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SERIOUS GAME DESIGN PRINCIPLES FOR MOTOR EVALUATION OF PATIENTS WITH NEUROLOGICAL DISEASES

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1. Introduction

Today, video games are widely used for medical training and practices as well as for surveillance, pain management, rehabilitation and rehabilitation measures for patients who acquire knowledge about their clinical pictures and possible therapy options. The use of games adapted to the treatment protocol has the advantage of creating a fun and interactive environment, adaptable to the capacities and interests of the users.

Number of games applied to healthcare are growing and are subjects of much research (Graafland et al., 2014). Their introduction into the healthcare field has been facilitated by the emerging digitization of medical processes. The use of games for the purpose of preventing and treating disease has many advantages, as it stimulates patients, promoting recreation, motor development, reasoning ability, the motivation to overcome patient's limitations (Göbel et al., 2010). In the digital environment, games are computer applications based on computer graphics and designed for entertainment. Digital games began to be applied to the health field when their ability to influence the attitudes of individuals was identified. Then, simulations in controlled environments are explored to work on issues such as health risks, personal care and self-training. But commercial games are not always suitable for therapy due to their lack of specific features and adaptations to patient conditions (Lange et al., 2009).

As a common example in Gertner Institute, Israel, motion-guided games for posture and movement recognition are actively used in addition to standard rehabilitation therapy for post-heart attack patients and children with cerebral palsy. Medical scientists from Gertner Institute also developed an application for Kinect, which allows for home-based rehabilitation therapy, practically effective from the therapists and patients points of view. Clinical studies have shown that serious games give patients a higher chance of returning to pre-infarction levels of mobility (Rand, 2013). The PRehab (Platform games for Rehabilitation) is a game designed for the rehabilitation of the arm by performing pointing tasks. Developed for patients with after-effects of stroke, the therapeutic objective is to increase the range of

motion of the arms, as well as the frequency of training during the rehabilitation sessions (Hocine et al., 2015). The Rehab@Home is also a serious game system indicated for the rehabilitation of patients with multiple sclerosis. The play environment uses the Kinect, and the goal of rehabilitation is to promote wide and fine movements of the arms and shoulders as the patient interacts in a virtual environment. The TANGO: H (Tangible Goals: Health) is a personalized and dynamically adapted game platform to perform exercises according to the player's profile. The objective is the rehabilitation of children hospitalized with different pathologies. The system uses a Kinect to recognize gestures, without the need for physical contact with traditional control systems (Gonzalez-Gonzalez et al., 2019). The ReaKinG platform is a system developed to reduce the physical effects of aging through activity sessions reproduced in a virtual 3D environment. The system also includes assessments that can be configured remotely by the therapist to include exercises aimed at improving patient mobility, aerobic capacity, strength, coordination and joint flexibility (Pedraza-Hueso et al., 2015).

2. The Design of Serious Games

2.1. Serious game characteristics and attention for users

Serious games are games developed on the basis of educational principles that address specific knowledge, aimed at teaching, training new skills or raising awareness of relevant topics (Argasinski and Wegrzyn, 2019; Marsh, 2011). According to Laamarti and Saddik (2014), serious games can be defined as an application of three components: entertainment, experience and multimedia (Figure 1)

1. Entertainment: essential dimension, linked to the feelings stimulation and emotions which add pleasure to the activity.
2. Experience: content, knowledge or skill disseminated by multimodal interaction (human-machine interaction thanks to more efficient, intuitive and easy-to-use interfaces) in different contexts.
3. Multimedia: information that can be presented through text, graphics, animation, audio, touch or a combination of them.

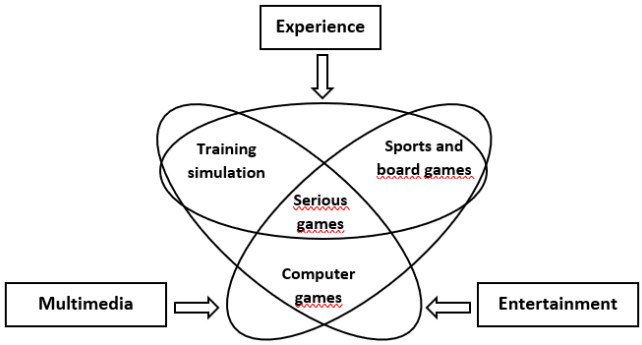


Figure 1. Definition of the serious games by three components (Laamarti, Eid and Saddik, 2014)

The use of games adapted to the treatment protocol has the advantage of creating a fun and interactive environment, adaptable to the capacities and interests of the users. Carabeo et al. (2014) and Paraskevopoulos et al. (2014) point out that in addition to entertainment, motivation and a willingness to perform tasks, serious games must offer functionalities to patients and therapists (users), such as matching the abilities and needs of patients, the execution of relevant tasks, or even the proposal of tools to guide the therapist in the evaluation of patients. In addition, the use of games as part of therapeutic protocols allows the introduction of a variety of equipment such as 3D sensors, tablets, mobile phones that can track and record human movement and facilitate kinematic analysis for physicians and therapists (Kizony et al., 2016; Tannous et al., 2016).

2.2. Design principles of Serious games

Game design methods are based on knowledge of gameplay (the set of mechanisms used to increase player enjoyment and satisfaction). These methods can be applied for the analysis and evaluation of

existing games or for new game projects. The game design method is adapted according to a taxonomy to facilitate the scientific treatment of digital games. For serious games, some authors have different creative approaches, prioritizing the criteria that they consider to have an important role in the success of the game. The taxonomic model proposed by Jantke and Gaudl (2010) has three dimensions: to consider the game as a computer program with all of its related properties, to consider the genre of the game, its content, and to consider the individual experiences perceived by the players. Ratan and Ritterfeld (2009) consider four dimensions into which games are classified: primary educational content, the principle of primary learning, the target age group and the platform on which the game is played. The taxonomy model of Laamarti and Saddik (2014) highlights 5 important characteristics to consider for the design of serious games: Scope, Activity, Modality, Style of interaction and Environment.

1. Scope refers to different relevant areas of application, such as health, education, communication for example.
2. The activity deals with the type of activity performed by the player, when performing tasks in the game.
3. Modality is the sensory channel through which information is communicated between the game and the player, the most common being the visual, auditory and haptic modalities.
4. The interaction style defines how the player will interact with the game, which can be for example by mouse, keyboard, etc.
5. The environment, which defines the digital game atmosphere and can be a combination of several criteria such as 2D / 3D technology, virtual or mixed reality environment, etc.

In the field of health, Wattanasoontorn et al. (2013) also classify serious games in other fields: patients in health surveillance, detection and monitoring of signs and symptoms, treatment or therapy, rehabilitation and education in self-managed care. It is essential to underline that the cognitive and motor capacities of the target patients must be considered. The theme of the game should be appropriate for the age and interests of the user. Regarding the language, Savazzi et al. (2018) suggest that the language is clear and based on concepts understandable to intended users. Disease characteristics should be a primary factor in the development of game exercises. They are used to define the skills to be assessed in the game and how they have to be approached. According to Paraskevopoulos et al. (2014), the story of the game is a basic element that must be prioritized, because it will have an influence on the participant's involvement. The author also emphasizes the need to use the context of family activities based on sports, recreation or other daily activities. Other important points relate to the automatic calibration of the requested execution and the level of challenge required, as well as the reward given to the player who responded with a level of skill and experience.

2.3. Serious game design for diseases assessment

The previous state of the art presented has shown that there are many cases of serious game developments to support situations of rehabilitation, assisted learning, etc (Argasinski and Wegrzyn, 2019; Marsh, 2011). On the other hand, to our knowledge no reference has been identified concerning examples of serious games, or design methods and tools applied to the development of a serious game dedicated to supporting assessment scales. However, many concepts and method principles have been mentioned and proposed. They can be used to propose contextual principles for designing a serious game within the framework of the Motor Function Measurement (MFM) assessment scale studied here. Despite the lack of information on existing examples of the use of serious games for motor function assessments, serious game approaches will be applied for motor function assessment of patients with neurological impairment.

Researchers point out that in addition to entertainment, motivation and willingness to perform tasks, serious games can guide therapists during evaluation of patients with the same success than for rehabilitation or assisted learning situations (Carabeo et al. (2014), Paraskevopoulos et al. (2014)). Serious games configurations can match the patient's abilities to the therapists' needs offering adapted functionalities to the both users' families.

In the following sections, the MFM protocol context and constraints will be explained, identifying the specificities that have to be integrated for the design of a serious game. The serious game development and constraints will be detailed especially by giving some design principles dedicated to this context of

motor function assessment. Finally, the technical implementation of the serious game allows to show some illustrations of the patient's interface.

3. Motor Function Measurement Assessment Scale

3.1. MFM Principles and applications

To better understand the evolution process of the patients' conditions, it is necessary to refer to the main source of restrictions – MFM assessment scale – hereafter referred as the MFM. It was developed to objectively assess and monitor the motor capacities of patients with Neuromuscular Diseases (NMD). The MFM protocol is made up of either 32 items (for patients aged from 7 to 60) or 20 items (for patients who are under 7). During an assessment session of about 30-35 minutes, the physiotherapist suggests that the patient performs a series of tasks by giving very precise instructions. He observes the completion of tasks, he judges movements by observing them and then assigns a score (4 levels). The evaluations are carried out in an appropriate room, which contains all the material necessary to perform the tasks described in the MFM manual (Figure 2a): ergonomic chair, ergonomic table, tennis ball, pencil, coins, CDs, etc. The physiotherapist must use the dedicated test sheet and can, if desired, consult the MFM manual. It describes in detail the situation (starting position, finishing position, and conditions for carrying out the task) and the assessment criteria for each item. It is therefore essential that the physiotherapist has it at his disposal when passing the scale. The scoring sheet (Figure 2b) is used to record scores and calculate final scores in each of the three areas of the MFM.

Figure 2. a. Necessary material to perform MFM assessment. b. Physiotherapist's scoring sheet

The items of the MFM are grouped into three areas (Figure 3): D1- Standing station and transfert (13 items for the MFM-32 and 8 items for the MFM-20); D2 - Axial and proximal motor skills (12 items for the MFM-32 and 8 items for the MFM-20); D3 - Distal motor skills (7 items for the MFM-32 and 4 items for the MFM-20).

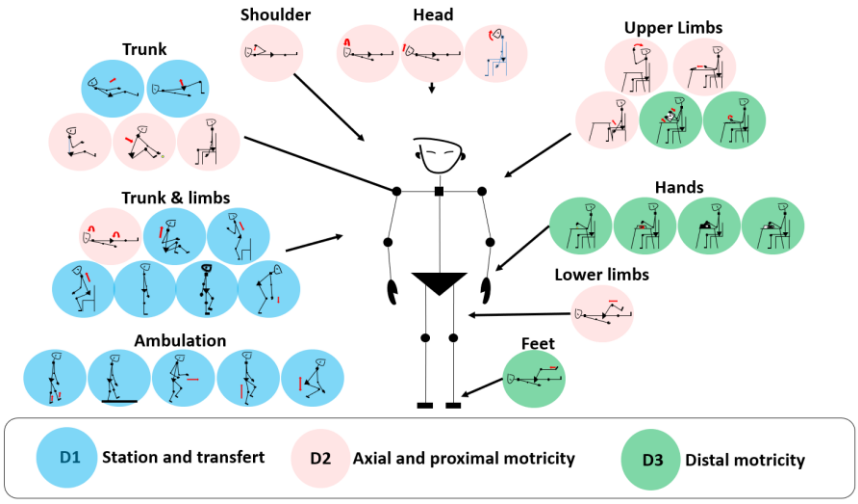


Figure 3. Global view of the 32 items of the MFM assessment scale into three areas

These items are organized in a logical sequence starting from a lying position, progressing to a sitting position, then standing - the latter also incorporating transfer situations. Table 1 gathers some items in ascending order, their field of membership, the patient's starting position and the brief description of the task to be performed in the item. This procurement order was defined when the MFM was created and is intrinsic to it.

Table 1. Description of some items from the MFM assessment scale

Items	Area	Starting position	Items description
22	D3	Sitting on a chair or wheelchair	A finger placed in the centre of a fixed square: lift the finger then place it successively in the centre of the 8 adjacent squares without touching the grid
23	D2	Sitting on a chair or wheelchair	Upper limbs along the body: place both forearms and / or hands on the table at the same time
24	D1	Sitting on a chair	Stand up without support from the upper limbs, feet slightly apart

Patients who need to undergo MFM can be children as young as 4 years old and into adulthood. The symptom common to all of these patients is progressive muscle weakness. For most conditions, patients retain cognition, intelligence and oral language.

3.2. MFM digital system

To improve the performance of measurements, the reproducibility of evaluations and patient participation, and after a to long time collaborative work with therapists, an MFM digital system, based on accessible technologies, is proposed to therapists (Coton et al., 2017). The system is developed along four research axes: (1) the choice of a 3D motion sensor, (2) the development of software on a Tablet for the assessment of fine motor skills, in 2D, (3) the proposal of a playful environment (serious game) to motivate the young patients during the evaluations and (4) proposals to integrate the tool into the current practices of the therapists. This working context suggests the use of a user-centred design approach (UCD), in which therapists and patients are asked to express their needs at each stage of the design process:

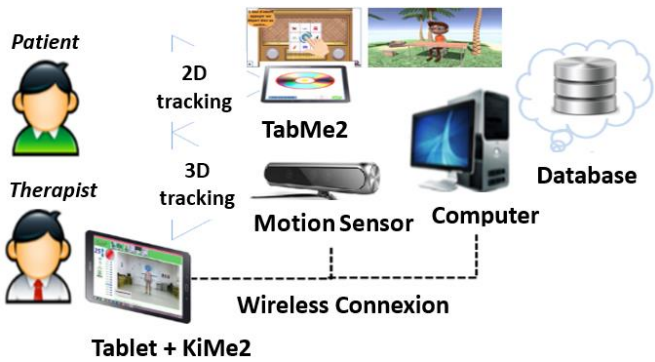
Stage 1: read scientific articles, manuals, reports and research on websites, training with in physiotherapists. A precise understanding of the process of the MFM and its objectives requires meetings, discussions, interviews and viewing of videos. This stage took place during approximatively four months, and were regularly updated.

Stage 2: carried out through frequent meetings with therapists (group of 5 specialists), two focus groups and patients.

Stage 3: to work on adaptation of the KiMe2 software to 2 new motion sensors, the development of the new software for automatic detection and scoring of the fine motor skills of the hands, this stage was very time-consuming.

Stage 4: evaluating the design proposals against the requirements of the physiotherapists during confrontations with therapists and numerous of experimentations.

As results (Figure 4), the Microsoft Kinect sensor was chosen as the best low-cost 3D motion sensor adapted to the observation needed (controlled on a tablet with the KiMe2 software). The automatic fine motor assessment TabMe2 software developed obtained very good results for 3 2D-items considered from the MFM (Gomes et al., 2018). Finally, an integration of all the tools developed is proposed



through a custom interface already familiar to physiotherapists (reproduced from the scoring sheet shown on figure 2a), to facilitate their adherence.

Figure 4. Architecture and components of the MFM Digital tool

3.3. Serious game dedicated to the MFM

The consequences of NMD are expressed by the irreversible losses of functional movements which result in a progressive inability to perform activities of daily living. Therefore, demonstrating their disability through an assessment is difficult for the patient. Thus, the 32 tasks proposed by the MFM often represent difficult movements, particularly for children, for whom functional motor acquisition is recent or has sometimes never been achieved.

To reduce the stigma of assessments and to make assessments run naturally and smoothly, a friendly approach between therapist and patient is very often developed. It is therefore common for the therapist to develop a friendly relationship with his patients, to try to make the assessment as pleasant as possible. In the case of young patients, therapists use certain tricks to make the evaluation more relaxed, for instance in the form of a game. This often results in the establishment of a ludic context proposed to the child, in the form of a story told by the therapist, in which the rules of the game are combined with the instructions of the MFM. In practice, it has been observed that this strategy makes possible to obtain good results with regard to the interest and commitment of the young patient in relation to the tasks to be performed. The objective is to have a more attentive, cooperative and motivated patient during the examinations. Physiotherapists claim that a patient with a positive attitude scores higher.

4. Definition of contextual Principles

The development of a game scenario to support the assessment protocol follows a different design logic than the one used for training or rehabilitation. Discussions with physiotherapists and others healthcare specialists explain that, from an assessment of a patient, follows a whole process of diagnosis and choice of appropriate therapy. If the assessment step is not perfectly realized, all the next steps of the disease treatment will not be effective. In the case of the MFM, the evaluation method, the rigor of the evaluations, the definition of the tasks and the organization of the equipment and sensors used during the evaluation are specific factors that must necessarily be considered to define the game. Other important points are (1) the adequacy of the game to the physical and cognitive capacities of the patient to perform a task and (2) the feedback given to the patient in case of partial accomplishment of the task, resulting in a low evaluation. In addition, in the MFM, the realisation of certain items requires the presence of the therapist. Thus, this must be reflected in the dynamics of the game, for instance by the possible introduction of new actor in the scenario or by secondary assistance to the patient in certain situations. In the MFM scale, some tasks impose positions that are difficult to detect by the Kinect. Previous research validated the relevance of using the Kinect for 14 of the 32 items of the MFM (Vincent-Genod et al, 2017). The technology deployed is therefore also an essential factor to consider in the creation of the game based on an evaluation protocol. The variety of technologies used should follow the logic of the assessment without adding more complexity to the therapist.

Knowing the constraints stated above, a specific design approach, that uses all of the features of the MFM scale motor assessment, is proposed. Thus, in order to develop dedicated MFM assessment tool, combining a serious game, by mastering all the characteristics of the assessment context involving the proposed technologies, the following contextual design principles are proposed. Thanks to similar projects developed in the state of the art described in previous section, authors proposed seven principles described below:

1. Define the assessment context: Definition of the assessment scale, its dedicated protocol and the patients' profiles.
2. Describe the activities: Description in detail of all the tasks to perform, knowing specific characteristics, originalities and statistics.
3. Define the development paradigm: For the development of a serious game applied to the MFM assessment scale, three main factors must be considered during the design:

- The assessment method: 32 or 20 items, sequence of the items, patients positions during the evaluations and evaluation time.
- The materials used: for the MFM scale, materials are defined and must be conserved (Figure 2).
- Human and material constraints: depending of patient's profile, certain tasks cannot be performed, or partially performed. In the same manner, serious game has to be designed and developed depending of technologies used: 3D sensors and tablet for instance.

4. Define the interaction mechanisms: Vision Based Interfaces (VBI) can be used to detect and analyse human movements. They allow the creation of an immersive environment and the monitoring of the patient who interacts with the system, thanks to his own actions. A tablet could also be used as an interaction input for some items. Be careful to the phases of technological changes: motion sensor to tablet or tablet to motion sensor. Physiotherapist has to manage these delicate moments in a fluid and intuitive way.
5. Define the role of feedback: For the MFM, the game must respond to user's actions based on the type of assessment performed through two types of feedback: visual and auditory. In the practice of MFM tasks, patients must always have positive feedback, whatever their results. The feedback can be given directly by the technological interface (visual and/or auditory), but in all cases in the last resort, the therapist decides the type of feedback to offer.
6. Define the game instructions: Instructions that are provided in the context of carrying out an evaluation protocol constitute a very important parameter, because they must express all the information useful for understanding and carrying out the task. Verbal instructions, called voice commands in rehabilitation, have a significantly positive impact on the actions of skeletal muscles (Silva et al., 2013). In this way, short, direct and imperative sentences will be prioritized, using a motivating vocabulary.
7. Ensure adaptability: Physiotherapist, who has access to the patient's pathological history, must therefore have access to a set of predefined models of different levels of the game in order to be able to offer the most adequate at the desired time. Thus, the therapist's observations and the technological options available to him must allow him to adapt quickly to his situation of interaction with the patient.

5. Serious game development and constraints

The seven contextual design principles detailed above are used to frame the development of a serious game for the MFM assessment tool. Once this framework has been set and the contextual parameters of development have been mastered, we propose a structural framework made up of three elements for the realization of the animations: it consists of

- A game scenario, made up of modifiable (the plot of the story, the character and the environment) and not modifiable (rules, starting position, task) elements.
- The animations, which are the transposition of the scenario, structured in a visual and sound way for an easy understanding and to validate the playful side of the game.
- And the feedback which will constitute the feedback of information to a patient, given via software or a therapist.

The three elements of the structural framework, discussed below, constitute what are called MFM animations. During the development of the different animation that constitute the scenario, experiences have been capitalized thanks to the implication of students who participate to this development. Questions, discussions and experimentations with therapists and patients have been analysed with the objective to resume the work into a structural framework. Beyond the structural elements of the animations, their development is carried out systematically bearing in mind the consideration of five recommendations, defined specifically for the present work, and which serve as a guide for the development of the animations of the prototype items:

1. The personalization of the animations: the games must allow visual and sound information and a level of difficulty adjustable by the physiotherapist. This element is associated with the score level, feedback and modifiable elements of the game scenario.

2. The capture of movements: it is linked to the characteristics of the interaction interfaces. The screen for the tablet and the various sensors for the movement sensor.
3. Feedback: a feedback system that should always be motivating and encouraging for the patient. Feedback should be given in real time, depending on the result of the scoring.
4. Implementation compatibility: the proposed animation must be compatible with the software and hardware technology used, related to the creation and presentation of animation.
5. Compliance with the protocol: the games designed must be in all respects faithful to the items of the MFM, respecting all the rules of installation and the conduct of the evaluation.

The creation of the animated scoring system began with the establishment of a play story. It is a story that follows a sequence of interconnected events to achieve an end goal. Two scenarios have been edited. They were communicated individually to five physiotherapists, all certified to perform MFM exams. They were asked to give their general impressions of the compatibility of the scenarios in relation with the MFM assessment scale (Table 2). Once the results analysed, the chosen scenario was reworked into a group of three expert physiotherapists in order to be developed in the form of animations.

Table 2. Some physiotherapists requirements for the scenario selection phase

Theme	Scenario that could be adapted to each age group and gender Should not promote feelings such as anger or pain Be careful not to associate contexts already experienced by patients
Language	Use a clear and precise vocabulary
History	Ensure logic and fluidity between actions linked to items
Adaptability	Try to propose actions adaptable to the levels of motor impairment of each patient in each test and for the three domains of the MFM items
Feedback	The game and its goal must be motivating, whatever the result of the evaluation
Usability	Make the duration in line with the MFM evaluation time of 30-35 minutes

A game scenario was developed on the theme "The shipwreck". It follows a chronological sequence of actions containing small intermediate objectives for the patient to achieve and which will lead him to a higher objective at the end of the game: "Shipwrecked on an island, you must find a way to communicate by radio with the nearest vessel to come and rescue you". Feedback from physiotherapists was very positive for the scenario presented and simulated. Some modifications were suggested, allowing then to proceed to the creation of the animations.

6. Technical implementation of serious game

The animations developed for tablet support have been implemented on Animaker and Adobe Premiere Pro / Adobe After Effects software. Animaker is a freemium (partially free), cloud-based DIY (Do it yourself) video animation software (availability of computer system resources on demand) that allows users to create animated videos using characters and models pre-created. Adobe Premiere Pro is video editing software, and After Effects is graphics animation, visual effects, and digital composition software. These last two software are often used together for reasons of complementarity of functions.
The animations related to the three items 18, 19 and 22 were implemented individually, with a focus on the actions proposed in the scenario and the visual and audio feedbacks associated with the story. Regarding these items, the evaluation focuses only on the fine movements of the hand, the animations must therefore strictly respect the quality requirements of movements requested in the protocol.
For each item, an animation illustrates before the achievement to be carried out by the patient, the way in which the task must be carried out, then highlighting the intermediate objective of the story and the rules to be followed in order to be able to validate this intermediate objective allowing you to go to the next step. The animations are supplemented by oral and written instructions. All the animations have been designed by default for a 4-level. The feedback offered consists of a written message and a sound. They are provided only after acceptance of the assessment by the therapist. The feedback is associated with the automatic score deduced by TabMe2 and KiMe2. Figures 5 show the visual interfaces available to perform item 22 (D3 - Distal Motricity) and item 23 (D2 - Axial and Proximal Motricity).

The MFM items which assess all body movements require a different approach to animation development than tablet development. In the digital environment offered to the patient, a main actor must therefore be defined. It represents the patient in the contextual environment through the game scenario. To implement the items associated with the motion sensor, the Blender software was used.

Figure 5. Interfaces developed into the MFM-animation for items 22 and 23.

Thanks to a digital scoring sheet designed from the current scoring sheet (Figure 2), the physiotherapist can control all the components of MFM Digital tool (Figure 4), score the items in real time, using or not the automatic score proposed by TabMe2 and KiMe2 and manage animations and feedbacks.

7. Discussions

(Lv et al., 2017) proposed an assistive tool that employs serious games as the attractive logic part, and running on the tablet with normal microphone and/or Kinect2 as voice input device. As the present paper proposed, the same interfaces are chosen to promote the interaction and the participation of the patient during the activity. In the same way, feedbacks are considered as essential information to give to the patient or by the therapist of thanks to the software.

In (Graafland et al., 2014), researchers proposed a research based on the insufficient understanding of design principles among the individuals and institutions that develop or apply a medical serious game compromises their use. This research provides the first consensus-based framework for the assessment of specific medical serious games. The framework provides 62 items in 5 main themes, aimed at assessing a serious game's rationale, functionality, validity, and data safety. In the present proposition, seven principles, a structural framework made up of three elements and a guide for the development of the animations are proposed. The structuration of ideas through principles or framework is shared by the researchers' community

Currently, feedback on TabMe2 is provided in the form of audio and written messages and is completed by the therapist. The simplistic model adopted here does not correspond to the complexity of this important parameter (Feedback) identified in the literature review. This step must be better explored and developed, it must integrate the specificities of each item, the various expressions of pathologies but also the different patients' psychological profiles.

The adoption of a 3D immersion screen was first imagined. It has been temporarily abandoned: according to the physiotherapist, the patient is too preoccupied with the avatar, forgetting the aim of the task to accomplish. Moreover, it would constitute an additional material to be integrated by the physiotherapist throughout the evaluation process.

As for the adaptability of the game, a database of global patient profiles was not developed yet. A request from therapists is the development of stories, scenarios and characters adapted to each age group and each gender. Complementary to this, an objective is also to create levels of challenges corresponding to the motor capacities of the patients. Instructions and demonstrations would be functions of the scores achievable by the patient. This step is imagined relatively complex in terms of movements modelling, because it is quite variable and specific to patients and their pathologies.

Design principles have been proposer based on the MFM context. The majority of serious games are developed for patient rehabilitation. Designing serious game for patient rehabilitation or for evolution diseases assessment is very different. In the second case, many parameters must be much more precise and adaptable to the patients, in order to achieve not only an evaluation that is as accurate as possible to make a good diagnosis and therefore good medical prescriptions, but also to limit the inter and intra evaluators variability.

8. Conclusions

In this research project, design principles and development of an assessment system based on playful animations (serious games), adapted to the MFM, was proposed in order to increase the motivation and commitment of the patient. The objectives of the proposition of designing serious game are on the one hand to involve more patients in the disability assessment step. With this proposal, their participations have to be more natural and motivated. One the other hand, this development will simplify the activity of practitioners and it must make the assessment more fluid and focused on the patient performance. Even if serious games are very well suited to rehabilitation activities, no reference was found regarding the definition of games designed for assessment scales.

The characteristics of serious games are preserved in our system, because it offers the main elements of a serious game: gameplay and rules, challenge (which determines the bonuses to be obtained at each stage), interaction with the patient and the material, objective to reach and attractive design.

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