

## **Promoting clinical best practice in a user-centred design study of an upper limb rehabilitation robot**

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**Dr Kim Brock** is a clinical physiotherapist and researcher in the field of neurological rehabilitation. Kim has extensive experience in subacute care and currently provides physiotherapy services to the inpatient rehabilitation services at St Vincent's Hospital, Melbourne (SVHM). She is a qualified as an Advanced Instructor in the Bobath concept (International Bobath Instructor Training Association accredited) and teaches post graduate clinical courses nationally and internationally. Kim also holds the position of research co-ordinator for the physiotherapy department, inpatient rehabilitation and community rehabilitation services at SVHM. In this position, Kim has facilitated a wide range of research endeavours from clinical audits to randomized controlled trials. Kim's specific research interests in rehabilitation include efficacy of interventions based on the Bobath concept for stroke and multiple sclerosis, goal setting, access to rehabilitation and long term outcomes after stroke. To date, Kim has 24 publications in peer reviewed journals.

**Professor Mary Galea, AM, BAppSc (Physio), BA, PhD**, is a physiotherapist and neuroscientist whose research program includes both laboratory-based and clinical projects with the overall theme of control of voluntary movement by the brain, and factors that promote recovery following nervous system damage. Professor Galea is Professorial Fellow in the Department of Medicine (Royal Melbourne Hospital) at the University of Melbourne, and previously Foundation Professor of Clinical Physiotherapy at the University of Melbourne and Austin Health. Her current research program is concerned with investigating the health of peripheral nerves after spinal cord injury, the use of technology to drive recovery after stroke, and wearable sensors to measure rehabilitation outcomes.

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Despite their promise to increase therapy intensity in neurorehabilitation, robotic devices have not yet seen mainstream adoption. Whilst there are a number of contributing factors, it is obvious that the treating clinician should have a clear understanding of the objectives and limitations of robotic device use. This study sought to explore how devices can be developed to support a clinician in providing clinical best practice. A user-centred design study of a robotic device was conducted, involving build-then-use iterations, where successive iterations are built based on feedback from the use cycle. This work reports results of an analysis of qualitative and quantitative data describing the use of the robotic device in the clinical sessions, and from a focus group with the treating clinicians. The data indicated that use of the device did not result in patient goal-setting and may have resulted in poor movement quality. Therapists expected a higher level of autonomy from the robotic device, and this may have contributed to the above problems. These problems can and should be addressed through modification of both the study design and device to provide more explicit instructions to promote clinical best practice.

Keywords: neurorehabilitation; rehabilitation; upper limb; robotics; stroke; brain injury; user centred design

## 1. Introduction

With a growing and aging population, and the incidence of neurological injury, the demand for neurorehabilitation is constantly increasing [1]. A dissonance between how neurorehabilitation activities are designed, the amount of practice time required for meaningful recovery, and limitations in the availability of therapists and beds within healthcare systems have significant effects in the outcomes for these patients. This is particularly true for upper limb disability, with studies suggesting that between 55% and 75% of patients have limited functional recovery of the arm 3 to 6 months after stroke [2].

Over the last 25 years, robotic devices have been suggested as a potential partial solution to this problem, as their physical interaction with and support of the patient allows the completion of novel rehabilitation activities with the promise of increasing the

quantity of therapy provided. More than 120 upper limb devices have been developed [3], and recent reviews have concluded that these devices can be effective in improving patient outcomes with respect to their daily activities [4].

Despite their promise, robotic devices have still seen limited penetration into public and private health systems, as indicated by a 2011 survey [5], showing that only 6% of the 233 therapists who responded had used robotic devices in the past. Whilst the authors have not found any studies which investigate the reason for this limited adoption, it is clear that the current devices do not align with therapists' expectation of such devices as shown by this study.

This may be due to the differences in clinical practice among clinicians. Various approaches are used, including repetitive task practice, motor relearning approaches [6], constraint induced movement therapy (CIMT) [7], or neurodevelopmental technique (NDT) or Bobath therapy [8]. Furthermore, patient presentations are similarly varied, both in the underlying neurophysiological damage, but also in level of disability. Thus flexibility – under different clinical settings, conditions and approaches – is vital to the usability and adoption of robotic devices. However, the availability of too many options can lead to confusion and uncertainty amongst clinicians, patients and hospitals alike, leading to an unused (and ultimately, non-useful) device. This presents a challenge in the development of such devices, which must balance flexibility with simplicity of use. The present study is part of the EMU project, which aims to develop a clinically useful upper limb rehabilitation robotic device. To address the balance between flexibility and simplicity of use, the EMU project follows a user-centred design process. User-centred design involves the incremental development of a product, based on feedback of the device in use. Studies have indicated the suitability of user-centred or user-based design for robotic devices [9] [10]. These studies assert that this approach is important to ensure that the needs of the end-user are met, rather than just those of interest to academic or clinical audiences. This is particularly the case in applications such as rehabilitation robotics, which have many different people involved in their use and delivery including therapists, patients, carers, and other clinical staff.

In the field of upper limb rehabilitation robotic devices, despite the large number of devices which have been developed, few studies document a user-centred design process. Studies utilising surveys have provided a baseline set of desired requirements of a prospective device [5] [9]. These results can be used to inform the design choices and

features for an initial prototype, however, these studies lack data associated with the actual use of a device. The survey-based studies have thus been followed by those involving a prototype [11] [12]. The analysis in these studies focus on an evaluation of the technical aspects and features of the device, however, a key unexplored area is around how these devices are used within the context of the treatment itself. That is – how can robotic rehabilitation devices be used to assist with the delivery of therapy within existing treatment frameworks?

The initial prototype of the EMU robotic device [13] used in this work was deliberately designed with flexibility in mind, including options to allow the patient to use the device in a virtual (gaming) environment or with real objects; while sitting or standing; with a free hand or with a handle; and with several different physical interaction modalities. The aim of this first trial was to reduce the challenge associated with understanding and using these many options, by identifying the features of the device required to fit within clinicians' clinical practice; identifying how these features could be used; and assessing usability in real-world conditions.

The present work has been reported at the conclusion of a trial at the first of three study sites. This work details how engineers and clinicians can work together to develop technologies for clinical benefit, particularly in the field of rehabilitation robotics, through a description of the process used in the EMU study. The results discuss how both study and device design affected the use of the device with respect to clinical best practice and key aspects of usability. Finally, recommendations for the design of subsequent studies and, more generally, implementation of robotic-based therapies are presented.

## **2. Methods and Materials**

Within this section, the parent study, of which the present study is a subset, is introduced, followed by further details about the present study itself. Methods of data collection, processing and reporting are then described, followed by the EMU robotic device, with a focus on features particularly relevant for this study.

### ***A. The parent user-centred design study***

The study presented here is part of a larger user-centred design study, which aims to investigate and implement a device which is sensitive to the users' needs and desires through iterations of a build-then-use process. That is, once a prototype has been

constructed, it is used by the intended end users of the device, and then updated according to observations obtained during this use. The study was approved by the Melbourne Health Human Research Ethics Committee, Application Number 2018.067.

As a user-centred design study, the device and interface were modified throughout. Within the context of the presented results, most changes were minor – for example, moving the location of the button on the interface or changing the straps used to connect the patient to the device. Whenever more important modifications were introduced, such as a new function or modification of an existing function, they were introduced to the therapists prior to the session.

The device was scheduled to be available at the clinical site nominally 3 days per week during the study period. Patients were selected for inclusion in the study by their therapists, according to their own clinical judgement, with the inclusion criteria left deliberately broad to enable investigation of the use of the device by patients with a wide range of clinical presentations.

## ***B. Study Protocol***

Within the present work, the focus was on the therapists' use of the device. The overall protocol for the therapists can be seen in figureFigure 1. The key items of interest for this work are the Training Session, the Clinical Sessions and the Focus Group.



Figure 1 – Outline of the stages of the study in which the therapists are participants.

### *i) Training Session*

The training session was a 2-hour group training session. The device (described in section 2E) was presented to the therapists and the therapists were shown all functions on all available user interface screens at the time of the session. The therapists were then given the opportunity to act as both a mock patient (to experience the physical interaction modalities and exercises), and as a mock therapist (to gain practice at driving the interface). This training session was essential to enhance understanding of the

device's features and interactions, so that the therapists were aware of all options before deciding on how they would use the device for each patient.

### *ii) Clinical Sessions*

The robotic device was made available for use in clinical sessions at the clinic. During the sessions, the therapist was given free choice over the exercises that the patient completed, and the settings for those exercises. These settings included the type of physical interaction modality (for example, providing dewatering support, or physical assistance towards a target), and the strength of this modality (for example, the strength of the assistive force), the required speed of the movements, and the area in which the game was to be played (allowing the therapist to define the range of motion of the movements).

Each session involved a single physiotherapist or therapy assistant, mirroring standard therapy practice. At least one research engineer was always present during the use of the device. The engineer provided support for the therapist should it be requested and ensured that the device was operated within safe limits at all times. Examples of support included setup support, advice about the features of the device and assistance with driving the interface if the therapist was unable to locate a certain feature.

### *iii) Focus Group*

A focus group was conducted with the participating clinicians after 6 weeks of device use. The goal of the focus group was to learn more about how the therapists used the device and perceived barriers to the use of the device within their own clinical setting. Questions guiding the focus group discussion were developed using the theory of planned behaviour (TPB). The TPB provides important information on health professional behaviour and behavioural intentions and how these are influenced by attitudes, norms and perceived behavioural control [14]. This theoretical model has been used in many studies aiming to explore, understand and change health professional behaviour [15]. The focus group followed on from the pre- and post-study surveys, which were developed using the Technology Acceptance Measure [14]. The focus group questions were as follows:

- (1) How did you decide which patient was appropriate for the robotic device?
- (2) How did you decide on the game / activity to use with your patient(s)?



- (3) Did you have specific goals or objectives for each session you used the robot?  
What were they? Why?
- (4) What do you believe are the advantages of using robotic devices in rehabilitation of the upper limb?
- (5) What do you believe are the disadvantages of using robotic devices in rehabilitation of the upper limb?
- (6) Are there any individual or groups who would approve of, or encourage your use of robotic devices in rehabilitation of the upper limb?
- (7) Are there any individuals or groups who would disapprove of, or discourage your use of robotic devices in rehabilitation of the upper limb?
- (8) What factors or circumstances make it easier to use robotic devices in your clinical practice?
- (9) What factors or circumstances make it difficult for you to use robotic devices in your clinical practice?

### ***C. Data Collection***

The results reported here leverage data collected in two parts of the study – first, data collected about the patient demographics, correlated with data from each individual session with the patients; and second, data collected from the focus group at the completion of the study at the first site.

Patient demographic data (Table 1) were collected by the treating clinician, based on their clinical assessment of the patient.

Table 1. Patient Demographic Data

<b>Goal</b>	<b>Measure</b>
Demographic	Age, Sex, Diagnosis, Affected Side
Nature of Impairment(s)	Communication, Cognition, Perception, Emotion/Behavioural or Vision
Movement Capability	WHODAS 2.0, Motor Assessment Scale (MAS)

Therapy session data (Table 2) were derived in two ways. Data describing device usability were collected by the robotic device during the sessions. Observational data were collected by the research engineers present at each of the sessions and entered during the session in a Microsoft Excel Spreadsheet.

Table 2. Therapy Session Data

Goal	Measure
Device usability	Setup Time, Device Practice Time, Number of movement repetitions
Observations	Device Configurations and length of time used, Device Activities, Informal clinician feedback

The focus group was facilitated by a researcher who had not been involved in the trials but did have knowledge of the features of the robotic device. The focus group was audio-recorded.

#### ***D. Data Analysis and Reporting***

Observations from each session were collated within a database and exported to a text file. The recording from the focus group was transcribed using an online transcription service (Rev). The transcript was reviewed by the authors for accuracy. Both sets of data were then entered into a web-based qualitative analysis tool (SaturateApp) and codified using a thematic analysis approach – a common technique used “for identifying, analysing, and reporting patterns (themes) within data” [15]. Results are presented with respect to these themes and supplemented with statistics generated from the numeric data collected from the therapy sessions.

#### ***E. The EMU Robotic Device***

This project describes the development of a robotic device for upper limb rehabilitation. For clarity, this is defined as a device which can be programmed to apply forces to a patient’s upper limb, which can be determined either automatically through software, or by specific instruction from the user. It is specifically noted that this differs from other types of technology, such as those which act as sensors only – e.g. AbleX (ableX healthcare Limited, New Zealand), Saebo ReJoyce (Saebo Inc., USA) - or those which provide non-programmable forces - e.g. ArmeoSpring (Hocoma, Switzerland), SaeboMAS (Saebo Inc., USA). Robotic devices are capable of physically interacting with the patient in different ways, such as providing varying levels of deweighting support,

providing physical assistance for movements towards a goal or target, or resisting the patients' movements.

The EMU device (Figure Figure 2) is an upper limb rehabilitation robotic device. It is an end-effector based device – that is, it is attached to the patient at only a single location along the forearm (usually close to the wrist). The device allows translational movement in three dimensions (up/down, forward/back, left/right), and can apply forces in these dimensions – including forces to passively mobilise the patient's limb, deweight the limb, or resist limb movement. In the prototypes used within this study, the forearm was also free to rotate. Thus, the device is unable to assist or resist movement rotation at the wrist. EMU also does not constrain the hand, allowing it to be used to interact with real objects, or to be manipulated by a therapist during exercises with patients (see figure Figure 3).



Figure 2 - The EMU robotic device with a patient (left) and therapist (right)



Figure 3 - EMU does not constrain the hand, allowing interaction with the touch screen or real-world objects.

The system consists of the robotic device itself, and a computer which acts as a user interface, to start, stop and configure the robotic device, as well as to display a user interface during the exercises through gamification. In the case of the device used in this study, the computer screen was a touch screen, so a keyboard and mouse were not required (by either therapist or patient).

The remainder of this subsection details two key features of the EMU robotic device, which were of particular relevance to the results reported in this work: the physical interaction modalities, and the touch screen gaming interface.

#### *i) Physical interaction modalities*

The first feature is the availability of different physical interaction modalities – that is, different ways in which the robotic device can apply forces to the patient. This flexibility in the interaction of the device is important to ensure it can respond to the variability of patient presentations and clinician practices. The EMU device was able to interact with the following different physical modalities (see also figure Figure 4):

**Deweighting** – where a constant upwards force was applied equal to a user-specified percentage of the weight of the patient’s arm<sup>1</sup>

**Passive Mobilisation** – where the device moves the patient’s arm along a predefined trajectory – either by following a clinician’s demonstration or towards a target on a screen.

**Tunnel** – where the device restricts (guides) the movement of the patient along a predefined path but does not assist the patient’s arm along the path.

**Shaping** – where the device only allows movement in the direction of the forearm.

**Resistance** – where the device provides resistance to the movement of the patient.

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<sup>1</sup> Note that the deweighting force differs from the one introduced in [24] as no additional sensors were employed

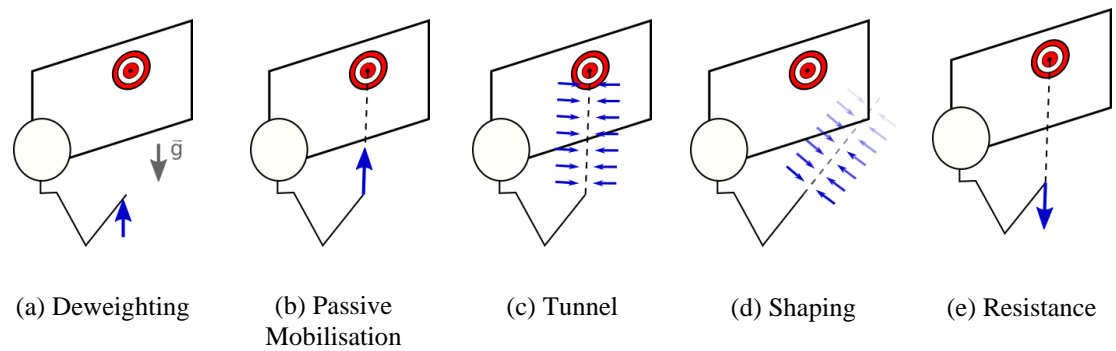


Figure 4 – Representation of different interaction modalities available on the EMU robot. Blue arrows represent the forces provided by the robot, dashed lines represent the direction of the movement of the hand.

Some or all of these modalities were available for use in two modes – *Exercise with Objects* and *Exercise with Screen*. Exercise with Objects was designed to be used with real-world objects on table tops, with the robot being ‘trained’ to know where the objects were. Exercise with Screen was designed such that the patient interacted with the touch screen. Games included reaching to a target on the screen – Reaching Target (repeating a sequence of lights on the screen by touching the lights in sequence), Memory, and Distal Tracking (tracing a path from one position on the screen to the other, whilst maintaining contact with the screen).

#### ii) Touch screen gaming interface

The second key feature is the use of a touch screen as the primary method of interaction with the virtual environment.

Touch screens have been used as rehabilitation devices in past – commercially available examples include the Myro (TyroMotion, Netherlands), and the Retouch (Rehabtronics, Canada). Touch screen-only rehabilitation devices are large devices, designed for use without robotic support. As such, they are designed for use with patients who have voluntary movement of their upper limbs, and thus do not need the physical support or assistance of a robotic device.

However, the use of the touch screen interface has not been employed in conjunction with robotic rehabilitation devices to the knowledge of the authors. Most existing robotic devices utilise a virtual environment which is presented on a computer screen. This environment maps the position or orientation of the patient’s hand or arm into the virtual space, which is then presented on the computer screen (see figure Figure

5). However, it is noted that this places additional burden on the patient's visuomotor loop, as they must make an additional association between the virtual space, and the physical space [16].

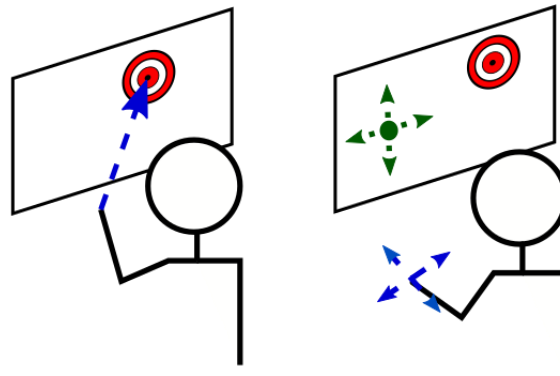


Figure 5 – Interaction in the physical space with a touch screen (left) versus interaction in a virtual space (right). Note that when a goal is presented in the physical space, the patient moves his hand directly to that goal. If a goal is presented in the virtual space, the patient must first identify what hand movement will achieve that goal, and then execute it.

The EMU was designed such that the patient's hand is unconstrained. This design choice facilitates use of either a touch screen or real-world, 'task-based exercises', which aligns with clinical guidelines from the Stroke Foundation (Australia) on rehabilitation exercises [17].

#### 4. Results

Seven patients provided consent to participate in the study. Their diagnoses were Acquired Brain Injury (N = 5), Spinal Cord Injury (N = 1) and Chronic Inflammatory Demyelinating Polyneuropathy (N = 1). These patients ranged in age from 29 to 76 years, and had Motor Assessment Scores (MAS) in the range of 4 to 26, and WHODAS 2.0 Scores of 28 to 51.

A total of 33 clinical sessions were completed, with an average of 20 minutes per session (range 15 to 30 minutes) for 14 minutes of active practice (range 8 to 23 minutes).

##### *A. Choice of Robotic Device Functionality and Purpose*

The Reaching Target game was used during the majority of the sessions (30 out of 33) whereas the Memory activity was used during 10 sessions and the Distal Tracking game was used in only 3. The games were used primarily with the Passive Mobilisation physical

interaction modality (50% of the activity time), followed by the Deweighting (40%) and the Resistive (7%) modes, whereas the other modes were marginally used (Tunnel: 2% and Shaping: 1%). It is noted that the Shaping functionality was only introduced after 27 sessions. The use of only three interaction modalities was surprising, given the large variety in different patient presentations.

Despite the availability of the *Exercise with Objects* functionality, it was also observed that the robotic device was used exclusively in the *Exercise with Screen* mode. This suggested that the interactive games presented on the screen were an important feature in the use of the device. This was confirmed by the therapists in the focus group, who noted that for some patients, “*engagement*” was a key objective for the session. This aligns with the common suggestion that entertainment and motivation is an important benefit of technology-enabled rehabilitation [18].

The focus group data also suggested a range of different approaches taken to decide which features were used for each patient. Due to the limited number of games, most patients were simply asked to do exercises that the therapist felt were at a suitable level:

*It was nice movement she was able to get throughout her whole arm with that one, so that was a good game for her.*

Others chose not to do games that were too challenging for their patients – “*It was too frustrating for him, so we didn’t do it*”, indicating again the importance placed on patient engagement and success for motivation.

However, it was also evident that some decisions regarding the use of the device did not follow standard clinical care:

*I’d normally go into my therapy with a clearer plan of what I wanted to achieve.*

This aligns with observations during the sessions themselves – in which the device was not significantly adjusted from its default location, apart from bringing the targets to within reach of the patient. As such, it was not clear that the sessions with the robotic device were made with a specific goal in mind. It was noted in the focus group, however, that the therapist considered their choice more clearly when presented with questions about what they would change about the device:

*That also made us perhaps think about that question, what is the goal of this session?*

### ***B. Movement Quality***

A key concern around the use of novel rehabilitation therapies, and especially robotics, is the quality of the movement that the patient performs. The arrangement of an end-effector based device in conjunction with a touch screen is unique to the EMU, and thus the effects of this arrangement on movement quality were of significant interest in this study.

As an end-effector device, the EMU did not constrain the movement patterns of the patients, and thus cannot physically enforce nor prevent any poor-quality movement patterns such as the typical flexion synergy [19]. This led to some patients performing poor quality movements, including movements with poor trunk posture and utilising this poor flexion synergy.

Observations during the sessions also suggested that the use of the touch screen contributed to poor quality movements – particularly amongst patients with high muscle tone:

*The high tone was a concern because we were worried about trying to get a good movement pattern.*

These conditions made it extremely difficult or impossible for the patients to interact with the touch screen using the tip of their index finger, as they were not able to achieve sufficient finger extension. Therapists resolved this by supporting the hand, facilitating the touch with their own hands whilst the device supported the weight of the arm. In some cases, they were able to use their knuckles to touch the screen, but a more common solution was the use of a touch screen stylus – either placed between the fingers, or through use with various holders (see Figure Figure 6).

Further, even with the use of the stylus and the holders, some patients were unable to achieve sufficient wrist extension for their hand to be in a functional position:

*Trying to get the hand in a functional position [was difficult] 'cause I didn't think there'd be much point in us practicing reaching without a functional hand. We did it anyway... It went better than I expected.*



In these cases, therapists again assisted with movement facilitation.

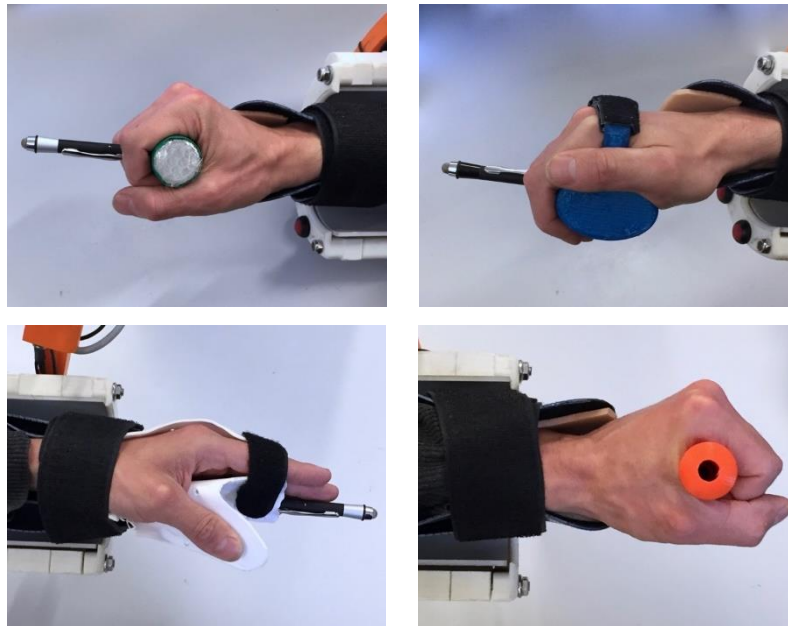


Figure 6 - Touch screen stylus solutions, including grasped holders, a splint, and a handle (for games which do not require touching the screen).

### ***C. Preconceived Ideas of Robotic Device Use***

The focus group revealed that the therapists had preconceived ideas about how the robotic device should be incorporated into their practice. Specifically, the therapists believed that it would be useful for mass repetition, noting that their belief the device would allow “*the hours and repetition that you can’t, as a therapist, physically put in*”.

However, it was also clear that the therapists had different perceptions as to how the device could be used, with a number of comments such as “*someone needed to be there the whole session to really assist it*” and noting that some patients “*required quite a lot of facilitation from a therapist or therapy assistant*”. These comments suggest that the therapist expected that the device would be capable of running more autonomously compared to the eventuated use in this study.

It is noted that within this study, some therapists elected to use the device as an adjunct tool within their own one-to-one sessions, where both the device and the therapist physically engaged with the patient. This was conveyed by one therapist - “*deweighting ability is really nice, because then you can just focus more on how they're moving*”. The

observational therapy session data indicated that this dual-contact arrangement was the case in half (50%) of the sessions.

#### ***D. Engineering Support***

A final key theme that emerged from the data was that of support from the engineers involved in the development of the device, and how this affected the use of the device. This support was provided fundamentally in two ways – support during the session itself, and changes to the device as a result of feedback from the therapist.

The therapists felt that support during the sessions from the engineers was vital for the success of the study:

*I do not think it would've been as successful without the support of the engineers ... having a chance to chat with them and them having to explain things, and to try to do it yourself, and then have them chip in very really helpful.*

Such support was required throughout the study – especially with respect to resolving issues around usability. Commonly-encountered issues included setting up the patient's arm within a functional posture within the cradle, calibrating the 'activity' area on the touch screen, the non-responsiveness of the touch screen, and the patient's hand obscuring vision of the target on the touch screen. The engineers in these cases were engaged to resolve these issues during the session, or propose and implement other solutions for future sessions (such as in the creation of the stylus holders).

This level of support provided the therapists freedom to attempt more. Furthermore, the therapists believed that the availability of engineering support for the adoption of the device was vital, *"I had a manual, I would've felt overwhelmed, but having a chance to chat with them and them having to explain things, and to try and do it yourself, and then have them chip in was really helpful."*

## **5. Discussion and Recommendations**

### ***A. Promoting Clinical Best Practice in the Development of Robotic Devices***

A reduced level of therapist involvement – allowing patients to get the mass repetitions required for cortical change – is often touted as one of the major advantages of having robotic therapy aides. Whilst this is certainly true, it is important the devices themselves

are developed to ensure that the mass repetitions performed are meaningful and promote recovery.

It is clear from the results of this study that these devices can be useful as tools within one-on-one clinical sessions – promoting engagement and/or augmenting the physical support from a therapist, while still promoting mass repetitions. Targeting these one-on-one sessions early in the development of therapy tools is important to ensure that such tools are usable within a clinical context and are used to facilitate clinical best practices. Within this study, two aspects were of concern – the choice of exercise activity, and the quality of the execution of the exercise activity.

#### *i) Exercise Activity*

Clinical guidelines suggest that rehabilitation should be driven by *goals*, which lead the identification of useful activities or exercises to be performed [17]. Within this study, it was not clear when the activities performed with the robotic device were made towards a specific goal. Although the selection of exercises in this prototype device was limited, the use of the device could be customised towards patient's individual goals. This customisation could occur through options including moving the touch screen to different locations or orientations to encourage reaching in the external direction, or movements against gravity. These options were not often used by the therapists. A contributing factor to this choice is likely to be the lack of familiarity with the exercises, and the comfort taken by choosing a 'safe' option which the therapist was confident that the patients could achieve. This course of action is important to ensure patient engagement but may not be the optimal exercise choice for the patients' recovery.

The study design could be adjusted to explicitly enforce these guidelines – for example, the protocol could be adjusted to incorporate a goal-setting session at the beginning of the patients' sessions including discussions about how this goal could be achieved. Further education around how the device can be used, and how its use can be customised may also help promote therapists' understanding of what activities can be completed using the device and promote exploration of different concepts.

It is also noted that the idea of robotic devices providing 'automated therapy' may also have hindered exploration in these devices – and thus have been counter-productive to the goals of the user-centred design process. From the focus group discussion, it was clear that the expectation was that the device was designed to be used in an unsupervised

or semi-supervised state. This may also have led to a belief that, although the device was a prototype device, all available options were available on the screen. In future studies, this may be addressed by being more explicit about this fact within the device's user interface.

### *ii) Quality of Execution*

As discussed in section 4B, the movement quality was a key concern amongst the therapists within this study. Ensuring good movement quality is a complex task and has been identified as a key area of interest in the development and use of robotic devices – even measuring the movement quality is seen as a very difficult task with current devices [20]. This was also the case in this study – the prototype device used within this study, did not have an automated way of monitoring the quality of the patients' movements. The Tunnel and Shaping interaction modalities were designed to encourage better quality movements, however, these were rarely used – indicating that these modalities were either ineffective at promoting good quality movements, or the therapists did not believe that they were suitable for the patients.

Therefore, a focus on one-on-one therapy for this study again presents itself as a potential approach for investigating how appropriate movement quality can be encouraged. This may be achieved through two means – first, observing how therapists encourage good movement quality given the present state of the device, and investigating methods of automating this within the device. A second option may be to investigate how the therapist chooses and sets up exercises to enforce a good movement pattern and including that as an instruction for the therapist. It is likely, given the difficulties in measuring movement quality, that a combination of these two approaches would be required. However, again, making this more explicit within the protocol and instructions of device use may lead to acceleration of these outcomes, and simultaneously lead to better movement quality practice during the study itself.

## ***B. Device Usability***

Of importance within this work is the arrangement of the end-effector based robotic device with a touch screen, and its usability with patients of varying capabilities. Within this study, it was observed that the device was usable with all patients who were selected to participate. It is noted that the treating therapists selected patients they thought would

benefit from the use of the device, and thus some selection bias may be present. Nevertheless, the device appeared appropriate for patients with both extremely limited upper limb movement capabilities and those with advanced capabilities (as indicated by their WHODAS 2.0 and MAS scores).

The major difficulty was the use of the touch screen – particularly for patients who had limited distal functionality. These cases required significant manual facilitation in addition to the robotic device to ensure a functional posture and good movement quality. There are a number of possible solutions to the issues encountered with the use of the touch screen. First, the inclusion of a *no-touch* mode, in which a ‘touch’ is registered when the patient moves close to the relevant point on the screen. This maintains the simplified visuomotor loop but reduces the need for distal function to achieve a successful reach. Secondly, within this work, the screen was always positioned in a vertical orientation (like a standard monitor). The screen may be positioned horizontally (like a table top), which may also make the reaching movement more relevant for daily activities (such as reaching for a cup on a table). Thirdly, instrumented objects with pressure-sensitive materials [21] may provide a more sensitive interaction, again with more relevance to activities of daily living.

## **6. Conclusion**

This work has presented interim results of a user-centred design study for an upper limb rehabilitation robotic device. After the initial portion of the study, it can be concluded that greater care should be taken to ensure that the prototypes are designed to promote clinical best practice and that the mass repetitions performed using the finalised design are optimal for patient recovery. However, the study demonstrated that the arrangement of an end effector robotic device had promise, particularly across the range of patients that used the device in the study. Furthermore, it is important to note that the paradigm of fully automated therapy using robotic devices can and should be challenged, particularly in the design stage of rehabilitation robotic devices and that an emphasis on therapists training regarding these devices is critical.

## Declaration of Interest Statement

In accordance with Taylor & Francis policy and our ethical obligations researchers, the authors report that the EMU device used in this trial is the subject of a patent application, currently lodged with the Australian Patent Office under application 2018/050515.

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