the relationship between a game and an exercise: since an exercise is defined through its structure, we derive that by introducing play into the exercise we manage to assemble a game inside the exercise itself. This last observation provides a natural definition for the term exergame:

4. “*An exergame is an exercise with a game built into its structure.*”

Compared to other definitions, this definition details the relationship between exercise and game, as it highlights the primacy of the exercise over the game. It follows that the game should not interfere with the correct execution of the exercise: this means that the exergame, when stripped of its gaming parts, should still work as a valid exercise.

This has a large impact on the game designer as game mechanics must be constrained by the exercise limits. The freedom of movement needed for the player to enjoy the game (its gameplay) must be designed such that it is contained inside the structure of the exercise, as visually suggested in Fig. 1. This constraint is even stricter than may seem at a first glance, because not only does the exercise constitute the structure for play, but it also dictates the allowed physical movements that the user may perform and their intensity. Game mechanics cannot modify such movements, as they are required by the exercise.

By understanding the relationship between the game and the exercise, we can now correctly treat primary and secondary goals. In a therapeutic exergame, primary goals can be easily merged into the gameplay, while secondary goals, such as movement correctness or compensatory motion prevention, can be addressed separately, although they should still provide feedback to the user. From these considerations, we propose here a more complete definition of therapeutic exergames:

5. “*A therapeutic exergame is an exergame that supports all primary and secondary goals defined for an exercise.*”

Only if all the aspects of an exercise are fulfilled a therapeutic exergame can be considered really effective and safe for the patient.

2.2. A methodology for the design of therapeutic exergames

We show here how the prior definitions can be translated into a suitable methodology to design effective and safe therapeutic exergames. This follows a four-step procedure (Fig. 2):

- **Exercise definition.** Starting from a therapy goal, a set of coherent exercises that covers all the needs of the therapy is chosen. Each exercise is properly structured in terms of primary and secondary goals.

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