Building user-centred rehabilitation technologies

Assoc. Professor Lynne Baillie
Director Interactive and Trustworthy Technologies Research Group
Talk structure

1. Introduction to how we approached designing technology for rehabilitation
2. Design of the technology
3. Testing of the technology in the lab and the home
4. Trials of the technology in the home
5. Results of the trials
Our work on the project

- envisage was a research project concerned with promoting independence by involving users in their rehabilitation through the use of visual methods

- We needed to design and develop a rehabilitation technology for patients who were recovering from a fall and knee replacement surgery that would:
  - provide patients with suitable technological hardware that can track their exercises in the home
  - provide rehabilitation software that would provide feedback that was suitable for knee replacement and falls.
Team

- Falls software, Dr Stephen Uzor
- Knee Replacement software, Dr Mobolaji Ayoade
- Sensors, Dr Lee Morton
Knee Rehabilitation

- In Britain, 1 in every 20 persons over the age of 65 is affected by knee osteoarthritis.
- This number is set to increase by up to 25% in a couple of decades.
- Knee replacement is an effective surgical intervention for severe knee osteoarthritis (characterised by excessive pain and stiffness of the knee).
- Over 35,000 TKRs are performed each year in the UK.
- An important part of the treatment is rehabilitation following knee replacement surgery.
- Research has shown that the long term success of knee replacement is highly dependent on the quantity and quality of rehabilitation received.
Rehabilitation Tool Design Objectives

- To encourage correct performance

- To improve adherence

- To objectively track progress
Falls

- Falls are one of the leading causes of disability in the elderly costing £2B in UK $34B USA.
- Muscle strength and balance decline with age, leading to an increased risk of falling.
- Rehabilitation can improve muscle strength and balance in the lower body, thereby reducing fall risk.
- However, adherence to home rehabilitation is low over long term.

Motivation: How can we use technology to encourage long term adherence to home exercise?
Project Timeline

Timeline

Basic Prototype

Usability studies

Clinical/Home studies

Design workshops

Design 1

Interviews with experts & Investigation of Technology

Design 2

Timeline
Falls

Visualisation

Games
Research Questions

1. Will the use of games and visual feedback for home rehabilitation show improvements in functional recovery and quality of life when compared to current standard care?

2. What impacts will games and visual feedback have on the understanding of rehabilitation, motivation to exercise and adherence to exercise program?

3. Would the system be effective and easy to use in the home unaided for the predominantly older user?

4. Can an effective video call check-up be provided to physiotherapists and patients who have undergone total knee replacement?
Project Timeline

Basic Prototype

Design workshops

Usability studies

Clinical/Home studies

Interviews with experts & Investigation of Technology

Design 1

Design 2

Timeline
Part of the work was to figure out what were the essential elements of motion capture systems used in laboratories that we would need in the home.

Then using this knowledge & with the input of the users, make a system that would work in the home environment.
Interviews with Medical Experts about Current Care
- Occlusion
- Free space
- Comfort
Project Timeline

Basic Prototype

Design workshops

Usability studies

Clinical/Home studies

Interviews with experts & Investigation of Technology

Timeline

Design 1

Design 2
Design Workshop: Phase 1

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Focus</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Investigate current situation with users</td>
<td>Current tools and interactions</td>
</tr>
<tr>
<td>Phase 2</td>
<td>1st demo of prototype system</td>
<td>Critiquing demo prototype</td>
</tr>
<tr>
<td>Phase 3</td>
<td>Suggestions for new system</td>
<td>Design &amp; Redesign</td>
</tr>
</tbody>
</table>
**Project Timeline**

**Design 1**
- Basic Prototype
- Interviews with experts & Investigation of Technology
- Usability studies
- Design workshops

**Design 2**
- Clinical/Home studies

**Timeline**
Phase 1: Investigate Current Situation

- Booklets feel passive to use
- Using the booklet is not motivating
- No feedback on performance from the video

Possible Solution: motivate users through the use of well designed interactive tools that give feedback
## Design Workshop: Phase 2

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Focus</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Investigate current situation</td>
<td>Current tools and interactions</td>
</tr>
<tr>
<td>Phase 2</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; demo of prototype system (hardware and software)</td>
<td>Critiquing demo prototype</td>
</tr>
<tr>
<td>Phase 3</td>
<td>Suggestions for new system</td>
<td>Design &amp; Redesign</td>
</tr>
</tbody>
</table>
Phase 2: Hardware

- The sensor needs to be smaller than this (quite small)
- The user should not have to wear special clothing to use the sensors
- The sensors should be easy to put on and take off
- It should be easy to see when the sensors are on
- Want to be able to use the system anywhere in the home
- The System should be easy to interact with and learn
Phase 2: Visualisation

**Negative**
- Not sure of minimum and maximum movement
- No repetition count
- No progress shown

**Positive**
- Can see my own movement
- Can adjust my movement when I see the visual mannequin doing something different
## Design Workshop: Phase 3

<table>
<thead>
<tr>
<th>Phase</th>
<th>Focus</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparatory Session</td>
<td>Planning &amp; collecting data</td>
<td>Interviews, literature review, current tools</td>
</tr>
<tr>
<td>Phase 1</td>
<td>Investigate current situation</td>
<td>Current tools, technologies, interactions</td>
</tr>
<tr>
<td>Phase 2</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; demo of prototype system</td>
<td>Critiquing demo prototype</td>
</tr>
<tr>
<td>Phase 3</td>
<td>Suggestions for new system design</td>
<td>Design &amp; Redesign</td>
</tr>
</tbody>
</table>
Phase 3: Suggestions for New Visualisation & Games

Exercise No. 5
Knee Flexion - (Heel slides up and down)

Lie on your back with the board under your operated leg. Slide heel towards your bottom bending your knee as far as you can. Repeat 10-15 times.

ANGLE OF BEND

BAD POOR GOOD EXC

SHOWN IN DEGREES.
Project Timeline

Basic Prototype

Design 1

Design 2

Timeline

Interviews with experts & Investigation of Technology

Design workshops

Usability studies

Clinical/Home studies
Software Development : Design 1

Visualisation

Game
Design 1: Hardware Development

Inertial Measurement Unit (IMU) above = Accelerometer + Gyroscope + Magnetometer
Project Timeline

Basic Prototype

Design 1

Design 2

Timeline

Interviews with experts & Investigation of Technology

Design workshops

Usability studies

Clinical/Home studies
Usability Studies Procedure

Phase 1

Exercise with Standard care

- 4 exercises using the booklet

Phase 2

Putting on the sensors

- Sensors were put on using on-screen instructions

Phase 3

Exercise with Visualization tool or games (+ Sensor task)

- 4 exercises using the visualization tool or games

- 12 Participants (6 lab and 6 home), average age: 74

- Time to complete each repetition was recorded

- We investigated the usability and acceptance of the technologies
Set up

Laboratory studies
- Controlled environment
- Ample space

Home studies
- Intended environment
- Limited space
User remarks

Maximum therapeutic benefit of exercise is not assured

Passive and not exciting
Repetitions from memory, so you forget
No feedback on performance

“Maximum therapeutic benefit of exercise is not assured”

Limitations of the booklet can be addressed

“It is good to see what you are doing”

The screen is too dark, can it be lightened?

“I only hope I’ll be able to stop playing because it is fun”

“This could give me the confidence and discipline that I need”

However: will these technologies encourage adherence over the full length of a rehabilitation programme?
Project Timeline

- Basic Prototype
- Design workshops
- Usability studies
- Clinical/Home studies

Interviews with experts & Investigation of Technology

Timeline

Design 1

Design 2

Basic Prototype

Design 1

Design 2
Wirless Motion Capture

Laboratory Motion Capture Technology

Home Motion Capture Technology
Final Design: Visualisation

Straight Leg Raise

Repetitions: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Well done, you've done 10. If you can, keep going to 15

Lift the operated leg keeping your knee as straight as possible.
Project Timeline

Basic Prototype

Design 1

Design 2

Timeline

Interviews with experts & Investigation of Technology

Design workshops

Usability studies

Clinical/Home studies
Study Design: Knee

Ethical Approval
University and NHS

Baseline assessment at discharge

Randomisation (n = 21 knee patients)

Control Group (n = 10)
Standard care & Phone
Dropout = 3

RVS Group (n = 11)
Standard care & Phone
Exercise visualisation
A video call from AOT
Dropout = 3

Week 6: Final assessment

Questionnaires and semi structure interviews
# Participant Demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Age (Range)</td>
<td>71 (47 - 85)</td>
<td>69 (50 - 78)</td>
</tr>
<tr>
<td>Female</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Male</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Novice PC user</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Occasional PC user</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Experienced PC user</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
The Home Rehabilitation Session

Locations: Bedroom, living room ...
Key Findings Knee - User Experience

System Usability Scale (SUS)

Best imaginable (Bangor et al., 2009)

Enjoyment
"She was excited getting into deep green, you could hear her screaming with joy" – (spouse of P3).
Key Findings - Improved Adherence

Median sessions per day
- Control Group = 4
- Visualisation Group = 3

... but

- 15 repetitions
- 8 exercises per session

“You see this really helped me to do the exercises. If I hadn’t the system, I will just say that it is alright and let it (rehabilitation) go” – (P05).
Key Findings - Rehabilitation Outcomes

Knee Extension

![Box plot showing angle (degrees) for Control (C) and Experimental (E) groups in Week 1 and Week 6.](image)

- Week 1:
  - Control (C): [Angle Data]
  - Experimental (E): [Angle Data]

- Week 6:
  - Control (C): [Angle Data]
  - Experimental (E): [Angle Data]

Recovery
Key Findings - Therapist-Patient Communication
Conclusions: Knee

Results
• The system was **acceptable and easy to use**
• The system **improved adherence and quality of home rehabilitation**
• The system **improved rehabilitation outcomes**
• The system **improved patient-therapist communication**

Key Elements
• Promotes correct performance in real-time
• Provides feedback on each exercise repetition
• Tracks progress in terms of quantity and quality of performance
## Falls Research studies – purpose, setup and hypotheses

<table>
<thead>
<tr>
<th></th>
<th><strong>STUDY 1</strong></th>
<th><strong>STUDY 2</strong></th>
<th><strong>STUDY 3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STUDY DESIGN</strong></td>
<td>Randomised Controlled Trial (2 groups)</td>
<td>Randomised Controlled Trial (2 groups)</td>
<td>Randomised Controlled Trial (3 groups)</td>
</tr>
</tbody>
</table>
| **STUDY GROUPS**     | • Recov-R group  
• Control group | • Recov-R group  
• Control group | • Recov-R group  
• Control group  
• Nintendo Wii group |
| **DURATION**         | 12 Weeks | 8 Weeks | 8 Weeks |
| **KEY HYPOTHESES**   | • Recov-R system improves adherence and reduces fall risk  
• Recov-R system can be used independently in the home | • Recov-R system improves adherence and reduces fall risk  
• Recov-R system can be used independently in the community housing | • Recov-R system improves adherence and reduces fall risk  
• Recov-R system can be used independently in community housing in the UK and USA |
| **PURPOSE**          | Pilot study of the system in seniors’ homes | Larger study to confirm results of Study 1 – with focus on community housing. | • Test Recov-R system against standard care and Nintendo Wii  
• Test Recov-R system in community housing in both the UK and USA |
Research studies – statistics/ demographics

<table>
<thead>
<tr>
<th>REGION (RECRUITMENT PARTNERS)</th>
<th>STUDY 1</th>
<th>STUDY 2</th>
<th>STUDY 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGION (RECRUITMENT PARTNERS)</td>
<td>Glasgow (NHS and Glasgow Housing Association)</td>
<td>Glasgow (NHS and North Glasgow Homes)</td>
<td>Edinburgh/ West Virginia (Various associations in Lothian regions and Institute for GeriOlympics and Active Aging, WV, USA)</td>
</tr>
<tr>
<td>MALES</td>
<td>4</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>FEMALES</td>
<td>13</td>
<td>24</td>
<td>33</td>
</tr>
<tr>
<td>PARTICIPANTS</td>
<td>17</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>RECOV-R GAME GROUP</td>
<td>8</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>CONTROL GROUP</td>
<td>9</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>AGE RANGE (MEDIAN AGE)</td>
<td>65 – 84 years (75.5 years)</td>
<td>65 – 99 years (76 years)</td>
<td>55 – 94 years (77.5 years)</td>
</tr>
</tbody>
</table>
The system encouraged the older adults to exercise regularly, compared to the standard care group, where there was a steady decline in adherence to exercise.

The findings on adherence are statistically significant using a comparative T-Test ($p = 5 \times 10^{-11}$) with a significance value of $p = 0.05$. 
Improvement in mobility (clinical outcome)

12/16, participants in the Game group (75%) improved in average walking speed compared to a corresponding 8/22 participants in the Control group (36%). This suggests that the system encouraged better quality of movement during exercise – leading to a reduced risk of falling.

The findings on walking speed are statistically significant using a T-Test (p = 0.047) with a significance value of p = 0.05.
There were significantly more seniors who improved in balance, after using the Recov-R system (75%), versus those in the control group who used standard care (41%). This demonstrates the system’s capability to improve physical function in terms of balance (necessary for reducing risk of falling).
Improvement in fall concern (Falls efficacy scale - FES)

There were significantly more seniors who were less concerned about falling, after using the Recov-R system (62%), versus those who used standard care (27%). This demonstrates the system’s capability to improve confidence and reduce fear of falling (and consequently reduce risk of falling).
The scale goes from 1. Not at all interesting/Enjoyable to 7 Very interesting/Enjoyable.

The high values on the ‘Enjoyment’ scale indicate that the games were very enjoyable to the seniors, and that they were primary motivator for exercise.

The high values on the ‘Value/Usefulness’ scale indicate that the seniors attach high value and usefulness to the Recov-R system for the purpose of physical rehabilitation.
Contact Details:
I.baillie@hw.ac.uk  (http://www.ittgroup.org)

Publications associated with research talk: