Published in final edited form as:

Health Informatics J. 2012 September ; 18(3): 171–180. doi:10.1177/1460458212443901.

Developing visualisation software for rehabilitation: investigating the requirements of patients, therapists and the rehabilitation process

David Loudon and Alastair S. Macdonald

The Glasgow School of Art, Glasgow, UK

Bruce Carse, Heather Thikey, Lucy Jones, and Philip J. Rowe

University of Strathclyde, Glasgow, UK

Stephen Uzor, Mobolaji Ayoade, and Lynne Baillie

Glasgow Caledonian University, Glasgow, UK

Abstract

This paper describes the ongoing process of the development and evaluation of prototype visualisation software, designed to assist in the understanding and the improvement of appropriate movements during rehabilitation. The process of engaging users throughout the research project is detailed in the paper, including how the design of the visualisation software is being adapted to meet the emerging understanding of the needs of patients and professionals, and of the rehabilitation process. The value of the process for the design of the visualisation software is illustrated with a discussion of the findings of pre-pilot focus groups with stroke survivors and therapists.

Keywords

biomechanics; rehabilitation; user research; visualisation

1. Introduction

This paper describes the ongoing process of development and evaluation of prototype visualisation software, designed to assist in the understanding and the improvement of appropriate movements during rehabilitation. The aim of the software is to provide patients with a visually comprehensible representation of their own movements, and to provide therapists with a tool to improve their explanation of what the patient is trying to achieve during consultations or therapy sessions. The process of engaging users throughout the research project is detailed in the paper, including how the design of the visualisation software is being adapted to meet the emerging understanding of the needs of patients and professionals. The value of the process for the design of the visualisation software is illustrated with a discussion of the findings of pre-pilot focus groups with stroke survivors and therapists.

2. Background

For many physical rehabilitation issues a biomechanical understanding of the problem and its solution is essential [1]. However, despite more than three decades of developments in the field, the potential of biomechanics to fully influence rehabilitation practice has remained under-exploited due to the problematic nature of communicating complex biomechanical data and analyses to other disciplines and to lay people.

A previous study by the authors [2] investigated the ability of professionals from different disciplinary backgrounds and lay persons to understand example visualisations of complex biomechanical information. The research found that through the use of visualisation techniques, data which would usually have been incomprehensible and required specialists in biomechanics to interpret could be understood by both lay and non-biomechanics professional audiences. Further, the visualisations were shown to enable new cross-disciplinary dialogues about the data between the professionals and lay members.

The ‘**envisage**’ project, funded by the Lifelong Health and Wellbeing 2 (LLHW2) initiative, builds on this previous research, and is investigating the potential of visualisations of biomechanical data to improve rehabilitation services and the treatments they deliver to patients. The project is a multidisciplinary collaboration between the University of Strathclyde, The Glasgow School of Art and Glasgow Caledonian University.

Five discrete work packages have been selected to investigate the application of the visualisation software to a range of rehabilitation processes and complexities of condition, namely:

- falls prevention advice and visual feedback to those at risk of falling,
- functional exercises for the rehabilitation of total knee replacement patients,
- lower limb stroke rehabilitation for acute stroke patients,
- upper limb stroke rehabilitation for acute stroke patients,
- diagnosis and fitting of an ankle-foot orthosis in late stage stroke.

3. Developing a flexible visualisation software tool

A new flexible, fully customisable visualisation software tool is being developed. This is essential to enable the exploration of different visual techniques to provide biomechanical information relevant to the rehabilitation concerns of the patients and therapists in each of the separate work packages. The software tool is flexible in two key ways.

Firstly, the software is flexible in the selection of the data input technology used. In each work package, the software will use motion capture data of the individual patients to generate visualisations of biomechanical data relevant to their rehabilitation programme. However, each of the different rehabilitation scenarios has different practical limitations including: size of room; shared spaces requiring regular setup and dismantling of equipment; and non-technical system operators. To meet these different requirements, the software has been designed to be able to use any of a range of different motion capture technologies (detailed in Table 1). Both the recording of motion capture data for visualisation, and the display of real-time streaming movement data is supported by the software.

Secondly, the tool is flexible in terms of the interface used and the visualisation options presented to the patient. Five different variations of the tool will be created, tailored to the different requirements of the patients and therapists participating in the work packages and the biomechanical information to be communicated.

For example, two of the work packages superficially share a common exercise: a knee lift exercise. However, both the way the participants interact with the tool, and the visual feedback needed will be completely different. In the first example (Figure 1(a)), an acute stroke patient is trying to regain lower limb function in a session with a therapist. The exercise will be specifically chosen, the patient’s range of motion determined, and the therapist will set a specific target to work to for the session. The visualisation will highlight

where the patient may be making compensatory movements, to ensure that the maximum benefit can be achieved from the session.

In the second example (Figure 1(b)), the participant is performing prescribed falls prevention exercises in their home. The software will automatically cycle through a prescribed exercise programme, of which the knee lift is only one. The emphasis of the visual feedback will be on performing the prescribed number of repetitions at the correct speed and rhythm.

4. User involvement in the research process

The primary question to be addressed in the research is quantitative i.e. whether the provision of the visualisation software during rehabilitation improves the clinical outcomes for the patient (e.g. walking velocity, variability in stride length etc). To address this question, each work package is evaluating the effectiveness of the visualisation software, used as a rehabilitation intervention, on patient outcomes in a Phase II randomised controlled trial (RCT), exploratory, as defined by the MRC and will follow MRC guidelines for the evaluation of complex interventions [3].

Although the RCT offers a rigorous research method for determining whether or not a cause-effect relationship exists between a treatment and its outcomes [4], the quantitative outcome measures alone would not provide any explanation of which aspects of the visualisation software were successful and which aspects were not. An essential and integrated component to the project will be to explore, using qualitative methods, the effects of the use of the software on the experience, the understanding and the value of appropriately executed rehabilitation exercises from the separate perspectives of, and interactions between, both the patients and therapists [5].

The qualitative outcomes will not only complement and explain the quantitative outcome measures, but will be essential in informing the design and development of a viable and usable visualisation tool to assist in rehabilitation. To optimise the potential for innovation, public and patient involvement (PPI) should happen as early as possible in the process [6]. As Savory states, “where higher orders of change are sought through PPI, a critical dimension is the point in the research cycle in which PPI is included” [7]. He goes on to say that in the “open innovation paradigm the role of users and customers is central to the development of innovations”.

The planned qualitative process, as conceived, is illustrated in overview in Figure 1. Each work package will have a staggered start date for the RCT, so different activities will be running in parallel. The current stage of the process, at the time of writing is that the initial focus groups and design workshops [8] have taken place, and the pre-RCT pilots are about to commence for the first RCTs to begin.

5. Examples of the value of user involvement from the Pre-RCT pilot focus groups

To illustrate the value already gained from engaging with representative users for informing the development of the visualisation software, some of the key outcomes from the pre-pilot focus group for the work packages are described.

5.1. Focus group overview

Two focus groups were held: the first (FG1) with stroke survivors, who had recently been through stroke rehabilitation (N=7); the second (FG2) with rehabilitation professionals

working with stroke patients (N=5, two orthotists, two physiotherapists, one occupational therapist). The aim of these sessions were to obtain the stakeholders' responses to early prototypes of the visualisations, in order to inform the design of the software for further pilots before the RCTs commence [9].

The same visualisations and the same core questions and prompts were used in each of the focus groups to enable a comparison of views between the two sessions. Supplementary questions specific to the stroke survivors or the rehabilitation professionals were also added where appropriate, recognising that each, whether professional or lay, may require specific, tailored information. Throughout the focus group, the exploratory questions were designed to uncover further important issues which may not have been identified by the research team. The focus groups were video and audio recorded, with a scribe noting down key points.

The focus groups were structured into seven sections which covered both generic and particular work package issues which the team identified as important to the design of the visualisations, centring around the themes of rehabilitation goals, progress and motivation. The following sections provide illustrative examples of two sections of the focus group which have been crucial in informing the design of the software interface and visualisations.

5.2. Example 1: The appearance of the figure

Three videos were presented to the participants, each showing the same motion capture data, but providing an example of a different approach to representing the person virtually on screen (Figure 3). The stroke survivor participants were asked to select which they would prefer to see during the stroke rehabilitation process and more importantly to explain their reasons for choosing that particular representation. In the professionals' focus group, the participants were asked to select which figure they would like to see, but additionally which one they would use with the patient.

There are two key outcomes from the comparison of the responses between the two groups. Firstly, there were a range of preferences in both groups, indicating that each of the figures would have a value in certain circumstances. In the subsequent discussion it was suggested that the ability to change the representation to suit the needs of the stroke patient and their stage in the rehabilitation process would be valuable. This would be particularly true in the early stages post-stroke, when the ability to strip back the visualisations to be very simple would be important.

Secondly, the participants in both groups seemed to ascribe more weight to the skeletal model as a way of seeing fine movements or more accurate detail than the other figures, despite all of the representations using exactly the same motion capture data. The motion capture data provides the joint centres and segment orientations of the body, but the skeletal model is generic and cannot show the exact position and shape of the bones. This suggests that the skeletal figure may actually mislead the viewer that the skeletal bones are accurately modelled.

5.3. Example 2: Communicating progress of rehabilitation

A sequence of videos were shown to the participants (Figure 4), of a patient's recorded walking movement being shown in relation to a normal walking pattern while dynamically changing the viewpoint and highlighting the different components of the movement which are causing the patient difficulty. The participants were asked whether they felt this approach would be helpful in the communication of the patient's progress through their rehabilitation. Three of the key findings from this section are described below.

Firstly, both groups responded in general positively to the videos and commented that this form of feedback would be very useful to gauge the patient's progress through their rehabilitation. However, both groups also identified that the normal walk for comparison should be slowed down to be more achievable for the patient as it could be de-motivating.

Secondly, there was a clear difference in response to seeing the affected figure from those who have been through stroke rehabilitation to the professionals treating it. Both groups commented that the footprints were effective and clear for showing the gait symmetry of the patient. However, an interesting difference was found between the groups in terms of the viewpoint used when observing the affected walking pattern. The professionals group thought that the aerial view would be confusing to show to patients as it would be unfamiliar to them. In contrast, in the survivors group, the participants preferred the aerial view as it may be more easily accepted by the patient – some of the participants found the views where the severity of the gait problems were clearly visible quite upsetting (e.g. Figures 4(a) and 4(b)), as they brought back strong memories of their walking difficulties at the start of their rehabilitation.

Thirdly, the display of numerical data was also thought to be a useful addition in both groups. One of the survivors commented that it could be used to 'compete with yourself' over time. In the professionals group, it was suggested that the use of numerical data would be useful to show when a patient had made subtle improvements which could not easily be seen visually e.g. gait symmetry.

However, the professional group had some reservations about numerical data which would need to be considered. There were concerns that it might be necessary to spend time explaining the numbers and where they came from, and that this could waste what is already limited therapy time. It was also suggested that some patients may respond to this level of detail, others may not, and the flexibility of when to show the data should be in the hands of the therapist. The ability to measure and track the quantitative progress of the patient was also seen as beneficial in providing the clinician with evidence that what they do has an impact and that they are right to continue to treat.

6. Discussion

6.1. Changing the software design based on the focus group findings

The focus group and design workshop findings have already had an impact on the design of the visualisation software.

An example of this is that the ability to flexibly switch between visualisations was going to be enabled in the pilots but the 'best option' chosen for the final RCT version. From the focus groups it was clear that there should not be a 'one size fits all' solution, but rather the ability for the patient and the professional to choose the option that suits them best during the trial should be provided. This flexibility is now being implemented, and the choices that the participant makes will be logged by the software for analysis post-trial.

There were also examples of where the visualisations were found to mislead some of the participants, for example in section 5.2, where the skeletal figure was thought to provide more detailed information on bone position than the data supported. A key question for the qualitative research post-trial will be investigate what the participants understood from viewing the data, to discover any instances of misinterpretation and any effects which it may have produced.

The focus groups were important in highlighting the sensitivity which will be needed in showing stroke patients the extent of their difficulties at a hugely distressing period of their life. Some of the participants in the stroke survivor focus group had an emotional response to the seeing the affected figure, as it 'brought them back to where they were'. However, as the stroke patients in the trial will be actively experiencing the condition at the time of viewing the visualisations, this may provoke a different reaction. The experience of the therapist will be key in this, in deciding what should be shown and when, with sensitivity to the patient's situation.

Another key finding was that there was an assumption by the researchers that the numerical data which generates the visualisations would only be shown to the stroke professionals. It emerged from the survivors focus group that the use of numbers, if explained in context, would be a useful measure of progress for the stroke patients as well. The ability to show numerical details to the patient is now being integrated into the tool, although the therapist will be given the flexibility to hide this option if the patient is not be at the stage where it would be useful.

6.2. Integrating qualitative research with an RCT

In healthcare research involving complex interventions, it is unlikely that the best clinical trial design can ever be totally uninfluenced by environmental or social influences, or by the complexity of the different motivational factors and personal circumstances of the individuals involved who have tended to be regarded as 'subjects'.

However, in seeking to address complex healthcare challenges, progress and innovation will likely come from using a mix of methods. This issue is discussed in a recent review of published studies involving the use of qualitative research methods along-side RCTs [5]. The paper recognises that qualitative research with an RCT is still relatively uncommon and the examples published to date have largely been poorly integrated, and this needs to be addressed in future studies: "*Complex healthcare interventions involve social processes that can be difficult to explore using quantitative methods alone. Qualitative research can support the design of interventions and improve understanding of the mechanisms and effects of complex healthcare interventions*".

From the experiences of the **envisage** project to date, there are several challenges which are presented by mixed methods research with an RCT.

1. The timing and level of PPI is an important trade-off. In traditional 'medical model' RCT studies, factoring in additional time at the start for people-centred qualitative and participative research processes may enhance understanding within research teams of the most appropriate and productive avenues for enquiry and development in advance of trials. The findings from the focus groups and design workshops support this. However, there is an inevitable trade-off between the time spent on these activities and commencing the RCTs within project timescale constraints.
2. The mix of methods (and by implication disciplines working together) results in complementary quantitative and qualitative outcome measures, and this presents a challenge in how to integrate the analysis. In the case of the **envisage** project the relationship between quantitative outcome measures (e.g., attendance rate, walking velocity, variability in stride length, and functional ambulatory category) and qualitative outcomes (e.g., enhanced understanding, reasons for actions/inactions, decisions, personal and emotional responses to / preferences for types of figurative representation etc) will be explored at the different stages pre-, during and post-trial.
- 3) The importance of flexibility in the design of the research to address

emergent understanding of the issues for the trial. Here, the original RCT research plan template has been augmented to accommodate increased qualitative research at the beginning to better understand the issues, and to continue throughout the research, up to, during and beyond the trials themselves.

7. Conclusions

In the **envisage** project to date, the qualitative research has been an essential part of the process, both in providing feedback on initial prototype visualisations and in challenging any assumptions which the researchers had made at the beginning of the project. The flexibility of the design of the visualisation software has also been a key component of this process so that it has been possible to respond to the developing understanding of the needs of patients, therapists and the rehabilitation process.

As a result of the mixed methods approach detailed in this paper, the design of the interventions to be investigated in the RCTs has developed significantly from its starting point. This process will continue through the pre-RCT pilots, and will be an essential driver of innovation and development of the visualisation software beyond the trials themselves.

Acknowledgments

This research is funded by the MRC Lifelong Health and Wellbeing programme (LLHW), grant number G0900583. LLHW is a cross council initiative in partnership with the UK health departments and led by the MRC.

9. References

1. Durward, B.; Baer, G.; Rowe, P. *Functional Human Movement: Measurement and Analysis*. Butterworth Heinemann; London: 1997.
2. Macdonald AS, Loudon D, Docherty C, Miller E. Project findings: Innovation in envisioning dynamic biomechanical data to inform healthcare and design guidelines and strategy [Internet]. Glasgow. 2009 Available from: http://www.idealstates.co.uk/biomechvisuals/GSA_NDA_FINDINGS.pdf.
3. Craig P, Dieppe P, Macintyre S, Michie S, Nazareth I, Petticrew M. Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ (Clinical research ed.)*. Jan.2008 337:a1655.
4. Sibbald B. Understanding controlled trials. Why are randomised controlled trials important? *BMJ: British Medical Journal*. 1998
5. Lewin S, Glenton C, Oxman AD. Use of qualitative methods alongside randomised controlled trials of complex healthcare interventions: methodological study. *Bmj*. Sep 10; 2009 339(1):b3496–b3496. sep. [PubMed: 19744976]
6. Macdonald, AS.; Loudon, D. Proceedings of CWUAAT 08. University of Cambridge; Fitzwilliam College: 2008. Who's the expert now? Developing value from visualised data in user research.
7. Savory C. Patient and public involvement in translative healthcare research. *Clinical Governance: An International Journal*. 2010; 15(3):191–9.
8. Uzor, S.; Baillie, L.; Skelton, D.; Fairlie, F. Identifying Barriers to Effective User Interaction with Rehabilitation Tools in the Home. Proceedings of the 13th IFIP International Conference on Human-Computer Interaction (Interact); 2011.
9. Mazza, R.; Berrè, A. Focus group methodology for evaluating information visualization techniques and tools. Proceedings of the 11th IEEE International Conference on Information Visualisation; Zurich. 2-7 July: 2007; p. 74-80.

Figure 1.

Knee lift exercise example, illustrating how different rehabilitation aims require a different interface and visualisations (a) Lower limb stroke rehabilitation: the aim is for the patient to attempt to move their knee to a virtual target without using compensatory movements (b) Falls prevention rehabilitation: the aim is for the patient to performing a set number of repetitions of the exercise at a steady speed.

Figure 2.
The qualitative research process for the envisage project

Figure 3.

Different options for the appearance of the figure shown at the focus groups (a) A simple stick figure (b) A skeletal figure (c) A more realistic human figure

Figure 4.

Dynamic interaction with playback of gait trial with patient. Different visualisations and viewpoints are shown to highlight specific information (a) Visualisation of uneven and slow gait of stroke survivor at baseline (blue figure) relative to improved gait symmetry and walking speed at 3 month follow-up (green figure). (b) Visualisation of the stroke patient's hyperextension of the affected limb at the knee joint during walking (c) Top down view highlighting differences in step length and variability of gait between the affected gait pattern and normal walking (d) Highlighting detailed numerical data on the step length and symmetry ratio of the stroke patient's gait.

Table 1

Rehabilitation Setting	Technology	Data capture
Hospital laboratory	Vicon, optical motion tracking, with Kistler force plates	Full body motion capture (kinematic, kinetic and spatiotemporal parameters)
Community centre (Portable 'mini-lab')	Polhemus, wired electromagnetic sensors Optitrack, optical motion tracking	Motion capture of trunk, affected arm and hand (kinematic and spatiotemporal parameters). Motion capture of lower limbs and pelvis (kinematic and spatiotemporal parameters).
Home	Custom-made wireless inertial sensors	Partial body motion capture (kinematic parameters)