Kinect-based biofeedback interfaces to improve upper limb rehabilitation

André Domingues
Instituto Superior Técnico
Universidade de Lisboa
Lisboa, Portugal
andre.domingues@tecnico.ulisboa.pt

ABSTRACT
A sedentary lifestyle and bad eating habits are leading causes of cerebral vascular accidents or strokes. Physical rehabilitation is often required to recover from upper extremity complications that commonly follow stroke. While computer-based interactive methods have been proposed to help defray person-hour costs, most require expensive hardware, lack good interfaces featuring user-centered biofeedback to detect compensatory movements or assist the collaboration between patients and physiotherapists. Our goal is to study the impact of the use of visual biofeedback tools in rehabilitation of patients with reduced mobility on their upper limbs in the physiotherapists day-to-day. We evaluated our prototype with physiotherapists and physical medicine and rehabilitation physicians. The study shown that all the professionals demonstrated receptivity in incorporating this system as a complement to their treatments and that this is a precursor to homebased rehabilitation, which can lead to a faster recovery.

Author Keywords
Rehabilitation; biofeedback; upper-limb; stroke; physiotherapists.

ACM Classification Keywords
H.5.2 Information Interfaces And Presentation: User Interfaces

INTRODUCTION
In the last decades, the population has been living a much more sedentary life, either because people sit or because they stand up all day without exercising their body. This lifestyle, combined with bad eating habits, are the leading causes of cerebral vascular accidents or stroke and they can also induce several injuries on tendons, joints and ligaments, reducing the well-being of the person and ultimately induce premature death [1, 2].

In 2014 were registered almost 23.000 cases of stroke in Portugal, with 86% of the cases being discharged from the hospital [4]. Despite the rehabilitation process does not reverse the neurological damages, it is often required to recover from upper extremity complications that commonly follow a stroke to better the patient’s well-being and overall condition.

It is known that there are health benefits correlated with regular physical activity that can prevent several chronic diseases (e.g. cardiovascular disease) and reduce the risk of premature death. There appears to be a graded linear relation between the volume of physical activity and health status, such that the most physically active people are at the lowest risk [5]. Therefore, including physical activity in the rehabilitation process of people who had a stroke and lost their mobility in the upper limbs is very important, both as a prehab, in order to prevent new episodes from happening, and as a rehab, to help improving the patient’s life despite the new physical limitations.

The rehabilitation process main goals are restoring the patient’s motor patterns, recovering cardiovascular health and musculoskeletal injuries. This process is divided into three distinct phases – evaluation, demonstration and execution. In the evaluation phase the physiotherapist does an assessment of the current health condition of the patient in order to choose the most adequate exercises to that particular case. Next, in the demonstration step the physiotherapist exemplifies how the patient should execute the exercises correctly. Finally, in the execution phase, the patient executes the exercises prescribed by the physiotherapist.

Most of the times, the execution step relies on some sort of guidance by a physiotherapist in order to perform exercises in the right way and build the right motor patterns. As there is not a one to one relation between the number of physiotherapists and patients, most of the times, the latter have to perform the exercises on their own. This creates the need of somehow assess if the person is doing the movements correctly and if there is any progression. There are three important concepts to have in mind in a rehabilitation process – repetition, feedback and motivation [6]. Learning motor patterns is a repetitive process that must be executed along with feedback in order to do the exercises correctly and motivation to keep the person doing the program prescribed.

The conventional rehabilitation approach has some problems associated with it. On one hand, it can be, most of the times, tedious and unattractive to the point that there is no motivation for the patient to complete the exercises. On the other hand, it can be very subjective as the physiotherapist does not registry all the measures that can be collected during the treatment process (e.g. the exact number of repetitions done correctly, the compensatory movements that occurred) either due to time constraints caused by the multitasking
demands of their profession or lack of ways to do so. Beside the presented problems, the conventional methods can also be expensive and not portable.

There are already some systems that try to make the rehabilitation process more attractive, portable and less expensive to the final consumer. All those solutions can track a person’s body and assess if the movements are being performed correctly. To do so, some require the use of kinematic sensors for the limbs [7, 8] but as they rely on using wearable hardware they can cause some discomfort and limitations to the natural movement of the body.

In order to try to counteract the use of wearables, there has been an investment in computer vision to track body movement. Two main types of systems are used – marker-based motion capture ) [9, 10] and RGB-D [11, 12, 13, 14, 15, 16, 17, 3, 18]. Marker-based systems use markers attached to the user’s body to track its position and movement in space while RGB-D systems use object recognition and depth to 3D map the body.

This type of systems also arises technical and scientific problems. Among the technical problems, we have the total cost of the systems being far from low and tracking the body motion accurately without using any wearables that interfere with the natural human movement. In a scientific perspective, we have problems like the usage of segment orientation to find if the user is doing compensatory movements during the exercise execution, and improving the collaboration and communication between the physiotherapist and the patient by using interactive and intuitive graphical interfaces. We consider that a compensatory movement is a movement that does not follow the right motor pattern to achieve a certain posture.

Scope and Objectives
In this work our goal is to study the impact of the use of interfaces as visual biofeedback tools to the physical condition evaluation, demonstration of exercises, and treatment of patients with reduced mobility on their upper limbs in the physiotherapists day-to-day. To achieve this, we propose a system called BROTHERS IN ARMS. This research project aims to create a system that can be used for rehabilitation at a physiotherapy clinic. The system must satisfy the following key points:

- Has non-invasive markerless motion capture;
- Assesses if the exercise is well executed;
- Has different GUI for the patient and physiotherapist;
- There is real-time visual and audible feedback to the patient;
- Can deal with physical limitations;
- Detect compensatory movements;
- Tracks progress along the treatment;
- Promotes collaboration and communication between the physiotherapist and the patient;
- It is relatively cheap;
- It is portable.

This work focused only on exercises that do not need any kind of equipment or objects to be in contact with the body. We expect that this system will not only help people to learn the correct execution of the movements in order to improve the performance of the patients, but also that they prevent injuries, the physiotherapists get less overloaded during their work and more people start doing some physical activity for their well-being.

Contributions
This master thesis presents both scientific and technical contributions to the physiotherapy paradigm. They include:

- A system capable of detecting compensatory movements during the execution of an exercise;
- A parameterizable system to adapt to the current physical condition of the patient;
- A system that can track the progress of the patient across the time;
- A study conducted along with physiotherapists and physical medicine and rehabilitation physicians and built iteratively accordingly their feedback;
- A system that does not require wearables to track the body motion;
- A portable and cheap system.

RELATED WORK
Rehabilitation
Recently there has been an effort in developing systems that allow patients to execute the exercises prescribed by a physiotherapist during a treatment process at home. Most of them focus on upper limbs rehabilitation, mainly on shoulder exercises. Despite existing systems that use wearable kinematic sensors for the limbs [7, 8], most of them rely on MoCap and tracking systems as Vicon [9], Optitrack [10] and Kinect [11, 12, 13, 14, 15, 16, 17, 3, 18]. There is also work made using a webcam [19].

In order to produce motor learning and cortical changes, a good rehabilitation system must not only rely on repetition, but also has to create a link between the repeated practice and incremental success in the proposed task (Fig. 1). Thus, it must follow the concepts of repetition, feedback and motivation [6]. Also, when dealing with repetitive exercises, the main goal should be divided into several sub-goals to increase the patient’s motivation either to perform and complete the task or to improve performance [10].

Architectures involving MoCap systems only are often preferred over the ones that require wearable markers or hardware. This happens due to the discomfort and, sometimes, natural body movement limitation that the wearables can provoke. Furthermore, if the sensors are placed incorrectly, they can generate errors in the measurements causing the collection of data that do not match with reality. Over this, there is also the inconvenient of, most of the times, this hardware being more expensive.
than the ones that only require a camera like Kinect [16]. Therefore, there are many systems which only need a camera and a display or a surface to display their interface.

One of the biggest problems of creating a solution that tracks the movement of the body properly and uses either VR or AR immersive techniques is the overhead of hardware used. There is a ratio between the quality of the data collected from the patient’s body and the cost of the equipment. Some authors refer that Kinect does not have the accuracy needed to be used in rehabilitation treatments because cannot detect well limb orientations and rotations, neither can deal well with occlusions, leading them to use other tracking systems [9, 10] like Vicon and Optitrack. But there is a downside to these systems. In order to get a better tracking performance, the patient needs to have markers on their body so the actual position of their limbs is known precisely, causing once again the same problems of discomfort and limitation of movement. Among the analyzed systems, there are a couple that require wearable accessories, like Physio@Home [9] and SleeveAR [10].

There are systems that rely on using multiple cameras, like Physio@Home and SleeveAR, in order to have multiple views and different capture angles, wearables to track the arm movement the costs of the system are far from low cost. Beside increasing the total cost of the system, the projector used by SleeveAR also requires a lot of physical space in a room, which is a problem if the patients want to do their exercises at home or without having a big reserved area in the physiotherapy clinic to the system.

Then, most close to the work we developed, we have rehabilitation systems that only require a Kinect camera and a display [11, 13]. Both systems are a lot cheaper and portable than the ones presented before, being this a big reason for us to explore the usage of Kinect as a clinical tool.

According to Morrison et al [12] Kinect can be used in situations where the patient does not need to hold big objects or wheelchairs that can lead the camera to think that it is a part of the body. This work also refers that games are a good motivation for rehabilitation treatments but they need to be configurable settings to define the velocity of the exercises to prevent frustration of the patient.

Finally, Krishnan et al. tried to build a low cost real-time motion tracking system using webcam technology [19]. The main difference between this system and one that uses Kinect is that this system works on the sagittal plane and the Kinect on the frontal plane. Despite they tried to make a low-cost system, they ended up spending ≈ $1100, which is a lot comparing to the price of a Kinect One (= $100).

Fitness
With the increase of people interested in living a healthy lifestyle there was a growth in the number of people in the fitness community. Alongside with this, there has been an interest in creating a system that allows athletes and the common user to train at home with some guidance without the need of having a coach in the same room. Although our work’s purpose is not solving an existent problem in the fitness community, all the works described in this section use Kinect as a tracking system [14, 15, 16, 17, 3, 18], which can be useful in order to adapt some of their ideas to the physical rehabilitation paradigm.

As referred in [20] by Tao et al., the optimal position of the Kinect is between 1.45 and 1.75 meters in front of the patient and 0.15 meters left or right (Fig. 2). This is considered a small space, which is convenient for people who use Kinect at home or in any other small rooms.

When performing free-weight exercises there is often equipment worn for safety reasons and to prevent the user from injuring themselves (e.g. wrist wraps, weightlifting belt, etc.) so a solution that does not have the need to use wearables is the best option, in order to be less obtrusive as possible [14].

Without the right execution of the exercises, injuries can happen and they can compromise the athlete’s life quality and physical performance. In [14] Connor et al. and in [15] Lisboa et al. shown that Kinect has sufficient precision to check if the user was doing the squat and the thruster, respectively, correctly.

With a bit different approach than the other fitness systems presented, Anderson et al. developed YouMove [3], a solution based the Kinect tracking system that uses an AR mirror instead of the usual screen. The idea behind the mirror is to emulate a traditional “ballet mirror” with graphic overlays for guidance and feedback. Despite the mirror presenting a real-time feedback it brings out space constraint problems and also elevates the total cost of the product. The authors also refer that Kinect has difficulty tracking movements that cause large amounts of occlusions.

All the rehabilitation and fitness systems presented until now consider non-collaborative activities, that is, the patient/athlete do not require the presence, either offline or online, of a physiotherapist/coach. On the other hand, Online-Gym [17] and Onebody [18] are systems where there are a direct relation between the athlete and the coach during the physical activity.

Cassola et al. presented Online-Gym [17], an exploratory project based on an online 3D virtual worlds platform that allows users to interact with the system through the use of a MoCap device such as Kinect. This system has the advantage of having multiple athletes being coached by only one coach but it lacks mechanism to assess in real-time if the exercises are being executed properly according to the movements of the coach.

Finally we have Onebody [18] a VR system for remote posture guidance using first person perspective proposed by Hoang et al.. The system utilizes a Kinect sensor for skeletal tracking of both the instructor and the student and each one uses an Oculus Rift has a display. Movements of both the
instructor and student are captured by Kinect sensors and rendered as virtual avatars in a virtual environment. By overlaying the virtual avatars of the instructor and the student, the system creates a visualization of first person perspective to deliver movement instructions, with the athlete "stepping into the instructor’s body". According to the author’s, training with concurrent feedback has a negative impact on skill retention, especially after the feedback has been removed, so Onebody is only aiming at the early stage if skill learning and not at skill retention. Like we analyzed before, the wearables are not comfortable to the users, being this a big complaint made to Onebody.

REQUIREMENTS ANALYSIS
Although there is already some research done on the field of AR and VR applications to the physical rehabilitation paradigm, we considered that talking with physical rehabilitation professionals was a good starting point to acknowledge their necessities and collect important requisites to the system we were trying to build. It is important to underline that we are trying to create a system that can be used in a real clinical environment.

In order to collect this requirements, we partnered up with professionals from Hospital Professor Doutor Fernando Fonseca (HFF) and Instituto Superior de Ciências da Saúde Egas Moniz (ISCSEM). There were several visits to both institutions to experience and talk about their daily practices while treating patients that suffered a stroke and had their upper limbs mobility affected. The main requirements collected from these meetings were:

- It must be possible to know how many repetitions were made and how many of those were successful;
- There must be a report where is registered what and how many compensations the patient has done during the exercise execution;
- The system must not give too much biomechanical data to their time constraints to analyze it;
- We should avoid infantilize the patients by using childish sounds or graphics;
- When a compensation is made the patient must start the exercise from the beginning;
- There should be rest periods;
- The system must be very graphically simplistic due to possible cognition constraints of the patient;
- The physiotherapists should be able to see the patients’ compensations in real time.

BROTHERS-IN-ARMS
After analyzing all the work made previously in using AR and VR in the rehabilitation and fitness paradigms and the collected requirements we detected that there are still some missing points in the current solutions regarding the information collected and real-world application. While computer-based interactive methods have been proposed to help defray person-hour costs, most require expensive dedicated hardware, lack good interfaces featuring user-centered biofeedback to better detect compensatory movements or assist the collaboration between patients and physiotherapists [21].

To approach these problems, we propose BROTHERS-IN-ARMS, a biofeedback tool built with inexpensive and commercial off-the-shelf hardware to help the demonstration of exercises, physical condition evaluation and treatment of patients with reduced mobility on their upper limbs in the physiotherapists day-to-day.

Architecture
In the previous sections we analyzed multiple systems that used different motion tracking systems like Vicon, Optitrack and Kinect. As we want to keep the BROTHERS-IN-ARMS’ total cost low we decided to use Kinect v2 (Kinect One) because, as it was shown in several works, it has the sufficient accuracy in the frontal plane to be used in rehabilitation. Beside this, we will be using a PC running Windows 10 to run the system and a pair of displays to show the interface. We chose to use displays to present the GUI over projecting it into a wall or the body of the user in order to minimize the physical space needed to use the system and also because of the cost reduction.

Unity application
To build BROTHERS-IN-ARMS we chose to use Unity3D platform due to due to its extensive list of open-source code, tutorials, projects and its simple integration with the Kinect v2. Our body recognition and composition is based on the official Microsoft example Skeleton Basics written in C#, which later we adapted to work in Unity3D. The collected body joints positions are all normalized so there is not a visual difference in the limbs size and distance to the camera when tracking distinct bodies with different sizes.

Prototypes
BROTHERS-IN-ARMS was built using a spiral development methodology, from which resulted the development of two prototypes.

On a biofeedback interface that helps the user to perform some type of physical activity, the visual feedback is very important. According to the physiotherapists from ISCSEM that we consulted, an ideal visualization comprehends a very minimalistic approach to avoid distractions and misleading the user to the point of affecting the exercise execution performance. So, in an effort to simplify the information that is shown to the patient, we split, in both of the prototypes, the app into two interfaces, one for the patient and the other one to the physiotherapist.

First prototype
This first prototype was intended to present the physiotherapists with the capabilities of the technologies we had at our disposal. It consisted on a visual playground with multiple biomechanical representations of the upper limbs. During the development of this first iteration we always kept in mind the need of minimalistic visualizations that allowed
to detect compensatory movements and in what ranges of motions they would happen.

Evaluation and results

After the development of the first prototype, informal evaluations were performed by two physiotherapists and three physical medicine and rehabilitation physicians to validate both interfaces. Each participant was asked to verify if the proposed interfaces could help analyze or aid the treatment of acute stroke patients with physical limitations of the upper limbs.

In the conducted interviews, all the interviewed participants indicated that distinct interfaces for the physiotherapist and patient is a meaningful feature, as the patient interface must be very minimalistic to avoid unnecessary distractions, whereas the physiotherapist must contain more data to help the detection of postural problems and compensatory movements.

For the patient interface, it is important to track the successfully completed repetitions, the session time of the proposed task and to display a few targets to be reached. As for the targets of the exercise, it was suggested to have multiple predefined exercises in order to accelerate the setup process.

As for the physiotherapist interface visualizing the arm movement angles is not very important because it is not a part of their tracking progress protocol. Hereupon it is more important for the physiotherapist to detect where the compensations occur and quantify them in order to track progress between sessions. It was also referred that was needed a way to track progress and was suggested to generate a report at the end of each therapy session.

Operational prototype

After the demonstration of the first prototype and the informal review by the health professionals we built an operational prototype based on their comments and suggestions. This prototype was built regarding some of the concepts studied in the previous works presented on the Related work section. We had into account that the system must have not only be repetitive but there should be an incremental success when doing the exercise correctly to promote a link between the correct execution and the success in the task proposed, so what we have built promotes the concepts of repetition, feedback and motivation.

Physiotherapist’s Interface

In the physiotherapist’s interface, the user starts by selecting the exercise from a list of predefined exercises that the patient should execute and which arm is going to be used. Then, the user is presented with a screen with multiple parameters that can be set in order to customize the exercise to the patient’s current physical condition. Under the customizable parameters the user can define the number of repetitions the patient must execute, the duration of a set and the duration of the rest period.

After defining these parameters, the physiotherapist has access to a new screen (Fig. 1 - a) in which is observable a humanoid, composed of capsules, that represents the patient’s body position in space and its movement. In this screen, the physiotherapist can also define which compensations should the system detect, having shoulders height unevenness and spine lateral inclination as options. In this case, there is the option to define misalignment thresholds because of what the physiotherapists consider a compensation depends of the current physical capacity of the person, which is assessed when the patient is diagnosed before the treatment. In order to be possible to fit these thresholds to the patient current mobility and to the exercise chosen, it is displayed the exercise path and targets to allow the simulation of the exercise execution before starting the session.

In this view, the physiotherapist has access to all the information about the current session, in which are included:

- The number of correct repetitions;
- The number of tries to do the exercise;
- The time elapsed since the beginning of the session;
- The time to the next rest period, the average time per repetition;
- The name of the exercise being executed and the count of compensations grouped in the number of times the patient has leaned, lifted the shoulders and was out of the predefined path;
- The path and targets of the exercise being executed.

This interface has also the capability of informing the physiotherapist if the patient is doing the exercise correctly without any compensation and, if not, either an arrow shows up near to the patient’s body representation to indicate where the compensation is occurring and how to correct it or the path turns red when the patient’s hand is out of path (Fig. 1 - b).

![Fig. 1 - (a) Physiotherapist’s exercise evaluation and demonstration before beginning the treatment session. (b) Physiotherapist’s compensatory movement visual feedback.](image)
**Patient’s Interface**

On the other hand, in the patient’s interface the user is presented with the exercise chosen by the physiotherapist. While executing the exercises in this view, we must ensure that only important information is shown in order to prevent distractions that can lead the user to committing errors.

Before starting the treatment session, the patient is presented with the same representation of its own body (Fig. 2 - a), like in the physiotherapist's interface, and the targets and path of the exercise that must be executed. At this time, the path and targets are only there as demonstration and evaluation steps, so the patient is able to simulate the execution of the exercise and the physiotherapist configure the compensation thresholds and learn how to execute the exercise properly.

Then, after the demonstration and evaluation, the physiotherapist starts the session and the user is presented with a countdown, so there is time to get into position to start doing the exercise (Fig. 2 - b).

![Fig. 2](image)

**Fig. 2** - (a) Patient's Exercise evaluation and demonstration screen. (b) Patient's countdown before starting the exercise.

After this, a series of targets that must be reached by the patient and a path between them is displayed (Fig. 3 - a) so the user can execute the exercise motion correctly and keep motivated to continue the exercise until the end. We chose to have multiple targets across the path so the exercise is divided in several sub goals and the patient is able to have an incremental success in between the start and the end of a repetition [8]. Whenever the system detects a compensation the patient is required to restart the exercise in order to avoid creating bad motor patterns.

Beside this, it is shown information that describe the current state of the exercise, like the total time of the session, the remaining time until the next rest period and the number of repetitions that were correctly executed. In this interface, there is also audio feedback when a target is hit. Finally, when the patient is done with all the repetitions defined by the physiotherapist a message is shown to congratulate the effort made (Fig. 3 - b).

![Fig. 3](image)

**Fig. 3** - (a) Patient's exercise execution screen. (b) Patient's exercise completed screen.

Regarding the visual feedback for the patient, it is only given when its hand goes out of the path. This was a thought-out decision made by the physiotherapists when we asked if the patient should have the compensations feedback. The feedback was discarded due to the possible cause of misinterpretations by the patients of what they are doing wrong and creating demotivation. In this situation the physiotherapists prefer to collaborate with the patient and explain how they can correct their motor pattern.

**Report**

As it is very important for the physiotherapists to collect relevant data about the performance of the patient in order to assess progression across time during the whole treatment process, a report is generated at the end of every exercise session (Error! Reference source not found.). The report is generated in the csv format which allows posterior generation of charts that allow to visualize the progress in more expressive manners (Error! Reference source not found.) (i.e. create a bar chart to compare the number of tries and correct repetitions of every session). Each exercise is represented by a csv file and each file contains the following information:

- Exercise name;
- Arm used;
- How long was session;
- Number of tries;
- Number of correct repetitions;
- Average time per repetition;
- Number of rest periods;
- Number of times the patient got out of path;
- Number of times the patient leaned left or right and lift the right or left shoulders above the threshold.

**EVALUATION**

Despite already existing some studies related to visual feedback in the physical rehabilitation paradigm, we have not found any study that validates the use of these type of biofeedback tools at a clinic in a real scenario that included...
daily basis activities like demonstration of the exercise, evaluation of the patient’s condition and execution.

As we wanted to assess the impact of the use of interfaces as visual biofeedback tools to the demonstration, physical evaluation, and treatment of patients with reduced mobility on their upper limbs in the physiotherapists day-to-day, we conducted all of our tests along with physiotherapists and physical medicine and rehabilitation physicians. Each session comprised 5 stages: 1) Introduction, 2) Free experimentation, 3) Task execution, 4) Questionnaire, 5) Semi-structured interview.

RESULTS

Participants profile
Our prototype evaluation was carried out with 13 health professionals, 6 were men and 7 were women, 3 with ages comprised between 25 to 35, 8 between 36 and 50 and 2 with more than 50. Among these 4 were physiotherapists, 6 were physical medicine and rehabilitation physicians and 3 were occupational therapists. 8 of the participants had 23 or more years of experience. Only 1 uses Mocap systems once a week while 2 uses once a month and 10 never uses. 6 already had experience in using Mocap systems to treat the patient’s. In terms of visual biofeedback interfaces, 10 never uses while 1 uses every day and 2 once a month.

Questionnaire results
The goal of the presented questionnaire was assessing if the choices we made for our interfaces were able to give the physiotherapist and the patient what they need and expect from a visual biofeedback system that promotes the upper limbs rehabilitation. On the following sections, we analyze the answers given by the health professionals to the questions made regarding both the physiotherapist’s and patient’s interfaces.

Physiotherapist’s interface questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Was the prototype easy to use? (Front raise)</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>2 - Was the prototype easy to use? (Lateral raise)</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>3 - Was the prototype easy to use? (Hand to mouth)</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>4 - Was the prototype easy to use? (Comb hair)</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>5 - Was the prototype easy to use? (Fill the cup)</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>6 - Was easy to define the compensation thresholds?</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>7 - Was easy to know how many repetitions were correctly executed?</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>8 - Was easy to know how many tries the patient made?</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>9 - Was easy to identify what compensations occurred? (Misaligned shoulders)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>10 - Was easy to identify what compensations occurred? (Spine misaligned)</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>11 - Was easy to identify what compensations occurred? (Out of path)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>12 - Is the final report useful?</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>13 - Do you think that the quantity of the presented information is the ideal?</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1 - Physiotherapist’s interface questions with median and IQR calculated from the responses.

By analyzing the responses given (Table 1), it is possible to conclude that almost every test subject thought that the physiotherapist interface was very easy to use and to setup for all the presented exercises (IQR = 1.5). Besides this, there was very little difficulty in analyzing the information presented on the screen, like the number of repetitions executed correctly, the number of compensations, etc. (IQR = 1.5). Regarding the visualization of the compensations seems to be less consensual and this might be because of the expectations they had of what a compensation definition is (IQR = 1.5 and IQR = 2). Like some doctors and physiotherapists said, they were expecting the compensations to be presented by the form of what muscles were being used to create the wrong motor pattern instead of pointing out that the posture was wrong and how should the patient correct it in terms of body position. Then there was also some disagreement regarding the usefulness of the final report. According to some physiotherapists it would be more useful for them to have some charts generated automatically that could be easier to interpret than an CSV. Finally, most of the testers thought that the presented information is sufficient to their needs.

Patient’s interface questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Median</th>
<th>IQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Was the prototype easy to use?</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>2 - Were the targets and paths easy to identify?</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>3 - Do you think that the quantity of the presented information is the ideal?</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>4 - Was easy to know how many repetitions were correctly executed?</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2 - Patient’s interface questions with median and IQR calculated from the responses.

Despite this evaluation being performed only with health professionals, we considered very important to collect their thoughts regarding the patient’s interface due to their direct relation to the patient’s and knowledge about their behavior. The analysis made to their answers (Error! Reference source not found. and Error! Reference source not found.) concludes that most of them considered that the prototype was really easy to use in the patient’s perspective (IQR = 1), the targets and path of the exercise and the number of repetitions correctly executed were fairly easy to identify (IQR = 2). As for the quantity of presented information there was a bigger disagreement (IQR = 2.5) that can be justified by some test subjects thinking that for some patients would be useful to have presented the compensations detection visualizations like the one presented on the physiotherapist interface. They think that some people with more cognitive capacity would benefit from having that feedback.

Interviews and discussion

While conducting the interviews we tried to understand how would this type of systems would affect, either positively and negatively, the physiotherapists daily work. Most of the
interviewed agreed that this prototype would be very useful in their daily activities to treat not only patients that have reduced mobility on their upper limbs caused by a stroke but also every other pathology that compromise the upper extremities range of motion (e.g. osteoarticular pathologies). According to the doctors and physiotherapists, there is also the possibility for adapting this system to be used at home by patients that do not have cognitive problems, which they affirm to be a great part of the population due to the simplicity of our system. This suggestion comes from a problem they are facing today, the lack of health professionals to rehabilitate the population. Having a system that could be used at home by the patients not only would allow the physiotherapists to treat more patients at the same time but also would allow to increase the frequency of training of that population, which could result in a faster recovery from the injuries. They consider that “homebased exercise will be the future”. Beside this, there was also the suggestion to adapt this system to a diagnose scenario to detect torso leaning in patients that suffer from Parkinson and even to detect imbalances in healthy people that practice repetitive motor patterns during their professional tasks (e.g. dentists, bricklayers, etc.). The physiotherapists also mentioned that this was one of the fastest setup they made on a system of this type due to the lack of using wearables and only being necessary for the patient to be in front of the camera.

As engineers, we try to translate everything into tangible metrics so it becomes easier to compare anything. Following this premise, we tried to make the treatment more objective and quantifiable by detecting and counting the number of compensations, counting the number of correct repetitions, etc. This approach was approved by all of the surveyed health professionals, with them affirming that their evaluation without this type of systems is very subjective and sometimes this leads to a hard time to explain to the patient what is incorrect on their cinematics, mainly on patients that have a wrong perception of how their body should be positioned. They also think that this is the only way to demonstrate efficacy of their therapeutic methods and publish valid results.

Being this a system built with the purpose to be used in a real rehabilitation scenario we always kept in mind that the system should be the most minimalistic possible, as the test subjects confirmed it should be, either due to the time constraints of the physiotherapist or due to the possible cognitive issues that the mistake come with. After testing our system, the physiotherapists have confirmed that despite the system might not be suitable for all the patients due to cognitive issues, there is a big part of the population that can enjoy of this new rehabilitation method.

The communication between the physiotherapist and the patient is one of the main pillars of the rehabilitation process and one of our goals was to improve it through the use of our system. All the test subjects affirmed that our prototype has the capability of improving the collaboration and communication between the patient and physiotherapist because the visual feedback given is an added value to help explain to the patient what is being executed incorrectly and how should it be fixed.

There are two types of diagnose that are made, the medical diagnoses done by the physical medicine, preformed before starting the rehabilitation, and rehabilitation physicians and the functional diagnoses made by the physiotherapists. On one hand, according to the physicians, this type of system cannot add or facilitate nothing to their diagnose, so in this case is not very useful. On the other hand, the physiotherapists said that they could use this system to detect changes in the patient’s motor patterns.

Despite the physicians and the physiotherapists foreseeing the potential of using these biofeedback tools that are emerging, they never consider them as tools that will replace the conventional rehabilitation practices but more as a complement that can accelerate the treatment process, at least with the features that they have available for now. I think that maybe when we become capable of detecting limbs rotation with very little error it will affect their opinion on this matter due to the limitations caused by not having a proper rotation detection method.

Since the beginning of the development, we had always kept in mind that we should follow a minimalistic approach in the interface design but we did not know how much simplistic it should be. Regarding the patient’s interface, despite most of the surveyed health professionals agreed that had enough information, there was a physiotherapist that suggested that there should be an option to allow people with none cognitive problems to see their compensations, as this would allow them to understand what they are doing wrong and try to counteract the negative feedback by using a trial and error approach. Regarding the physiotherapist’s interface, they affirmed that it could be more complex as long as it remains simple to use. For instance, although most of the physiotherapists can predict in which side the compensation will occur in a unilateral exercise, there are some patients that might compensate on the opposite side. Adding to this, on bilateral movements, it will be much more difficult for them to predict in what side the compensation will occur, so it is important to us to add this information to the interface. They also added that the data collection should be the most sensitive possible and that the physiotherapist should have the option to show/hide all the information available.

Being the visual feedback one of the main purposes of this biofeedback tool, we wanted to know if the presented graphics were enough or if they should be still improved. Most of the professionals thought that the humanoid representing the patient’s body, despite it does not represent the limb rotations, was sufficient to evaluate instantaneously the patient’s cinematics but it still misses some personalization options, like adding the patient’s face to the the avatar’s head. From a medical stand point, the physicians
affirmed that it makes total sense to add back the old amplitude of movement visual representations that we implemented on the first prototype, although it does not serve any purpose while executing exercises, it could be useful for the physician to track the progression of the patient during the treatment. As for the graphic elements that represent the compensatory movements (arrows, colored lines, etc.) all the professionals agreed that were enough to represent what compensation was occurring and how should it be corrected.

Despite the enthusiasm and the happiness demonstrated by all the participants while using our system because, in their words, “this was the most sensitive system of this kind” that they ever used, we also wanted to know if they felt that we were missing some features. Almost everyone agreed when asked if the avatar should be displayed in other planes because, for instance, if we display the avatar in a lateral plane (sagittal plane) we could detect more compensations (e.g. torso inclination in this plane). Regarding the compensatory movements detection, it was also suggested that we should consider the cephalic tilt in exercises like combing the hair or hand to the mouth due to its frequency in these movements. As for audio feedback, some suggested that audio feedback would be useful only for people with vision problems and it should be used to inform the patient if something is being executed incorrectly and to congratulate when the exercise is over. To the rest of the population, audio feedback must be avoided because, as the physiotherapists said, “it affects the neurologic structure of the motor pattern learning”. This being said, it is important to have some audio feedback but with the possibility of turning it off.

All the exercises presented were defined as a proof of concept and, as it was depicted by the professionals, the amplitudes defined assumed that the patient would achieve a full range of motion in the exercise proposed, which most of the times is not what happens in a real scenario. Despite being able to adjust the compensation detection threshold and they thinking this is very useful in some exercises, it is not enough for people who have limitations. Hereupon they suggested that the physiotherapists should have the possibility to define the placement of the targets so it could be adapted to the current physical condition of the patient. Finally, they underlined the importance of our system being able to work when people were holding objects like bottles and cups in the fill the cup exercise and to do the exercise while sitting.

At the end of the interviews several physiotherapists shown interest in keeping the system in their clinics so they could test it with their patients and two of them even mentioned that “the project is following a good path of development in order to achieve a final product with a great potential to be used in our work”.

CONCLUSION
In this document, we address the impact of the use of interfaces as visual biofeedback tools to the demonstration of exercises, physical condition evaluation and treatment of patients with reduced mobility on their upper limbs in the physiotherapists day-to-day.

There are already some systems that try to make the rehabilitation process more objective and quantifiable but they still have some challenges to address. This type of systems still arises technical and scientific problems. Among the technical problems, we have the total cost of the systems being far from low and tracking the body motion accurately without using any wearables that interfere with the natural human movement. In a scientific perspective, we have problems like the usage of segment orientation to find if the user is doing compensatory movements during the exercise execution, and improving the collaboration and communication between the physiotherapist and the patient by using interactive and intuitive graphical interfaces. We consider that a compensatory movement is a movement that does not follow the right motor pattern to achieve a certain posture. Besides this, we have not found any relevant study that was totally conducted along with health professionals, like physiotherapists and physicians, that confirmed that these systems could be used in a real rehabilitation scenario.

To solve the stated problems, we proposed BROTHERS-IN-ARMS, a biofeedback tool built with inexpensive and commercial off-the-shelf hardware to help the demonstration of exercises, physical condition evaluation and treatment of patients with reduced mobility on their upper limbs in the physiotherapists day-to-day.

We conducted an evaluation with both physiotherapists and physical medicine and rehabilitation physicians in order to prove if this biofeedback tool could be used by them in a daily basis to treat patients with upper limb movement limitations. The tests concluded that despite the system is still missing some key points that would make it full usable in a real treatment, like allowing the physiotherapist to define by its own the targets, all the professionals demonstrated receptivity in incorporating this system as a complement to their treatments, to the point that several physiotherapists asked if we could leave the prototype running in their clinic. It was referred that this could help accelerating the treatment process, due to the short setup time and creating some independency in patients that have cognitive capacities to execute the exercises by themselves and that this is a precursor to homebased rehabilitation, which can lead to more frequency in exercise execution and consequently to a faster recovery. As so, it is possible to assume that we are making the right decisions in creating this type of biofeedback tools adapted to the physical rehabilitation process. The future passes by turning the rehabilitation process more objective and quantifiable and this can be achieved by systems like the one we present in this work.

ACKNOWLEDGMENTS
I acknowledge the financial support supported by national funds through the Portuguese Foundation for Science and Technology with reference IT-MEDEX PTDC/EEI-SII/6038/2014.
REFERENCES


