Winning Compensations: Adaptable Gaming Approach of Rehabilitation Sessions based on Compensatory Movements

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Abstract
Upper-arm physical disabilities are amongst the most common types of physical impairments and most of them can lead to abnormal motor synergies commonly known as compensatory movements, that hinder movement correctness. Dynamic difficulty adjustment can bring variability into upper-limb physical therapy making treatments more effective, adjusting progression to the patients’ capabilities and limitations. The main focus of our research is to assess the impact of dynamic difficulty adjustment of upper-limb physical rehabilitation exercises on the effectiveness of prescribed treatments, based on compensatory movements through a gamification-based visual biofeedback interface that uses the Kinect One sensor for motion capture. We propose a set of exercises that dynamically adapt several difficulty parameters to the performance of the user, while allowing manual tweaking of those parameters, for enhanced customization. The study includes one contextual inquiry, two co-design sessions and 15 usability tests for the prototype with both professional physiotherapists and finalist Physiotherapy students. The tests include system usability scale (SUS) questionnaires and semi-structured interviews. From the results obtained in the questionnaires, the average scores for the first, second and third exercises were 74.8, 78.2 and 74, respectively. The participants considered the system highly usable in the clinical context. From the Semi-structured interviews, the greatest value of the solution lies in the customization possibilities that both dynamic and manual adjustment of difficulty parameters could bring to the effectiveness of prescribed upper-limb physical rehabilitation treatments and all participants even expressed the will to implement the system into their own patients’ treatment, in the near future.

Keywords: Rehabilitation, difficulty adjustment, biofeedback, compensatory movements, upper-limb, Kinect One

1. Introduction
According to the World Health Organization (WHO), there is a wide variety of upper-limb disabilities that, inevitably, require physical therapy to mitigate or alleviate the resulting impairments caused to patients [7]. Cerebral vascular accidents and musculoskeletal conditions are the two most common sources of physical impairments, according to the WHO. Shoulder impingement, for example, is the most common cause of shoulder pain in overhead athletes [9], which practice sports that involve intense and repeated activation of the scapulohumeral muscles. Hence, the process for recovery implies several hours and different types of exercises that the patients must perform, all in accordance to their specific difficulties, capabilities and limiting conditions. There are several studies about the use of visual biofeedback interfaces to make physical therapy better, more engaging for the patient, more objective and with more significant data for the health professionals and overall more effective. Serious games are some of the examples [16, 13].

One important application is the possibility to effectively detect compensatory movements during the execution of functional upper-limb movements such as reach[17]. These are incorrect movements that can even be harmful to the patient since they negatively affect their rehabilitation process. Compensation can also be defined as a behavioural substitution, meaning that alternative behavioural strategies are used to complete a task [4].

Difficulty adjustment is of the utmost importance in any physiotherapy session. There are several methods to implement variability into physiotherapy exercises and adapt the difficulty to the spe-
cific context of different patients [19]. Although the results were not conclusive, previous works have tried to compare conventional physical therapy exercises to self-managed frameworks to perform upper-arm rehabilitation exercises, in which external difficulty factors, such as therapeutic bands or weights are included, and the progressions are based on objective symptomatic responses to the treatments, such as pain [10].

Our work will focus on shoulder joint physical impairments to which there is also a wide variety of exercises that can be prescribed for an effective treatment, amongst which are the open chain, closed chain and minimally loaded range of movement exercises. Dynamic difficulty adjustment of exercises has already been proven in other studies as very important, when it comes to an adaptive tweaking of parameters such as range of motion and amplitude [18]. The main contributions we aim to have in both the scientific and the technical aspects of the upper-limb physical therapy paradigm include the Dynamic Difficulty Adjustment for performance-based adaptation of the difficulty level of prescribed motor tasks and the possibility for parameterization for manual exercise adjustments to match the capabilities and limitations of the patients throughout their physical therapy process.

Research Questions
The research questions are the guidelines that define the objectives of the assessment methodology we designed to evaluate Winning Compensations.

- Is dynamic difficulty adjustment effective in the adaptability of upper-limb rehabilitation exercises?
- Is quantitative data regarding the performance of upper-limb exercises, important for better progression assessment by the physiotherapists?
- Can Serious Games be implemented as viable complements to the physiotherapists’ daily tasks?
- Can biofeedback interfaces effectively monitor compensatory movements and optimize upper-limb rehabilitation exercises accordingly?

Once the research questions were defined, the main aim of the user tests was to answer these questions by collecting valuable feedback from the participants. The corroboration of these questions will dictate the success of the development of Winning Compensations. Positive results will translate into a high potential for our system to be used in a practical clinical context.

Contributions
This work aims to contribute both in the scientific and technical aspects of the physical therapy context. These contributions must include some important key-points:

- Dynamic Difficulty Adjustment for performance-based adaptation of the difficulty level of prescribed motor and cognitive tasks;
- Possibility for parameterization for manual exercise adjustments, to match the capabilities and limitations of the patients throughout their physical therapy process;

2. Background
Bakhsh et.al [2] describe the four joints that comprise the shoulder complex, as well as their respective main functions in several upper-limb movements.

- Glenohumeral (GH) joint is a “ball-and-socket” joint, the “ball” being the humeral head and the “socket” being the glenoid [2]. This joint is cushioned superiorly by a sub-acromial bursa that facilitates motion;
- Acromioclavicular (AC) joint is surrounded by an independent joint capsule and pain at this joint is commonly known as shoulder separation since its main function is to facilitate shoulder motion relative to the remaining axial skeleton [3];
- Scapulothoracic (ST) joint is the articulation between the scapula and the thorax or rib cage. It is responsible for elevation and depression to change the plane of shoulder motion, allowing the great flexibility of the shoulder;
- Finally the Sternoclavicular (SC) joint has only 50% surface articulation, and is enveloped in an independent capsule. It has the fundamental function of allowing the elevation of the arm without requiring motion of the thorax.

And also some of the complex network of muscle structures that provides the mobility and functionality of this joint in all the movements it can perform [2].

- The Deltoid muscle is the most prominent one, superficially, and is responsible for the contour of the shoulder. Its main function is the abduction of the arm. Since it has anterior and posterior segments, the deltoid also assists with arm flexion and extension;
• **Pectoralis major** is responsible for chest contour and its major functions are flexion and adduction of the arm. It also plays a significant role in internal rotation of the arm;

• The **Trapezius** is a supportive muscle that stabilizes the scapula and allows rotation to enable movement in the scapula-thoracic plane.

• The **Biceps brachii** is a key shoulder muscle that allows supination and flexion of the forearm, but it also has a role in arm flexion and adduction.

• The **Rotator cuff** is a complex of four different muscles which serve the primary purpose of force-coupling at the GH joint, allowing for appropriate joint-reactive forces to be maintained for shoulder active range of motion [14].

Shoulder pain is not only one of the main indicators of physical impairments of the upper-limb, but also one of the most common musculoskeletal complaints. Stroke and postoperative scenarios are two of the causes for physical impairments, which, in turn, can be defined in two different ways [15]:

1. **Impairments of body function** such as significant deviation or loss in neuromusculoskeletal and movement-related function, related to joint mobility, muscle power, muscle tone and/or involuntary movements;

2. **Impairments of body structures** such as a significant deviation in structure of the nervous system or structures related to movement, such as the arm.

Raghavan et al [15] also state that the impairments are not static and may evolve as the motor recovery proceeds, thus, the treatment must be prepared to adapt to the conditions of the patient and status of their impairment at any given point in time. From stroke-related physical impairments may also result a learned bad use of the paretic limb. This means that, through forced movement, the patient may feel sensory abnormalities and pain, which prevent normal movement, hence, cause compensatory movements to occur. Besides this, the development of abnormal motor synergies may also cause compensations.

The incidence of compensatory movements is the occurrence of abnormal motor synergies, in which functional movements such as reaching and grasping, become altered and are performed incorrectly, with unnecessary or entirely wrong movements. For example, the excessive elevation of the shoulder joint in a normal arm abduction or flexion movement, as well as accessory lateral flexion of the trunk in reaching and abduction movements. Some other examples are those of patients with stroke that perform trunk flexion rather than elbow extension, to reach for objects, and forearm pronation and wrist flexion rather than neutral forearm position with wrist extension, to orient the hand for grasping [15].

In any set of physical rehabilitation exercises, there can be closed chain (Figure 1.Bottom) exercises and open chain exercises (Figure 1.Top).

![Figure 1: (TOP) Closed kinetic chain exercises (A: shoulder flexion at 90°, B: shoulder flexion at 90° in scapular protraction position, C: shoulder flexion at 125°, D: shoulder flexion at 125° in scapular protraction position) and (BOTTOM) Open kinetic chain exercises (A: shoulder flexion at 90°, B: shoulder flexion at 90° in scapular protraction position, C: shoulder flexion at 125°, D: shoulder flexion at 125° in scapular protraction position)](image)

Open chain exercises are performed with free movement of the opposite extremity of the affected joint, in this case, the hand. Some functional examples are the reach movement we perform when we grab something, the abduction and adduction pure movements, flexion and extension as well, and all of them without any constraints imposed to the movement of the hand [20].

Closed chain kinematic exercises are the opposite, in the sense that the hand is against a wall or another hard surface and, thus, the shoulder has only so many degrees of freedom to execute the exercises. Some examples of closed chain exercises include weight transfers with forearm support, weight transfers on all fours and weight transfers with arm support against a wall [20].

According to professional physiotherapists, the conventional ways for adjusting the difficulty of physical rehabilitation exercises mostly involve the use of external factors that allow a progressive increase in difficulty, whether through adding resistance (e.g. elastic bands and weights) or increasing the number of simultaneous tasks that the patients must perform (multi-tasking is a valuable addition to variability in the exercises, not only from a musculoskeletal point-of-view, but also at a cognitive level) or even the range of motion and speed at which the patients must perform functional tasks.
And so, despite the variety of methods possible for difficulty adjustment in physical rehabilitation exercises, the physiotherapists always have the critical task of accompanying their patients and following their progress, to ensure a successful recovery. This is true for both conventional methods, as well as for visual biofeedback-based interfaces which aim to approach physical therapy in more quantitative and effective ways, especially in what concerns difficulty adjustment of prescribed exercises and compensatory movement correction.

3. Winning Compensations

The setup and overview of the system we developed consists only of the Kinect One and a computer, where the app runs on. Choosing the Kinect as the preferred motion capture device follows the lines of the project BROTHERS-IN-ARMS, which Winning Compensations is based on. Some of the reasons for this choice were the sufficient accuracy in the frontal plane, to be used in the several exercises implemented, and also the total low cost that this technology incurs [6]. The computer on which the system runs can be a laptop, with Windows 10, at least one USB 3.0 port to function with the Kinect and one screen large enough to provide good visibility of the interface.

Technology

The software part of the system was developed in the Unity3D game engine, version 2019.1.0f2, using the C# programming language in the Microsoft Visual Studio 2017 IDE. This technology has been widely used in all sorts of gamification applications, not only for physical rehabilitation, but also in conventional gaming applications and in other areas, such as medical training [8].

We used Microsoft’s Skeleton Basics SDK to obtain the virtual skeleton of the user’s joints, also in C#, and then adapted to work with Unity3D. The normalization of the virtual model of the joints, based on [6], served the purpose of maintaining the size of the skeleton regardless of the size of the patient or their distance to the Kinect sensor.

The Microsoft Kinect One produces an image in which each pixel has a three-dimensional position, by projecting an infrared light pattern and then analysing the distortions encountered, when that pattern bounces back to the camera from the environment [12].

Workflow

The first screen that shows once the system is started is the category selection screen (Figure 2.a). In the current state of the prototype, the option available refers to the core feature our system uses in accomplishing the objective of monitoring and correcting compensatory movements in physical therapy, through difficulty adaptation, based on performance: Dynamic Difficulty Adjustment. The next screen is the side selection screen, in which the user is prompted to select the arm with which they are to perform the exercises (Figure 2.b). Since the exercises were implemented for musculoskeletal shoulder conditions in the orthogonal position, this screen contemplates choices only for either one of the arms. In future work, other choices may be implemented if new features for other body segments are developed. Once the side and arm are selected, the user is prompted to define specific parameters for the performance of the exercises (Figure 2.c). Those parameters are:

- **Maximum Repetitions**: In this field, the physiotherapist fills in the maximum number of correct repetitions the user has to perform so they can advance to the next exercise. The default value is 10 repetitions.
- **Time per set**: Here the PT defines the total maximum duration of each set. The default value is 60 seconds.
- **Number of sets**: It is even possible for the physiotherapist to define the total number of sets the user is to accomplish in each exercise. The default value was set to 3 sets.
- **Rest Duration**: Between each set, there is a rest timer which stops the exercise and visually counts down for how long has been defined in the rest duration parameter. Thus, this is the time the user has, to rest between two different sets. The default value for this parameter was set to 60 seconds as well.
- **Exercise selection**: Through small thumbnail-nails, representative of each exercise, the PT can see and select which exercises the user will be performing throughout the session.

The Exercises

Winning Compensations currently consists of three exercises with different objectives and features. In every exercise, the ratio between correct repetitions and total tries is calculated in real-time, to provide an objective measurement of the performance throughout the exercise.

\[ \text{Correctness} = \frac{\text{CorrectRepetitions}}{\text{CorrectRepetitions} + \text{CompensatoryMovements}} \times 100 \]  

Although each exercise is unique, they all share some common elements such as the compensation matrix, which monitors and detects compensatory movements, in real-time. Figure 3 represents the interfaces for all three games implemented so far:
• **Target Reach:** The goal of this exercise is to activate objective targets that are instantiated at varying amplitude ranges and distances from the patient’s medial line. These variations occur according to three different sub-levels of difficulty, and each level is triggered based on the performance of the patient, more specifically, as the patient executes the exercise correctly, it gets more difficult. On the other hand, if compensatory movements are detected or the exercise is performed incorrectly, the difficulty will decrease, as well as the correctness ratio.

• **Line Draw:** The idea for this exercise came from some of the feedback gathered from professional physiotherapists. In this session we discussed one of the methods they used to work with their patients, which involved several repetitions of consecutive flexion/extension and lateral abduction/adduction movements using a marker against a whiteboard, hence, drawing a series of straight lines. This exercise has a vertical variant and a horizontal variant, for the flexion/extension and the abduction/adduction movements, respectively.

• **Shapes:** This exercise focuses on much more function-oriented, compound movements, rewarding an ample range of motion and precision. It also allows for much greater stimulation of the cognitive senses of the user, since the exercise requires fine movements and a good sense of proprioception (also referred to as kinaesthesia[1]), which is the self-notion of the location and precision of the movement of the several body segments. Thus, this exercise is different from the rest and its objective is to activate a series of targets, similar to the LineDraw, but organized into six different shapes. The user has to follow the suggested paths correctly, with the minimum amount of compensations and as effectively as possible. If they take too long to activate all targets forming the shape, it will disappear and give place to the previous one in the array of selected shapes, hence reducing the correctness of the exercise.

### The Interface

Besides the workflow of the exercises, a clear interface of the system is crucial to achieve a viable, easy to understand tool to help both physiotherapists and patients. In each implemented exercise, the part of the interface that is relevant for the physiotherapist changes according to which parameters can be manipulated to customize that exercise and its difficulty progression.

Although, there are some elements of the interface that are common across all the exercises:

• **Compensation types and count:** This section of the interface shows the number of shoulder-lift and trunk-lean compensations the user has done during the session;

• **Time parameters:** The time elapsed since the beginning of the session, the time until the next rest and the average time per repetition are all available on-screen for continuous monitoring;

• **Amplitude values:** On the right side of the interface there is a model of the trunk with constant monitoring of amplitude values for the shoulder and elbow joints. It measures real-time amplitudes of the normal and lateral abduction/adduction movements of the shoulder joint, and the flexion/extension movements of the elbow joint;

• **Countdown:** Before the session starts there is a countdown timer that lets the user know the session is about to begin;
• **Name and changeable parameters for each exercise:** For each exercise, the interface shows its name and the several parameters that the physiotherapist can adjust to adapt the exercise to the specific needs of each patient;

• **Correctness and completion:** These two ratios measure how well the patient is performing the several exercises and how close they are to completing them, respectively;

• **Repetition and set-related monitroization:** In the bottom right section of the interface, the several numbers are indicating the correct repetitions, total number of tries, maximum amount of repetitions (defined by the physiotherapist), the number of sets the user has completed, and the correct repetitions performed in the previous set.

### Compensatory Movements

The two compensatory movements monitored in Winning Compensations are the elevation of the shoulder and excessive lateral flexion of the trunk. The compensation matrix in our system is the same as in BROTHERS-IN-ARMS[6]. Therefore, the shoulder lift compensation (or shoulder misalignment) is calculated by comparing the Y coordinates (vertical axis) of each shoulder position, with a certain distance threshold, defined by the therapist (which dictates the tolerance of the matrix). On the other hand, the excessive flexion of the trunk (or trunk tilt) is calculated by comparing the X coordinates (horizontal axis) of two different spine joints in the virtual avatar, one at shoulder level and the other at the base of the spine, both obtained through the Kinect motion capture.

### The Report

Throughout the sessions, a lot of data is immediately accessible for the therapists to analyze and interpret, from the interface alone. Although, this is not enough to to fully understand the patient’s progression, and so it is critical that the most relevant data is exported into a report file and accessible at any time, after the sessions. This is done in our system as well. At the end of each set performed by the patient, some of the most important information is summed in a .csv data dump file so that the therapist can assess progression from one session to the next.

### Difficulty Adjustment

In Winning Compensations, each state of the state machine implemented will be defined as a different class and correspond to each one of the exercises implemented in the system. There are several advantages in using Unity interfaces like this:

- The system becomes completely plug-and-play;
- Each different state can be developed and worked on separately from the others, making the solution completely modular;
- The fact that each state is a different class greatly increases reusability.

Each interface implemented consists of only three different main functions that dictate how the exercise will work.

- **Enter()** is the function that dictates what happens once the exercise begins. Here is where all the necessary variables are initialized and the exercise enters a ready-to-execute state;
- The **Execute()** function is where everything concerning the functioning of the exercise runs. It is in this function that the several transitions between the difficulty sub-states occur, according to constant frame-by-frame, assessment of the performance of the patient. The difficulty parameters intrinsic to each exercise, such as amplitude, speed, precision, compensation tolerance and others, are tweaked inside this function, to consistently adapt to the capabilities and limitations of the patient executing the exercises;
- Finally, the **Exit()** function closes the exercise and defines which exercise will be played next, according to the exit conditions that resulted from the performance of the patient.

Each interface corresponds to a state and each state corresponds to a different exercise. The state machine that we implemented will be responsible for performing the transitions between the several exercises, according to the conditions that are met in their respective **Exit()** functions. Figure 4 provides visual support to this explanation.

Every exercise we implemented has a different set of parameters that are dynamically adjusted according to the performance of the patient, namely, the ratio between the correct repetitions and the total amount of tries.

In the **Target Reach** exercise, the professional can manipulate the size of both the targets and the cognitive spheres, the difficulty level of the exercise regarding amplitude and range (distance parameter) and the reaction time that the patient must have to activate each target successfully. The physiotherapists can also remove the cognitive spheres entirely if they are causing too much cluttering or confusion for the patient.

In the **Line Draw** exercise, the therapist can adjust the time available for the patient to activate
all the targets in each path. Naturally, less time increases difficulty. The therapist also chooses whether the exercise will be based on Horizontal or Vertical paths, and it is a mandatory choice, since the exercise won’t start if nothing is selected.

Finally, the Shapes exercise allows the therapist to select the different shapes that will dictate its difficulty and progressions, thus making it very customizable. The progressions are selected by the professional and adapted to each user’s specific needs. If the patient is not yet familiar with the exercise, the therapist may select from the simplest shapes in the selection library (as many or as few as they decide) and the exercise will just develop around those shapes. As the patient progresses, the physiotherapists can insert more variability into the exercise through combinations of simpler with harder shapes, as they see fit.

4. Prototype Evaluation

Usability

To collect the users’ perspective on the usability of the system in a clinical context, at the end of each test session, participants were asked to fill in a questionnaire on Google Forms, for each exercise implemented, designed according to the officially approved Portuguese version of the System Usability Scale[11]. The SUS questionnaire consists of 10 statements that the participants score according to a Likert scale that ranges from 1 (Totally disagree) to 5 (Totally agree). The total score of a SUS questionnaire can range from 0 to 100 and as stated in Martins et.al[5] an overall score of 68 or higher is considered above average usability while, on the other hand, less than 68 total score implies below average usability [11]. To calculate the IQR, first we needed to order the data set of the several scores for each statement, in each questionnaire, from lowest to highest, and determine the median of that range of values. Since the total amount of users was an odd number (15) the median was the value found in the middle of the data set by splitting it into two halves. Once the median is determined, we calculated the IQR using Equation 2:

\[ IQR = Q_3 - Q_1 \]  

(2)

With \( Q_1 \) and \( Q_3 \) being the median of the lower and upper halves of the ordered data (first and third quartiles), respectively.

Table 1 represents the values described earlier, calculated for each of the three exercises, using the QUARTILE.INC function from Microsoft Excel,
Table 1: Median and IQR values, calculated for each question in each of the three questionnaires filled in by each participant.

<table>
<thead>
<tr>
<th>Statements</th>
<th>Target Reach</th>
<th>Line Draw</th>
<th>Shapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think that I would like to use this system frequently.</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>I found the system unnecessarily complex.</td>
<td>2</td>
<td>2</td>
<td>2,5</td>
</tr>
<tr>
<td>I thought the system was easy to use.</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>I think that I would need the support of a technical person to be able to use this system.</td>
<td>2</td>
<td>2</td>
<td>1,5</td>
</tr>
<tr>
<td>I found the various functions in this system were well integrated.</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>I thought there was too much inconsistency in this system.</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>I would imagine that most people would learn to use this system very quickly.</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>I felt very confident using the system.</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>I needed to learn a lot of things before I could get going with this system</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 5 shows boxplots and whisker charts produced from the data in Table 1. Table 2 translates the data in the plots by showing the several quartiles, the Mean and the Range of each Boxplot-Whisker pair, for the Median and IQR of each questionnaire.

6. Conclusions
Winning Compensations is a gamification approach to physical rehabilitation exercises in the form of a visual biofeedback interface that uses dynamic and manual difficulty adjustment to monitor and help correct compensatory movements of patients with physical impairments of the upper limb, with a non-expensive setup and off-the-shelf hardware that allow for a cost-efficient and highly applicable solution, in the clinical context.

In the evaluation of the prototype, professional physiotherapists and finalist physiotherapy students provided us with expertise-based feedback on the viability of the solution in the clinical context they are used to, in their daily practice with patients with upper-limb physical limitations. To improve Winning Compensations, some suggestions for future work implementations were as follows:

- **The difficulty progressions in Target Reach** can be optimized to better suit the amplitude progressions that the physiotherapists usually do with their patients. The suggestion was to have Level 1 be the two inferior colored areas in the grid, Level 2 from the yellow to the red areas and Level 3 from the yellow to the green areas;

- **In the Line Draw and Shapes exercises**, the physiotherapists felt there was a need to better understand when the objective had been accomplished, not only through the audio cue. The color of the final target should be changed from green to another, more evident for the pa-
Table 2: Representation of the minimum value, first, second and third quartiles, maximum value, mean and range for the median and IQR values in each questionnaire (one per exercise).

<table>
<thead>
<tr>
<th>Questionnaire</th>
<th>Median</th>
<th>IQR</th>
<th>Median</th>
<th>IQR</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>FQ</td>
<td>2</td>
<td>0.625</td>
<td>2</td>
<td>0.625</td>
<td>2</td>
<td>0.125</td>
</tr>
<tr>
<td>Median</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>TQ</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Max</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>1.5</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>Mean</td>
<td>3.1</td>
<td>0.9</td>
<td>3.1</td>
<td>0.8</td>
<td>3</td>
<td>0.75</td>
</tr>
<tr>
<td>Range</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1.5</td>
<td>2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Figure 5: Boxplots and Whisker charts with the Median and IQR values for the three questionnaires

- Patient to know when the repetition was successful;
- **A Tutorial** before the start of each exercise, in the form of a virtual avatar demonstrating the exercise was also a common suggestion amongst the physiotherapists;
- **Changing the language of the interface**
  The fact that the Interface was written in Portuguese was pointed as a potential obstacle for the understanding of the system by some patients;
- **An End screen** with the main results from the current session in comparison with those of previous sessions was also an insightful feedback for future iterations of the project.

In summary, we achieved a functional prototype for a visual biofeedback interface in the form of a gamification tool to dynamically adjust upper-limb exercise difficulty based on compensatory movements. To assess the system, we evaluated its usability in a real clinical scenario with physiotherapy professionals. Future versions can take advantage of Winning Compensation’s modular architecture to easily improve the system.

7. Acknowledgements
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