ARCADE: Augmenting Rehabilitation Centres to assist physiotherapists through Digital Environments

Afonso Vicente Faria
afonso.faria@ist.utl.pt

Instituto Superior Técnico, Lisboa, Portugal

October 2018

Abstract

With the increasing number of people who need rehabilitation, this medical field is becoming increasingly important. A proper rehabilitation process guarantees a better lifestyle for the patients. Thus, it is paramount that therapists can perform their tasks with quality and as efficiently as possible. However, taking into account the number of patients under their care, coordinating the environment becomes a challenge that can reduce the quality of their work. Many solutions for improving the rehabilitation exercises have been proposed throughout the years. Despite this, there is a lack of solutions that help rehabilitation professionals. We purpose a proximity-based context-aware system, that aims to improve the situational awareness of the clinicians and to facilitate communication with the patients, with the intent of improving the therapists work quality. We created a tool to evaluate if a context-aware system can be useful for a rehabilitation workspace. Finally, we conducted an evaluation with the professionals. The results showed that physiotherapists are in need of technologies that can give more quantitative data about their patients. We also showed that a context-aware system aligned with visualizations that are centred on the challenges of a rehabilitation gymnasium can help the professionals control more patients at the same time. No paragraph breaks.

Keywords: Rehabilitation, Context-Aware, InfoVis, Physiotherapists, Situational Awareness, Proxemic-aware.

1. Introduction

There are several disabilities that rely heavily on physiotherapy to be mitigated and reduced. Cerebral Vascular Accidents (CVA) are one of the most common problems of the modern society, according to the World Health Organization (WHO). Each year, 15 million people suffer strokes, leaving 5 million of these dead and other 5 million with serious permanent disabilities. Following CVA's, and also accordingly to the WHO, musculoskeletal conditions come in as the second largest contributor to disability, worldwide. Rehabilitation is key to help stroke patients, musculoskeletal, or any other individual with a condition that requires this type of care. Physical therapy and occupational therapy are the most common types of rehabilitation used to give these patients a better life.

To regain the ability to perform normal daily tasks, the patients must go under several hours of therapy per week. With the number of Cerebral Vascular Accidents and also the time that is needed to correctly treat these patients, the rehabilitation clinicians have a hard time to perform their daily tasks. Therapy workplaces are often very crowded and the number of clinicians sometimes is not enough to effectively treat everyone. Furthermore, rehabilitation gymnasiums lack equipment that helps the therapist keep track of all the patients and exercises that are being performed. Traditional tools are not aware of the rehabilitation ambient, making it hard to perceive all the interactions between patient and therapist. This can impact the overall situational awareness (SA) of the clinicians. Situational awareness is the perception of the surrounding environment elements and it can be measured[**?**]. A situational aware professional can perform their tasks with quality, enhancing his relationship with the patient. Rehabilitation is continuously evolving and new techniques are being discovered. However, technologies that help the therapists are still lacking behind.

1.1. Problem

Physiotherapy environments are non-linear and dynamic, making it hard to support every patient in the same way. Most of the clinicians have more than one patient at the same time and the only way of dealing with this problem is by leaving the patients alone doing a defined set of exercises. It is impossible to always keep track of the patient exercise performance, which can lead to less effective rehabilitation or, in a worst case, to injuries due to incorrectly performed exercises. Healthcare environments are not completely strange to context-aware workspaces. However, most of the previous work that was developed in this field, focus on Hospital settings. Just like any other medical environment, rehabilitation sites are very crowded and dynamic, so the clinicians have to always be aware of each patient's conditions to guide them to a better performance. Furthermore, most of the tools used by clinicians, focus on showing historical medical data from the patients and not data that is being processed in real time from the exercises that the patients are performing. In addition, patients who are cognitively able to perform stationary tasks, like upper-limb exercises, sometimes perform them with the help of a clinician. That is because the available tools do not give enough information to the professionals in order to have good situational awareness, which allows them to leave the patients performing exercises by themselves.

2. Related Work

In this section, we will be discussing the pros and cons of the studies from the state of the art that are suitable for our proposal. With our proposal in mind we started by analyzing context-aware environments in a healthcare setting, right away we can find that the majority of the studies in this field are executed in a hospital workspace, this is extremely important because, in spite of being a similar environment, the rehabilitation centres have some characteristics that are unique to those types of workspaces and there is no solution that focus on a more physiotherapy centered design. The study that Bardram et al. [2] performed showed that traditional technology is not suited for these types of workspaces, to create a more pervasive environment all the devices must be as easy to use as possible, all the devices used to developed context-aware spaces in the articles studied in the related work, are easy to use. Most of the technologies used to develop pervasive environments are intended to be as seamlessly integrated as possible, J. Favela et al. [1] explains perfectly how ambient displays are important to create an ubiquitous workspace where all the devices are well integrated and disguised, a good example of a practical use of ambient displays is the Hello.Wall created by Prante et al. [5] that uses light patterns to transmit context-dependent information. With the analysis it is clear that context-aware environments use devices and technologies with characteristics that are oriented to a more dynamic workplace like a rehabilitation centre. Despite the Pervasiveness of ambient displays, our system will rely on normal displays to communicate with the clinicians and patients, Su et al. [7] produced a set of guidelines that can help positioning large displays on an interactive workspace like a rehabilitation centre. It is also clear that position and proximity play an important role in the implementation of a context-aware system, in a rehabilitation environment clinicians maintain a close contact with the patients, thus, our system will have to be proxemic-aware to better understand the workspace context, being the main tool that we will have to use to be as context-aware as possible, i.e a context-aware application based on proxemics. Viswanathan et al. [8] also concluded that future ubiquitous healthcare environments will have non-intrusive sensors and will use real-time data to help with the care of the patients, these conclusions are extremely important because our system will evaluate real-time data of the patients exercises without any type of invasive sensors, making it as ubiquitous as possible.

Visualizations are also very important to the development of a rehabilitation context-aware environment, studies like T. Wang et al. [9] did, that focus more on medical records and historical data, often use a more standard and impractical visualization that takes longer to analyze, rehabilitation-oriented visualizations have, in addition to the standard ones, physical kinematic visualizations to better understand data from exercises and to help improve future rehabilitation work, B. Ploderer et al. [4] used in different occasions upper body figures allied with heat maps to describe the patients performance, these visualizations are easy to understand making them perfect for a dynamic environment that is characteristic from a rehabilitation centre. M. Rahman et al. [6] also uses a combination of standard visualizations with a two-dimensional visualization to better detect patterns in patients exercises, facilitating the clinicians' work. The main target of our work are the Physiotherapists, thus, our visualizations will guarantee that all the information available, is useful to improve the clinicians' work. The proxemics awareness of the system will allow the visualizations to adapt to the professionals, fulfilling their work needs. Because our exercises will be performed by patients with a high degree of autonomy and with good cognitive capabilities, our visualizations will not only help the clinicians but they will also provide feedback to the patients, in order to, like in the system GEAR [18], keep their motivation and good performance.

We can also see that the most used tool in rehabilitation systems is the Kinect, studies like C. Chang et al. [3] did show that the tracking features and the low price make this equipment perfectly suitable to be used in a Pervasive environment where it can, not only, track the patients movements with a relative high precision, but it can also be used as a tool to understand the workspace and its surroundings. Wearables are also very commonly used and are very precise, but they take time to set up and can only track the patients movements without an understanding of the environment.

3. Design Guidelines

In an initial phase, after collecting the desired information from the available studies on the field, we performed a field study that would guarantee that we could take the development of our system through the desired path. We wanted to understand how a real rehabilitation environment worked and we wanted to get the input of the physiotherapists on the idea that we had. The study was performed in Hospital Prof. Doutor Fernando Fonseca and with the professional from Corperativa de Ensino Superior Egas Moniz.

After this initial phase, it became clear that we had to follow some design rules to produce a system. This system would be useful for a rehabilitation environment and should be good enough for the physiotherapists. In order to make sure that this could happen we synthesized the following guidelines:

- Develop a robust system that could handle any type of rehabilitation gymnasium;
- Develop a system that could handle different patients and exercises;
- Develop a system that could facilitate the daily tasks of the professionals. It should facilitate the evaluation of several patients at the same time;
- Develop a system that could inform the condition of several different patients;
- Develop a system that could give confidence to the clinicians to leave patients performing exercises by themselves;
- Develop a system that could always warn the professional if there is something wrong with the patient's exercise;
- Develop a system that could reduce the difficulty of controlling different patients at the same time;
- Develop a system that is easy to use and to set up in order to help the daily tasks of the professionals;
- Develop a system that does not use any type of equipment that obstructs the patients' exercises;
- Develop a set of visualizations that are easy to interpret and to facilitate a fast exercise evaluation;
- Develop a system that deliverers relevant information at all times;
- Develop a system that understands the information needs of the professionals;
- Develop a system that could be used with other equipment (i.e, equipment that is used during the exercises, like weights);
- Develop a system that is robust and versatile to avoid the usage of "improvised equipment" (like the floor tiles);
- Develop a system that could be used in different rehabilitation methods (ex: circuits);
- Develop a system that could improve the overall efficiency and quality of the work performed in the rehabilitation centers.

The previous list was very important to the overall development of the system. We used these guidelines to ensure that we were developing a useful system to the professionals. Despite having these leads to follow, it was important that we could maintain the communication with the clinicians to make sure that our approach would be coherent with what they wanted.

4. Approach

The primary goal of the system is to give physiotherapists the ability to control several patients at the same time without compromising the rehabilitation process of each individual, clinicians cant be always helping the same patient performing the exercises and rehabilitation activities, but with the introduction of our system they will be able to get a continuous stream of information of all the patients that are under their care. To accomplish this we wanted to create a context-aware system that could understand its surroundings to give to the professionals what they wanted at all times.

Proxemics is the study of human communication through space, it studies how people behave and communicate while interacting with others in defined spaces. In the system that we created, we took our own approach to proxemics interaction. The key interaction of our system is the relationship between professional and patient, all the context awareness of our tool comes from the distance between this two parties. Basically, our visualizations change with this parameter. After this phase we had to find out how the system would change, the distance is key but from the observation phase, we noticed that the professionals are always moving inside the gymnasium area making it impossible to be always changing the interface with minor distance changes. Furthermore, continuously changing the interface would be very distracting not only for the professionals but for the patients as well. To be efficient, therapists need to work with a system that does not overload their senses, the system should make its changes as seamlessly as possible to facilitate the usage of several systems at the same time (one per patient) in order to make the clinicians more aware of its surroundings.

To solve the problem we looked at the interpersonal distances from proxemics interaction studies that use these metrics to describe the space around an individual. There are four different spaces around a person:

- **Intimate space:** The closest someone can get to a person, the intimate space is normally characterized by interactions between people with closer relationships. Normally ranging in between fifteen and forty five centimeters from the individual;
- **Personal space:** From forty five to one hundred and twenty centimeters the personal space is normally occupied with close friends or family members;
- **Social space:** The social space is normally occupied with people that are interacting with the individual but do not know him as well. This spaces ranges from one hundred and twenty to three hundred and fifty centimeters;
- **Public space:** Finally the public space is normally used when someone is talking for an audience or is giving any type of public speech;

Our approach in interpersonal distance terms was to use the first three spaces as a threshold that would be detected by our system. Whenever the physiotherapist changes between the intimate, personal and social spaces from the patient, the system detects this and changes accordingly. This approach guarantees us that the system does not overwhelm the people that are in the gymnasium and maintains the desired context-awareness. In the implementation section, we will discuss how we tried to make the system change between these spaces as smoothly as possible in order to not distract and surprise the therapist the patients.

4.1. Architecture

We wanted to develop a system that is easy to use and easy to set up without having to use hardware like computer mouses and keyboards that (as we saw in the related work) could reduce the ubiquity of the system. This ubiquity is very important in context-aware systems and we should take it very seriously. In order to improve the usability of the application we used a touch display that could be used to set up all the exercises and compensations thresholds. This solution was the most minimalist way of giving to the physiotherapists the ability to interact with the system without having to use any other equipment, making the system as ubiquitous as possible.

The final architecture of the station ended up with only a computer with Microsoft Windows 10 that could run the system's application on Unity3D accompanied by a Microsoft Kinectv2 and a big display with touchscreen capabilities.

5. Implementation

In order to achieve the desired goals, we had to carefully adapt the representation of the metrics within each interpersonal space. As we said before the behaviour of our interface changes with the transition between spaces. If the professional is closer to the patient he should get a more detailed set of metrics to better judge the performance of the individual. The balance between spaces is very important and the system should flow in a way that the professional comprehends the changes and responds accordingly.

5.1. Social space

The approach in this stage was very clear, we had to display the most important metrics to know if the patient is doing the exercise correctly in the most simple way. Despite being one of the most simple interfaces, these visualizations were in fact very hard to build because we had big amounts of information to display in a minimalist and simple manner. The solution that we found was to display only two metrics, the session time and the success metric. This section is strategically placed on the top of the display to guarantee that the components are seen from everywhere.

The idea behind these two visualizations was to have the minimum information needed to ensure that the professional can assess the current performance of the patient. In conjunction with the session time, the success viz informs the clinician if the patient is achieving the goals of the exercise. This success metric is a derivation of two joint metrics, the compensatory movements metrics and the out-of-path metric. If one fails, the success percentage is reduced.

Figure 1: Social space interface

5.2. Personal Space

When the physiotherapist reduces the interpersonal distance with the patient and enters in the personal space our system reacts and changes accordingly. In this stage, the professional is closer to the individual and is able to filter more information and probably is even more interested in the patient condition due to the fact of being closer to the individual. With the entrance in this interpersonal space, the interface gains two new sections and adapts the visualizations that already existed in the social space.

We wanted to create visualizations that were easy to understand. The first new section was a more kinematic section with two visualizations included. In this section, there is an amplitude visualization that shows three planes with the amplitudes of each joint in a body representation, (it shows the maximum. minimum and current values of each plane) and an average time per repetition visualization. In the other section, there is another body that has a visualization with three zones. Each zone represents a compensatory movement and the color of respective zones changes with the number of compensatory movements.

Furthermore, due to the fact that the therapist is closer to the patient, the components that were already on the screen reappear with more information about the exercise. The time left to the next repetition on the left and the metrics that derived the success visualization on the right.

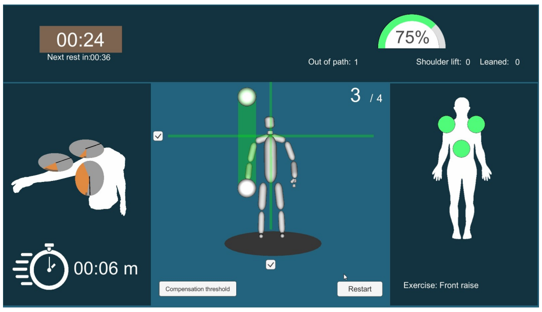

Figure 2: Personal Space

5.3. Intimate Space

The intimate space is the closest to a person that we can be in terms of interpersonal spaces and it is in this space that the physiotherapist is fully focused in the patient and in the patient's exercise. It is only in this space that we can display more complex information because we have the certainty that the clinician can dispense some time analyzing the patient's performance.

The objective in this final space was not only to display more information but also to display the information that we already had with more precision. Until this point, we showed several metrics to the professionals that were easy to understand but had no precise report of the metrics that our system could handle. Therefore, to transmit all the information that we could display we added to several visualizations precise information of each metric.

All the visualizations that did not have enough detailed metrics, like the amplitudes component and the compensatory movement visualization, received an update. Both of them show the metrics with precision by the addition of text with the right information.

Furthermore, to complete this part, we added the time per repetition visualization the information of the time of the last repetition.

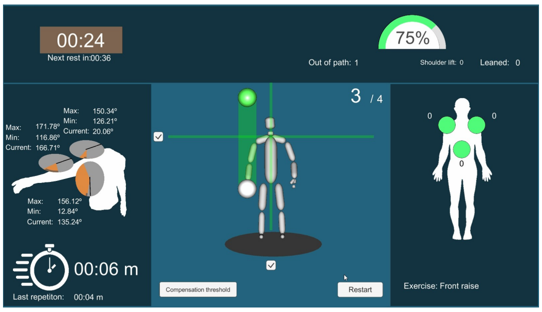

Figure 3: Intimate Space

5.4. Patient interface

The patient's part was the central part of our interface and was the only visualization that the patient should focus. It was very important to not change this central part throughout the interpersonal spaces because it should be isolated from the physiotherapists part. We tried to put only the things that made the exercise possible in order to not distract the patient. Furthermore, this section is isolated from the other making it clearly distinct from the rest of the items in the display.

The section was composed by the avatar of the patient, a compensation matrix that could help both the patient and the physiotherapist and the number of successful repetitions compared to the total number. Furthermore, there was a menu with the compensation thresholds that gave to the clinicians the ability to adjust the compensation sensibility.

5.5. On-demand metrics interface

Lastly, to achieve a complete system that could help the physiotherapists, we added two last features that should give more insight into the patient's exercise. This last two visualizations had the goal of giving additional information to clinicians but this information could not always be present during the exercise because it could only be displayed in the patient's interface that could not be disturbed. Furthermore, this information belongs to a more analyze driven part and should not be present at all times during the exercise. To solve this issue, we used a different type of method to show the metrics. This metric was call "On-demand" and as we previously showed it was suggested by the clinicians in the workshop.

The first one is an additional information of the compensatory movements that the patient did during the exercise, The objective of this visualization was to display an agglomerate of skeletons that corresponded to the body positions of the patient when he performed a compensatory movement. The goal of this approach was to allow the recognition of any sort of patterns that the patient repeated during the exercise.

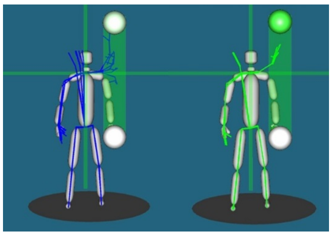

Figure 4: Skeletons

Finally, the last visualization that we implemented was a movement/trajectory heatmap that could show the movement of each individual arm joint during the exercise. The approach that we had with this feature was different from all the others. One of the characteristics of the Kinectv2 is that it can track several bodies and several joints per body and we knew that we could use this to our advantage.

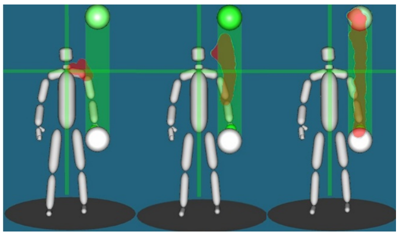

Figure 5: Joints' heatmaps

Because we were only focused on upper-limb exercises we decided to only track the joints that would be used during these types of exercises. Depending on which arm, left or right, we tracked the position of the shoulder, elbow and hand joints during the completion of the exercise. After recording this information, the system creates a heatmap of the path of each joint that is used to help the patient's evaluation. This heatmap visualization works by displaying with bright red the spaces where the joint spent the most time during the exercise and with less bright colours, like green and blue, the places where the joint spent the least time.

6. Evaluation

In order to collect the desired the desired feedback, we created a set of questions that could initiate a conversation about different parts and features of the system. The goal was to create questions that would be used in a unstructured interview to "extract" the desired information from the clinicians. The questions for the interview were the following:

1. Is ARCADE effective in illustrating the patients' performance(exercise quality)?
2. Does ARCADE enable physiotherapists to monitor several patients simultaneously?
3. Is ARCADE's biofeedback useful to assist a upper-body exercise?
4. Are proxemics interactions useful in rehabilitation environments?

6.1. Procedure

The goal with the evaluation session was to understand the capabilities of the system and if it would be a helpful tool to be used in a rehabilitation context. In order to keep the clinicians motivated throughout the session we divided it in two different parts. In the first phase we demonstrated the overall capabilities of the system by performing a small simulation of a upper-limb exercise. In the second part we did a small experience to collect some data about the weaknesses and strengths of the system. Both of the phases were performed in a isolated room and each evaluation was executed with only one professional at each time to maintain a controlled environment and to not compromised the evaluation with the other participants. In the room there were only three individuals, two that participated in the evaluation and another one to take pictures and to record the session audio.

6.2. First Phase:

In the initial phase we tried to explain all the ins and outs of our system in a dynamic matter in other to motivate the clinician to give a more in depth opinion of the interface and system functionality. Before starting the session we asked to the participants to always say what they where thinking and to not hesitate if they wanted to give any type of feedback. This is called Think-aloud and it is a very well known method of extracting qualitative data from the participants. In our case this was very important because we wanted to perform a Thematic analysis that we will described in later sections.

Firstly, we asked the clinicians to pretend to be the patient and to move themselves to the front of the screen where the Kinectv2 could track them.

In this simulation, the person who was conducting the study had the role of the physiotherapist to explain to the participants how they could interact with the system. For the demonstration we selected the "Front raise" exercise and showed to the participants the menus where they could personalize the session times, repetitions and the adjustments of the sensibility of the compensatory movements. After this we wanted to uncover the mental model of the participant by asking them to describe what they see and to try to guess the purpose of each visualization. This method is very common in UX design and it is used to understand how the participants form their visualizations mental model.

We started by showing the interface in the social space followed by the personal space and the intimate space to demonstrate a real situation in a rehabilitation environment. After switching between spaces to show how the system works and how the visualizations change with the distance we showed the on demand metrics that we collected during the exercise simulation, the skeleton agglomeration and how it works and finally the heatmap visualization with its unique toggle features. Finally, after the simulation, while the participants were testing the system, we performed a semi-structured interview in order to collect any missing feedback that could be critical to our evaluation.

Figure 6: First phase of the evaluation session

6.3. Second Phase:

In this last phase we wanted to perform a small experience to compare our system to a normal exercise evaluation. The participants had to evaluate six exercise samples with a questionnaire that we handed to them. Firstly we showed to the individuals the questions that they would be answering in order to understand what they should collect during the visualization of the sample. The participants performed in total six evaluation from six available samples where there were images of the final screen of our system. Three of the samples were videos of an individual performing a upper-body exercise. To maintain the exercise fidelity, the samples were shown only once within a limited time interval.

The samples were handed to the participants in a random order every time to maintain the results with the minimum error possible. Despite being six samples, there were only three exercises, each exercise had two different samples, one from the system and another from a video. Each video was shown in the exercise screen and each system sample was given to physiotherapist in a way that they could interact with it like they would if it was on the screen. After the evaluation of all the samples, we performed a small discussion of the results of each questionnaire to understand if the participants understood that there were only three exercises. We also wanted to understand what was their opinion about the system evaluation compared with the video one.

7. Evaluation Analysis

Because we were only focused on upper-limb Because of the innovate nature of our system we decided that performing a qualitative analysis would be more adequate to evaluate the ARCADE application. Thus, we opt to use a thematic analysis to analyze the transcripts that we got from the evaluation sessions. As we went through the data, we collected several codes that were later grouped and with those groups we created themes that emerged from this field study. This analysis allowed us to collect the qualitative results that we will discuss. This method was used to group similar patterns in the therapists' feedback.

Additionally, we used the results from the questionnaires aligned with the discussion that we had after the experiment to identify some interesting patterns on the results. The goal with the questionnaires was not to perform a precise statistical analysis but to use the results to see if there was any type of interesting patterns that aligned with the discussion that we had with the professionals could give a more in-depth insight of the performance of our interface. Despite this, we will collect centrality and deviation metrics and we used a Wilcoxon Signed-ranked test to compare two related samples.

7.1. Results

With our research questions, we aimed to find out and assess if our system had enough functionality to be implemented in a rehabilitation workplace. It became clear that, in order to talk about our conclusions, we have to link and create bridges between the questions that we set up.

To begin with, we would like to talk about the visualizations and the biofeedback that is given to the patient (first and third questions). Luckily, the overall feedback was very positive. The physiotherapists were very interested in the metrics that were available, and in the way the information was displayed. The visualizations were able to interact with each other. With little effort, the physiotherapists could join several metrics from several components to perform a better assessment of the exercise. The physiotherapists could also discover hidden information that could only be achieved by using several visualizations at the same time. Despite this, there was some visualization that could be improved with historical data, which can be very useful for a long-term evaluation. Furthermore, the patient biofeedback section could be improved. The system needs to be more adaptable to each individual and the customization of the system is very important. The results show that it is possible that these visualizations could be used to assess the quality of the exercise, despite the fact that there is a need for customization and for a better collection of information (more metrics and elements).

The other two questions also had to be together because, as we understood from the feedback, they are directly connected with each other. The way the information flows with the distance between the patient and the clinician is very important to give enough confidence to the professionals. It is important for them to be able to leave independent patients performing upper-body exercises by themselves. The different visualizations between spaces, not only help the therapists, but they could also help the patients. Participants said that the patient could feel that he is being watched and that he is being taken care of. Furthermore, the biofeedback and the visualizations are also very important for motivational motives. In fact, there was a participant that wanted to have a better motivational incentive. The visualizations were also crucial to leave the patients by themselves. With the available components, the participants agreed that the system knew what kind of information should be displayed and that it could inform the therapist if something was going wrong. This power could make it possible to control several patients at the same time and to reduce the number of clinicians that exist in a rehabilitation gymnasium. Despite liking the context-awareness, the rehabilitation staff said that they would want to lock the system in certain spaces. This would be for them to be able to have a better control over the situation and to use the total available information when they wanted.

The results that we gather from the quantitative analysis were also aligned with these statements. The non-parametric Wilcoxon test revealed that most of the sample do not have signification differences. This could mean that the system is as good as a video analysis.

In conclusion, the feedback was very positive and the system is a great base to create a tool that will, in the future, help the rehabilitation professionals. Based on the results, it is possible to say that the system could be able to improve the overall situational awareness of the system. However, it is impossible to know it for sure without implementing the system in a real-world scenario. Furthermore, there are still some flaws that can be easily addressed to make the system as robust and useful as possible.

8. Conclusions

In this work, we addressed the challenges behind the creation of a system that aims to assist physiotherapists in their daily tasks. We created a tool with the purpose of aiding the evaluation of upper-body exercises, that can be performed by several patients at the same time. The goal was to have a system that would not only help with one patient, but it would also help with the treatment of several patients at the same time. This would be accomplished by understanding the environment where it is inserted, with the usage of proximity-based context-aware technologies.

There are already several systems that try to help patients with their rehabilitation exercises. However, the focus of this studies is never on the challenges that a physiotherapist encounters in his daily life. Furthermore, the systems that are used for tracking purposes, are normally very expensive and have a long set-up time, making them unusable for the daily challenges of a rehabilitation workspace. Moreover, there is a lack of context-aware solutions, that aim to help a rehabilitation environment being normally focused on hospital workspaces. Those workspaces, despite being similar, have different features that make the implementation of the same systems in a rehabilitation gymnasium, unpractical. Rehabilitation workspaces have their own challenges and characteristics that, when studied, show that these problems could be mitigated with the usage of the right context-aware technologies. These challenges are not only related to the context-aware solution, but also to the way information is displayed in these environments. These rehabilitation scenarios are normally very crowded. The retrieval of information by the clinicians must be very fast, in order to give the correct aid to a patient, while performing the exercise. There is a lack of simple and intuitive visualizations that help, in real-time, these information needs, which are vital to professionals.

In order to reduce the problems that are found in the types of workplaces in this document, we purpose ARCADE: a clinician focused tool that is easy to set-up and uses equipment to create a proximity-based context-aware system. It can not only give relevant information that can be quickly interpreted but also gives to the professionals the ability to control several patients at the same time. The objective of a system like this is to always inform the condition of the patient, no matter where the therapist is in the gymnasium. With its context-aware capabilities, the system can interpret the distances between patient and professional, to display the correct information at all times, anticipating the clinician needs. Furthermore, the system is prepared with the most intuitive forms of communication, making the relation between the user and the system as ubiquitous as possible.

Throughout the development of this project, there was a continuous relation with the physiotherapists. That was created in order to develop a system that could fit their needs and that would be useful to be used on real-world rehabilitation center. This user-centered started by visiting rehabilitation workspaces, to understand the challenges that we would face when creating a context-aware tool that would be fitted to these environments. This relation culminated in an evaluation session, with several physiotherapists, to understand if the created system could, in fact, be deployed in a real-world scenario. The results of the session revealed to be very promising. The clinicians liked the overall concept of the interpersonal distances and also thought that it would be very useful to be implemented in a scenario where each professional has more than one patient. Furthermore, the professionals were very interested in the visualizations and in the relationship that they could create between them. They thought that the components were well constructed, despite wanting a little bit more of historical data to compare sessions. They really liked the quantitative part of the system, but they wanted it to be more personalizable to fit every situation and every patient.

A future system would be more fitted to the patient. One of the main challenges of a rehabilitation system is to fit all the patients that are going to use it. The disabilities are very different between all the patients, and the system has to be robust enough to handle all the types of individuals. ARCADE revealed to be a great start to contribute to rehabilitation systems. It can improve the job quality of the physiotherapists and ultimately reduce the number of professionals that there is in a rehabilitation gymnasium.

9. Future Work

Like every other project, there is always room for improvement and our project is not an exception. The evaluation sessions gave a great insight into what should be done to improve the system, as well as continuing to develop an incremental product. That product can, after several iterations, be used as a real rehabilitation tool that can aid physiotherapists in their tasks. Our system is still on early stages and there are many things that are essential to make it usable.

We integrated a project that despite its strengths, has many issues that are very important to the correct implementation of the system. The exercises were very simple and they need to be adjustable to the patient. To improve this integration, the system should give to the physiotherapists the ability to create the path that the patient is going to make during the exercise. There should be a recording phase where the clinician records with his hand the path he wants to build for the patient. This is relatively easy to implement and it would drastically change the personalization of the system, making it very robust and adaptable. Following this change, the system should also incorporate a profile for each patient that could integrate the exercises created for each patient. It should also incorporate the data from previous sessions, in a way that gives the ability to compare those several sessions, to understand how a patient is recovering throughout the rehabilitation time. Furthermore, there is a need to collect more data. In future iterations, the system should also record more precise compensation movements as the head movement, to give a more ample set of metrics to the professionals.

Regarding the visualizations, there are still many changes that can be done to improve the communication between the therapist and the interface. Firstly, the time per repetition visualization should be revisited. This visualization should show more historical data, to give the full session context that is very required to the evaluation of the exercise. This visualization should remain simplistic but should display more information. For example, it could show the time of the last repetition inside a radial stacked bar chart, on which each bar was the time of one repetition.

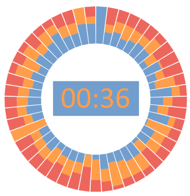

Figure 7: Time per repetition visualization sketch

The feedback that we received in the evaluation sessions, was that the professionals should have the training to use a system like this. So, in order to take advantage of this situation, the system could have visualizations that were specially coded in a way that only the professionals could understand. There could be some information that the patients should not see, in order to complete the exercise without any external interference. Paring these types of coded visualizations with the normal ones could give to the physiotherapists the ability of only showing to the patients what they think that will motivate them to perform a better exercise.

Finally, as for the implementation of a context-aware, there are also some improvements that could be done to improve the system's pervasiveness. Sometimes, the therapists want to display all the information at all times and the system should be aware when these situations happen. Because of the complexity of the situation, in a first phase, the simplest way of solving this problem is to use some type of toggle interface. The professionals could use it to activate and deactivate this feature. Furthermore, a smartwatch could be used not only for this purpose but also to give alerts about the patients' situations. This device would be intuitive and easy to set up and it would improve the overall situational awareness of the user.

Acknowledgements

First of all, I would like to thank all my family and close friends that guided me through this amazing journey. Without them it would not be possible to achieve the very important milestone that were planed on the beginning of this adventure. Being on Instituto Superior Tcnico was very challenging and there was a lot of hard work involved, but this university gave me skills that will be very helpful for the rest of my life. For this reason, i would also like to thank all the professors and professionals of Instituto Superior Tcnico for the amazing support.

However, I have to demonstrate my special gratitude to my supervisors, Prof. Dr. Hugo Nicolau and Prof. Dr. Daniel Lopes. It would be impossible to complete this work without their continuous support and motivation. Their quality advisory and guidance was essential to achieve the desired goals. For this reason, thank you very much. Furthermore, i would also like to thank to my college Alexandre Gordo for being present throughout all the stages of the completion of this work. His help on the preparation and execution of several tasks was key for the success of it.

Finally, I would also thank as well the the health professionals of the Hospital Professor Doutor Fernando Fonseca, E.P.E. give special thanks to the physiotherapists from the Hospital Garcia de Orta and the professionals over at Instituto Superior de Ciencias da Sa ude Egas Moniz who kindly worked with us in every phase of the research. I would like to thank, as well, the financial support granted by the Portuguese Foundation for Science and Technology through project IT-MEDEX, PTDC/EEI-SII/6038/2014.

References

[1] C. A. Alemán and J. Favela. Ambient displays to assist caregivers monitoring the sleep of people with dementia. In *Ubiquitous Computing and Ambient Intelligence*, pages 40–45. Springer, 2016.

[2] J. E. Bardram. Hospitals of the future–ubiquitous computing support for medical work in hospitals. In *Proceedings of UbiHealth*, volume 3, 2003.

[3] C.-Y. Chang, B. Lange, M. Zhang, S. Koenig, P. Requejo, N. Somboon, A. A. Sawchuk, A. A. Rizzo, et al. Towards pervasive physical rehabilitation using microsoft kinect. In *PervasiveHealth*, pages 159–162, 2012.

[4] B. Ploderer, J. Fong, M. Klaic, S. Nair, F. Vetere, L. E. C. Lizama, and M. P. Galea. How therapists use visualizations of upper limb movement information from stroke patients: a qualitative study with simulated information. *JMIR rehabilitation and assistive technologies*, 3(2), 2016.

[5] T. Prante, C. Röcker, N. Streitz, R. Stenzel, C. Magerkurth, D. Van Alphen, and D. Plewe. Hello. wall–beyond ambient displays. In *Adjunct Proceedings of Ubicomp*, volume 2003, pages 277–278, 2003.

[6] M. Rahman, B. Wadhwa, A. Kankanhalli, Y. C. Hua, C. K. Kei, L. J. Hoon, S. Jayakkumar, and C. C. Lin. Gear analytics: A clinician dashboard for a mobile game assisted rehabilitation system. In *User Science and Engineering (i-USEr), 2016 4th International Conference on*, pages 193–198. IEEE, 2016.

[7] R. E. Su and B. P. Bailey. Put them where? towards guidelines for positioning large displays in interactive workspaces. In *IFIP Conference on Human-Computer Interaction*, pages 337–349. Springer, 2005.

[8] H. Viswanathan, B. Chen, and D. Pompili. Research challenges in computation, communication, and context awareness for ubiquitous healthcare. *IEEE Communications Magazine*, 50(5), 2012.

[9] T. D. Wang, K. Wongsuphasawat, C. Plaisant, and B. Shneiderman. Visual information seeking in multiple electronic health records: design recommendations and a process model. In *Proceedings of the 1st ACM International Health Informatics Symposium*, pages 46–55. ACM, 2010.