Limited use only. How can the design of an everyday object help chronic stroke patients to overcome the learned nonuse of the upper limb?

Mailin Lemkea, Edgar Rodríguez Ramírezb, Brian Robinsonb

a School of Design, Victoria University of Wellington
b School of Nursing, Midwifery and Health, Victoria University of Wellington
*Corresponding author e-mail: mailin.lemke@vuw.ac.nz

Abstract: Stroke causes significant damage to the brain and symptoms commonly affect one or both limbs on one side of the body. Compensatory movement is the preferential use of the non-affected limb and is a common phenomenon after a stroke, leading to a learned nonuse of the affected side. This learned nonuse of an upper limb can be overcome through constraint induced movement therapy (CIMT) during which the non-affected arm is physically restrained to enhance the use of the affected arm. This paper presents the outcomes of a design course with undergraduate students in which the students developed design solutions based on CIMT components that encourage the use of the affected arm. Six design solutions were evaluated by therapists with experience in stroke rehabilitation. Their feedback indicates that the designs have the potential to be used in a self-directed way by stroke survivors and that they contain a therapeutic value.

Keywords: stroke rehabilitation, constraint-induced movement therapy, CIMT, design strategies, medical device design, research-through-design, shaping, part-task training, behaviour change, iterative design, industrial design

1. Introduction

Stroke is a form of brain injury that is caused by lack of blood flow or oxygen delivery causing irreversible injury to parts of the brain. It affects approximately 15 million people annually, causing the deaths of one third, while another third survives with persistent disability (McKay & Mensah, 2004). The impact on an individual survivor depends on the location and severity of the stroke within the brain (Mallory, 2006) and can comprise physical as well as psychological symptoms. Stroke survivors can experience unilateral motor impairment in the form of hemiparesis, which is weakened muscles, or hemiplegia, which involves the paralysis of muscles (Colman, 2009). They are likely to compensate for lost motor function of an arm with movement of their less affected side, leading to a
learned nonuse of the affected arm (Taub, Uswatte, Mark, & Morris, 2006). Constraint-induced movement therapy (CIMT) originated from studies with primates that demonstrated learned nonuse of the affected arm can be overcome by applying a physical restraint on the less affected arm to restrict its use (MacKenzie & Viana, 2016). The intervention is criticised in clinical practice for being expensive and resource intensive (Viana & Teasell, 2012) and stroke survivors experience the physical constraint as a significant limitation (Page, Levine, Sisto, Bond, & Johnston, 2002).

With the worldwide trend of moving from hospital to home-based healthcare and rehabilitation, systems are needed that assist therapists to facilitate CIMT through independent home-based therapy. Designing everyday objects that encourage the use of the affected arm offers the potential to deliver a meaningful form of self-directed rehabilitation. This paper’s focus is on different design concepts that aim to evoke an initiation of the affected arm and hand. The design concepts were developed based on a design brief that uses elements of part-task training, named ‘shaping’ that is part of CIMT. Shaping offers a detailed description of its components to guide the design process.

2. Constraint-induced movement therapy

CIMT consists of three main components: a physical constraint on the less affected arm, intensive and repetitive practice using the affected arm for multiple hours a day and adherence-enhancing behavioural methods (Morris, Taub, & Mark, 2006). The intervention targets the learned nonuse post stroke. Outcomes of the intervention are increased quality and quantity of use of the affected arm and hand (Morris, Taub, & Mark, 2006). The enhanced quantity of use can be attributed to the increased initiation of use of the affected arm during activities of daily living. The original CIMT protocol is rather time consuming but has evolved over time with the modified version, mCIMT, outlining 2 to 3 hours of training per day for 15 consecutive days. This modification acknowledges criticism by therapists and allows for the limited motor capabilities of patients (MacKenzie & Viana, 2016).
2.1 Constraining the movement

Figure 1. During CIMT the participant wears a mitt or cast on the non-affected side

The original CIMT protocol uses a sling or protective safety mitt (see Figure 1) on the less affected arm to shift the focus of use onto the affected one. The safety mitt has recently become the preferred form of restraint and enables the arm’s use in case of balance problems (Morris, Taub & Mark, 2006).

2.2 Repetitive task-oriented training

The restraint is worn during most of the participant’s waking hours and during the repetitive practise directed and accompanied by the therapist. CIMT applies two different forms of practise: part task training, named shaping, and practising everyday tasks. Shaping uses activities of daily living that the patient wants to focus on and breaks them down into sub tasks according to the participants’ motor capability, for example picking up a fork instead of eating a whole meal. Each functional activity is addressed in a set of ten 30-second trials and starts with the physical demonstration of the correct behaviour. The activities can be objectively measured by the therapist to assess progress and improvement. To enhance outcomes, shaping is accompanied by explicit, specific, and quantitative feedback. Each set is specifically outlined and its components defined, and constantly increases in difficulty according to the participants’ progress (Morris & Taub, 2006).

2.3 Adherence-enhancing behavioural strategies

To transfer the regained motor capabilities into the patient’s real-world environment, adherence-enhancing strategies in form of a ‘transfer package’ are embedded within the intervention. Techniques include, for example, a behaviour contract that is a formal written agreement between
3. Aim

The aim of this paper is to explore different design strategies based on shaping characteristics that encourage the initiation of use of the affected arm post stroke.

This paper outlines the outcomes of an industrial design course named ‘Tangible Interactions Design’ that took place for 5 weeks with 31 undergraduate design students at the School of Design, Victoria University of Wellington. We focused on the task of eating, which therapists mentioned in previously conducted interviews as being an important task. The following design criteria that are based on shaping (Morris & Taub, 2006) were used as a design brief:

1. The movement of the less affected arm needs to be restrained to motivate the user to use their affected arm (initiation)
2. The movement of the affected arm needs to be repetitive
3. The interaction with the object needs to get more challenging over time
4. Feedback needs to be provided
5. A behaviour contract needs to be incorporated

3. Methods

3.1 Study procedure

The study consisted of four stages:

1. Understanding the problem

An introduction to the condition and stroke symptoms, and a detailed description of CIMT was given to the students to offer a better understanding of motor impairments and shaping. Two videos were presented during the introduction showing the assessment process and different shaping tasks (Blakey, 2014; University of Alabama at Birmingham, 2014). The students received the design brief based on the characteristics of shaping and a list of eating tasks described in the motor activity log (MAL), which is a structured interview used as an assessment tool within CIMT (Morris & Taub, 2006). The students further received two different persona descriptions (Canadian Partnership for Stroke Recovery, 2016) to guide the design decisions. One persona showed signs of a left arm impairment, see Figure 2, while the second persona showed signs of a right arm impairment.
2. Concept development

The students were provided with eating equipment to carry out different eating tasks to break them down into their movement components (see Figure 3). While one student performed the task following the think aloud protocol (Ericsson & Simon, 1998), two students were videotaping him and taking notes. They developed a storyboard based on the observation and comments that showed the different movement components.
Figure 3. Eating equipment to perform eating tasks and break them down into shaping tasks

Figure 4. Storyboard showing an eating task
3. Prototype development

The students worked individually in an iterative design process. Sketches led to different form prototypes using cardboard, foam, and a 3D printer generation to test and adjust the form of the object. For the final hand-in, the students submitted a working prototype and two videos: one showing the formative usability evaluation with peer students and one showing the intended use of the device.

4. Formative usability evaluation

The formative usability evaluation (Hartson, Andre, & Williges, 2001) is done during the design process to improve design outcomes. The working prototypes were used for two different usability evaluations: one with peer students and one with therapists with vast experience in stroke rehabilitation. Six projects were chosen for assessment by two physiotherapists and one occupational therapist. This expert-based evaluation explores the task performance of the designs and helps to encounter usability problems the same way the user would (Hartson, Andre & Williges, 2001).

For the evaluation with peer students a two-step protocol was used, focusing on the think aloud protocol. The student started by presenting the design and asking the tester for a description of what they believed was the intended use of the design. In a second step the tester could use the object and recommend changes.

The expert evaluation process started with the presentation of the video that the students handed in expressing the intended use of the object. The therapist then had the opportunity to test the working prototypes and recommend changes.

4. Results

Thematic analysis (Braun & Clarke, 2006) was used to determine common design approaches in the design concepts. In the following sections 4.1-4.5 the five main elements, applied strategies and design outcomes that the students developed to address the design brief will be outlined.

4.1 Restraining the movement

The stroke survivor is asked to wear a physical constraint on the less affected arm in order to focus on the use of the affected side (Morris & Taub, 2006). Three different strategies were employed by the students to encourage the participant to use a specific side without needing a physical constraint – see Figure 5.

The three approaches were:

1. Ergonomic restriction
2. Bilateral task to occupy the non-affected arm
3. Intuitive use of an object
Figure 5. Design strategies used to restrain the movement

An example of an ergonomic restriction can be seen in Figure 6. ‘Smart sticks’ are chopsticks designed so they are usable only with the right hand. Focusing on a bilateral task for the restraining effect is shown in Figure 7. The less affected arm is essential in the task to unlock the object’s full functionality.
Figure 6. Smart Sticks chopsticks by Xavier Strom

Figure 7. Fluve decanter by Nicole Hone
Cirgo is an example that relies on the intuitive use of an object with the right hand, Figure 8.

![Cirgo knives](image)

**Figure 8.** Knives by Evangeline Martin named ‘Cirgo’ that rely on the intuitive use of a knife with the right hand

### 4.2 Enhanced repetition

The positive effects of CIMT seem to be closely related to intense and increased repetition of the movement provided as part of the therapy (MacKenzie & Viana, 2016).

Two different design strategies were applied to deliver a repetitive movement (see Figure 9).

1. The design is part of a repetitive movement, for example cutting food with a knife
2. The functionality of the design is reduced, leading to increased repetition
‘Fluve’ is a concept that reduces the functionality of the object to increase repetition in an efficient way. The amount of water that the user can pour into a cup is limited, requiring the user to repeat the movement multiple times in order to fill the cup. The vessel contains a mechanism in the handle that fills up with water each time it is rotated 90 degrees. The mechanism is invisible from the outside and just allows a certain amount of water to be poured out, see Figure 10.
4.3 The interaction needs to become more challenging over time

The tasks that are trained during shaping constantly increase in difficulty to improve motor capabilities. Progress depends on the participant’s ability to carry out the task in order to decrease frustration (Morris & Taub, 2006).

The different design strategies that were used can be separated into four different strategies that partly overlapped (see Figure 11).

1. Progress is determined by the user
2. Progress is determined by the object
3. Progress is incorporated in one design object
4. Progress is incorporated in multiple design objects
Figure 11. Design strategies used to offer progression in the interaction

Most students chose the form of progress that the user was able to self-determine. A design concept offering such a form of progression is a water bottle (see Figure 12). The bottle has a lid that limits the amount of water coming out of it to increase the difficulty of the interaction.
Further designs that used a self-determined progress are shown in Figures 13 and 14. These designs focused on multiple design elements to offer progression in the interaction. The minority of concepts incorporated a predetermined progress by the object. Those design concepts used materials that changed over time. The longer the object was used the smaller the surface area got to hold the object making it more challenging for the user to use it.
Figure 13. Coffee mugs and lids by Katie O’Brien

Figure 14. Lottiel by Ashleigh Kennedy
4.4 Feedback

Feedback is an essential element in shaping and is provided in an immediate, specific, quantitative, and positive form (Morris & Taub, 2006). The students were encouraged to include augmented feedback in the design concepts equivalent to that given by a therapist during the rehabilitation. However, none succeeded in implementing such a form of feedback. The most common form of feedback (Wensveen, Djaadjiningrat, & Overbeeke, 2004) was functional feedback, which is the actual function of the design; for example, that it pours water.

![Feedback chart]

Figure 15. Design strategies used to provide feedback

4.5 Behaviour contract

The behaviour contract is essential to evoke a feeling of responsibility in the participant (Morris & Taub, 2006) and to translate gains made during the rehabilitation into the participant’s real world context.

The different design strategies, see Figure 15, included:

1. Adding an additional, removable behaviour contract to the design
2. Including the behaviour contract in the design’s packaging
3. Including the behaviour contract within the physical form of the design
5. Expert evaluation

Two physiotherapists and one occupational therapist evaluated six of the student design concepts in a 30-minute usability evaluation. The intended use was presented in the form of six 30-second videos, after which each design was presented for testing.

Fluve

The therapist appreciated the aesthetic of the object but stated that it still appeared therapeutic. The design is supposed to hang on the wall to decrease shoulder pain during use but criticism was that its use would be difficult and frustrating over time. One therapist suggested using a stand might be more feasible to offset the weight.

Lottie

The therapists appreciated that the top part can be used on normal water bottles as well, but they indicated that stroke survivors often struggle with a normal water bottle because they squeeze it too hard. One therapist recommended adding more texture on the bottle and the top part to make the motion easier. Adding additional feedback in the form of an element that measures the water flow or letting the water appear coloured was suggested.
Smart Sticks
The intended use of the object was not clear and the therapists identified it as a kind of scissors. They recommended a square pad at the end of the chopsticks to ease the picking up of items and using elastic bands to add resistance during use. They further suggested that it could be used for playing a board game or for picking up objects. One mentioned that tongs are already used in the rehabilitation process.

Coffee mugs
The mugs require extension of the fingers, and especially the thumb, that would be too difficult for a stroke survivor. The purpose of the different lids was not understood and the handles were too small to be used as a support for the hand. The surface was criticised as being too smooth and it was recommended additional texture be added. Two of the therapists questioned the therapeutic value of the device and considered it impracticable.

Cirgo knives
Cutting is a huge challenge for a stroke survivor and a dangerous task to train. Adding more texture on the sides of the knife would offer more support during the task. Two therapists questioned how different this design is from what is currently available on the market, while one therapists stated this design solution offered a lot of potential.

Water bottle
The size of the bottle was criticised as being too big to hold, and adding more texture was recommended. An additional strap that supports the hand would make the use of the bottle feasible for a stroke patient.

6. Discussion
6.1 The design process
The students expressed problems relating to the medical condition and physical limitation of the intended user. They preferred to design according to their own preferences and liking and had issues designing for people with specific motor impairments. It was emphasised during the course that the intervention is not just based on the physical constraint but that augmented feedback and a behaviour contract were equally important in the process. The shortcomings in including those components might have been caused by the short course timeline and the students’ focus on industrial design.
6.2 The design outcomes

Table 1: Overview of design elements

| Design brief | Design strategy                        | Number of concepts |
|--------------|----------------------------------------|--------------------|
| Restraint    | Ergonomic restriction                   | 10                 |
|              | Bilateral task                          | 11                 |
|              | Intuitive use                           | 10                 |
| Enhanced repetition | Task is already repetitive             | 14                 |
|              | Increased repetition                    | 5                  |
| Progress     | Self-chosen progress                    | 19                 |
|              | Object determines progress              | 2                  |
|              | Progress in one design element          | 7                  |
|              | Progress in multiple design elements    | 12                 |
| Feedback     | Inherent feedback                       | 2                  |
|              | Functional feedback                     | 21                 |
| Behaviour contract | Included in the design                | 1                  |
|              | Additional element                      | 1                  |
|              | Included in the packaging               | 6                  |

Different design strategies were used to address the design brief and incorporate shaping aspects. Some strategies such as ergonomic restrictions were frequently used, while other elements were seen to be rather challenging to include in the design. CIMT is often reduced to the applied physical constraint but data suggests that the other elements involved also play an essential role (Morris, Taub, & Mark, 2006).

Elements that are part of the therapeutic package of CIMT like the behaviour contract and augmented and specific feedback were included in the designs but in a modified way. The behaviour contract increases the participant’s engagement in the process and evokes a feeling of responsibility. It is a formal written document signed by the therapist and participant (Morris, Taub, & Mark, 2006). The different behaviour contracts in this study took more of the form of a reminder that the user sees on the packaging or the object itself. Tests with stroke survivors need to evaluate whether those reminders have the same effect as the original contract. The purpose of design solutions that relied on one design element to provide progression and constant challenge were understood, whereas design concepts with multiple elements caused some confusion about the intended use.

One of the therapists pointed out that the design outcomes contained a therapeutic value but that the use of those objects did not deliver a shaping task. Shaping is provided in a clinical environment and uses ten 30-second trials and explicit feedback is provided (Morris, Taub & Mark, 2006). The designs presented in this paper do incorporate principles of shaping but they can be used in a self-directed way in the participant’s home environment without any time restrictions and without a therapist being present.

Criticism of the design concepts often concerned the lack of texture and the size of the objects. Sensory loss in the hands is a common symptom among stroke survivors and adding a rough texture offers more grip and allows retraining of the lost function (Carey, Macdonell, & Matyas, 2011).
Extending the hand, and especially the thumb, to the degree that most designs required was stated as being too challenging. Reducing the size and diameter was pointed out as a way to improve the designs.

During the evaluation, questions were raised concerning how the designs made the task easier. Everyday objects used by stroke survivors are often assistive devices to enable them to interact in their environment. The focus of this course was not to design assistive devices, but rather to generate designs that challenge the user and evoke a behaviour change that initiates the use of the affected arm and hand.

7. Conclusion

The findings of this study indicate that shaping aspects can be used to create everyday objects that encourage the initiation of use of the affected arm in stroke survivors. Feedback provided by stroke therapists shows that this study produced designs with a therapeutic value. The design outcomes need to be further tested with stroke survivors to validate the usability and efficacy of the designs and evaluate the behaviour change that they intend to evoke.

The design outcomes presented in this paper focus on industrial design solutions and do not employ any form of digital technology such as sensors or software applications. However, design solutions could potentially benefit from them. Further research focusing on these applications offers the potential to extend our proposed design strategies.

The strategies proposed in this paper need to be tested more extensively in order to be useful and inspirational for other designers. We are currently working on a set of design method cards that have the potential to be used by designers in a self-directed way to develop everyday objects for stroke survivors. Those objects aim to initiate the use of the affected arm and hand and have the potential to be used as part of a home-based and self-directed rehabilitation process.

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About the Authors:

**Author 1** Mailin’s research interest includes behaviour change techniques that are used in product design solutions to increase the user’s engagement as well as tangible interfaces in the context of medical devices.

**Author 2** Edgar leads the Smart Interactions Design team as an investigator in the Center of Research Excellence in Medical Technologies (CoRE MedTech). Smart Interactions Design investigates how to improve people’s medical conditions and management through smart devices connected to digital interfaces.

**Author 3** Brian’s research experience includes clinical pathophysiology. His current research interests include the design, safety and ergonomics of biomedical devices leading to the safe introduction new health technologies.

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