Towards an Awareness Interpretation for Physical and Cognitive Rehabilitation Systems

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Abstract. When collaborating remotely, being aware of other participants (their actions, locations, status, etc.) is paramount to achieve a proper collaboration. This issue is magnified when talking about rehabilitation systems, whose users may require additional specific awareness information, due to their cognitive or physical disabilities. Moreover, because of these disabilities, this awareness may be provided by using specific feedback stimuli. This constituted the main motivation of this work: the development of an awareness interpretation for collaborative cognitive and physical therapies. With this aim, an awareness interpretation already applied to the collaborative games field has been modified and extended to make it suitable for these systems. 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.

Keywords: Awareness · Collaboration · Virtual rehabilitation rooms · Physical rehabilitation · Cognitive rehabilitation · Case study

1 Introduction

Although there is no a widely accepted definition of eHealth [1], there certainly is a consensus about both its meaning and its usefulness in the short and long term. Basically, eHealth environments promote the synergy of health care and technology to provide patients and practitioners with proper solutions according to their specific needs. These needs have been categorized into three main areas [2]: (1) storing, managing, and transmission of data; (2) clinical decision support; and (3) facilitating care from a distance. Among these areas, the third one, also known as *tele-rehabilitation* [3], has special interest as it helps to move healthcare from hospitals and care centres to patients' home exploiting computing technologies, telecommunications, etc. This results into important benefits from the point of view of both patients and policymakers. First, patients with mobility problems are not dependent on their relatives to move to hospital for their rehabilitation but they can do it just at home. Second, policymakers are able to offer rehabilitation to more patients at reasonable costs [4].

When developing tele-rehabilitation systems there are several technological challenges that must be addressed. First of all, they should be designed to provide specialists

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with facilities to design *bespoke therapies*, that is, therapies adapted to the patients' abilities, disabilities and needs. This has led us to develop a tool [5] that enables therapists to design bespoke therapies which is part of Vi-SMARt, a system whose final aim is to provide support for physical and cognitive rehabilitation [6–9]. These therapies, once designed, are executed, monitored and adapted thanks to a fuzzy inference system that has been integrated into Vi-SMARt [10].

Second, and equally important, the fact that patient is at home may hamper its interaction and, thus, the outcome of the rehabilitation process unless specific facilities are considered in the design of the tele-rehabilitation systems. These systems should be able not only to monitor patient's status to detect stress or any other kind of discomfort but also they should provide him with the *feedback* necessary to conduct his therapy. The design of this feedback can be specially challenging when developing *virtual rehabilitation rooms*, one of the main features of Vi-SMARt [7], where they can collaborate, cooperate and communicate for the achievement of both personal goals and group goals. These virtual rehabilitation rooms are being integrated into Vi-SMARt because different studies, such as [11], have highlighted the importance of collaboration with other peers as a facilitator of the rehabilitation.

If we considered those virtual rooms just as usual CSCW systems, then patients should be provided with *awareness* [12] information, that is, they must know who is in the virtual room, what the collaborators are doing, where they are, how and when certain action happened, who did it, etc. However, they are not usual CSCW systems, but systems whose users have their abilities hampered by some kind of trauma, congenital problem, etc. These systems are also technology-demanding, as these virtual rooms have virtual reality interfaces, haptic devices, auditory devices, etc. Therefore, Awareness Interpretations defined up to now should be adapted to consider the special needs of this domain. This is the main aim of this work, to define an awareness interpretation for developing Physical and Cognitive Rehabilitation systems. This awareness interpretation has been distilled thanks to our experience of developing rehabilitation systems during the latest years in different domains such as Acquired Brain Injury [6, 13, 14], Children with Special Education Needs [15] or Gerontechnology [10], as well as of working with CSCW systems [16, 17].

This paper has been structured as follows. After this introduction, Sect. 2 describes the related work in the area. Then, Sect. 3 describes our proposal, an awareness interpretation for physical and cognitive rehabilitation systems. Section 4 presents by means of a case study how this proposal can be put into practice. Finally, the drawn conclusions and our future work are described in Sect. 5.

2 Related Works

Over the last years several proposals, commercial [18, 19] and academic [10, 20–22] ones, have been developed to offer new ways to carry out physical and cognitive rehabilitation therapies, allowing patients to perform these activities not only in specialized centers but also at home, making use of tele-rehabilitation systems. Although all these systems have been created to be managed by different patients, in general these solutions have been designed to implement specific therapies [20]. Anyhow, there are some solutions where the therapists can adapt some features to the patient's skills [23, 24] or create their own therapies from scratch [10].

Some collaborative features have been already included in these systems. For instance, they provide therapists with facilities to control the therapy execution, to connect collaboratively with the patient while he is carrying out his rehabilitation task. However, although in the commercial solutions it is frequent to use some collaborative feature, such as video-conference [25] to facilitate the communication between therapists and patients, it is not so frequent to find systems that exploit 3D tele-immersive feedback [26] as part of the rehabilitation process. Moreover, only few proposals [5, 10] have been designed as collaborative environments that enable several specialist to collaborate in the design of a therapy. It is uncommon to find proposals that enable several patients to collaborate while they carry out a specific therapy. For instance, as far as we know only TANGO [27] offers this feature but patients must be located at the same physical space.

As we have already highlighted, tele-rehabilitation systems are collaborative in nature. Therefore, it is evident that relevant concepts used in the design of CSCW systems should be also analyzed when they are developed. One of the main CSCW concepts is *awareness* that has been defined in the computer collaboration field as "the up-to-the-moment understanding of another person's interaction within a shared workspace" [12]. There are multiple awareness interpretations [17], being the most well-known interpretations Collaboration Awareness, Situation Awareness, Workspace Awareness, Context Awareness, Social Awareness and so on. In a previous work [17], they were analyzed and it was concluded that it is not possible to cover all the features of modern complex collaborative systems by using just only one of them. For this reason, we carry out a thematic analysis [17] to define a novel awareness definition, Gamespace Awareness that integrates the main of the previous proposals in order to provide guidance in the specification of the awareness of one of the most complex collaborative systems: collaborative video-games. Therefore, in this work we use this novel awareness definition to evaluate its relevance in the design of another complex domain: Physical and Cognitive Rehabilitation Systems.

3 Awareness Interpretation for Physical and Cognitive Rehabilitation Systems

This section presents the awareness interpretation defined in order to deal with the awareness needs of tele-rehabilitation systems for physical and cognitive therapies. This interpretation has been developed by adapting Gamespace Awareness [17] to make it suitable for our target systems. Due to space constraints, in this article we focus just on the present awareness elements, which are paramount for providing patients with real-time awareness of what is happening during a rehabilitation session. Therefore, the other elements of Gamespace Awareness related to future, past, etc., will be adapted for our target systems in a future work.

The elements that this awareness interpretation identifies are shown in Table 1. They are categorized into four different categories, depending on what awareness information they are providing. More specifically, they deal with *who* is participating, *what* and *where* they do anything, and *how* to do it. Along with these awareness elements, a set of questions have been defined aimed at helping designers to identify the awareness needs of a rehabilitation system. As an example, consider a remote physical rehabilitation system whose patients work collaboratively. In order to collaborate, they should be aware of *who* is available in the rehabilitation session with, *what* the other patients are doing to coordinate their actions, *where* they are located in their own space and *how* to interact with remote patients. This awareness information, which could be considered obvious in a non-remote and non-computer-assisted rehabilitation systems, is crucial when dealing with remote collaboration. Therefore, one of the goals of this awareness interpretation is to make remote rehabilitation as understandable and fruitful as local rehabilitation.

As Table 1 shows, for each awareness element it has been also identified which feedback stimuli should be used to provide participants with the desired awareness. That is, *visual* (by using a computer screen or a virtual reality headset), *aural* (by emitting sound or audio messages) or *haptic* (by receiving vibrations on different parts of the body). Moreover, the possibility of providing awareness information through different stimuli is paramount when dealing with disabled people. For instance, if a deaf user is being rehabilitated, audio messages must be replaced by screen notifications or haptic signals. It is worth noting that not all awareness elements could be provided properly by using every stimulus. For instance, making the participants aware of the login of a new user in the system (element *Identity*) by using haptic feedback make no sense since it would require to codify each new participant ID as a different haptic stimulus. This could be overwhelming for users and difficult to implement as the number of users increases. However, providing this awareness information by using an audio message (e.g. "John is now online") could be easily understandable by most of the participants.

Moreover, Table 1 also provides some examples of how to implement each awareness element, i.e. how to gather such awareness information and how to provide participants with it. As an example, the *Status* element, which is related to the participant's physical and emotional status could be gathered by using either a biometric sensor to obtain biometric data such a heat rate or skin conductance [28], or a camera along with an emotional analysis software to analyze participants' emotions [29]. Besides, this awareness information could be provided by using different stimuli. For instance, if what we want to make a participant aware of the other participant physical status by a measurements of the heart rate, this awareness information could be provided by using the three considered stimuli. First, visual stimuli can be easily used by presenting animated heartbeats on the screen to represent the heart rate of the remote participant. Second, aural stimuli can also be considered and implemented by playing heartbeats thought audio. Finally, it could be possible to use haptic stimuli as well, thus emulating heartbeats by using haptic impulses that the participant will feel on a specific part of his/her body.

Table 1. Awareness elements for physical and cognitive Rehabilitation

Category	Awareness element	Specific questions	Recommended feedback stimuli[a]			Implementation examples	
			V	A	H	Gathering	Providing
Who	Presence	Is anyone in the system?	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	X		Face recognition	Recognized participant ID
	Authorship	Who is doing that?	X	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
	Intention	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
	Disabilities	What are the participant disabilities? What are they not able to do because of such disabilities?	X	X		Manual input	Visual warnings of disabled participants
	Perception	What are the other participants perceiving? (Looking, touching, hearing…)	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 at?	X			Eye tracking	Visualization of other participants gaze
	Reach	Where can the participants/ avatars reach?	X			Motion detection	Visualization of reach area
	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
How	Device	How do I use a certain device to interact?	X	X		Hardware detection/ Manual input	Audio and video instructions

[a](V)isual, (A)ural, (H)aptic

4 Case Study

Once the awareness interpretation has been presented, it will be exemplified in this section by means of a case study based on a physical-cognitive collaborative rehabilitation exercise. This rehabilitation exercise is offered as a game whose two users play collaboratively yet remotely. The interaction with the exercise is done by using a motion sensing device that translates the participants' movements into avatars movements. Figure 1 shows an example of how a rehabilitation systems of this type could be. It can be seen a motion sensing device such as Microsoft Kinect [26] to gather the participants' movements as well as a high definition camera to record the users' face and analyze interpret their emotional status using a specific software [29]. Moreover, a head-mounted eye-tracking device (e.g. Tobii Pro Glasses 2 [30]) could gather the participants gaze and a wristband (e.g. Apple Watch [31]) will both measure their heart rate and provide them with haptic stimuli.

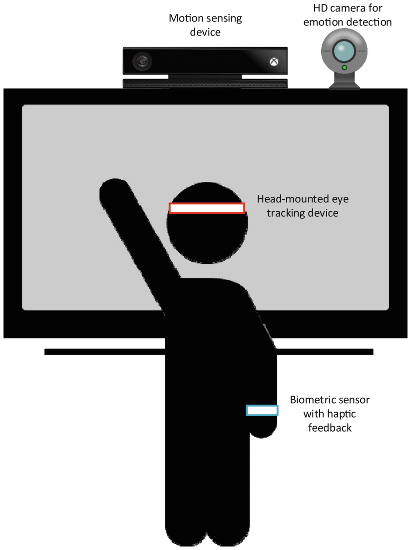

Fig. 1. Participants' hardware environment

Regarding cognitive rehabilitation exercise it is really an *association image-writing* rehabilitation pattern. This was defined in [6] to improve patients' front executive capability. The participants' avatar will be located in a virtual scenario in which different virtual coins will have images and words on it. The implementation of the rehabilitation pattern consists in requesting participants to find and touch a virtual coin related to a specific concept. For instance, if the system request 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 one do so with the coin shown the word "pear". Figure 2 illustrates two different avatars, blue and red, will touching the requested coins collaboratively.

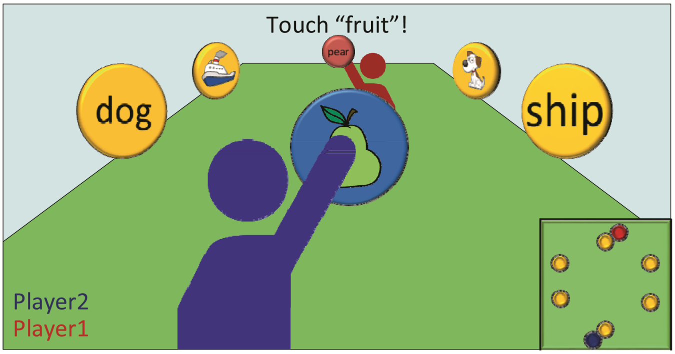

Fig. 2. Prototype of participants' user interface (Color figure online)

Besides, as far as physical rehabilitation in concerned, the therapist will be able to place the virtual-world coins' in different places to encourage the participants' movements. As an example, if a participant needs and upper limb therapy, the therapist could locate the coins in a high position, so that the participant will have to lift his arm in order to touch such coin. Moreover, the size of the virtual world could be customizable according to the displacement requirements of the therapy to be performed.

Furthermore, the therapist will have a different view of the system to monitor the therapy execution, thus enabling her to see each participant view, as well as the participants themselves (Fig. 3). Such view will also provide the therapist with the participants' heart rate, their gaze (gathered by means of a head-mounted eye tracking device), as well as with their emotional status (obtained by using a facial analysis software).

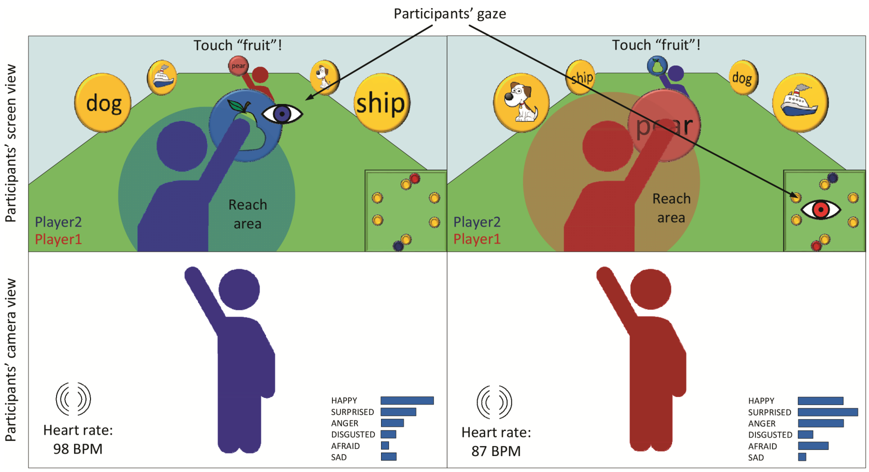

Fig. 3. Prototype of therapist's user interface

In order to exemplify how the awareness interpretation presented in Sect. 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 of Table 1:

- *Presence*: Participants have to be aware of the presence of a new participant with who 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* stimuli indicating the presence of a team-mate 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* or *aural* signal indicating a new log-in into the system.
- *Identity*: Participants have to be aware of who is the participant related to an avatar. Similarly for this awareness element, a *visual* list of participants (bottom-left corner of Fig. 2) could associate the avatars' color with the identity of the participant. Moreover, when a new participant logs in into the system, the *aural* message "the player [participant name] is ready" will be played.
- *Authorship*: Participants have to be aware of who activated a coin in the virtual world. The requirement would be: the color of such coin (*visual* representation) could change to match the color of the participant's avatar. Figure 2 shows that the pear (image) coin has been touched by the blue player, meanwhile the other pear (text) coin was touched by the red player. Alternatively, an *aural* message indicating who activated that coin will be emitted.
- *Task*: The therapist have to be aware of what the participants are doing. It could be achieved by means of a *visual* remote view (Fig. 3). In this sense, it could be seen both what the participants are doing in the virtual room (through their avatars) and the real world (real streamed video of the participants). In order to reinforce this feedback, an *aural* message such as "Participant 1 has activated the dog coin" or a *haptic* signal representing a coin activation could be sent to the participants.
- *Intention*: The participants have to be aware of their goals. For example, this goal, i.e. the coin they will have to touch, could be communicated by means of both a *visual* message on the screen and an *aural* notification. Thank to this double awareness system the participants would have instant information about the goal as soon as it changes but they would be always able to watch it on the screen (at the top of Fig. 2).
- *Object*: The participants have to be aware of the coin that he as well as the other participants have activated. For instance, likewise to what happens with 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 to the coins that will be played when that are touched, thus helping the participants to identify them.
- *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 to the therapist who would be able to interrupt the session or adjust if needed. For instance, if one participant's

heart rate was considerably high or he was in a bad emotional state, the therapist could interrupt the session and adapted according to the participant's needs. Instead, the heartbeats of a participants could be coded into *aural* beats or *haptic* vibrations aimed at making the therapist aware of a participant's heartrate.

- *Disabilities*: The system have to be aware of any participant's disabilities in order to avoid and/or adapt provided stimuli. Prior to beginning a session, the therapist will indicate whether any participant have disabilities in order for the system to be configured. For instance, if a participant 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.
- *Perception*: Related to the *task* element, the therapist have to be aware of what the participants are seeing thanks to a remote *visual* view of their screens. Moreover, she may also listen to the *aural* messages of the session and be aware that a participant has received *haptic* feedback (vibration symbols on the bottom part of Fig. 3 can be taken of an example of the implementation of this awareness element).
- *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 (bottom-right corner of Fig. 2). 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 circles with the same color than the participants' avatars.
- *Gaze*: The therapist has to be aware of where the participants are looking at, aiming at detecting cognitive problems. For instance, the therapist may see the point of the screen where the participants are looking at on the therapist's view in a *visual* manner (eye icons on Fig. 3). Therefore, if a participant was constantly looking at a screen point where no coin or participant were present, a cognitive issue could be identified.
- *Reach*: The therapist has to be aware of what the participants' can reach. For example, the therapist may see on her screen a *visual* representation of each participants' reach area, which may 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).
- *Position*: Participants have to be aware of the position of the coins. Just as it has happened with the *location* element, thank to which the participants may see their locations, participants may know the position of the elements by using this *visual* map (bottom-right corner of Fig. 2). 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 [17]. To reinforce this feedback, the concept of nearness to the coin could be represented as *aural* messages with a variable pitch or increasingly the *haptic* signal depending of such nearness.
- *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.

Thanks to the implementation of these awareness elements, the participant of a rehabilitation system like the one presented at the beginning of this section will be able to interact with it, collaborating with remote participants, as well as enabling the therapist to monitor and adapt the therapies.

5 Conclusions and Future Work

Awareness information is paramount to achieve a proper collaboration while interacting with remote participants. This issue is magnified when dealing with rehabilitation systems, whose participants suffer from any cognitive or physical disability. This turns the awareness information into a crucial element to provide patients with a proper rehabilitation process. In order to guide in the identification of such awareness requirements when developing cognitive and physical rehabilitation systems, we have adapted an already existing awareness interpretation, namely Gamespace Awareness [17]. It was developed to deal with the awareness requirements of collaborative games. However, in this work we have adapted it to make it suitable for rehabilitation systems featuring ambient intelligence facilities. This new interpretation comprises 14 awareness elements (classified into 5 different categories) that will provide both patients and therapists with the awareness information required to facilitate collaborative and remote rehabilitation. Moreover, along with this collection of elements, this interpretation provides a series of questions aiming at helping designers of new rehabilitation systems to identify their awareness requirements. Furthermore, 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.

In order to exemplify the awareness interpretation created for this target system, a case study has been presented. It describes two 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 is used to make the therapist aware of the patients' physical and emotional status.

This awareness interpretation deal with the most relevant elements of a remote real-time collaborative system, which are those related to the present. However, as a future work, it is planned to broaden this interpretation with a whole new set of elements related to the past, future and social aspects. Therefore, they will enable the therapist to make a comprehensive analysis of the therapies performed (past) as well as they will improve the participants' performance by enabling them to prepare their actions (future). Moreover, more participant will be able to participate in collaborative therapies by including social awareness elements. Finally, once the interpretation has been enriched with the aforementioned elements, a proper evaluation will be performed using a real rehabilitation system in order to assess the suitability of the awareness interpretation in a real scenario in order to evaluate out proposal properly.

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