DEVELOPMENT OF A KNOWLEDGE-BASED SYSTEM FOR HELP IN DECISION MAKING: A MEDICAL APPLICATION

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Abstract

A part of the work of a physiotherapist consists on analysing its patients' motion capacities. In the case of motion analysis, some difficulties can hinder the evaluation process: attention can be diverted, situations can be delicate to evaluate. The consequence is an inter-individual variability and uncertainty during the evaluation. New motion sensors make it possible to record and analyse the motions with another point of view. Those tools can be used to help in the capture, but the restitution of the recorded information needs to be adapted to the user knowledge with the aim to be interpreted. In this paper, the authors propose to put the user at the center of this tool in an application of the UCD principle by proposing a method to return information based on a Knowledge Based structure. The restitution modules and tools are constructed on different levels of knowledge represented in a knowledge-based expert system. The knowledge has been structured into 4 levels (from the most factual to the most abstract) and were linked to 4 levels of restitution (from the most textual to the most graphical). A case-study using the assessment scale "Motor Function Measure" is presented.

Keywords: Biomedical design, Decision making, Visualisation, Case study

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1 INTRODUCTION

For individuals whose movements are threatened by diseases or environmental factors, physical therapy is an important service to develop, maintain and restore a maximum of movements and functional abilities (Wikström-Grotell and Eriksson 2012). Several valid measurement protocols have been developed to assess the motor function's evolution and to quantify the disease situation. Among them, various standardized scales have been created with the aim to produce valid, reproducible and sensitive measurements of the patients' motor functions (Nelson et al. 2006)(Cano et al. 2014). Those scales are often composed of several exercises with the aim to assess precise movements or activities.

In our case, we focus on the progressive neuromuscular disease Spinal Muscular Atrophy type 2 and 3 disease (SMA) (Lunn and Wang 2008) and the "Motor Function Measure" scale (MFM scale) (Vuillerot et al. 2013) which is dedicated to this pathology. In this scale, physiotherapists rate 32 exercises from 0 (fails to execute the motion/activities) to 3 (do the activities "normally" with a controlled motion, regular speed etc.). Each exercise has a rigorously defined starting position and clear instructions for each rating of what can be done and what will be a rule-breaker.

If the validation study of the MFM (Bérard et al. 2005) has proven it to be a clinical valid tool it also indicates a lack of intra and/or inter repeatability in the rating of some exercises that could be improved. This has driven the MFM development team to search new tools to improve this scale performance and to improve the capacities to evaluate and differentiate the pathology evolution. The aim of this paper is to present the new evaluation tool for therapist which aim is to reduce this uncertainty and to allow new representations of the motor movement to improve the pathology's expertise. This tool needs to integrate the medical knowledge, the understanding of the clinical practice and of the measurement scales.

New technologies could be used as an assistant for those types of cases. Sensors could be used to reduce those uncertainties by providing more accurate and repeatable information. One solution is to provide automatic evaluation but this may not be reliable in our case: an automatic scoring system would always be dependant of the cases used during its construction and will not be able to face to novelty, it will lose the adaptability and a part of the therapist's knowledge and expertise. Moreover, if the therapist cannot understand how the systems work, he may become suspicious of it and will not use it. On the other hand, an assistant, such as an aid-decision system, providing some opinions and given access to standardized data may help the therapist in its evaluation and decision. Those sensors technologies could become a new sensory organ for them.

To responds correctly to the therapists' requirements, the medical devices design process has to mobilize a user centred design approach. Indeed, the user, the requirements and the medical expertise knowledge have to be correctly specified. To do so, the systems need to represent the domain knowledge and be structured on it (Sajja and Akerkar 2010). This will increase the likelihood of producing a device that is not only clinically effective but also easy and satisfying to use.

This research project led us to the following question: How to facilitate, with new precise and reproducible tools, the decision making of physiotherapists in muscular-neuromuscular disease diagnostic according to the MFM scale? Which information and representation can help efficiently the therapist in its evaluation?

2 STATE OF ART

For this aid-decision system we need a physical sensor and its analysis service. We do not wish to automate the evaluation but to support the therapist in his decision. The fully automatic learning-machine are thus put aside. The therapist needs to understand the system process and approve of the systems results and information, the analysis needs to be correctly represented. This calls for an open system using medical terminologies. In regards to this we decided to focus on a user-centred type of design process and more specifically the knowledge engineering domain.

2.1 Motion analysis devices

Technologies are already use in a lot of medical field, for example in articulations reconstruction, operations planning, or movements analysis (for example the walking test). In the case of the motion analysis, several tools and techniques exist. Techniques evolved greatly since their introduction and marker-less systems tend to make their ways (Chen, Wei, and Ferryman 2013)(Mündermann, Corazza,

and Andriacchi 2006). Several motion analysis systems exist and are validated by medical communities (Zhou and Hu 2008), those are mainly tools of reconstructions with the need of clinical technicians to provide the final results presentation.
Images retrieval in medical practice is prolific but rarely attain the "in use" phase (Müller et al. 2004). Motion analysis continue to be limited to specific activities mainly because of the needed investment in terms of time, competence, tools and price. Domains that manage to use it are: high performance sport and ergonomic, medical operations planning, specific motion protocols or for the cinema and video games. Those can use several tools: video analysis augmented with graphical tools such as the free software Kinovea, wearable sensors such as Captiv to reconstruct a skeleton and obtain articulation and body angular position are used in sport and ergonomic. Then comes the optic sensors with markers such as the VICON and marker-less "cave" systems such as Mocap which are used in most domain needing movement comprehension (sport, medical, ergonomic, cinema, games). Most of those activities are enable for specific projects which have the investments of money, times and specialised workers. If we want this system to be used in a regular clinical environment by current therapist, it should thus provide or limit those investments: it should be usable by a therapist without need for technical comprehension, affordable and not time consuming. Otherwise this solution will inevitably be considered impracticable and thus abandoned.
Technologies such as the Kinect sensor made the motion analysis more accessible: almost no installation time, it does not need for markers or additional accessories and have a price accessible for all. While this technology is less accurate and performant than prior described tools, studies begin to prove that such a tool may be used in medical practice (Hondori and Khademi 2014).
In every case, those sensors provide computable data of the motions recorded. Those data are usable by an engineering team but will need to be automatically processed to be understandable and manipulated directly by a medical expert. To traduce and manipulate those sensors' data we tried to focus on user-centered design and knowledge engineering.

2.2 User-Centered Design (UCD)

The user-centered approach consists on putting the final user at the center of the design process and was normalized in the (ISO 9241-210 2010). When designing a device for a population with such specific expertise, expectancy and knowledge, it is important to be able to integrate them correctly on its construction and representation (Rinkus et al. 2005). This means a very first step is the needs analysis and the establishment of a common vocabulary (or an assimilation of the medical vocabulary is needed). But this also means there is a high risk of having an incomplete or misinterpreted context analysis. The UCD approach allows to tackle this problem by being in an iterative cycle. The specifications, interpretation and solution is regularly evaluated and updated if needed. The knowledge needs to be verified regularly with therapists to prevent interpretation error.
The gap of knowledge between the designer and the users (a physiotherapist) asks for an efficient communication between the design team, the developed device and the user. The co-creation should allow a correct analysis and functionality of the system but also to propose a result in a comprehensible format for them, a medical population.

2.3 Knowledge engineering

In the case of a product for a specific population (here the medical population) the understanding and communication between the device and the user (medical practitioner) is essential: the user needs to always understand what the devices is used for and how to use it. It should provide him with "the right information at the right time". This problematic is the center of the Knowledge Management and the Knowledge Representation and Reasoning (Brachman and Levesque 2004). Different systems were developed in regards to this notably the knowledge engineering domain and the knowledge-based systems.
A Knowledge-based system (KBS) is a computer program that uses artificial intelligence to solve problems within a specialized domain that requires human expertise. KBS have been used in medical area to standardise knowledge into ontologies and to organize this knowledge to support its use in computational applications (van Heijst, Schreiber, and Wielinga 1997). Notably knowledge engineering was already use to help provide medical diagnostic (System MYCIN) (Studer, Benjamins, and Fensel 1998). With the apparition of accessible new technologies (low-cost, non-invasive, etc.), researchers

decided to use knowledge engineering for movement analysis. Some studies already try to provide annotations automatically on a video with sematic analysis (Saad, Mahmoudi, and Manneback 2012).
In our research context, the proposed tool will need to be oriented toward its users (therapists in our case). With the same objective, Antón et al. proposed an innovative home telerehabilitation system. Their system is able to transform raw data collected from motion capture sensors into statistical information (performance of a member during a rehabilitation session) that can help the physiotherapist to valid and guide the rehabilitation sessions (Antón et al. 2015). Their system is composed of a Knowledge Base, an Inference Engine and a User Interface. These three elements are often represented as core components of a Knowledge Based System (KBS) (Alder et al. 2014). This structure offer a product architecture which we shall design: it provides information based on knowledge and language understandable by a medical expert (a therapist in our case). The relationships being explicitly defined can be provided to the therapist and thus prevent a black box effect on the results. Each elements of the KBS can be used to support a restitution tool for the therapist.

2.3.1 Usability and user requirements

The user-interface and the representation provided by the tool should also be oriented towards its users. For an ergonomic user-interface, the common design rules will be the 10 heuristics of Nielsen and the Norman's principles. The emphasis being into the "visibility of the systems status" and "the match between the system and the real world" (the system need to speak the language of the user, no code) and a good "help and documentation". The interface need to be easy to learn and manipulate (good feedback, minimal aesthetic design, error proof and consistency). While the systems should made accessible all data required, it should be sufficiently constrained to prevent any misuse.
In addition to those, some more features are needed: notably an accessibility in terms of availability and price, to be easy to install in terms of space and time since it should not be used in a specific environment other than the hospital and clinic. Finally, as good as can be this system, the therapist needs to have visible and accessible assertion of the viability of the system. Clinical studies should validate the reliability of the system and/or the components and make it visible to the therapists.

3 METHOD

The information restitution proposition will be based on the construction of the knowledge based system (KBS). The first part of this section will explain the KBS used and its structuration based on heuristic classification. A second part will then explain the levels construction of the KBS and how the information is returned according to the KBS level: the KBS will be constructed on 4 levels (1 to 4 layers) which will be mapped with 4 levels of information restitutions for the user (A to D layers). Finally the results will propose a usage of those restitution modules depending on the profile of the therapist.

3.1 Knowledge engineering: level construction

To construct a KBS, several things are needed: a database of common medical knowledge used during the evaluation (knowledge base) and the relationships between those data and the result (problem-solving method). Different problem-solving method exist (classifier, decision tree…)(Studer, Benjamins, and Fensel 1998). The probabilistic methods and/or learning models suppose that we can clearly index all possible movements (or a good part) in sufficient quantities. This will be difficult in 2 points: in one part the patient are not really constrained in their movements which means the number of movement is quite high especially when considering the capacities of improvisation of pathological patients and secondly the patients are affected with rare diseases which make the record of data all the more difficult. In addition the rating stipulate a list of criteria which have to be absolutely validated and cannot be approximated. Finally the description of each rating is heuristic in itself, this description being understood and validated clinically makes the use of this technique natural. In regards to those points the heuristics classification (see Figure 1) was used. This classification uses different types of knowledge:

- Observables, abstract observables, solution abstractions and solutions.

It also use different methods/actions to pass from one type of knowledge to another:

- Abstraction, heuristic match, and refinement.

The patients' data (or sensors data of the patient in our case, see n°1 Figure 1) are converted into **observables (factual knowledge, n°2 Figure 1):** they are data describing the state of the subject at hand. They can be obtained from the patient, from a sensor, or by the senses and knowledge of the therapist. By definition, they are factual (or calculated), they hold no judgemental value. *Example: the articulation angles (numerical values) can be observables.*
They have to be transformed into **abstract observable (conceptual knowledge, n°3 - Figure 1)** that apply a qualifying adjective to the variable. *Example: depending on the articulation angles states, the adjective "flexion" or "extension" can applied to the variable, and depending on the states of several articulation angles, a posture name such as "sitting" or "standing" can be applied to the subject.*
Then **"linguistic rules" (heuristic match)** can be formulated by the medical expert to extrapolate solution. Different **solution abstractions (n°4 Figure 1)** can be validated and have to be refined to propose a unique **solution**. *Example: IF there is a flexion of the elbow AND NO movement of the shoulder THEN the rating is 3*

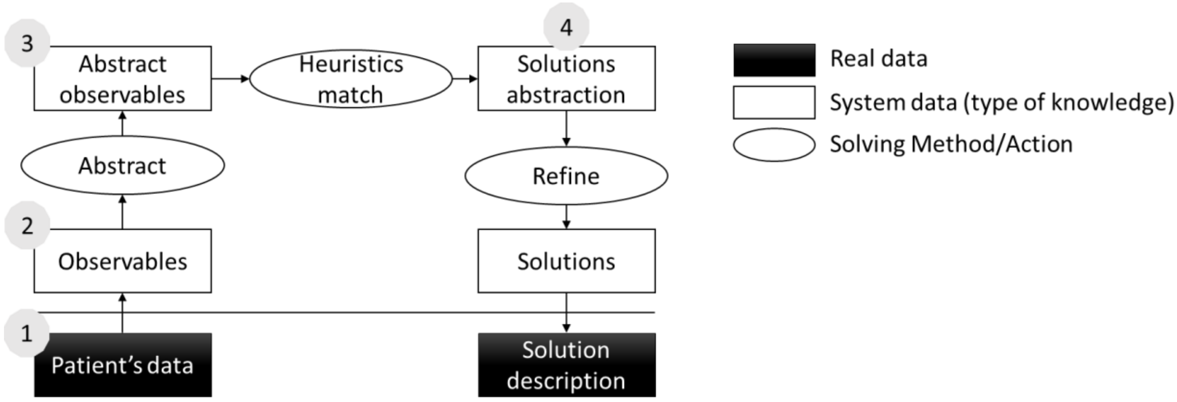

Figure 1. Treatment modelisation (Clancey 1985)

3.2 Application to the MFM scale

The problem-solving method described above was applied with the following knowledge type: (2) observable, (3) abstract observable, (4) solution. In the case of the MFM protocol, the (1) data provided by the sensors (numerical skeleton) are the patient's real data and are not always what the therapist used as observables (articulation angles for example). An informatics module is then used to convert those raw data into the system observables. Thus, the analysis system (observable, abstract, and solution) is independent of the sensor used. The following decomposition (illustrated by the Figure 2) was applied:

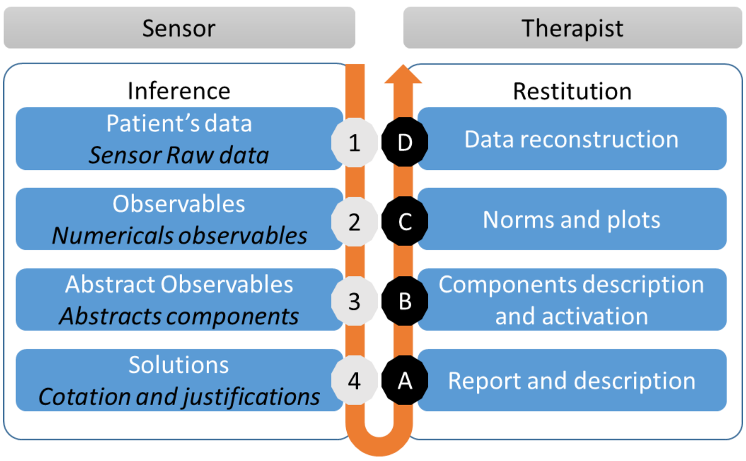

Figure 2. Information decomposition and restitution

3.2.1 Decomposition into 4 levels (Sensor):

Each level is defined by the amount of knowledge mobilized:

- Level 1 Data: raw data provided by sensors (for example it be a numerical skeleton) or information stored in the system
- Level 2 Observable: factual data used by the therapist. In our case, it will be mainly numerical data. For example, it will be the displacement of each point of articulation or angular variables.
- Level 3 Abstract observable: symbolic data. The application of a qualifying adjective on the exercise state. For example, if the segment/person is straight or a posture, name will be attributed to observables, if the articulation point was in movement, in flexion…
- Level 4 Proposition, report (solution): provide a rating with the lists of motion attained and compensations encountered or avoided (commentaries).

3.2.2 Restitution into 4 levels: Information tools for the therapist

The information are constructed on the knowledge decomposition proposed above: its goes from the more abstract and conceptual form (level A) to a more technical and factual knowledge (level D).

- Level A : Textual report
  - Description provided by the system justifying its rating. The therapist can easily see if the system has the same rating and for what reasons
  - Commentaries of validated and invalidated components
- Level B : Access to mobilized components (abstract observables and linked observables)
  - Verify the data activated and its technical uncertainty
  - Concept validation plot : the validation timeline is coherent with the therapist's point of view
- Level C : Access to numerical data
  - Access to observable plots
  - Access to the normalization of this plot when possible
- Level D : Access to raw data
  - RGB video
  - Sensor data reconstruction / representation

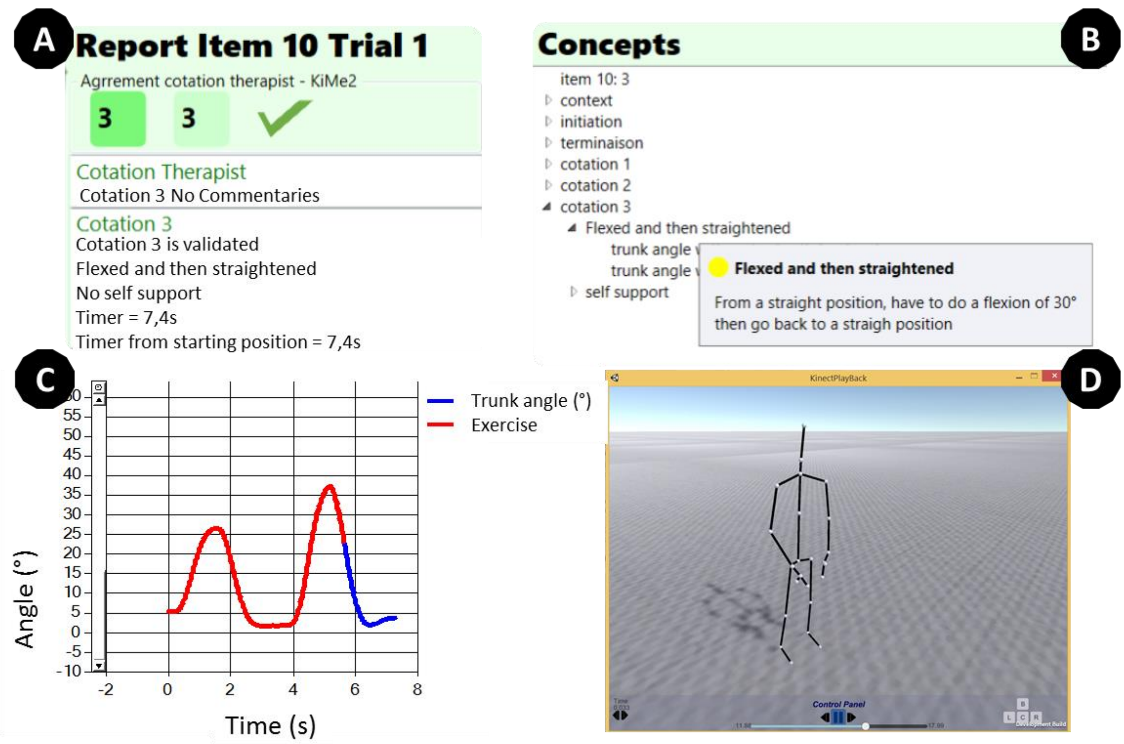

Figure 3. Example of feedback (a) Report (b) Components (and their description) (c) Plots (d) Data Reconstruction

Level A and B information tools are for quick analysis by the therapist, they use symbolic knowledge (macro analysis): they permit to see the agreement between the rating (by the therapist and the system) and what type of knowledge were mobilized (provide insight of the algorithm that generate the rating

and thus limit the "black box" effect). Level C and D are for micro-analysis, they are used to verify data at a numerical level or for a replay use.
Examples of restitution modules are provided in the Figure 3 above. In the example the exercise is to do a flexion of 30° without using its hands as support. The sensor used in this example is a Kinect which provide as raw data a numerical skeleton constituted of 25 joints. The level A will be the report containing the rating of the therapist and of the system and the commentaries of the system and of the therapist if provided. The level B will explain the mobilized knowledge and which observables were used to their calculations. Each knowledge of the level B is linked to a graph which can be generated with a click (level C). The data reconstruction (level D) for this sensor will be the reconstruction of the skeleton in a 3D space.

4 RESULTS

The therapist will do the evaluation and decide the rating, but depending on its profile he may use the support technology to help him to choose. The restitution tools used may be dependant of the degree of uncertainty of the therapist and its degree of agreement with the system:

Case for evaluation assistance

- **1st case, Therapist-System agreement without ambiguity - module(s) used: level A maybe B**: the therapist has no doubt on the rating. The restitution module level A of the system provide the same result and causes. The validation can be done without further development.
- **2nd case, Therapist-System agreement with ambiguity - module(s) used: level A and B**: the therapist has a doubt on its rating but its assumed rating is in agreement with the system level A information. To clear its uncertainty, he may use the level B module to verify that the rating components where rightfully analysed and in agreement with its opinion.
- **3rd case, Therapist-System disagreement with ambiguity - module(s) used: level B, C and perhaps D**: the therapist has a doubt on its rating and its assumed rating is in disagreement with the system level A information. The therapist may verify why the system disagree and take a decision depending on the result (if the system provides a point that eluded the therapist or if a sufficiently accurate compensation was found, he may change its decision but if it was an error or an inaccurate component, he will be comforted in its decision of disagreeing).
- **4th case, Therapist-System disagreement without ambiguity - module(s) used: level D:** system is bypassed, the therapist may verify if the system failed with the raw data.

Case for research assistance

- **Advanced medical research**: Independently of the evaluation, the therapist may seek information to understand the natural evolution of the disease. He may then seek specific information. If the range of a data is especially interesting, the norms and plots of level C will be the best tool of verification. If it is the global posture evolution that is interesting, such as for transfer exercises, the level D will be more adapted and the level C will only be used punctually to verify a contact or an angle or distance value.

In summary the restitution tools Level A and B will be used to understand what type of data was calculated and observed. They should be used when there is low doubt on the result or to comprehend the system before going into more specific knowledge. The level C and D will be used to verify specific data when uncertainty plague the evaluation and to verify the system performance. The level C will allow the analysis of amplitude, timer, quantify some compensation and level D will provide global information such as posture, contact and an understanding of the quality of the recording. Finally the level C and D may be used independently from the evaluation when the therapist seek to understand a compensation or evolution without the need to attribute a rating but on a medical research point of view. Thus, the restitution levels can be used as described in the flowchart in Figure 4.

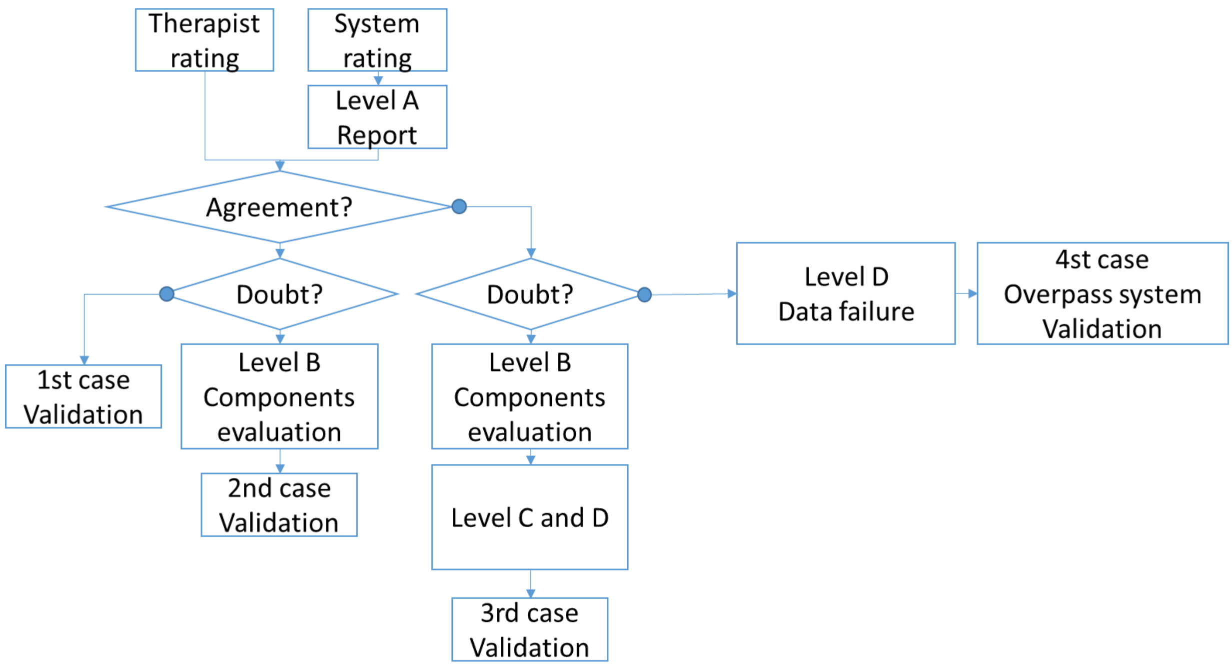

Figure 4. Flowchart for cases use

Analysis with SMA Patients

14 exercises out of the 32 of the MFM were selected to calibrate the system. 10 patients passed the MFM scale with their therapist and the capture software recorded the selected items. 87 records were made and analysed with the structure presented in this paper (see Figure 5).

47 records out of the 87 have a result in agreement with the therapist (correct rating and correct justifications, use of level A and B of the restitution module).

15 out of the 87 were in disagreement with the therapist but the inspection of the components description, plots and data reconstruction allowed a quick understanding of the cause. In this case a component for the evaluation were usually not implanted in the calculation, this was deduced from the level B component description. But those components were accessible with lower level such as the data reconstruction.

Finally, 25 out of the 87 were in disagreements and the inspection of the of the components description, plots and data reconstruction proved that either the sensor failed or provided values in disagreement with the therapist opinion. The system results were thus overridden.

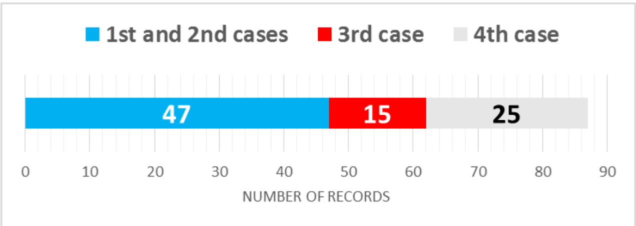

Figure 5. Cases repartition in analysis

5 DISCUSSIONS

The restitution module and KBS aim to enable the creation of a core common knowledge that can provide more standardisation during evaluation of the motor function. By providing an identical analysis module to all users this may help in standardising and thus reduce the inter-variability of the rating process. This knowledge will be stocked and improved in time. Those data (knowledge) will be more systematically stored and may contribute to improve the general understanding of the disease, especially in the case of rare genetic disease. On the other hand, the knowledge acquisition, as well as the updating of the system, can be difficult because of the difficulties to perform the methodological approaches to collect, interpret and use information (Hagedorn, Grosse, and Krishnamurty 2015). The inclusion of a knowledge management team in the designing and follow-up activity is ultimately essential to the functionality of such a medical product (Shah and Robinson 2007).

An improvement this system can bring is the new type of information and representation it can provide. Complex information that cannot be easily described with word or an image can be expressed with representations such as kinetic plots, normalized plots or 3D videos. Quantified data on the exercise can be defined and a new representation of the exercise will be available. On the other hand, those extra tools and information may increase the workload. The presence of the analysis tools may unintentionally push the therapist to use it systematically, thus taking more time than necessary to evaluate. This should be prevented or limited to the minimum. Those tools have to be used in case of doubt or to evaluate an evolution of the disease across the year or as support for inter-personal discussion. But it should not be use when not needed: the structuration into 4 levels (A, B, C and D) may help making this distinction. While the level A and B are directly accessible, the level C and D have to be activated by the therapists.

CONCLUSION

This paper aims to reduce the variability during decision phases and increase the possibilities of evaluations by proposing a system providing new information and new representations and more repeatable information. For that, we need a system (1) that the therapist can trust and (2) which provide the sought information. To enables this, a UCD process was put in place to provide a system and a representation of information adapted. In regards to this, an aid-decision tool in medical motion evaluation was developed. To answer the first need, we proposed an open system allowing the therapist an understanding of the rating system. For the second need, we provide access to all the intended information based on standard and reproducible calculation to lower the inter-variability of the evaluation and support the therapist in its decision making. A drawback that may render the tools impracticable for the users is the "Black box effect". If the users cannot know how the analysis of the systems is produced and how much he can trust it, the tool will be rejected and not used. The restitution module decomposition into different levels aim to prevent this problem. The level A and B are to allow a quick comprehension of how the evaluation was done by the system and the level B provide an indication of the viability of the data (if it is a very accurate one or less accurate, defined by clinical validation studies). The level C and D provide a representation of what was "saw" by the system. This vision should highlight the potential errors or misinterpretations of the system. The reliability of the described data still need to pass clinical validity and the usages will need to be evaluated and confirmed or improved in situations.

REFERENCES

Hondori, H.M. and Khademi, M. (2014), "A Review on Technical and Clinical Impact of Microsoft Kinect on Physical Therapy and Rehabilitation", *Journal of Medical Engineering*, Hindawi Publishing Corporation.

Rinkus, S., Walji, M., Johnson-Throop, K.A., Malin, J.T., Turley, J.P., Smith, J.W. and Zhang, J. (2005), "Human-centered design of a distributed knowledge management system", *Journal of Biomedical Informatics*, Vol. 38 No. 1, pp. 4–17.

Chen, L., Wei, H. and Ferryman, J. (2013), "A survey of human motion analysis using depth imagery", *Pattern Recognition Letters*, Elsevier B.V., Vol. 34 No. 15, pp. 1995–2006.

Clancey, W.J. (1985), "Heuristic Classification", *Artif. Intell.*, Vol. 27 No. 3, pp. 289–350.

Hagedorn, T.J., Grosse, I.R. and Krishnamurty, S. (2015), "A concept ideation framework for medical device design", *Journal of Biomedical Informatics*, Elsevier Inc., Vol. 55, pp. 218–230.

Bérard, C., Payan, C., Hodgkinson, I., Fermanian, J. and The MFM Collaborative Study Group. (2005), "A motor function measure scale for neuromuscular diseases. Construction and validation study", *Neuromuscular Disorders*, Vol. 15 No. 7, pp. 463–470.

Nelson, L., Owens, H., Hynan, L.S. and Iannaccone, S.T. (2006), "The gross motor function measure is a valid and sensitive outcome measure for spinal muscular atrophy", *Neuromuscular Disorders: NMD*, Vol. 16 No. 6, pp. 374–380.

Müller, H., Michoux, N., Bandon, D. and Geissbuhler, A. (2004), "A review of content-based image retrieval systems in medical applications-clinical benefits and future directions.", *International Journal of Medical Informatics*, Vol. 73 No. 1, pp. 1–23.

Mündermann, L., Corazza, S. and Andriacchi, T.P. (2006), "The evolution of methods for the capture of human movement leading to markerless motion capture for biomechanical applications.", *Journal of Neuroengineering and Rehabilitation*, Vol. 3, p. 6.

van Heijst, G., Schreiber, A.T. and Wielinga, B.J. (1997), “Using explicit ontologies in KBS development”, *International Journal of Human-Computer Studies*, Vol. 46 No. 2–3, pp. 183–292.

Cano, S.J., Mayhew, A., Glanzman, A.M., Krosschell, K.J., Swoboda, K.J., Main, M., Steffensen, B.F., et al. (2014), “Rasch analysis of clinical outcome measures in spinal muscular atrophy.”, *Muscle & Nerve*, Vol. 49 No. 3, pp. 422–30.

Brachman, R. and Levesque, H. (2004), *Knowledge Representation and Reasoning*, 1st ed., Morgan Kaufmann.

Lunn, M.R. and Wang, C.H. (2008), “Spinal muscular atrophy”, *Lancet (London, England)*, Vol. 371 No. 9630, pp. 2120–2133.

Shah, S.G.S. and Robinson, I. (2007), “Benefits of and barriers to involving users in medical device technology development and evaluation”, *International Journal of Technology Assessment in Health Care*, Vol. 23 No. 1, pp. 131–137.

Wikström-Grotell, C. and Eriksson, K. (2012), “Movement as a basic concept in physiotherapy – A human science approach”, *Physiotherapy Theory and Practice*, Vol. 28 No. 6, pp. 428–438.

ISO 9241-210. (2010), “ISO 9241-210:2010 International Organization for Standardization. Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems”,.

Alder, H., Michel, B. a., Marx, C., Tamborrini, G., Langenegger, T., Bruehlmann, P., Steurer, J., et al. (2014), “Computer-Based Diagnostic Expert Systems in Rheumatology: Where Do We Stand in 2014?”, *International Journal of Rheumatology*, Vol. 2014, pp. 1–10.

Antón, D., Berges, I., Bermúdez, J., Goñi, A. and Illarramendi, A. (2015), “Knowledge-Based Telerehabilitation Monitoring”, in Chbeir, R., Manolopoulos, Y., Maglogiannis, I. and Alhajj, R. (Eds.), *Artificial Intelligence Applications and Innovations*, Springer International Publishing, pp. 237–249.

Vuillerot, C., Payan, C., Iwaz, J., Ecochard, R. and Bérard, C. (2013), “Responsiveness of the motor function measure in patients with spinal muscular atrophy”, *Archives of Physical Medicine and Rehabilitation*, Vol. 94 No. 8, pp. 1555–1561.

Saad, S., Mahmoudi, S. and Manneback, P. (2012), “Semantic analysis of human movements in videos”, *Proceedings of the 8th International Conference on Semantic Systems - I-SEMANTICS ’12*, ACM, Graz, Autrsia, p. 141.

Studer, R., Benjamins, V.R. and Fensel, D. (1998), “Knowledge engineering: Principles and methods”, *Data & Knowledge Engineering*, Vol. 25 No. 1–2, pp. 161–197.

Sajja, P.S. and Akerkar, R. (2010), “Knowledge-Based Systems for Development”, *Advanced Knowledge-Based Systems: Models, Applications and Research*, Kolhapur, India, pp. 1–11.

Zhou, H. and Hu, H. (2008), “Human motion tracking for rehabilitation—A survey”, *Biomedical Signal Processing and Control*, Vol. 3 No. 1, pp. 1–18.

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