

Research Article

Exploiting Awareness for the Development of Collaborative Rehabilitation Systems

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Physical and cognitive rehabilitation is usually a challenging activity as people with any kind of deficit have to carry out tasks that are difficult due to their damaged abilities. Moreover, such difficulties become even harder while they have to work at home in an isolated manner. Therefore, the development of collaborative rehabilitation systems emerges as one of the best alternatives to mitigate such isolation and turn a difficult task into a challenging and stimulating one. As any other collaborative system, the need of being aware of other participants (their actions, locations, status, etc.) is paramount to achieve a proper collaborative experience. This awareness should be provided by using those feedback stimuli more appropriately according to the physical and cognitive abilities of the patients. This has led us to define an awareness interpretation for collaborative cognitive and physical systems. This has been defined by extending an existing proposal that has been already applied to the collaborative games field. Furthermore, in order to put this interpretation into practice, a case study based on an association image-writing rehabilitation pattern is presented illustrating how this cognitive rehabilitation task has been extended with collaborative features and enriched with awareness information.

1. Introduction

Health care systems are one of the main concerns of both developed and developing countries. To provide their citizens with a proper treatment becomes a must as health is usually considered one of the main pillars of their quality of life. However, offering such services at reasonable costs is not a trivial issue. In this context eHealth [1] has emerged as a proper alternative that facilitates the exploitation of technology to provide both patients and practitioners with solutions according to their specific needs. According to Black et al. [2] eHealth technologies can be categorized into three main areas: “(1) storing, managing, and transmission of data; (2) clinical decision support; and (3) facilitating care from a distance.” Among these areas, the third one, namely, *telerehabilitation* [3], can be considered of special interest because of the important benefits it can offer from the point of view of both patients and policymakers. First, it offers healthcare to patients at their home by using computing technologies, telecommunications, and so forth so that patients

with mobility problems do not depend on their relatives to carry out their rehabilitation. Second, policymakers are able to provide more patients with rehabilitation services at reasonable costs [4].

While analyzing the literature of available rehabilitation systems, several technological challenges were detected that must be addressed. One of them is related to the diversity of deficits and diseases a patient may suffer. This means that a telerehabilitation system should provide facilities to design *bespoke therapies*, that is, facilities to adapt the therapy to patients’ abilities, disabilities, and needs.

In addition, as aforementioned, these systems are thought to deploy the rehabilitation at patients’ home, limiting their interaction with their therapists and with other patients. This means that these systems may hinder the rehabilitation process because of the isolation feeling they may cause. To mitigate such feeling, they may be turned into *collaborative rehabilitation systems* exploiting the concept of *virtual rehabilitation rooms* where they can collaborate with other peers, an important feature that recent studies, such as [5],

have identified as key. For the design of such rooms, an important concept that must be considered from the very beginning is *awareness* [6]; that is, patients must be aware of who is in the virtual room, what their peers are doing, where they are, and so forth. Awareness is a concept that has been traditionally used and exploited in the development of Computer Supported Cooperative Work (CSCW) systems [7]. However, *virtual rehabilitation rooms* are not usual CSCW systems, but their users have their abilities hampered by some kind of trauma, congenital problem, and so forth. Moreover, their development is also highly complex, as virtual reality interfaces, haptic devices, auditory devices, and so forth are used to facilitate users' interaction and to control properly the therapy process. That is, they may be used as different communication channels to provide those feedback stimuli more appropriately according to the physical and cognitive abilities of the patients.

Different awareness interpretations have been defined so far that focus on the identification of awareness for different types of systems. However, none of them focuses on telerehabilitation systems and, thus, they do not consider important characteristics as the users' deficits. In order to address this problem, in this work a new awareness interpretation is presented. It has been defined thanks to our experience of developing rehabilitation systems during the latest years in different domains such as acquired brain injury or children with special education needs, as well as our proposals with CSCW systems. It has not been defined from scratch but extending our previous proposal in a very challenging and demanding domain: video-games development. A set of guidelines is also presented to describe how to put it into practice, as well as a case study to exemplify each awareness element identified in this new interpretation.

This paper has been structured as follows. After this introduction, Section 2 describes the related work. Then, Section 3 describes our proposal, an awareness interpretation for physical and cognitive rehabilitation systems, as well as a set of guidelines for its application. Section 4 illustrates a case study of how this proposal may be applied to design a virtual rehabilitation room. Finally, the conclusions and future work are presented in Section 5.

2. Related Works

The use of Information and Communication Technology advanced (ICT) proposal in the rehabilitation field is not a new approach. As Brennan et al. stated [8], the first solutions of *telerehabilitation* systems date back to almost forty years ago. But, although nowadays it is possible to find different commercial proposals, such as [9, 10], the problem has not been yet solved. The great majority of those commercial applications exhibit several limitations that motivate new researches in this area.

During these forty years of use of ICT in the rehabilitation field, several challenges have been addressed to make the most of the technology. For instance, initial proposals in the area focused on facilitating the communication between therapists and patients, such as [11] who proposed a closed-circuit television to simulate the remote communication.

Nowadays, many proposals have revolved around providing new types and complex rehabilitation tasks. For instance, it is possible to find proposals that offer therapies for the treatment of physical [12, 13] and cognitive diseases [14, 15]. Moreover, because of the great diversity of diseases and deficits a patient may suffer, it is difficult to design a general solution applicable to every patient. Other factors [16] such as age, education, and experience with technology must be also considered in the design of these telerehabilitation systems. The availability of systems that therapists may use for the design of bespoke therapies emerges as a solution to address the aforementioned concerns.

Although most of these solutions have been designed to implement specific therapies [17], some of them also enable therapists to adapt some features to the patient's skills [18, 19] or create their own therapies from scratch. Pirovano et al. [20] make use of rehabilitation games and a fuzzy system to adapt such games according to the players' performance. They also offer certain configurability to control the physical stress of the patient. All these proposals that offer therapies adapted to the patient can improve some relevant aspects, such as user motivation and engagement [21].

Along with the need of designing personalized therapies for each specific disease, the use of multisensory feedback is also relevant for improving the rehabilitation of a specific patient as it facilitates a high number of communication channels between patient and system. Even though there are few proposals about the use of multisensory feedback in the area of rehabilitation [19], its inclusion improves the ecological validity of the therapies as the most appropriate communication channel may be selected depending on the specific patient's features. Usually, as Gutiérrez et al. [22] noticed, virtual reality (VR) environments offer a proper solution because of their capabilities to use different communication channels such as visual, aural, and haptic one. Moreover, the exploitation of different channels also helps to enhance how realistic a virtual environment is perceived by the user [10]. For example, the use of haptic sense could enable the transmission of some alerts or information for improving the completion of the task requested [23].

Furthermore, as Cranen et al. claim [24] some of the main advantages of using ICT in the rehabilitation process is to reduce the number of visits to the care center, increase the time available for the therapies, and decrease the treatment costs. However, they also identify some problems resulting from this teletreatment. Namely, patients miss the presence of the therapist and are less motivated when they need to carry out complex exercises. Patients also remark another problem related to their social isolation. Therefore, an advantage as a reduced number of visits to the care center may become a problem, because the direct interaction with therapists and with other patients is also reduced.

In order to mitigate these isolation problems, some authors offer video conference solution [8, 25] and others [26] integrate some social networks in their telehealth systems for improving the interpersonal communication. However, few proposals offer social interaction through some collaborative features that enable patients to collaborate while they carry out a specific therapy [21, 27]. Moreover, similarly to real

environment, other people could play a relevant social role in such collaborative therapies: *observers* and *motivators*. Observers are people who are not doing the therapy but provide some social interaction with the patient. Not only do motivators observe the therapy but they can also cheer the patients up by using their voice or making some gestures that patients could perceive. Usually, these observers and motivators are the relatives of the patient, or some specialists.

The introduction of collaborative features entails the use of concepts already applied in the design of Computer Supported Collaborative Work (CSCW) or groupware systems [28]. One of the main CSCW concepts is *awareness* that has been defined as “the up-to-the-moment understanding of another person’s interaction within a shared workspace” [6]. In a previous work [29] the available awareness interpretations (collaboration awareness, situation awareness, workspace awareness, context awareness, social awareness, and so on) were analyzed concluding that it is not possible to cover all the features of modern complex collaborative systems by using just only one of them. To solve such problem a thematic analysis was conducted that led to the definition of *Gamespace Awareness* that integrates the existing proposals in order to guide in the specification of the awareness of one of the most complex collaborative systems: collaborative video-games. In addition, in the telerehabilitation domain some other elements should be taken into account, such as how to provide users with the necessary feedback while they are carrying out their rehabilitation tasks. Therefore, in this work, based on these needs already identified in [30] and our previous proposal [29], we propose an awareness interpretation to be used in the design of collaborative physical and cognitive telerehabilitation systems, identifying both which awareness elements may be of interest and which stimuli may be used to interact with patients making the most of their rehabilitation process.

3. Awareness Interpretation for Physical and Cognitive Rehabilitation Systems

The awareness interpretation developed to deal with the awareness features of telerehabilitation systems for physical and cognitive therapies is presented next. This interpretation has been defined by adapting Gamespace Awareness [29] to make it suitable for this kind of systems.

Table 1 presents the elements identified for this awareness interpretation. They are categorized into four different concerns related to either the temporal stages the awareness is related to (present, past, and future) or those related to social and group dynamics. Within each concern, each awareness element is classified depending on what awareness information they are providing. For instance, within the *present* concern, the awareness elements deal with *who* is participating, *what* and *where* they do anything, and *how* to do it. Aimed at helping designers to identify the awareness needs of a rehabilitation system, a set of questions have been defined along with these awareness elements. For instance, consider a remote physical rehabilitation system whose patients have to work in a collaborative manner. In order to perform such collaboration, they must be aware of *who* is available to

collaborate with while performing the rehabilitation session, *what* the other patients are doing to coordinate their actions properly, *where* they are located in their own space, and *how* to interact with them. This awareness information, which is easily perceived in a nonremote and computerless rehabilitation environments, is key when collaborating remotely. Consequently, this new awareness interpretation aims at making remote rehabilitation as straightforward and fruitful as face to face rehabilitation.

As shown in Table 1, for each awareness element, it has been also defined which feedback stimuli could be used to provide participants with the required awareness, that is, *visual* (by means of a computer screen or a virtual reality headset), *aural* (by playing sound or audio messages), or *haptic* (by receiving vibrations on different parts of the body). Furthermore, when dealing with disabled people, providing awareness information through different stimuli is paramount since certain stimuli may not be received or understood by disabled users. For example, when a deaf patient is using a telerehabilitation system, audio messages may be replaced with visual notifications or haptic signals. However, not all awareness elements can be properly provided by using any stimulus. As an example, making the participants aware of the log-in of a new user in the system (element *Identity*) by using haptic feedback would not be practical since it would require codifying each new participant ID as different haptic signals. This would cause that our users were overwhelmed due to the constant vibrations received, and it would be difficult to implement as the number of users increases. Nevertheless, providing the same awareness information through an audio message (e.g., “John is now online”) is comprehensible by most of the participants.

Table 1 also presents several examples of how each awareness element could be implemented, that is, how to gather such awareness information and how to provide participants with it. For instance, the *status* element, which is related to the participant’s physical and emotional status could be obtained by using either a biometric sensor that gathers physical data such as heart rate or skin conductance [31], or a camera along with an emotional analysis software to analyze participants’ emotions [32]. Moreover, this awareness information may be provided by using different stimuli. For instance, if it was required to make a participant aware of other participants’ heart rate, this awareness information could be provided by using the three considered stimuli. Firstly, visual stimuli may be easily used by playing animated heartbeats on the screen, thus representing the heart rate of the remote participant. Secondly, aural stimuli can also be considered and implemented by playing heartbeats through audio. Finally, it could be also possible to use haptic stimuli as well, thus emulating heartbeats by sending haptic impulses that the participant will feel on a specific part of his/her body.

3.1. How to Put into Practice the Awareness Interpretation. Once the awareness interpretation has been presented, it will be explained in the following how to put it into practice. For this aim, let us start from the specification of the tasks of a rehabilitation system to be developed. To perform such specification, any requirement engineering specification

TABLE 1: Awareness elements for physical and cognitive rehabilitation.

Category	Awareness element	Specific questions	Recommended feedback stimuli*			Gathering	Implementation examples	
			V	A	H		Providing	
Who	Presence	Is anyone in the system?	<i>Present</i> X	X	X	Motion sensing	Notification of participant login	
	Identity	Who is participating? Who does this avatar belong to? Who is available to collaborate with?		X		Face recognition	Recognized participant ID	
	Authorship	Who is doing that?		X		Motion sensing	Notification of current action's authorship	
What	Task	What are they doing? What is the difficulty of this task?	X	X	X	Motion sensing	Visualization, hearing, and haptic feedback of remote action	
	Goal	What goal is that task part of?	X	X		Manual input	Notification of current goal	
	Object	What object are they working on? What object can I work with?	X	X		Motion sensing with object recognition	Visual notification of currently used objects	
	Status	What are the participants' status? What are their feelings? What is the objects' status?	X	X	X	Biometric sensor/emotion detection	Visualization, hearing, and haptic feedback of participant's status and feelings, as well as object's status	
	Disabilities	What are the participant disabilities? What are they not able to do because of such disabilities?	X	X		Manual input	Visual warnings about their disabilities	
	Perception	What are the other participants perceiving? (Looking, touching, hearing, etc.)	X	X	X	Head-mounted camera with mic and motion sensing	Visualization, hearing, and haptic feedback of other participants' perception	
Where	Location	Where are the participants/avatars participating? Is it a physical or virtual location?	X			Motion sensing/GPS	Map locations	
	Gaze	Where are the participants looking/facing?	X			Eye tracking	Visualization of other participants gaze	
	Position	Where is an object? How near is it?	X	X	X	Object and proximity detection	Visualization, hearing, and haptic feedback of position and nearness of objects	
	Mobility	What is the participants' mobility range?	X			Motion sensing	Moving avatars showing participants moving range	
How	Device	How do I use a certain device to interact?	X	X		Hardware detection/Manual input	Audio and video instructions	

TABLE 1: Continued.

Category	Awareness element	Specific questions	Recommended feedback stimuli*			Gathering	Implementation examples	
			V	A	H			
How	Object history	How did this object come to be in this state?	X			Motion sensing with object recognition	Visual evolution of object state	
		When did that event happen? How often? Is there any network delay?	X			Motion sensing with object recognition	Timestamp of object changes	
		Who was here and when?	X			Face recognition	Log-ins list	
		Where has a participant/avatar been?	X			Motion sensing/GPS	Heat maps of participants' locations	
		Where has an object been?	X			Object and proximity detection	Trajectories of objects' positions	
Where	Mobility history	What were the participants' mobility ranges?	X			Motion detection	Moving avatars showing participants previous moving ranges and date	
		What has a participant/avatar been doing?	X			Motion sensing	Visual list of past tasks	
		<i>Future</i>						
		When will the next event happen? How often?	X	X	X	Scheduler	Visualization, hearing, and haptic feedback prior to the event	
		Who will be the next participant?	X	X		Face recognition	Notification of the identity of the new participant to join the session	
Where	Next location	Where will a participant/avatar be?	X			GPS-based predictor	Possible next location on map	
	Next position	Where will an object be?	X			Scheduler	Alert of new position on map	
	Next mobility	What will the participants' mobility ranges be?	X			Motion sensing-based predictor	Moving avatars showing participants future moving range based on current progress	
What	Next task	What will happen next?	X	X		Scheduler	Visual and aural alert of next task to do	
	Next status	What will the participants/avatar next status be? What will the next status of the object be?	X	X		Biometric sensor-based predictor	Visual and aural warning of participants' dangerous physical state	

TABLE 1: Continued.

Category	Awareness element	Specific questions	Recommended feedback stimuli*			Gathering	Implementation examples	
			V	A	H		Providing	
Who		<i>Social & group dynamics</i>						
	Members	Who are the members of my rehabilitation group? Has anybody joined/left the group?	X			Manual input	List of rehabilitation group members	
	Other members	Who are the members of the other rehabilitation groups?	X			Manual input	List of all rehabilitation group members on therapist view	
	Specialist	Who is the specialist conducting the rehabilitations session? Is he/she following the session?	X	X	X	External log-in	Visualization, hearing, and haptic sensing of the specialist conducting the session	
	External participants	Who is participating externally in the rehabilitation session? Are they motivators or just observers?	X	X	X	External log-in	Visualization, hearing, and haptic sensing of remote participants	
What	Belonging	What rehabilitation group do I belong to?	X	X		Manual input	Visual or aural notification of current group's name	
	Role	What is my role within my group?	X			Manual input	Visualization of participant role	
	Others' roles	What are the roles of my group's members?	X			Manual input	Visualization of all participants' role on therapist view	
	Group goal	What are the goals of my group?	X	X		Manual input	Notification of current group goal	
	External motivation	What are other participants doing to motivate me to carry out my task?	X	X	X	Remote voice and commands	Visualization, hearing, and haptic sensing of remote cheering	
How	Inner communication	How should I communicate with each rehabilitation session participant?	X	X		Audio recording	Text and audio instructions of how to communicate with the other participants	
	Outer communication	How can I communicate with the therapist/external viewers?	X	X		Audio recording	Text and audio instructions of how to communicate with the therapist/external viewers	

* (V) visual, (A) aural, and (H) haptic.

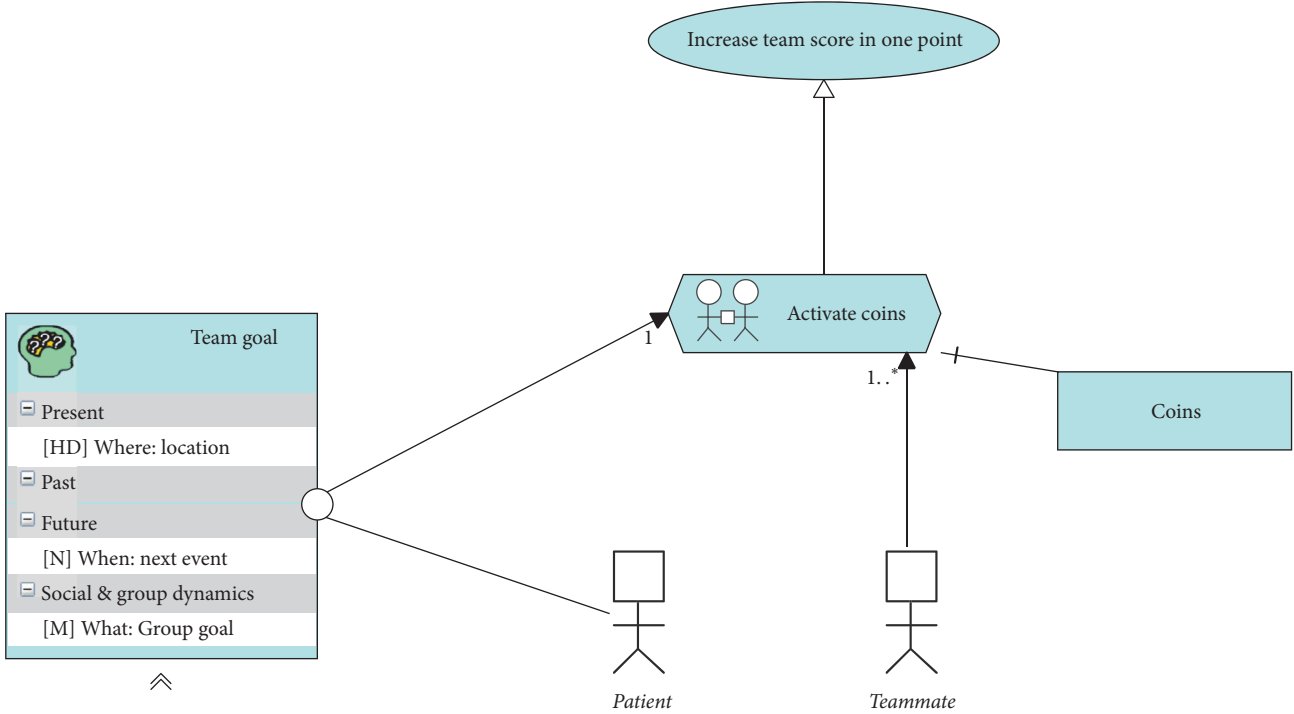


FIGURE 1: Example of CSRMF diagram specifying a collaborative task with awareness needs. * means N ; that is, from 1 to N teammates can be related to activate coins.

technique may be used. However, due to its collaboration and awareness modelling capabilities, we recommend using the Collaborative Systems Requirements Modelling Framework (CSRMF) [33].

Once the tasks of the system have been specified, those awareness features considered necessary to ease the interaction between the user and this system can be defined. For this aim, Table 1 provides a set of questions that will help us to identify the awareness needs of our system. As an example, let us consider the first awareness element on Table 1, *Present-Who-Presence*. Such element includes the *specific question* “Is anyone in the system?” Therefore, to assess whether or not this awareness element should be included among our system’s requirements, we would ask ourselves “Do our users need to know if there is anyone in the system?” If so, this awareness element will be included among our system’s requirements. In Table 1, *Present-Who-Presence*, such element includes the *specific question* “Is anyone in the system?” Therefore, to assess whether or not this awareness element should be included among our system’s requirements, we would ask ourselves “Do our users need to know if there is anyone in the system?” If so, this awareness element will be included among our system’s requirements.

Once we are in the design phase of the system, the stimuli to provide each awareness element must be specified. With this aim, Table 1 also includes the *recommended feedback stimuli* column that suggests what stimuli may be used to communicate the awareness information. For instance, the *presence* element could be offered by using visual, aural, or haptic stimuli (or a combination of them). Table 1 has the *recommended feedback stimuli* column that suggests what

stimuli may be used to provide the awareness information. For the considered *presence* element, it could be provided by using visual, aural, or haptic stimuli (or a combination of them). Moreover, Table 1 also includes *implementation examples* for each awareness element. In this case, the information to provide the *presence* element may be gathered by employing a motion-sensing device when it detects that there is a new user in the scenario, provided by notifying the log-in of a new participant using a visual message, playing a log-in sound, or sending a haptic signal.

Figure 1 shows a different example of how to model a task and specify its corresponding awareness needs by using CSRMF. This is a collaborative task whose participants, namely, a *player* and his/her *teammates* must *activate several coins* in a virtual world to fulfil their goal: *increase the team score one point*. For this aim, it is *mandatory* (M) that such player be aware of what the coin he/she has to activate, that is, *what the group goal is*. Moreover, it is *highly desirable* (HD) to know *where* the other players are *located* in the virtual world. Finally, it would be *nice to have* (N) information about *when the next event* will happen, that is, when new coins will appear. This task will be implemented in the case study that will be presented in Section 4.4.

4. Case Study

In the previous section, an interpretation aimed at identifying the awareness requirements of a rehabilitation system was presented. Therefore, to put it into practice, this section presents a case study based on a physical-cognitive collaborative rehabilitation exercise. Aimed at making the

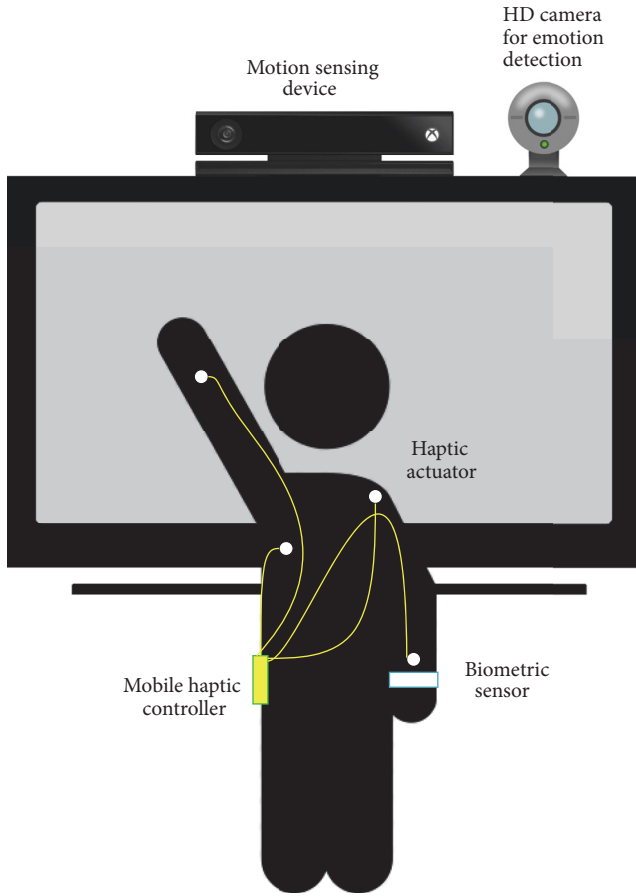


FIGURE 2: Participants' hardware environment.

performance of such exercise enjoyable, it will be presented as a game whose users will play collaboratively yet remotely grouped in several teams. In this game, patients will be represented as avatars. Hence, to interact with this game when performing the exercise, a motion-sensing device will be used to translate the participants' movements into avatars movements. Figure 2 exemplifies how the hardware environment for this rehabilitation system could be. A motion-sensing device such as Microsoft Kinect [18] will gather the participants' movements. Besides, a high definition camera will capture the users' face and forward it to an emotional analysis SDK [32] that will analyze and interpret their emotional status. A wristband will also interpret their emotional status measuring their heart rate. This physical and emotional information will be sent to the therapist to follow the evolution of the patients. Finally, a wearable haptic controller with several actuators will be used to make the user feel certain events of the game. Hence, 4 actuators will be used, located on both patients' hands (to feel the game objects), chest (to feel heartbeats), and shoulder (to feel encouragement pats).

As far as the cognitive rehabilitation exercise is concerned, it is based on an *association image-writing* rehabilitation pattern. This pattern is defined in [34] as an exercise to improve patients' front executive capability.



FIGURE 3: Prototype of participants' user interface (patient's avatar located in the center of the interface using a third-person view).

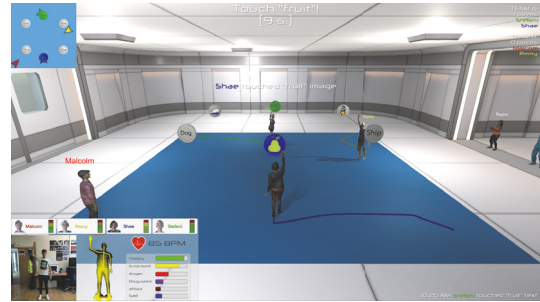


FIGURE 4: Prototype of therapist's user interface.

Regarding the game itself, the participants' avatars will be in a virtual world where several coins with images and words on them will be scattered around the game field. Therefore, the implementation of the aforementioned rehabilitation pattern consists in asking the teams of participants to find and touch a virtual coin related to a specific concept. As an example, if the system request is to find and touch the "fruit" coin, one participant will have to touch the coin with the image of a pear on it; meanwhile the other does so with the coin showing the word "pear." Figure 3 illustrates two different avatars. The avatar controlled by the current player is trying to activate a coin; meanwhile the green player has already activated the "pear" coin.

Besides, regarding physical rehabilitation, the therapist will be able to place the coins in different locations to encourage the participants' displacements and movements. For instance, if a participant needs an upper limb rehabilitation therapy, the therapist could locate the coins in a high position, so that the participant will have to lift his arm to activate such coin. Moreover, the size of the game field can be customizable according to the movements requirements of the therapy to be performed. For instance, if a patient could not walk, all the coins would be located around the avatar to avoid displacements over the game field.

Furthermore, the therapist will have a different view of the system (see Figure 4) to monitor the therapy execution, enabling her to see each participant view, the participants themselves, as well as their emotional status (obtained by using a facial analysis software).

Finally, external participants (neither patients nor specialists) can participate into the system. Specifically, these



FIGURE 5: Prototype of observer's user interface.

external participants will adopt the role of *observers* and *motivators*. Hence, observers can watch the rehabilitation session (see Figure 5). Besides, motivators can also cheer the patients up by using their voice that patients may hear during the rehabilitation session. It is worth noting that both observers and motivators, as well as therapists, will be also represented in the game by using avatars to make patients aware of the presence of such participants (see Figure 3).

Aimed at exemplifying how the awareness interpretation presented in Section 3 could be used in the design of such rehabilitation exercise, in the following it is explained how several awareness elements could be implemented and presented to the participants for the recommended feedback stimuli described in Table 1. Notice that several elements could not be implemented in this case study since they are not suitable for this exercise. For instance, in this game every participant has the same responsibilities within his/her team, without having a specific role. Consequently, the *role* and *others' roles* awareness elements were not used.

4.1. Present. The first awareness elements are those related to what is happening in the rehabilitation session at the very moment of its performance, namely, the *present*. Hence, the implemented elements belonging to such concern are the following ones:

- (i) *Presence*. Participants have to be aware of the presence of a new participant with whom to collaborate. Following the suggested implementation described in Table 1, the exercise could be implemented according to the following requirements: when a motion-sensing device detects a new participant, the system will provide the already-connected participant (if any) with a *haptic* stimulus indicating the presence of a teammate with whom to perform the rehabilitation session. Therefore, it would not be necessary that a logged-in participant is continuously looking at the screen to know whether there is another user in the virtual rehabilitation room, being warned with a vibration on his wrist when the session is ready. However, this awareness information could also be provided by means of *visual* (by showing the participant's avatar) or *aural* signals to indicate a new log-in into the system.

- (ii) *Identity*. Participants have to be aware of which participant is related to which avatar. With this aim, each participant's avatar will have a tag with the participant's name over the head (Figure 6). Moreover, each participant name will have a different color aimed at easing the visual identification of participants.
- (iii) *Authorship*. Participants have to be aware of who activated a coin in the virtual world. The requirement would be the following: the color of such coin (*visual* representation) could change to match the color of the participant's avatar. As an example, Figure 3 shows that the pear (image) coin has been touched by the blue player.
- (iv) *Task*. The therapist must be aware of what the participants are doing. It could be achieved by means of a *visual* remote view (Figure 4) to observe both what the participants are doing in the virtual room (through their avatars) and the real world (real streamed video of the participants). To reinforce this feedback, an *aural* message such as "Malcom has activated the dog coin" or a *haptic* signal representing a coin activation could be sent to the participants.
- (v) *Object*. Participants have to be aware of the coin that they as well as the other participants have activated. For instance, similarly to the *authorship* awareness element, the color of the coins (*visual* representation) could provide awareness information regarding what object they are interacting with. However, different sounds (*aural* representation) could be associated with the coins that will be played when they are touched, thus helping the participants to identify them. For instance, if a participant activated the "dog" coin, a dog bark could be played through the audio system. Finally, in order to make a participant aware of the fact that the target coin has been activated, not only will it change its color according to the participant's color, but also he/she will receive a long haptic signal on the hand he/she activated the coin with.
- (vi) *Status*. The therapist has to be aware of both the participants' heart rate and emotional status. To implement this awareness element, the participants' heart rate and emotional status could be presented in a *visual* manner (Figure 4) to the therapist who would be able to interrupt the session or adjust if needed. For instance, if a participant's heart rate was considerably high or he was in a bad emotional state, the therapist could interrupt the session and adapt it according to the participant's needs. The heartbeats of the participants could be coded into *aural* beats or *haptic* vibrations to make them aware of their own heart rate, that is, of their own physical status.
- (vii) *Disabilities*. The system has to be aware of any participant's disabilities in order to avoid and/or adapt the stimuli provided. Prior to start a session, the therapist will indicate whether any participant have disabilities to configure the system. For instance, if a participant

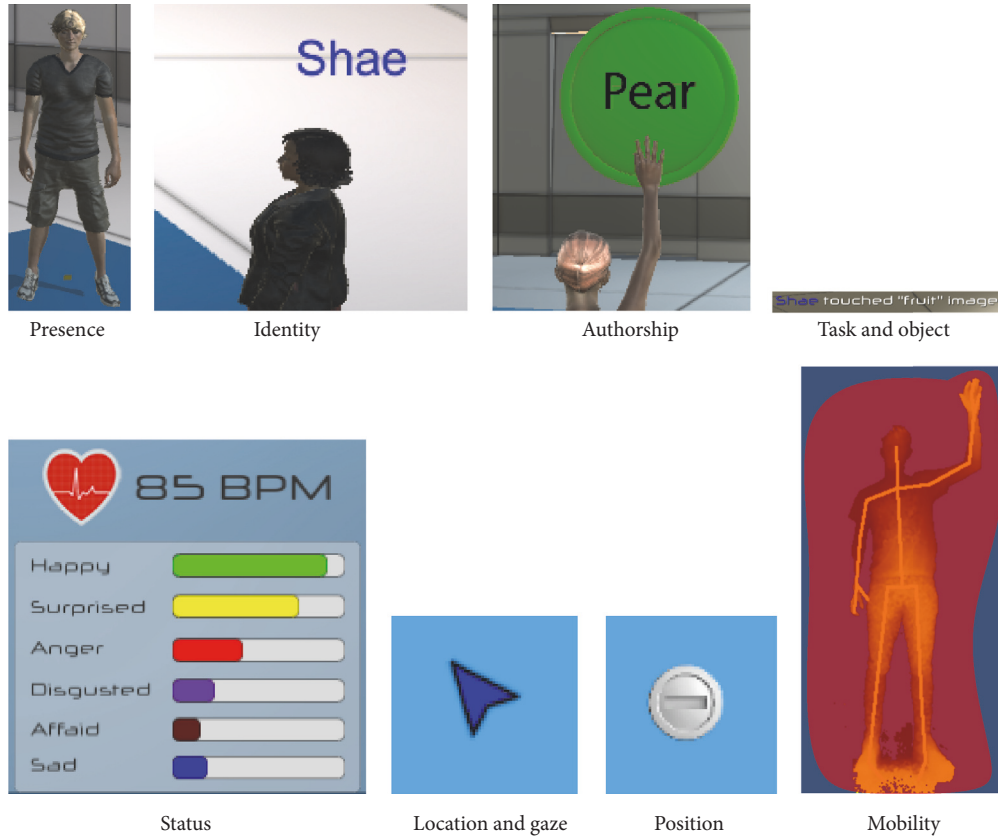


FIGURE 6: Visual implementation of present awareness element.

is deaf, audio messages will be presented by using *visual* closed captions. Besides, blind participants may interact with the system by receiving *aural* messages about the coins' location. Moreover, if a participant is unable to walk, all the coins will be located within the participant's reach area.

- (viii) *Location*. The participants have to be aware of their locations. The patient will know such location by looking at a *visual* map of the scenario (top-left corner of Figure 3). Moreover, by looking at this map, he may obtain information about the position of the other participants. It is worth noting that this map may represent the participants as arrows with the same color as the participants' name.
- (ix) *Gaze*. The direction each participant is facing can be seen in the map by means of the arrows representing the participants (Figure 6). In this sense, the arrow will point towards the direction where the participant is facing. However, if the therapist had to be aware of where the participants are looking to detect cognitive problems, an eye-tracking system could be implemented. For instance, the therapist could see the point of the screen where the participants are looking on the therapist's view in a *visual* manner. Therefore, if a participant was constantly looking at a screen point where no coin or participant was located, a cognitive issue could be identified.

- (x) *Position*. Participants must be aware of the position of the coins. Similarly to what happens with the *location* element, participants may know the position of the elements by using this *visual* map (top-left corner of Figure 3). Thanks to this awareness feature, the participants could be aware of the presence of coins positioned behind them that cannot be seen in a 3D third-person view. For a more detailed analysis of the difference between location and position please refer to [29]. To reinforce this feedback, the concept of nearness to the coin could be represented as *aural* messages with a variable pitch or increasing the *haptic* signal depending of such nearness.
- (xi) *Mobility*. The therapist has to be aware of what the participants' can reach or where they can move. For example, the therapist may see a *visual* representation of each participant's reach area on a postsession screen (see Figure 4). This image could be generated based on their previous movements. Therefore, the therapist will analyze if the physical rehabilitation process has been successful by measuring a possible enlargement of such reach areas (i.e., the participants are able to reach further with their limbs than before starting the rehabilitation process). This image could be generated based on their previous movements. Therefore, the therapist will analyze if the physical rehabilitation process has been successful by

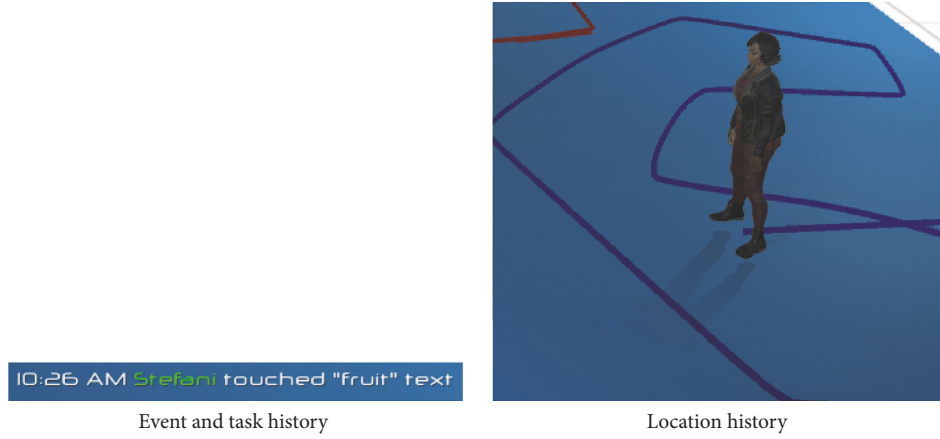


FIGURE 7: Visual implementation of past awareness element.

TABLE 2: Examples of present awareness elements implemented through aural messages.

Awareness element	Aural message example
Presence	[Participant log-in sound]
Identity	Shae has joined the game
Task and object	Malcom has activated the dog coin
Object	[Dog bark]
Status	[Heartbeat]
Position	[Pitch-variant sound]
Device	Walk toward a coin and raise your hand to touch it

measuring a possible enlargement of such reach areas (i.e., the participants are able to reach further with their limbs than before starting the rehabilitation process).

- (xii) *Device*. Participants have to be aware of how to interact with the system. For instance, the interaction with the system in this case study will be performed by means of the motion-sensing device. Therefore, if the system detects that a participant was not aware what he has to do, a *visual* or *aural* message would be displayed or played, respectively, thus informing such participant about how to interact (Table 2).

4.2. Past. Once the awareness elements related to the present have been presented, those related to the *past* will complement the participants' awareness with information about facts that happened prior to the current time:

- (i) *Object history*. Once the session is finished, a post-game interface could provide detailed information of the different states each coin had had. In other words, this will implement a log detailing the interaction of participants with the game coins.
- (ii) *Event history*. The game interface will show the exact time when something happened. This information

will be reflected in the actions log located at the bottom-right corner of the interface (see Figure 3).

- (iii) *Presence history*. The presence of participants in the system will be logged to be queried by the therapist when required. Hence, the system will record both the log-in and log-out time of each participant. With these data, the therapist could analyze whether or not the participants have been performing their assigned therapies regularly.
- (iv) *Location history*. To make both participants and therapist aware of the previous location of a participant's avatar, they will leave a trail behind as they move around the game field (see Figure 7). This trail will have the same color of the participant's name, and the time that it will remain shown can be configured.
- (v) *Position history*. This awareness element will complement *object history* by adding information about where each coin appeared. In this sense, the game log will also include the position of each coin in the map. This could be implemented graphically (indicating the position of the coins by using a map) or textually (just by indication of the coordinates of the position of each coin in meters, departing from the center of the game field).
- (vi) *Mobility history*. Closely related to the *mobility* element from the present concern, the mobility history can represent the evolution of the patient's mobility over time. In this sense, it can be analyzed how the patient's mobility range has been evolved from the very beginning of the rehabilitation therapy. Therefore, the therapist can assess whether or not the therapy has been fructiferous for each patient.
- (vii) *Task history*. The system will record and show all the tasks performed by the participants. Therefore, a task history will be shown in the bottom-right corner (see Figure 3). It is worth noting that, in order to ease the identification of participants in this list of tasks, each name will be colored according to the participant's color.

TABLE 3: Examples of future awareness elements implemented through aural messages.

Awareness element	Aural message example
Next event	Next coin in 9 seconds
Next participant	A new participant will join team 1 in 15 seconds
Next mobility	After this session, your right arm mobility could improve 2%
Next task	The next coin will be "Animal." Get ready!
Next status	[Warning sound]

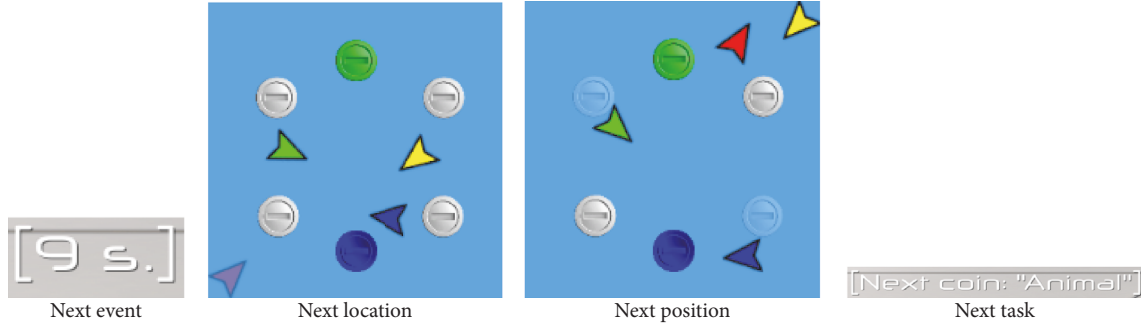


FIGURE 8: Visual implementation of future awareness element.

4.3. *Future*. Next, we will deal with those awareness elements related to the *future*. Such elements make the participants be aware of something that will happen in a near future which could affect the current development of the rehabilitation session somehow. The future awareness elements are the following ones:

- (i) *Next event*. In order for the participants to anticipate their actions, this element will provide them with information about what the next event will be. In this example, this element will show the remaining time that a new coin will appear in the game field (see top of Figure 3).
- (ii) *Next participant*. During a game, no new participants can join it. However, when a new coin is going to appear, a new participant can join the game, sending an audio message to the current participants (Table 3). Hence, they will be aware that a new participant will join the game soon, as well as what team he/she will be part of.
- (iii) *Next location*. Related to the previous awareness element, prior to the appearance of a new participant, his/her starting position can be signaled on the map (Figure 8). In this sense, not only will current participants be aware of an upcoming new participant, but they will also know where he/she will be located initially.
- (iv) *Next position*. Similar to the previous element, when a new coin is going to appear, it could be signaled on the map so that participants get ready to touch such coin (Figure 8). Thus, they could anticipate the appearance on this new coin moving towards the new position where it is supposed to appear.

- (v) *Next mobility*. Based on *mobility history*, the system could analyze the progression of the patients' mobility over time. Therefore, the system could predict what the future mobility of the user will be if he/she keeps on following the rehabilitation session. This information can be used to motivate patients prior to the performance of a new session by making them aware of what they can achieve during the next sessions.
- (vi) *Next task*. The element *next event* was used to make participants aware that a new event will happen. Complementarily, such awareness information can be enriched by adding details of such event. In this example, this information could advance the next task that participants will have to perform, namely, the coin that they will have to touch next.
- (vii) *Next status*. This awareness element could be used to make a patient (and the therapist) aware that he will be in a specific emotional or physical state based on past measurement. As an example, if the participant is having a high heart rate in combination with a negative emotional status (sad or disguised), the system could recommend that he/she suspend the rehabilitation session.

4.4. *Social and Group Dynamics*. Finally, the last awareness elements are related to a nontemporal concern, namely, social and group dynamic. Hence, the elements belonging to this last concern are the following ones:

- (i) *Members*. The participants will be able to know who is participating in their team at any time during the rehabilitation session. With this aim, a list of players belonging to his/her own team will be shown on

TABLE 4: Examples of social and group dynamics awareness elements implemented through aural messages.

Awareness element	Aural message example
Specialist	This session is being supervised by Dr. Smith
Belonging	You will play as a member of team 2
Inner communication	Speak to communicate with your teammates. They will hear you!
Outer communication	You can always communicate with your therapist by using your voice Let him know if you have any problem while performing the therapy

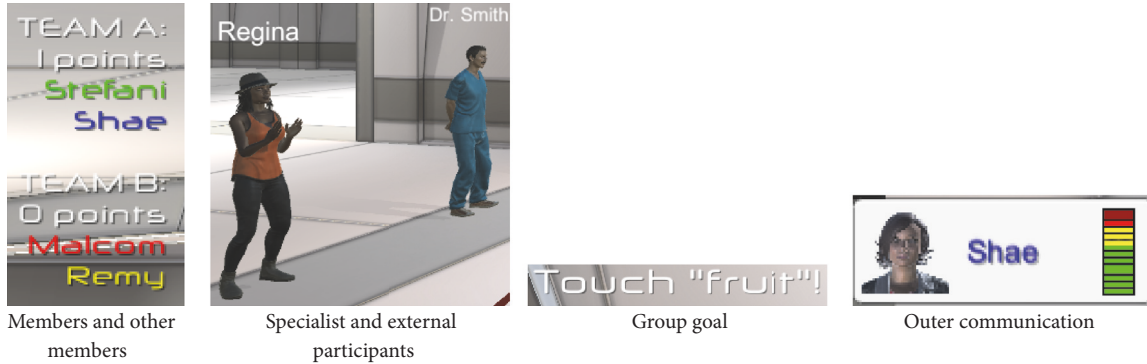


FIGURE 9: Visual implementation of social and group dynamics awareness element.

the participant user interface (see top-right corner of Figure 3). Moreover, to ease the identification of team members, the name of the teammates on this list will be colored with each participant name color.

- (ii) *Other members.* As happened with the previous awareness element, a different list will show the members of the rival teams with their corresponding character colors (see top-right corner of Figure 3).
- (iii) *Specialist.* The participants will be able to know who is the therapist conducting the session. Moreover, to recreate a real scenario, an avatar representing the therapist will be included in the game interface, also showing the therapist's name (Figure 9).
- (iv) *External participants.* During the sessions, two kinds of external participants are allowed to interact, namely, observer and motivators. The former will be able to watch the session; meanwhile the latter can also cheer the participants up by using their voice. Therefore, to make the participants aware of the presence of such external participant, they will be represented as avatars observing or cheering up the session from outside the game field (Figure 9).
- (v) *Belonging.* In this example, participants are not allowed to choose the team they belong to since the therapist decides these teams in advance. Because of that reason, the system will make them aware of the team they belong to at the very beginning of the session through an audio message (Table 4).
- (vi) *Group goal.* The participants have to be aware of their group goals. For example, considering as goal the coin they will have to touch, it could be communicated by means of both a *visual* message on the screen and an

aural notification. Thanks to this double awareness, participants would have instant information about the goal as soon as it changes but they would always be able to watch it on the screen (at the top of Figure 3).

- (vii) *External motivation.* When remote participants acting as motivators are monitoring the session, they can cheer the participants up. This can be done by using the three considered stimuli. First, they can make their avatars clap so that the participants could see and hear them. Moreover, this motivation may be also transmitted by using the motivators voice so that the patients will hear the encouragement voice messages of the remote participants. Finally, motivators may also send haptic commands. In that sense, patients will receive and feel a haptic pat on their shoulder.
- (viii) *Inner communication.* If the therapist decided so, the participants will be able to communicate with their teammate by using their voice. Hence, if this interaction is enabled and the system detected that one participant is not speaking at all, an audio message will inform such participant that his/her voice will be heard by the other team member (Table 4).
- (ix) *Outer communication.* Once again, the therapist can decide whether participants can interact verbally with the external participants as well as with the therapist himself/herself. Once again, the system can remind the participants that their voice will be heard by those external participants. Moreover, the therapist will be also able to see a VU meter corresponding to each participant's microphone to be aware visually when a patient is speaking (Figure 9).

Thanks to the implementation of these awareness elements, as well as the others belonging to the present, past, and future concerns, participants will be able to interact with a rehabilitation system like the one presented at the beginning of this section. This will enable collaboration with remote participants, and it will enable the therapist to monitor and adapt the therapies to the participants needs.

5. Conclusions and Future Work

In order to achieve a proper collaboration while interacting with remote participants, they have to be aware of their collaborators (i.e., what they are doing, where they are, etc.). Therefore, dealing with awareness information properly is paramount for the success of a collaborative system. This issue is even more crucial when dealing with rehabilitation systems, whose participants may suffer from any cognitive or physical disability. This turns awareness information into a cornerstone of telerehabilitation systems, where awareness may lead to a suitable interaction. In order to guide the identification of such awareness requirements when developing cognitive and physical rehabilitation systems, an already existing awareness interpretation, namely, Gamespace Awareness [29], has been chosen as the foundation of our proposal. Such awareness interpretation was initially developed to deal with the awareness requirements of collaborative games. In this work, it has been adapted to make it suitable for rehabilitation systems featuring the monitoring of patients by using mobile sensors and providing feedback by using different kinds of stimuli (visual, aural, and haptic). This new interpretation comprises 39 awareness elements (classified into 4 different concerns) that will provide both patients and therapists with the required awareness information to ease collaborative and remote rehabilitation therapies. Furthermore, along with such collection of elements, the awareness interpretation provides a series of specific questions which will help designers and developers of new rehabilitation systems to identify awareness requirements properly. Moreover, we also provide recommendation of which feedback stimuli could be used to provide each awareness element (visual, aural, or haptic), as well as implementation examples for gathering and providing each one. Finally, in order to ease the usage of this awareness element in the development of a new rehabilitation system, a series of guidelines have been provided (Section 3.1).

In order to exemplify the awareness interpretation defined for this type of systems, a case study has been presented (Section 4). It describes several participants while performing a collaborative physical and cognitive rehabilitation exercise. The interaction with the system is performed by means of motion-sensing devices that translate the participants' movements into avatars' movements in the virtual world. Moreover, biometric devices and emotional analysis software are used to make the therapist aware of the patients' physical and emotional status.

It is worth noting that the game presented as case study is just a prototype. Therefore, as a future work, the final game will be implemented. Indeed, to perform this implementation, the postgame user interfaces will be implemented. This

functionality will enable therapists to follow the evolution of their patients towards a successful rehabilitation. With the game fully implemented, it will be integrated with our rehabilitation management system to enable us to start the testing of such game by involving real users.

Disclosure

This paper is an extension of Teruel et al. [35].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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