

## User perspectives on the design and setup of lower limb mirror therapy equipment after stroke: a technical report.

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## Abstract (237 words)

**Objectives:** To co-design lower limb mirror therapy (MT) equipment and setup by working directly with stroke survivors and physiotherapists.

**Design:** Co-design approach through focus groups.

**Participants:** Twenty-six participants. Sixteen stroke survivors and ten physiotherapists.

**Data collection and analysis:** Data were collected in an iterative process through two sets of focus groups. Firstly, prototype one of the MT equipment was presented to the participants. They were encouraged to use and comment on it. Then, the key requirements for ankle exercise with MT were presented, and participants discussed whether the prototype one was able to deliver these requirements. These findings informed iterations to the device, and a second prototype was produced and discussed in the second set of focus groups. The final prototype was then produced based on the participants' feedback. All focus groups were audio-recorded, followed by verbatim transcriptions and thematic analysis.

**Results:** Main characteristics required of the lower limb MT device were found to be: the ability to produce MT ankle exercise from an upright sitting posture, an adjustable angle between 5 to 15 degree from the midline to allow clear lower limb reflection during seated exercise, and a lightweight device to enable easy use for stroke survivors.

**Conclusion:** This work produced an iteratively co-design lower limb MT to be used with stroke survivors.

**Contribution of the paper:** This study provides user-centred design of lower limb mirror therapy equipment and set up for use in clinical practice and subsequent research.

**Keywords:** Mirror therapy; lower limb; stroke; rehabilitation; user-centred design.

## 1 Background

2 Mirror therapy (MT) is a non-invasive rehabilitation intervention that was first used to reduce  
3 phantom pain in people with a limb amputation [1]. Subsequently, MT has been reported to  
4 have benefits for improving upper and lower limb function after stroke [2,3].

5  
6 The majority of research has concentrated on the use of MT for upper limb function after  
7 stroke [2]. Studies of MT for the upper limb have used comparable equipment, set-up pf  
8 equipment and upper limb functional exercises. These similarities ease the translation of MT  
9 into clinical practice [2]. However, there are relatively few studies of MT for the lower limb  
10 and the equipment and its set-up is more varied [4–9]. Furthermore, many reports provide  
11 insufficient detail of MT equipment and its set-up (e.g., mirror dimensions and participant  
12 positioning). Therefore, replicating of research studies and translating findings into clinical  
13 practice is challenging.

14  
15 Although most study reports state that the mirror was placed in a parasagittal plane between  
16 the legs the mirror dimensions varied, e.g., 40×70 cm [4,5], 60×90 cm [6,7], and 50×70 cm  
17 [8]. The positioning of participants also varied. For example, a half-lying position [5,9], and  
18 a sitting position [4,6]. Important features such as placing the mirror to observe a good  
19 reflection, and/or obscuring the sight of the more paretic lower limb are described  
20 infrequently. Moreover, there is little, if any, evidence that the users of MT have been  
21 engaged in the development of the evaluated equipment despite considerations that user-  
22 centred design is crucial to the uptake and use of such technology [10–12]. These limitations  
23 hamper the use of evidenced-based lower limb MT by stroke survivors and clinicians.

24

25 The purpose of the developmental work presented here is to co-design lower limb MT  
26 equipment and its set-up through working directly and iteratively with stroke survivors and  
27 clinical physiotherapists.

28

## 29 **Methods**

### 30 **Design**

31 A co-design approach employing two sets of focus groups to understand the users' needs and  
32 to engage them closely in the iterative development of the lower limb MT equipment and its  
33 setup. This approach enabled: user exploration of the idea; consideration of prototypes; and  
34 capturing user-identified design benefits and challenges for production of an acceptable and  
35 user-friendly final version [13]. This approach adheres to the central need for meaningful  
36 partnerships with key stakeholders to develop innovative technologies [14]. Here the key  
37 stakeholders were stroke survivors, and clinical physiotherapists with experience in stroke. In  
38 addition, we were guided by the GRIPP checklist [15].

### 39 **Participant characteristics, recruitment and setting**

40 The inclusion criteria for stroke survivors were:

- 41 • aged 18 years or more;
- 42 • expressed willingness to participate in the research.

43 The inclusion criteria for physiotherapists were:

- 44 • qualified physiotherapist registered with the Health Professions Council;
- 45 • experience in stroke rehabilitation.

46 Overall, twenty-six people participated in the study: 10 physiotherapist and 16 stroke  
47 survivors. The age of stroke survivors ranged from 30-70 years. They were all more than six  
48 months after stroke onset and were living independently in the community. All participants  
49 provided informed written consent before recruitment.

50

51 Stroke survivors were recruited from local stroke support groups. The first contact was made  
52 through emailing gatekeepers of the support groups to inform them about the study and  
53 provide them with the ethically-approved participant information sheet (PIS). The  
54 Researcher also asked if she could visit the support group to tell its members about the study.  
55 On receipt of an invitation from a gatekeeper, the Researcher attended a support group  
56 meeting to explain about the study. Those support group members who were interested in  
57 taking part were provided with a PIS and had any questions answered. Stroke survivors who  
58 provided informed consent were recruited as participants in this study.

59

60 The subsequent focus groups were held in the support groups to which participants belonged.  
61 We aimed to include the same participants in both focus groups but recruited additional  
62 participants to replace any people who withdrew.

63

64 For clinical physiotherapists, the Researcher first contacted the gatekeepers of local stroke  
65 services. The introductory email explained about the study and provided the ethically-  
66 approved PIS. If the gatekeeper agreed, then the Researcher conducted the focus groups  
67 with clinical physiotherapists during their break time.

68

### 69 Procedure and data collection

70 Ankle exercise was chosen as the focus for lower limb MT as it is an advocated component  
71 of therapy to improve sit-to-stand ability and walking endurance [16]. Before focus groups  
72 were undertaken, the research team derived the key requirements for lower limb MT to  
73 induce the visual illusion of movement of the paretic ankle:

74

- enable a clear reflection of the less paretic foot and lower leg in the mirror;

- 75 • ensure that the more paretic foot and lower leg are unable to be seen by the stroke  
76 survivor;
- 77 • ensure that dorsiflexion and plantarflexion could be produced through their full  
78 anatomical range;
- 79 • ensure upright and symmetrical comfortable sitting posture that allows a 90 degrees angle  
80 at the hips, knees, and ankles;
- 81 • mirror therapy equipment needs to be light enough for stroke survivors to set it up/down  
82 easily, portable, storable in peoples' homes when not in use, and sufficiently robust so  
83 that the possibility of breakage is minimised.

84

85 The research team then tried out a popular device that is commercially available. The major  
86 challenges using this device were: participants were unable to see the reflection of the  
87 moving foot while sitting upright and it was difficult to keep the mirror in place whilst  
88 allowing a clear reflection of the moving foot. Consequently, it was decided there was a need  
89 to develop MT equipment and its set-up.

90

91 The requirements for lower limb MT, set out above, were used to produce the first prototype.  
92 This was then demonstrated to the first set of focus groups. Participants were encouraged to  
93 use Prototype One and provide feedback for improving the device with specific attention paid  
94 to meet the key requirements. Feedback from the focus groups was used to produce the  
95 second prototype, and the process was repeated with the second set of focus groups. This  
96 feedback was used to inform the production of the final device. Data collection ceased in  
97 each set of participants when data saturation was reached, i.e., no new information was  
98 generated, and there were no changes to the identified themes [17].

## 99 Data analysis

100 The focus group audio recordings were transcribed by the Researcher on the same day they  
101 were made. These transcriptions were examined using deductive thematic analysis [18] where  
102 the codes were predefined to meet the study aims, determined by research team  
103 discussion. These pre-defined codes were:

- 104 • mirror size
- 105 • reflection of the less paretic foot.
- 106 • the base of the mirror
- 107 • the foot support
- 108 • how to hide the more paretic side so user cannot see it.
- 109 • sitting posture
- 110 • storage and portability
- 111 • safety features.

112 Data were coded using NVivo (NVivo 12 Pro). A second member of the research team read  
113 the transcripts and checked agreement or otherwise with the researcher's analysis [19]. In  
114 addition, transcripts were re-checked for any emergent themes not aligned to the pre-defined  
115 codes, that could contribute to device design. It was planned for any disagreement to be  
116 discussed and referred to a third party, but no major disagreement occurred between the  
117 researchers. Findings were then discussed with the whole research team and fed iteratively  
118 into modifications to the design in producing the final (prototype-two) device.

119119

## 120 Results

### 121 Participants

122 Prototype One was considered by 14 stroke survivors (four focus groups) and ten  
123 physiotherapists (one focus group). Prototype Two was considered by nine stroke survivors

124 (two focus groups) and five physiotherapists (one focus group). It was planned that the two  
125 prototypes would be considered by the same participants, but seven stroke survivors and five  
126 physiotherapists were unable to attend. Therefore, two additional stroke survivors were  
127 recruited to consider Prototype Two (Fig 1).

128

### 129 [Prototype One characteristics \(Fig 2\):](#)

130 The specific characteristics were:

- 131 • mirror dimensions 90×60 cm;
- 132 • Mirror mounting board dimensions 100×70 cm;
- 133 • square corners to the mirror mounting board;
- 134 • mirror separated from the base;
- 135 • mirror angle and the foot support adjustable using screws.

136

### 137 [Changes to the design required for Prototype Two](#)

138 Eight design aspects emerged from participants' consideration of Prototype One (Table 1).

139 Prototype Two is illustrated in Fig 2. The main changes were:

- 140 ▪ adjustable angle of the mirror to the base between 5 and 15 degrees to allow clear  
141 reflection of the less paretic foot;
- 142 ▪ people undertaking MT to be seated in a regular dining chair for back support to allow an  
143 upright posture and minimize fatigue;
- 144 ▪ adjustable position of the foot support using a system of pins and holes to allow easy  
145 adjustment according to the leg lengths of individuals;
- 146 ▪ round corners to the mirror and its mounting board to minimise injury potential;
- 147 ▪ mirror dimensions reduced to 60×40 cm.



148   ▪ base and mirror mounting board made with a plastic material, to enable easy cleaning.

149

#### 150   Changes to the design required for final MT equipment and setup

151   Participants identified four aspects of the design of Prototype Two that needed improvement  
152   (Table 2). The three key changes needed were:

153   ▪ the equipment needed to be smaller so that it can be carried around and stored in the  
154   home;

155   ▪ the equipment needed to be lighter so that it can be carried using one hand only.

156   ▪ the angle of the mirror to the base needs to be limited between 5 and 15 degrees because  
157   outside of this range there is a distorted image of the shank and foot.

158

#### 159   Main characteristics of the final MT equipment and setup

160   The final MT equipment and setup is illustrated in Fig 2. Essentially:

161   ▪ users can sit in an upright posture on a regular dining chair with back support whilst  
162   seeing a good reflection of their less paretic foot;

163   ▪ the more paretic lower limb is covered by white fabric attached to the back of the mirror  
164   mounting board;

165   ▪ the mirror is made from good quality plastic with rounded corners;

166   ▪ the mirror dimensions are 51×37 cm.

167   ▪ the dimension of the mirror mounting board is reduced to 15 x 7.5 cm;

168   ▪ the mirror mounting board is connected to the baseboard with a hinge so that it can be  
169   folded flat and has a 14 cm wide handle for carrying;

170   ▪ the mirror-to-base angle is adjustable in positions of 5, 10 and 15 degrees from the

171   vertical using an adjustable frame attached to the back of the mirror mounting board;

- 172   ▪ the foot support is adjustable with a pin and holes system providing five different  
173       positions for different leg lengths;
- 174   ▪ the dimensions of the base are 43 ×35 cm, and 43×17cm when folded to allow ease for  
175       storage.
- 176   ▪ The MT equipment weighs two kilograms.

177

## 178 Discussion

179 This study has produced the lower limb MT equipment and set-up for use in stroke survivors’  
180 homes to deliver ankle exercise. To our knowledge, this is the first co-designed, with stroke  
181 survivors and physiotherapists, MT equipment and set-up for lower limb rehabilitation after  
182 stroke.

183

184 There were a few studies available to assist us with the initial design of the mirror and its  
185 setup [20]. but, these used a mirror twice the size of our final product [4,6,9]. Although the  
186 larger mirror should ensure obscuration of the more paretic limb, the stroke survivors in this  
187 study preferred using a sheet to cover the more paretic lower limb as this reduced the weight  
188 of the equipment.

189

190 Most of the stroke survivors preferred to use the mirror in the midline between their lower  
191 limbs as used in an earlier investigation [2]. However, they preferred to perform the ankle  
192 exercise MT in an upright sitting posture using a standard dining-type chair and preferred to  
193 adjust the equipment rather than bending their back or tilting their head to see the reflection.  
194 Interestingly, other investigations do not appear to have considered participants’ posture and  
195 how sustainable this is over the exercise period. For example, participants are reported as  
196 being in half-lying or a sitting position involving trunk flexion [9] with the trunk inclined

197 towards the less paretic side to allow the view of the reflection of the lower leg in the mirror  
198 [21]. In respect of the mirror angle, a few study reports have mentioned it, for example, an  
199 angle of between 75 and 85 degrees [22,23]. However, participants in this study highlighted  
200 the importance of the angle to avoid shifting the body to see the reflection. They  
201 recommended that the mirror angle needed to be limited between 5 and 15 degrees from  
202 vertical to prevent distortion of the images.

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204 The main strength of this study was the use of an iterative process to incorporate the views of  
205 stroke survivors and clinical physiotherapists for improving the design of lower limb MT  
206 equipment and its set-up. The strength of this approach could have been improved with the  
207 use of multidisciplinary team meetings, including the participants and the workshop  
208 technicians. This was precluded by the resources available.

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210 In conclusion, the results of this study provide information to clinical physiotherapists who  
211 are already using lower limb MT with stroke survivors. And, the lower limb MT equipment  
212 and set-up produced through this study can now be tested for clinical efficacy in subsequent  
2132 research.

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215 [Ethical approval](#)

216 Ethical approval for the study was granted by the Research Ethics Committee of X, 10

217 University of X (Ref. 2017/18 - 117). All participants provided informed consent before

2182 they were recruited as participants in this study.

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224 **Conflict of interest**

225 No conflicts of interest

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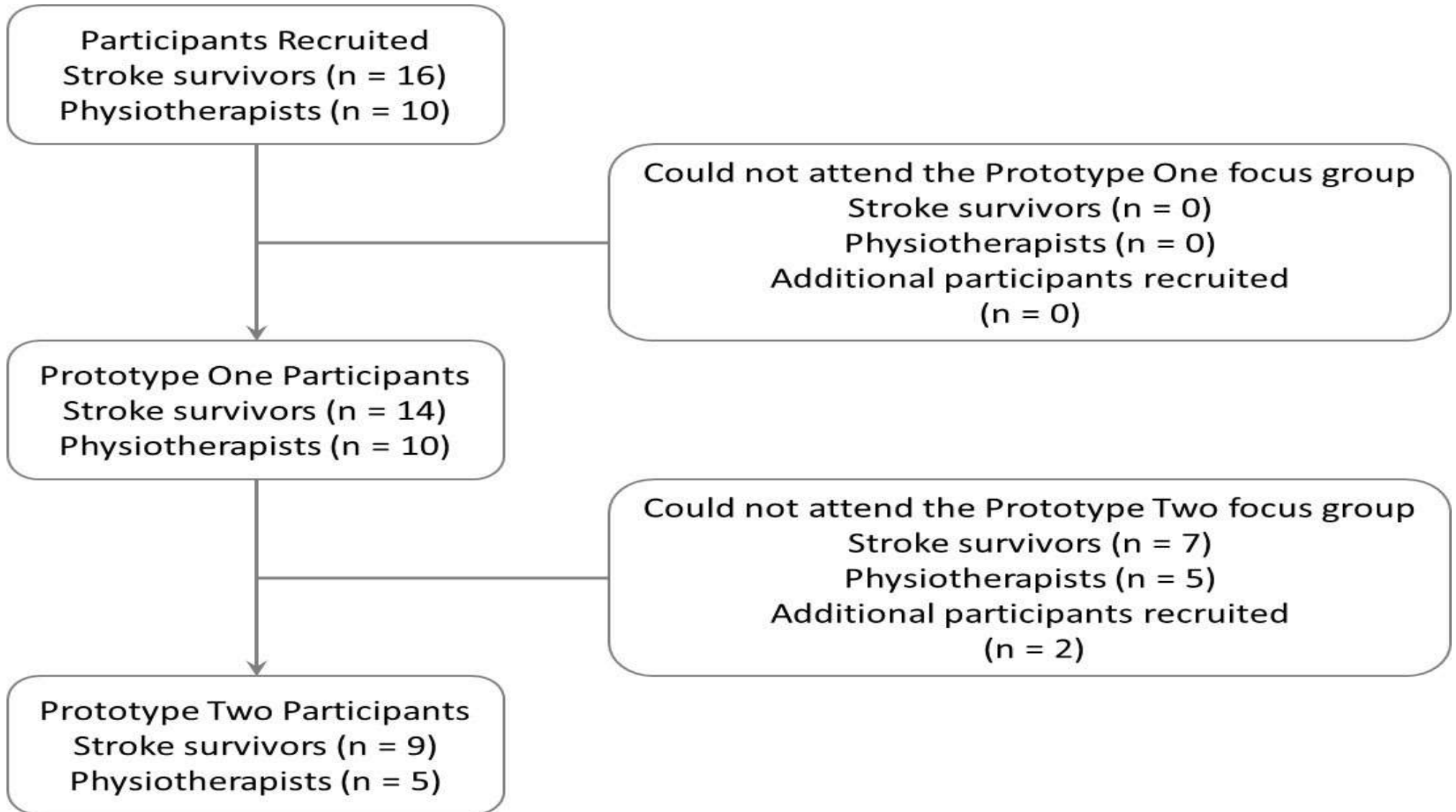
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**Figure 1. Flow of participants through the study****Figure 2. Prototype One, Prototype Two and final mirror therapy equipment and setup**

*A. Prototype One: The mMirror was supported by screws at the base to adjust the angle. Also the ankle supporter was attached to the base with screws and, the mounting board was bigger than the mirror size with a sheet attached at the back to cover the weak side.*

*B. Prototype Two: Changes in the size of the mirror and the base, the ankle supporter was adjustable with a pin and holes system and the corners of the mirror were rounded.*

*C. Final mirror therapy equipment and setup: An overview of the mirror with rounded corners, with handle at the top, the foot is rested on the ankle supporter with the sheet covering the weaker side. An adjustable frame at the back of the mirror with three slots at the base allows the angle of the mirror to be set at 5, 10 or 15 degrees.*