RIABLO: a game system for supporting orthopedic rehabilitation

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ABSTRACT
In this paper we present a complete game system specifically designed for orthopedic rehabilitation. The system is focused in supporting patients both in the hospital and following them up during their home-based rehabilitation. RIABLO provides the patients with the tools for independently executing the therapy exercises in a correct and pleasure way thus increasing the quality of the whole rehabilitation process. The potential of games in the domain of orthopedic physical rehabilitation is analyzed, challenges discussed and the lessons learnt provided.

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Rehabilitation devices; gaming interface; motivation.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: Miscellaneous; J.3 [Life and Medical Sciences]: Health;

General Terms
Serious Games, videogames, e-health.

INTRODUCTION
Starting with the delivery on the market of the Nintendo’s Wii mote and WiiFit Balance Board controllers in 2006 [8], the availability of commercial video game systems based on motion tracking technologies has increased [2], making these technologies known to the greater public and contributing to increase of their acceptance in common life. Since then, these technologies have grown more and more robust, affordable and usable. Currently their main application domains are exergaming and fitness [1], but they are rapidly conquering the “games for health” domain.

Rehabilitation centers may adopt various types of technologies and tools for supporting the patient therapy. These are usually highly specialized and costly machines not suitable for home usage. In some cases a very basic gaming interface is added on top of them, with the purpose of providing more a friendly interaction for patients with the supporting devices: included as a fun and innovative option, these games often lack the necessary qualities for being entertaining, when compared with popular games, and are therefore less engaging for patients.

The trend in physical rehabilitation favors the use of videogames as therapeutic modalities, supported by an increasing availability of clinical literature describing their use in different contexts. The availability of motion tracking technologies at an affordable cost has stimulated the research on the usage of off-the-shelf fitness and casual games in the rehabilitation field. Clinical trials have been conducted using available commercial exergames, such as Nintendo Wii Fit or MS XboX Kinect, for addressing various types of pathologies, often involving motor rehabilitation after neurological problems or addressing balance and proprioception rehabilitation.

These research works highlighted the benefits of using games for rehabilitation: it has been demonstrated that their use as adjunct to patient rehabilitation can be an effective support in some pathologies (e.g. balance rehabilitation), even when the games themselves were not specifically designed for this purpose. Still, some limitations do exist.

Unlike in fitness games, in physical rehabilitation real movements difficulties may exist due to the presence of pain, muscular weakness and possible joint blocks. For this reason, rehabilitation supported by generic exertion games foresees that the patient should be helped and guided by a specialized staff within a rehabilitation path. Such a path is part of the therapy, personalized for each patient, in which specific reachable objectives are set. For this reason, most of these applications are used only at clinics or hospitals rather than at home.

In this paper, we report on our current work with RIABLO, a complete game system that specifically addresses the physical orthopedic rehabilitation. It was designed with the purpose of supporting the independence of patient during the execution of a program of exercises, both in clinic and at home. For this reason it takes into account the issues such as of the adherence to the therapy at home and the correctness of its execution and self correction. To this...
extent, game elements have been incorporated into the system in order to motivate and engage the patient, while providing feedback on the correctness of the executed exercises. When the patient is following the therapy at home, therapist can monitor the progresses of his or her patient remotely by asynchronously accessing the data collected during the rehabilitation sessions. Additionally, the physiotherapist can remotely adjust the therapy program of exercises to patients as needed, assigning new exercises or adapting the difficulty of the existing ones.

**RELATED WORK**

Recently, it has been seen an increasing interest on motion tracking games usage in physical rehabilitation both within the clinic and home [4][5]. Research have proved the benefits of using game based tools for the physical rehabilitation of patients with neurological damages, where the rehabilitation main goal is the recovery of motor function through intense skillful practice [6]. After an injury or disease to the nervous system (such as stroke, spinal cord injury (SCI), or traumatic brain injury (TBI)), the rehabilitation program usually includes exercises for improving patients’ standing balance, strength, coordination and activity tolerance, or occupational therapies. For neurological injuries, studies has been conducted also with the use of virtual reality, where the patient can control the movements of an avatar, and have an elaborated feedback on the performed activity [3][10][12].

Current research in motor rehabilitation addresses mainly neurological and cognitive related injuries, but little research works specifically addresses orthopedics, and its specific needs. Even if neurological and orthopedic rehabilitation have some points in common, and may seem to some extent similar, some requirements change, influencing the design of the game and of the application in general. The shift from the need to recover from a centralized brain injury, to the need to recuperate from a peripheral damage (such as a damaged joint or a broken limb) changes the rehabilitation approach. The intervention often involves moving an operated and still vulnerable joint or limb, therefore requiring a precise monitoring of the movement in order to avoid compensation patterns or movements that may increase the risk of injury. Exercises have the objective to tone up the muscles, reacquire mobility, and functionality, however, overworking or straining of the injured part during this period can compromise the success of a chirurgic intervention itself.

Complete systems for rehabilitation, addressing also home and whole process, are still a research issue. Even if there are works addressing various aspects, there are still open research questions, especially when it comes to full developed systems and clinical trials.

**THE ORTHOPEDIC REHABILITATION PROCESS**

When considering rehabilitation from orthopedic and traumatic pathologies, the recovery potential can be very high and the objective of the rehabilitation is often the complete recovery. For being effective, rehabilitation must be early, intensive and repetitive. Soon after surgery, treatment is carried out in a rehabilitation center. The patient feels stimulated to carry out the exercises and confident in the correctness of his or her own movements thanks to the presence of the physiotherapist. When the first critical phase is concluded, much work is required to be done by the patient by its own following a “to do list” and going to periodical checks with doctors. The patient can get back to normal life but has to continue the rehabilitation at home by its own: it is at this stage that often motivation starts to decrease and the lower control he or she has on the exercise can made the effort completely useless from a therapeutic point of view. At this stage, the patient’s motivation and adherence to the rehabilitation project becomes a fundamental component in the healing process [7][11], highlighting the importance of providing continuity of care at home.

In orthopedics rehabilitation, the work done at the hospital is complemented, at different degrees (depending on the seriousness of the injury), by a program of exercises to be executed independently at home. The patients are taught at the hospital on how to perform correctly the exercises, but when alone at home, they must be able to execute the program without support. The success of a therapy depends on continuing the prescribed exercises once the patient is at home: exercises are often repetitive and sometimes painful, therefore motivation can be an issue, especially in the latest rehabilitation phases, when the main physical functions are recovered and the patient can get back to normal life. Therapist monitors the advancement of the therapy during the periodical checks, during which they may also check if the patients has found difficulties in executing the home program.

![Figure 1. (a) Screenshots of the low-mid fidelity prototype a game controlled by the patient’s balance), and (b) its demonstration with physiotherapists at the Villa Igea Hospital (Trento, Italy).](image-url)
THE DESIGN PROCESS

The RIABLO prototype was developed following a various stages. First, user requirements and concept were defined based on interviews with stakeholders (physiotherapists, doctors, patients), on observation of physiotherapists at the hospital and on research on rehabilitation systems in use. Also a questionnaire was distributed to physiotherapists, in order to have a reference of the different backgrounds and approaches involved and different degrees of usage and knowledge of technologies. This survey involved 70 physiotherapists of different nationalities.

Based on the initial concept, a low-mid fidelity prototype, based on Nintendo WiiMote and WiiFit balance board controllers, was developed. It was then used to demonstrate to physiotherapists, physiatrists and patients the potentialities of the approach (see Figure 1) and to involve them into the design process.

The same low-mid fidelity prototype was used for conducting an early evaluation in order to define an initial set of design goals for the RIABLO prototype. The prototype was evaluated with 20 healthy users, performing exercises commonly used in rehabilitation for increasing proprioception. During this evaluation we were also able to collect motion data useful for defining the technical requirements of the motion tracking system.

The initial design goals of the system are the following:

Integration Between the Rehabilitation Process and Gameplay

In therapeutic games, rehabilitation tasks are associated to playful actions, in order to transform them from repetitive and boring activities into engaging and enjoyable ones. Since these activities have also clear rehabilitation goals such as acquiring muscular strength, resistance, movement precision, improved coordination, and movement amplitude, design have to take into account additional requirements related to the concrete needs and problems of the rehabilitation tasks. For example, the game should keep the right pace and avoid over exercise, sudden movements or movements that can compromise the healing process: the patient should be able to keep the control of the exercise, in order to perform it correctly and safely. In addition, since we are addressing the whole rehabilitation path, the system should integrate it into the gaming experience, in order to support patients’ motivation along the whole healing process. The capacity of dynamically adapting both the game and exercise difficulty/challenge according to patient performance and abilities is a key factor for maintaining user engagement and interest.

Providing Continuity of Care at Home

The patient should be able to use the system at home autonomously, therefore it should be easy to set up and use. Additionally, implemented games should scaffold the patient and support them in executing the exercises correctly. The user should feel reassured in their activity, and on the correctness of their performance.

Physiotherapists should be able to remotely control the patient’s progress, in order to support him or her, to provide feedback and advice, and to adapt the exercise program as needed. Besides, it should provide therapists the tools for remotely managing patients and creating new therapy programs.

Support a Wide Variety of Users

In orthopedics rehabilitation, patients came from wide variety backgrounds and have different expectations from the rehabilitation. Typically sportsmen and women are extremely motivated patients and aim to recover their own abilities in the smallest time possible. More sedentary people, instead, during rehabilitation have to face the problem of performing physical activities that they are not familiar with. In this last case, exercising alone at home can be really tough and challenging. Since we are not addressing patients with a particular background and skills, no need for computer or video game experience should be required. For this reason simple game concepts (valid for all the types of users) should be used.

Based on the initial design goals and the feedback collected, RIABLO prototype was developed, following three iterative cycles of design, development and evaluation. At each cycle of the prototype was refined in terms of usability, game design, appropriateness to rehabilitation tasks and technical aspects. At the end of this process, the prototype was mature enough for being used in clinical trials in a home like setting.

![Diagram](image)

**Figure 2 - Prototype architecture**

PROTOTYPE DESCRIPTION

Based on the above design objectives, an advanced prototype was developed with a limited set of features. The architecture of the system is based on tree main
components: a gaming system (composed by a console, a set of sensors and games), and a web application for physiotherapists and a backend server (see Figure 2).

The gaming system was designed for being used at home by the patient. In the meanwhile the back end system collects all patient data and maintains the information related to the rehabilitation path. The Web App allows the therapist to follow the patients’ progress remotely and keep track of their day by day progress, highlighting possible points of problems. In the following the various elements of the system are described in detail.

**Motion tracking hardware - Data acquisition system**

Our initial evaluation with the mid-low level prototype, revealed that the data collected by off-the-shelf fitness games controllers didn’t fit the requirements for orthopedics rehabilitation tasks, especially when implementing games for more the complex exercises. For this reason we choose to use five minimal intrusive high precision wearable sensors composed by one 3D accelerometer and one gyroscope, connected with Bluetooth and positioned on the body with elastic stripes (as shown in Figure 3). Besides the sensors, a board with pressure sensors completes the game data collection system. The sensors continuously monitor the parameters relevant to the orthopedics rehabilitation therapy, such as joint angles, angles of the limbs, distribution of weight, balance, etc.

![Figure 3](image)

*Figure 3. Position of the wearable sensors in the prototype: five accelerometers were used, one for the chest, one for each thigh, and one for each shin. They are worn using a strip with different color codes for easy sensor identification and...*  

**Patient interface - Games**

The patient interface has been designed considering both rehabilitation and patients’ requirements. A set of platform games were designed in order to allow the execution of different exercises types, such as isometric or mobility exercises. Exercises are organized in daily programs, defined by the therapist for each patient. The therapist can tailor the exercises on the patient, thanks to a set of configurable parameters that define the range within which the exercise is considered correct during execution.

The patient is guided in the execution of the exercise by the game: relevant user movements are captured by the sensors while performing the exercise, when the exercise is correctly executed the patient is able to collect rewards and increase his score. Game mechanics is designed according to the goals of the exercise. For example, games associated to mobility exercises gradually propose the patient with movements of increasing amplitude (see Figure 4.b). Games are also designed to monitor the patient’s progress in order give the right weight and pace to the different phases of an exercise, thus avoiding dangerous movements. The patients receive feedback on the correctness of the exercise, thanks to a mechanism which alternately rewards or penalizes the gamers in terms of points collected.

![Figure 4](image)

*Figure 4 - Exercises and Game Interfaces: (a) Squat; (b) Weight shifting; (c) Hip abduction*

The developed games allow the execution of over twenty exercises, mostly tailored for different phases of knee rehabilitation. Games differ by the number of parameters monitored and exercise typology. For example, exercises that require monitoring only two parameters (for instance knee joint angle and leg angle with respect to an horizontal plane) are associated to a 2-D game; if three physical parameters need to be monitored (e.g. the weight balance, knee joint angles and the position of the feet) a 3-D game is chosen. As an example, in the 2-D bear scenario (shown in Figure 4.c) one parameter controls the movement of the bear (up or down), while a second one controls the speed with which the bear move. Similarly, examples 3-D games are shown in Figures 4.a and 4.b (associated respectively to squat and weight shifting exercises).
The system gives the patient an active role in the therapy, acting on the patient motivation and supporting him or her in performing the assigned exercises correctly and independently, thus improving the effectiveness of the therapy.

**Web application for physiotherapists**

A web application was created for allowing the physiotherapist to set up a personalized rehabilitation program for each patient (creating a calendar with assigned exercises and selecting the type of exercise to include into the program, setting the exercises’ frequency and difficulty, defining the number of repetitions or exercise dynamic pattern) and to remotely monitor how well the patient is performing (see Figure 5). Physiotherapists can asynchronously access to the data recorded during session and adjust the program as needed.

**EVALUATING THE PROTOTYPE**

The prototype was evaluated in every development cycle development by actual patients in treatment at the Villa Igea hospital (Trento, Italy). Each evaluation period lasted one week, during which the system was installed in the gym of the hospital. Rehabilitation sessions with the RIABLO system were conducted under the supervision of a physiotherapist and a physiatrist, with a total of 42 participants, with ages ranging from 14 to 74 (Table 1). Most of the patients had suffered a knee injury and started the rehabilitation after a churrurgic intervention. A smaller part of patients were in treatment for chronic back pain and hip injuries.

<table>
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<tr>
<th>Evaluation cycle</th>
<th>Male</th>
<th>Female</th>
<th>Age (average)</th>
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<td>0</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>2(^{nd})</td>
<td>12</td>
<td>10</td>
<td>37</td>
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<td>3(^{rd})</td>
<td>4</td>
<td>3</td>
<td>30</td>
<td>7</td>
</tr>
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*Table 1. Demographics of evaluations’ participants.*

Users involved into the evaluation included both patients at the initial-medium stage of their therapy (and still conducting their sessions at the clinic under the supervision of the physiotherapist) and patients that already started the therapy at home by their own. Patient participated up to 3 sessions with the RIABLO system, during which they were asked to perform the same exercises as their usual rehabilitation session but with the help of the system. For all patients, each session lasted between 30-40 min. The correctness of the exercises’ execution where monitored by the presence of a physiotherapist, who was instructed to minimally interfere with the rehabilitation session.

In Figure 6 some moments of the validation sessions are shown: on the left picture, a patient in the first rehabilitation stage performing an isometric exercise; on the right, a patient in the second rehabilitation stage performing a squat exercise.

**Methodology used**

The data collection method was centered on interviews to the patients, questionnaires and on observation. We asked to the patients to answer to a background questionnaire.
before the experiments during which participants reported their present age rehabilitation experience, usual physical activity, and their use of technologies such as computers, internet, and games. Patients were asked to think aloud and comment the games and exercises during the session. Post-sessions interviews were conducted in a semi-structured format with questions probing people's gaming experience with the system as well as their preferences and concerns regarding the usage of the system in general and at home. Patients were asked also to answer to a questionnaire with questions regarding the usability of the system, game elements, flow, aesthetics and motivational aspects.

Interviews with physiotherapists were conducted, in order to collect feedback on the Web App application.

**PRELIMINARY RESULTS**

During the evaluation important information on all aspects of the system were collected, both from user point of view and from physiotherapist point of view that allowed us to improve the system on different aspects:

- **Usability**: related to the game interface, the ease of use, the sensors bands, and the web app. The majority of users that evaluated the system had little experience with videogames, or weren’t videogame lovers. Most of participants found the dynamic and goals of the games intuitive and easy to follow. Nevertheless some aspects of the interface had to be adjusted after the users’ feedback.

- **Game mechanics**: Evaluation with users was important for correctly balancing the games with respect exercises goals. Games sometimes were perceived as “too easy”, and therefore not challenging, even if the physiotherapist present at the session judged the exercises executed fairly correctly. This suggested that the parameters range calibration was an important component of the game, and motivated to introduce more complex game mechanics could.

- **Game user experience**: every user was able to complete the task within a reasonable amount of time and with a good game score. The proposal of adding random and non predictable elements could improve the system was not welcomed by all the participants. While some found this element could make the sessions more interesting, others see it as a negative and distracting factor.

- **Usage of the game environment for rehabilitation**: patients preferred executing the exercises with the games instead that without it. The integration with the games contributed to make the session less monotonous. The majority of participants gave more importance at having a feedback on the degree of correctness of the exercises rather than on the collection of rewards. This suggests that mastering the exercise can be a good leverage for engagement. Some users where able to indentify differences during the execution of the exercises between different sessions that would otherwise remain unnoticed, thanks to the feedback given by the gaming interface.

In all of cases the participants agreed upon the fact that the system could be useful if used at home, even if for different reasons: the possibility of controlling the performance of her or his own training session, both real time in the game and between sessions; the remote supervision of the physiotherapist; being able to control the correctness of the exercise execution; being engaged by the game while performing otherwise boring tasks.

**CURRENT WORK**

At the moment, clinic trials are being conducted for understanding the effectiveness of the system for home rehabilitation. Patients were divided in two groups: a control group that is following the usual therapy path, and a second group that is using the RIABLO system in a home like environment. For this purpose, a small gym was set up at the Corehab premises in order to make the system available to the users at their convenience. The purpose, besides to evaluate the clinical validity of the approach, is to test the system in an environment as similar as possible to the one for which the system was conceived (i.e. the patients’ home) with a significant number of users.

**LESSONS LEARNT AND NEXT STEPS**

Exploring new modalities with which patients are stimulated and motivated to continue carrying on the exercises at home with remote supervision of the physiotherapist, has a great importance for the therapy. A potential increment in the period during which the patient exercise is under the control of the operators, has an effect also on the control of the recovery time. Interviews confirmed that the core of the system should focus on the whole rehabilitation process, and that the integration with game elements should be included at different levels. In particular we plan to improve the system in different directions:

- **Gamefulness**: including non predictable events in the game flow, improving the rewarding system and aligning it with the users’ goals.

- **Rehabilitation process**: including adaptation engine that follows the patient’s learning curve.

- **Study the effectiveness of incorporating a social dimension**, e.g. including competitiveness or collaboration

- **Cover a broader range injuries and pains**: e.g. including chronic back pain rehabilitation.

We plan to extend trails to broader use cases, in order to include rehabilitation programs for shoulder, back and hip rehabilitation
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