Tele-Rehabilitation Platform for Upper and Lower Limb in Elderly Patients, the HEAD Project.

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***Abstract*—Tele-rehabilitation systems have been increasingly studied, becoming an important complement to traditional therapy as they can provide high-intensity, repetitive and interactive treatments of the injured extremities. Several systems have been developed in research projects and some of these have become products mainly for being used at hospitals and care centers. After the initial rehabilitation performed at rehabilitation centers, patients are obliged to go to the centers, with many consequences, as costs, loss of time, discomfort and demotivation. However, it has been demonstrated that patients recovering at home heal faster because surrounded by the love of their relatives and with the community support. So, there is a strong need for rehabilitation systems to use at home. There are already some devices available on the market for home care: their main weakness is the limited strategy for motor learning. The ambition of the Human Empowerment Aging and Disability (HEAD) project is to combine assistance with appropriate feedback to close the loop in motor learning strategy for the home. HEAD platform challenging objective is to develop a novel tele-rehabilitation system and related provision services for a holistic rehabilitation aiming at restoring limb motor functional abilities, and at launching both system and services at home. The tele-rehabilitation system is based on the use of low cost sensors, connected with a gaming module for cognitive-motor rehabilitation, and integrated with an infrastructure connecting the patient at home with therapists at hospitals who monitor the rehabilitation exercises.**

Keywords*–*Tele-rehabilitation; Gaming; LeapMotion; Kinect.

I. INTRODUCTION

According to the World Health Organization (WHO), within the context of the action plan 2014-2021 entitled 'Better health for persons with disabilities', currently there are 150 million adults, i.e., 1 out 7, worldwide who are experiencing significant difficulties functioning. Not only, it is foreseen that the disability prevalence will increase more and more. As stated by the EC communication on Disability Action Plan (2006 2007), ageing is strictly interconnected with disability prevalence. 30% of people aged between 55-64 suffer of some form of disability, and 63% of the people with special needs are older than 45. According to the European Disability Forum (EDF), there are 80 million Europeans with disabilities. This is over 15% of the whole population. According to the European DG Health and Consumers, ageing is one of the greatest social and economic challenges of the 21st century for European societies. It will affect all EU countries and most policy areas. Let us consider that according to The World Bank Database, today the European population aged 65 or over is 18%, (90 M people), and it is expected that by 2025, more than 20% of Europeans will be 65 or over, with a rapid increase in numbers of over-80s. Unfortunately, ageing is also related to an increase of diseases and disabilities. Strictly related to the ageing of the population, stroke is the most common cause of adult disability in Europe. Currently, the European incidence is equal to 2 every 1000 persons (that is, around 1M people), but also in this case, it is foreseen that this number will double in the next 50 years. Due to the improvement on the medical stroke treatment, the 75% of people who have been affected by a stroke can survive, however about the 50% of those survivors suffer from serious disabilities, thus being not able anymore to live independently at home. It is, therefore, possible to state that with a population that more and more gets old, thus encountering more disabilities, there is the need to find new solutions for improving the quality of life of these people, by helping them in recovering their motor and cognitive skills. Today, approximately half of stroke survivors access some form of rehabilitation on discharge from acute services. Moreover, it has to be taken into account that the rate of people with disabilities or long-term health problems all over the EU Member States is estimated at 15.7% of the working-age population (around 49 Millions of the EU's overall working-age population). Thus, disability is one of the main challenges to be faced at different levels (EU Communication European Disability Strategy 2010-2020: A Renewed Commitment to a Barrier-Free Europe).

In order to improve the quality of life of the people with special needs, the WHO has drafted some recommendations: - make health care affordable; - invest in specific services such as rehabilitation. Specifically, the ambition of HEAD Platform is to strengthen and extend rehabilitation services, including community-based rehabilitation, and assistive technology. Because patients with disabilities have different healthcare requirements, the HEAD platform will be adapted to patients needs so as to provide adequate care and remain financially sustainable. There are also reasons related to the social rights, which urgently require EU to address rehabilitation issues. A study by the European Foundation for the Improvement of Living and Working Conditions has highlighted that there are ten risk factors for social exclusion. Among them we have: the disability, long-term unemployment, low quality employment or absence of employment record, health. Moreover, people with disabilities have often to stay in hospitals or residential houses, in order to be able to perform the rehabilitation. In Europe, hundreds of thousands of people with disabilities, mental health problems, older people live in large institutions. There they are alone, not connected with the society. And also, according to the European Disability Forum, more than 200.000 disabled persons in Europe are forced to live in closed institutions deprived of the most fundamental social rights. The Europe 2020 strategy has set ambitious targets for inclusive growth requiring action to be taken to promote integration and adequate livelihood of people with special needs. The HEAD results will be fundamental to contribute to the enhancement of the possibilities of people with disability to do the rehabilitation at home, surrounded by the love of their relatives, and also with the support of the community where they live.

A. Main ideas, models and assumptions involved

On the basis of the considerations discussed in the introduction, it follows that the society needs new rehabilitation systems dedicated to upper and lower limbs with additional capabilities, features and related services that have a more holistic approach to rehabilitation:

- offering a more effective and customized therapy for the rehabilitation of upper and lower limbs, which address cognitive and motor deficiencies, allowing for an easy customization and definition of exercises tailored on specific patients and specific rehabilitation targets, enhancing human-computer interaction through gaming, and engaging the patients in a more motivated and long-term rehabilitation program by focusing on complex, global and rewarding exercises;
- offering the possibility of performing rehabilitation programs in autonomy, without the need of the continuous presence of therapists, but under their continuous monitoring, and which can be performed quietly at home;
- allowing therapists to use a complete and rich set of data recorded from the exercises executed by the patients to improve knowledge on rehabilitation and therapies.

B. The innovation potential of HEAD Platform

The innovation potential of the HEAD Platform is:

- at technological level: novelty of the integration of low cost tracking devices (kinect, LeapMotion, etc.), combined with games, in the rehabilitation sector;
- at rehabilitation therapy level: more effective therapy that is customised to patients, motivating, rewarding, monitored, plus a novel knowledge based system for therapists and physicians;
- at socio-economic level: better quality of life for impaired patients and their family, thanks to a better rehabilitation service, and decrease of social costs of the rehabilitation practices; better exploitation of therapists skills and time, which also means an increased number of patients they are able to assist.

The HEAD Platform system features have an innovation potential on the kind of rehabilitation therapy that it will be possible to perform. Patients will be able to make the rehabilitation at home, on a regular basis, enjoying themselves and with more motivation and consciousness of the improvements, and being remotely monitored by the therapists. This will have an important effect on the patients. It is foreseen that patients will be able to reacquire the lost motor skills in shorter time because they can practice more often, for longer time, executing dedicated and customised exercises. Besides, it is expected a lower abandonment of the therapy, as it will be more pleasant and motivating. Extremely important is the fact that the rehabilitation will be performed in a family context. It has been demonstrated that patients recovering at home after a period spent in hospital, being with their loved ones and with their belongings, heal faster. So, being at home is very important from the psychological point of view, and this impacts on the quality and time of the recovery. Therefore, we can say that the innovation potential of HEAD Platform will bring benefits for patients, and consequently, there will be also important effects on society and societal costs. First, family members won't be obliged any more to absent work to accompany the patients to care centers. Then, if the skills will be reacquired more rapidly and completely (or very close to) the persons can improve their general quality of life, reacquire their independence and eventually can be re-integrated in the workplace.

C. Main outcomes

Therefore, HEAD Platform aims at addressing rehabilitation problems and shortcomings as listed in the Introduction:

1) Patients will be more motivated to do therapy following the prescription of the therapist thanks to the playful and entertainment character of the system. The hospitals participating to the project expect that along the rehabilitation treatment at least 60% of patients perform therapy in a more exactly and individual adapted way than now (with habitual rehabilitation treatment), and also that after the neuromotor stabilization rehabilitation (when patients usually are discharged from rehabilitation centers), 70% of patients will continue rehabilitation activities at home, on a regular basis. This would be a higher percentage compared to the present figure of 10%.
2) The clinic partners make the assumption that patients will be more motivated to perform the exercises when using the HEAD platform, so they are expected to exercising on a regular basis as prescribed by therapists, and also that the system will allow therapists to customize exercises to be more focused to the specific psycho-motor problems of a single patient. Consequently, it is expected that the recovery of the skills that one can get is in a shorter time compared to those obtained through the rehabilitative practice currently in use. The estimate is that the time is shortened by 20%.
3) As a result of the fact that the patient will be more relaxed during the sessions of rehabilitation, which can be made using a modality entertainment and even at home, the patient's psychological state and well-being will certainly increase considerably. In order to assess if the HEAD platform will definitively improve the general well-being of the patients, a set of 'quality life questionnaire' will be prepared. It will be administered to the patients at the beginning of the rehabilitation treatment, at an intermediate period (according to the length of the rehabilitation treatment) and at the end. The questionnaire will be also administered to the caregivers of the patients, so as to gather a larger perspective on the issue.

The paper is organized as follows. Section 2 presents an overview of related about gesture interaction systems. Section 3 presents the HEAD Platform architecture. Section 4 describes one example of the HEAD rehabilitation exercise. Section 5 describes user study approach and its preliminary validation. Finally, Section 6 draws some discussion and conclusions.

II. Gesture Interaction

We have developed a visualization and interaction system integrated with the gaming module that visually renders the virtual environment for rehabilitation and also the user's virtual hands and body in real-time. This functionality requires tracking the user's hands and body in the physical space. In order to provide a realistic immersiveness, the tracking and the representation of the user's hands and body in the virtual environment should be accurate and timely. In fact, some studies have shown that if the users are able to see the virtual rendering of their hands and legs and their movements relative to the movements of other objects there is a much better chance that they will feel that the virtual hands embodies their intentions and actions [1].

In designing the system, we have considered the new generation of so-called 'natural user interfaces' (NUI) technologies [2], which track the user's hands, fingers, or entire body in 3D, without wearing any kind of invasive device. Free-hand gestures can provide effective and natural methods for 3D interaction with virtual shapes, which can provide fluidity in the interaction.

Traditional haptic systems [3][4] and desktop interaction approaches, typically based on devices, such as keyboard and mouse and touch pad interfaces, are often designed for 2D interfaces and consequently are less effective and usable for 3D interaction [5]. In addition, many of the techniques that are used for 3D interaction require the user to wear or hold 3D tracking devices and also require several markers attached to the user's hand or body. The use of markers can make the system more difficult to configure and is inappropriate for some scenarios. Reasonably precise 3D sensing techniques, which can recognize freehand movements, are now available at low cost (e.g., Microsoft Kinect, Asus Xtion, and Leap Motion). These types of devices do not require on-body attachments or hands-on tracked devices, thus enabling very low configuration interaction. In this way, users can interact with the system naturally through their hands or body movements, without using complex commands.

However, simply because the interface is based on 'natural' gestures, this does not reduce the need for careful interface design [8].

Gestural interaction techniques have been investigated for a long time and different gesture types have been designed and evaluated. For example, for the selection of occluded targets on small touch screens using a finger [9]. Gestural selection has been explored in order to select distant targets on large displays [10]. Early freehand interaction systems needed fiducial markers on the users or data gloves in order to track the user's gestures. For example, the authors in [11] used the movements of fingers to simulate "mouse-clicking" and also to investigate freehand gestural interaction with ambient displays [12] developing design principles and an interaction framework for interactive public ambient displays. Bimanual marking menu selection [13] used a kinect system at clese range to track the finger's pose and movement to select from a marking menu. However, this method requires setting up the camera under the desktop at a specific angle, so losing the convenience of free hand interaction. In [14] is presented a Kinect One sensor-based protocol for the evaluation of the motor-performances of the upper limb of neurological patients during rehabilitative sessions. Freehand gestural input has also been explored for virtual object manipulation [15] including on curved surfaces [16] and projected directly on to everyday objets [17]. In this research, it is illustrated the importance and immediacy of freehand gestural interaction in daily life use cases. Participants felt that freehand pointing is intuitive but needs more precise operation. There is a lot of previous research on object and option selection in both 2D and 3D interfaces, however, most previous research used hand-held tracked devices or fiducial markers to enable camera-based tracking [5].

III. The HEAD platform

The HEAD platform allows us to implement a set of exercises for upper-limb and lower-limb rehabilitation. The interaction with virtual objects is performed through hand and body movements and gestures. The most innovative aspect of the platform is that the interaction is performed by using the LeapMotion and the Kinect sensors in a unique platform. The following section describes the HEAD platform components in detail.

A. Hardware components and software modules

The system is easily customizable and provides a simple environment for project deployment to use with multiple platforms, with no need for additional configuration. The HEAD platform consists of the following hardware components:

- a computer;
- Leap Motion controller, used to track the users' hand movements and to detect gestures;
- Kinect controller, used to track the users' body movements and to detect gestures;
- FITBIT bracelet which measures the amount of physical activity.
- PC speakers or headphones, used to render sounds.

For what concerns the software modules, after comparing several gaming engines, Unity3D R5 environment [6] has been selected for the implementation of the visualization and interaction. The main reason for selecting Unity3D is that it has a powerful interface that allows visual object placement and property modification during the interaction. In particular, the required features of Unity3D for the development of the games application are as follows: 3D rendering of virtual shapes; Graphical User Interface (GUI); Physics engine (used for handling collision detection); Collision detection; Integration with Leap Motion and KINECT (used for user's gesture recognition).

B. Head Platform Architecture

The HEAD platform is used by the patients, by the neurologist in charge of the patient and by other clinical specialists (e.g., by the neuropsychologists and physiotherapists). Each of the users has proper functions: the patient can see the daily exercises therapy, the neurologist can assign, modify or evaluate the therapeutic plans, the medical personnel can check how the rehabilitation is going. The main characteristic of the HEAD platform are related to the possibility for the clinicians to assign rehabilitation plans to be performed at home, and the holistic approach to rehabilitation, as the plan includes physical, cognitive and behavioural therapies/exercises. The interaction of the different users and the logical architecture of the platform are showed in Figure 1.

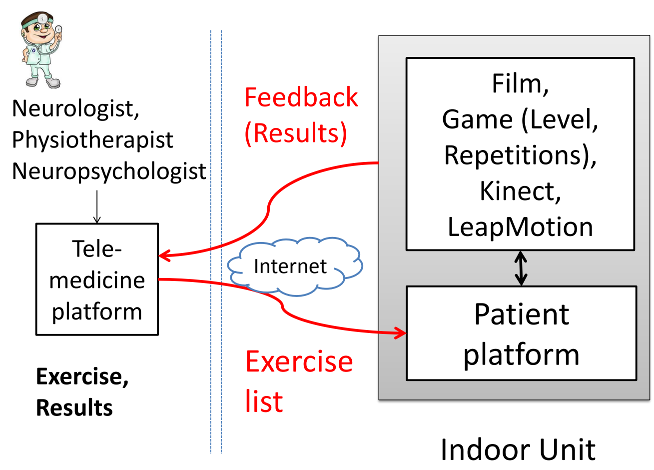

Figure 1. Head Platform Architecture.

The Indoor Unity represents the patient's interaction with the platform. The patient might be equipped with different devices that can be provided with the HEAD platform: a dedicated PC, used by the patient to see the daily activity exercises; an activity tracker (FITIBIT©) to measure the amount of physical activity of the patient. The platform foresees also other devices, which are used only at the hospital (e.g., an EEG portable helmet to measure variations in the brain activity of the patients during specific cognitive or attentive tests). All the patients data is stored in a clinical based certified database which is managed by TELBIOS [7] a local industrial partner of the HEAD Project.

IV. HEAD Rehabilitation Exercises

The HEAD exercise database consists of three different categories which are connected through a film database and a picture database. A film is used in order to catch the attention of the patient.

- **Category 1:** Film $\Longrightarrow$ Exercise $\Longrightarrow$ Film: All the exercises which are inside this category starts with the visualization of a film, after a few seconds the film stops and the rehabilitation exercise starts using a picture keyframe of the film. Once the rehabilitation exercise has been completed, the film is enabled and the patient can see again the next part of the film. After few seconds the film stops again and the rehabilitation exercise starts again, and so on. This category has been designed for motor-limb rehabilitation.
- **Category 2:** Film $\Longrightarrow$ Exercise: In this category, the exercises have been designed in order to start with a film without stopping or pausing the film visualization. The rehabilitation exercise starts once the film is completed. This category of exercises allows neuro-motor rehabilitation.
- **Category 3:** Exercise $\Longrightarrow$ Film: This category of exercises starts directly with the rehabilitation exercise and the video is seen by the patient only if the exercise has been completed. The film is used as an award.

V. Users Study

A tele-rehabilitation system should be validated in order to demonstrate its usefulness. Before a rehabilitation environment can be used in a rehabilitation protocol it is necessary to perform several tests and see if the proposed exercises are usable and potentially effective.

In our research, a user study has been carried out in order to test the tele-rehabilitation platform initially with healthy people. In particular, we were interested in checking if any issues may arise during the use of the HEAD application, in particular any issues related to gesture interactions.

A. *User study with healthy subjects*

10 healthy users, 6 female and 4 male, aged between 18 and 23 participated to the preliminary tests. Before the test, the participants were asked to fill in a pre-test questionnaire with their data, confidence to use games and also hand gestural technologies. In addition, we asked the participants to compile a symptoms check-list related to the sense of sight.

Figure 2-a shows part of the HEAD platform in which the clinical team is able to select the different parameters for the rehabilitation exercise. It is possible to select the video, the level, the device and the arm/hand side which will be involved in the exercise therapy.

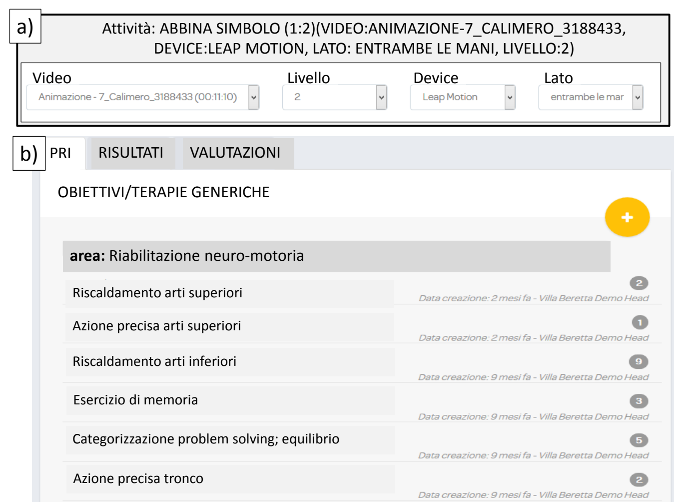

Figure 2. HEAD Platform for the clinical side.

Figure 2-b shows the general therapy and all the different rehabilitation areas.

Participants were instructed about the task, and they were allowed to use the hand gestural approach until they felt sufficiently confident. The task consisted in using the '**match**

the symbols' exercise. Two tests were performed, in different conditions.

First test. The participants were asked to perform the '**match the symbols**' exercise and to use the non dominant hand to interact with the virtual objects. This was made to introduce in the users some difficulties typical of patients with upper limb disabilities.

Second test. The participants were asked to complete again the task using the dominant hand.

The two tests lasted approximately 8 minutes (4 minutes per each test). Figure 3-a shows the HEAD platform once is started by the patient and after performed the login via user-name and password. The patient selects the rehabilitation exercise, in this case the '**match the symbols**', which consist in matching the three similar figures (Figure 3-b). The system counts as an error if the patient does not match properly the figures. If the three figures are matched accordingly, the main figure changes its color to green and the patient is able to grab the three pictures group in to the blue container (Figure 3-c). Once all the pictures groups are matched the patient is able to see the film as an award. When the film finished the system shows the final score in form of stars (Figure 3-d). Then, the results are immediately stored to the collector database.

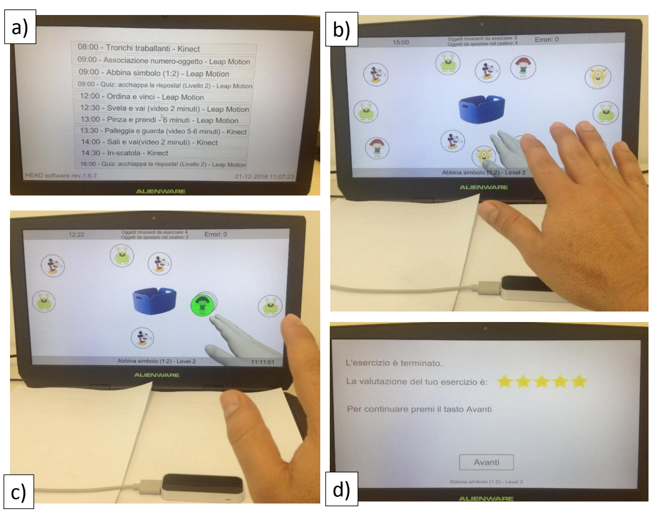

Figure 3. '**Match the symbols** exercise'.

After completing the two tests, participants were asked to fill in a post-test questionnaire aimed at evaluating the following aspects:

- general impression of the exercise, including the proposed concept, the system as a whole, the willingness to use it again, its easiness of use;
- knowledge acquired in using the scenario, including the easiness when started using the rehabilitation exercise, the effectiveness of the information displayed, and the willingness to use the system again in the future;
- evaluation of the system functionalities, including the quality of the graphic user interface, the perceived quality of the exercise, and sound feedbacks, and finally the ability of the hand/finger interaction modality.

The questionnaire was organized in a 6 points Likert-scale, from 1 (which is the most negative value) to 6 (which is the most positive value).

B. *Analysis of the results*

The charts on Figure 4 show the results of the questionnaires.

The HEAD application achieved a high evaluation rate relatively to the aspects concerning the system in general, a quite positive evaluation of the easiness in using it as a whole (chart **a** in Figure 4).

The *knowledge acquisition* section of the test intended to go more in details in understanding and evaluating the system from the user's perspective. Chart **b** in Figure 4 shows the results. Overall, the collected data show a positive evaluation. Only one user assigned a very low rate for what concerned the easiness of using the system the first time. But the same user was convinced that the following time it would have been easier and more natural to use it.

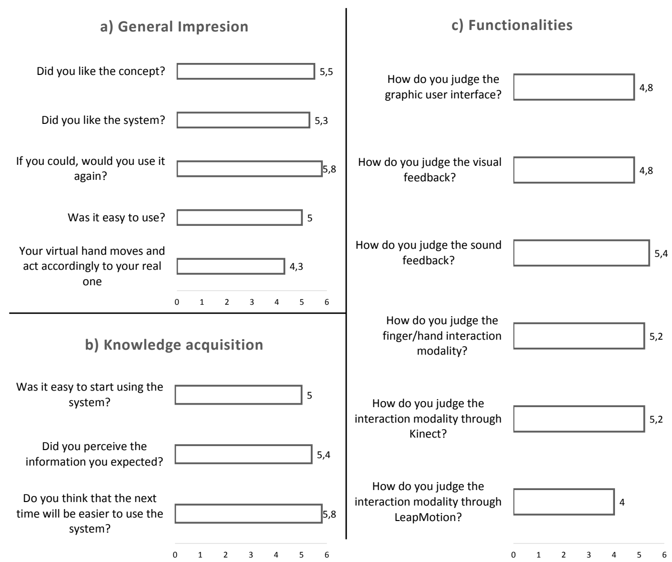

Figure 4. Results of tests performed by the healthy subjects.

It is possible to observe from chart **c** in Figure 4, that the participants have judged interesting the gesture interaction modalities proposed (finger/hand gestures) through the Leap-Motion and Kinect sensors. A positive evaluation has been given also to the visual and sound feedbacks which were coherent with the user's interaction.

All the objects (images and films) in the exercise are clearly recognised by the participants. All participants agreed to feel more confident in using the hand gesture interaction system towards the end of the test than at the beginning, and they felt to be able to improve their performance after using it for a longer period.

Five participants reported some incongruence between their real hand movements and the virtual hand avatar. This is due the Leap Motion controller, which sometimes produces anomaly reading data, such as reporting identical position although the finger had moved, or reporting false positions far away from the actual fingers [18]. These anomalies however, were usually short-termed and did not represent a significant impact in the user's performance, and in general in the overall results. Nevertheless, these anomalies were known to happen [19] and therefore expected. This preliminary study was designed to cope with these issues.

Additionally, in this study we evaluated only the process of selection of the objects (e.g., images through the gesture interaction) in the rehabilitation exercise. These two conditions were performed separately. In general, more sophisticated actions can be performed while interacting with a different rehabilitation exercise, such as advanced manipulation (e.g., changing position and orientation of virtual objects, activating some interactions through the pinch gestures), which will be considered in future works.

VI. Discussion and conclusion

The use of tele-rehabiliattion systems for upper and lower limb rehabilitation has been demonstrated in literature to be a valid approach.

In this view, the paper describes a tele-rehabilitation based on hand and body gesture interaction. We have performed some preliminary tests in order to prove the HEAD approach. The preliminary test results reported in the paper are positive for what concerns the quality of the hand and body gesture interaction while executing the rehabilitation exercise. On this basis, we conclude that the gestural interaction system provides users with an effective and natural method to interact with the rehabilitation exercises.

The clinical protocol implies that each patient is able to use the HEAD platform 12 times in the rehabilitation center and 60 times at home. The total patients involved in the HEAD project are 100. All of them are using the HEAD platform in the rehabilitation center and at least 30 at home.

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