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ORIGINAL REPORT

IMPLEMENTATION OF A TECHNOLOGY-ASSISTED PROGRAMME TO INTENSIFY UPPER LIMB REHABILITATION IN NEUROLOGICALLY IMPAIRED PARTICIPANTS: A PROSPECTIVE STUDY

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Objective: **To evaluate the implementation of a technology-assisted programme to intensify upper limb rehabilitation after stroke and other neurological conditions in an Australian community cohort.**

Methods: **A "Hand Hub" was established in a tertiary hospital. Intervention was delivered via individual or group sessions for a period of up to 6 weeks, in addition to the patients' regular therapy. Patients were assessed before and after the programme using validated measures.**

Results: **A total of 92 participants completed both assessments (mean age 57 years (standard deviation 17 years), 58% male and 88% with stroke). Post-intervention, participants showed significant improvement in arm function and strength ($p<0.001$, effect sizes (r) = 0.5–0.7), streamlined Wolf Motor Function Test score ($p<0.05$, r = 0.2–0.4), improved muscle tone on the Modified Ashworth Scale ($p<0.001$, r = 0.4), Functional Independence Measure (locomotion, mobility and psychosocial subscales ($p<0.05$, r = 0.2–0.3). Quality of life (EQ-5D) and overall health also improved significantly ($p<0.01$ for all, r = 0.3–0.6).**

Conclusion: **The "Hand Hub" programme is feasible and showed promising results for upper limb function in persons with neurological disorders. The findings need to be further confirmed in a larger study sample, with a longer follow-up.**

Key words: rehabilitation; function; upper limb; participation; quality of life.

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INTRODUCTION

Functional recovery of the paretic upper limb after stroke continues to be a significant challenge faced by rehabilitation professionals. Although most patients regain walking ability, 30–60% of stroke survivors fail to regain functional use of their arm and hand (1). Deficits in upper limb function also occur in other neurological conditions, such as multiple sclerosis (2, 3) and traumatic brain injury (4). In stroke survivors deemed to have recovered by traditional standards, the long-term stroke-related disability remains under-estimated (5). Persisting upper limb activity limitations negatively impact upon patients' ability to engage in domestic, leisure and vocational activities, placing considerable burden on informal caregivers (6) and support agencies (7).

Appropriate rehabilitation involving use of the paralysed limbs induces re-organization of the undamaged cortical areas and leads to functional recovery (8). Animal studies have shown that task-specific and repetitive exercise are key factors in promoting synaptogenesis and are central elements in rehabilitation of motor weakness following stroke (9). Clinical interventions for the paretic upper limb that have the strongest evidence share a common emphasis on task-specific training applied with a higher intensity than usual care (10–14). Skill acquisition and transfer of skills to other activities have been shown to be more effectively achieved with the incorporation of context-relevant task-specific meaningful activities compared with rote exercise or passive modalities (15).

In order to improve the upper limb outcomes following stroke or any other neurological insults, and to maximize the patients' time in inpatient rehabilitation, the amount of practice of arm and hand activities needs to be increased. In practice, rehabilitation of the arm is frequently given a lower priority than training of walking (16). After discharge, there are few opportunities for patients to continue rehabilitation for their impaired upper limb. Despite the published clinical guidelines (17, 18), it is clear that the current practice for upper limb rehabilitation is not adequate to drive the neural reorganization needed to promote functional improvement (19). Without attention to this matter, poor recovery of arm function after stroke or other neurological condition becomes a self-fulfilling prophecy. However, there are major barriers associated with addressing this evidence-practice gap, including limited rehabilitation resources, time constraints, difficulties with travel to rehabilitation facilities, adherence to exercise

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programmes, and, for the more severely impaired patient, the need for external assistance or guidance.

We adopted a Plan-Do-Study-Act approach (20) to address the evidence-practice gap. First, we identified that technological advances could provide a potential solution. In recent years, several relatively inexpensive devices have been developed that utilize computer games to motivate and encourage patients with upper limb impairments to move their affected arm (21, 22). Trials of such devices in the clinic and in home settings have shown that they can have positive effects on patients' function (23). Testing the concept of making a range of devices available to stroke patients in an "Arm Studio" to increase the intensity of arm rehabilitation, showed that this concept may be more effective than additional individual physiotherapy sessions (24).

Secondly, in order to encourage referral and streamlining of the management of patients with upper limb dysfunction, an Upper Limb Clinic was established in the Royal Melbourne Hospital (RMH), a tertiary referral centre in Victoria, Australia. Thirdly, the "Hand Hub" was created to harness the use of technology as a means to provide a low-cost way of enabling additional practice/exercise of the affected upper limb to maximize recovery of function in patients with neurological conditions. Small iterative trials of the Upper Limb Clinic and Hand Hub were undertaken to refine the referral methods and the practical management and staffing of the Hand Hub. The aim of this study was to evaluate the feasibility and effectiveness of the Hand Hub programme for people following neurological insults (stroke, multiple sclerosis, benign brain tumour) to improve their access to rehabilitation services and enhance arm function.

METHODS

Design

This study was a prospective observational cohort study using a clinical practice improvement approach (CPI) approach (25), which acquires prospective data without disrupting the natural milieu of treatment. This method allowed inclusion of heterogeneous groups of patients, as well as collection of treatment and outcome data. It also allowed investigation of the implementation under real world conditions, reflecting the full range of patients and clinicians who would be using the Hand Hub.

Settings and participants

This study was conducted as part of the rehabilitation outcomes research programme at the RMH. All patients with upper limb dysfunction resulting from neurological conditions referred for rehabilitation from public and private medical clinics across Greater Melbourne in Victoria were invited to participate in this study. The inclusion criteria were: aged over 18 years and fulfilled standard diagnostic criteria for the neurological conditions (stroke, multiple sclerosis (MS), brain tumours); assessed by a rehabilitation physician at the centre for upper limb impairments and potential benefits of the programme, and able to communicate in English. Those with expressive dysphasia were included if they were consistently able to follow therapist instructions. Inclusion criteria were deliberately kept broad in order to maximize generalizability and external validity (25). Patients were excluded if they were medically unstable or unable to travel to the centre for the programme, or if they had significant musculo-tendinous or bony restrictions or severe spasticity, significant co-morbidities (end-stage cardiac failure etc), severe cognitive deficits, or severe receptive dysphasia.

All eligible patients were invited to participate in the study by an independent project officer and those providing signed consent were recruited. *A priori* compliance was set at 80% attendance in the Hand Hub Clinic. The participants were informed that it could take up to 2–3 months before they received a programme, consistent with usual practice. Such a wait time is necessary due to operational issues within a publicly funded hospital (and limited resources) involved in providing the programme to a number of patients at the same time.

The study was approved by the Melbourne Health Human Research Ethics Committee (Project 2013.144) and informed consent was obtained from all participants.

Intervention

The Hand Hub comprised several workstations of relatively inexpensive machines, which can facilitate activities that are appropriate for patients with varying levels of severity of arm and hand impairment (Box 1). The Hand Hub was medically supervised and staffed by an occupational therapist (OT) and/or OT assistant. Treatment was provided in a group setting with 5 participants per group. The programme comprised up to 60 min of arm and hand training using the device prescribed by the OT, at least 3 times per week for a period of 6 weeks (18 sessions). Based on the individual requirements, treatment focused on all upper limb functions including reaching in different directions, pronation/supination, and grasp and release. The graduated difficulty of the 3 exercise devices (Box 1) enabled severely affected patients to move from the table-top device (Able-M) through the Able-X to the ReJoyce workstation as their function improved. In those with poor motor function, the focus of treatment was on shoulder activity through the use of the Able-M device on the table-top. Once some antigravity movement was present, participants progressed to the use of the Able-X. Participants with moderate levels of function undertook activities on the ReJoyce workstation, which was particularly useful for practice of various forms of grasping. The tasks and repetitions were recorded by the game software programme. Participants practised the tasks independently, with some guidance from the therapist or assistant when necessary. Any other therapy received was recorded on a standardized case report form following consultation with the therapists involved.

Outcome measures

This study used a repeated measures design, and each patient was assessed at baseline (T0) and at the completion of the programme (T1). All interviews and assessments (30 min each) were conducted using a structured format by 2 independent trained physicians and 2 OTs (in the clinic), who received 3 half-day training sessions in cognitive and functional ability assessments. The assessors were not in contact with any of the treating team, did not share information about participants or assessments, and received separate and different clinical record forms at each interview. The assessors did not prompt patients, but provided assistance for those who had difficulty with completing the

Box 1. Equipment

1. The ReJoyce workstation, a spring-loaded arm with a manipulandum assembly comprising 2 horizontal handles, a pressure gripper, a doorknob, a key, a peg, a jar top, and 2 coin simulators, allowing for simulation of many tasks of daily living (Rehabtronics Inc., Edmonton, Canada).
2. The Able-X arm exerciser, a lightweight air mouse and handlebar for those able to lift their arm against gravity (Im-Able, Auckland, New Zealand).
3. The Able-M, a tool for enabling table-top exercise for those with limited arm function (Im-Able, Auckland, New Zealand).

questionnaires. Appropriate rest breaks were provided during these sessions. All assessments were secured and filed, and opened at the time of entry into the database by an independent project officer. Data collected included: patient-related variables (demographic and medical information, perceptual, motor planning, and/or cognitive deficits) and functional ability assessment and health-related quality of life (QoL) measures using standardized instruments.

Measures of upper limb activity. A streamlined version of the *Wolf Motor Function Test (sWFMT)* (26) was used to measure functional tasks according to time for completion. This version comprised 6 of the original 17 functional tasks (extend elbow, hand to box, lift can, lift pencil, turn-key in lock and fold towel) that had shown the best correlation with improvement in a study of arm rehabilitation after stroke (27). This version of the test has been separately tested for reliability and construct validity (28), and was more practical to use in the clinical setting.

Maximal *grip and pinch strength* (29) was measured with standard grip and pinch dynamometers (Jamar, Asimow Engineering Co., Lafayette, IN, USA) using validated protocols.

The *Arm Activity Measure (ArmA)* (30) assessed passive and active functional arm movement. It comprised a 7-item passive function subscale (range 0–28) and 13-item active function subscale (range 0–52).

The *Modified Ashworth Scale (MAS)* (31), a 6-item scale, evaluated the degree of upper limb spasticity.

Secondary measures

The *Depression, Anxiety Stress Scale (DASS)* (32), a 21-item instrument comprising 3 7-item self-report scales, measured the negative emotional states of depression, anxiety and stress.

The *Euro-Quality of life (EQ-5D)* (33) rated 5 health dimensions: mobility, self-care, daily activity, pain/discomfort, and anxiety/depression. An index-based summary score for the EQ-5D was generated using a published crosswalk algorithm, which provides index-based scores ranging from –0.594 to 1.0 in the UK population, with lower values signifying worse health (34, 35).

The *Functional Independence Measure (FIM)* (36) comprising 18 items (13-item motor scale and 5-item cognition scale) was used to assess function (activity) and need for assistance in 5 subscales: Self-care, Transfers, Locomotion, Sphincter control and Cognition.

Statistical analyses and sample size considerations

Descriptive statistics were generated for each of the measures used. Sixty-three participants were required to detect a minimal clinically important change (MCID) of 1.1 points on the active function subscale of the ArmA, with alpha of 0.05, 80% power and accounting for a 20% drop-out rate. A similar number is required to detect a MCID of 4 points on the change in DASS subscale scores. Additional analyses were conducted on the subscale scores of ArmA, sWMFT, MAS, DASS, FIM and EQ-5D. Given the skewed distribution, primary analyses were conducted using non-parametric tests (Wilcoxon signed-rank tests), comparing the post-treatment scores with the baseline scores. Effect size statistics (r) were calculated and assessed against Cohen's criteria (0.1 = small, 0.3 = moderate, 0.5 = large effect) (37). A "complete case" approach was used with only those participants who provided information at both time-points included in the final analyses. All data were entered twice to avoid errors on data entry and Statistical Package for Social Sciences (SPSS), v. 22.0 (SPSS Inc., Chicago, IL, USA) was used for analysis.

RESULTS

A total of 92 patients with various neurological disorders completed both baseline (T0) and post-intervention (T1) assessments. Three participants did not comply with the treatment protocol and were not able to complete the post-intervention assessment (T1), two discontinued as a result of progressive disease, and one relocated to another state). There was 97% compliance with the treatment programme, as per the *a priori* compliance definition. No adverse effects were reported.

Participant characteristics

The socio-demographic and disease characteristics of study participants are shown in Table I. The mean age of the participants was 57 years (standard deviation (SD) 17) (range 19–89 years), the majority were male (58%) and married (81%). Over three-quarters (88%) had stroke, 7% had MS and 2 (2%) had brain tumours. The majority of participants (90%) were referred to the programme from the hospital outpatient clinics. Surprisingly, 35% of the participants reported having had any form of inpatient rehabilitation in the past and only 48% had some form of outpatient rehabilitation. Thirty-seven percent had high blood pressure and 40% were currently on medication. Thirty-nine percent reported mood problems and

Table I. *Demographic characteristics (*n = *92)*

Characteristics	
Age, years, mean (SD) [range]	55.6 (16.9) [18.5–88.8]
Sex, male	53 (57.6)
NESB, *n* (%)	11 (12.0)
Diagnosis, *n* (%)	
Acquired brain injury (stroke)	81 (88.4)
Multiple sclerosis	6 (6.5)
Brain tumours	2 (2.2)
Referral source, *n* (%)	
Outpatient	83 (90.2)
Inpatient	7 (7.6)
Others (GP)	2 (2.2)
Inpatient rehabilitation, *n* (%)	32 (34.8)
Outpatient rehabilitation, *n* (%)	44 (47.8)
Aetiology (*n* = 77), *n* (%)	
Trauma	7 (9.1)
Vascular	45 (58.4)
Comorbidities, *n* (%)	21 (69.6)
Hypertension	34 (37.0)
Diabetes	4 (4.3)
Depression	3 (3.3)
On medication, *n* (%)	37 (40.2)
Independent transfers, *n* (%)	46 (50.0)
Gait aid, *n* (%)	20 (21.7)
Symptoms, *n* (%)	
Expressive dysphasia	24 (26.1)
Hearing problem	5 (5.4)
Attention deficit	26 (28.39)
Memory deficit	28 (30.4)
Executive function	22 (23.9)
Perception	29 (31.5)
Dyspraxia	4 (4.3)
Emotional issues	34 (37.0)
Mood problem	36 (39.1)
Fatigue	32 (34.8)
Pain	26 (28.3)
Vision	17 (18.5)
Falls risk	14 (15.3)

NESB: non-English speaking background; GP: general practitioner; SD: standard deviation.

37% reported high levels of emotional issues. Furthermore, 28% reported pain, 35% fatigue and 19% visual impairments.

Outcome measurements change scores

Summary data for all outcome measures at different time periods are provided in Table II. At the post-intervention assessment (T1), participants showed significant improvement in arm function and strength in all ArmA items: "caring for the affected arm", "completing tasks/activities", "impact on participation" and "symptoms" ($p < 0.001$ for all) with large effect sizes (r = 0.5–0.7). There were significant improvements in overall muscle tone in all muscles measured, according to the MAS data: total ($p < 0.001$, r = 0.4), shoulder abductors ($p < 0.001$, r = 0.4), elbow flexors ($p = 0.003$, r = 0.3), forearm pronators, wrist flexors and finger flexors ($p = 0.001$ for all, r = 0.3–0.4). There was also improvement in sWMFT scores post-intervention in all 6 functional tasks ($p < 0.05$ for all) with low to moderate effect sizes (r = 0.2 to 0.4); however, time improvements were only significant for "extend elbow" ($p = 0.043$, r = 0.2) and "lift pencil" ($p = 0.023$, r = 0.3) tasks. Similarly, both grip and pinch force improved post-intervention in most participants (Table III).

As shown in Table II, there was significant improvement in FIM "locomotion" ($p = 0.035$, r = 0.2)) and mobility ($p = 0.006$, r = 0.3) and "psychosocial" ($p = 0.003$, r = 0.3) subscales. The QoL and overall health of the participants post-intervention improved significantly (EQ-5D and overall health scores) ($p < 0.01$ for all), with moderate to large effect sizes (r = 0.3 to 0.6). There were no significant, short-term effects on other measures.

DISCUSSION

To our knowledge this is the first report of the implementation of an upper limb rehabilitation programme using computer-based technology in a heterogeneous group of patients with neurological insults in an Australian community cohort. The findings from this prospective study demonstrate the feasi-

Table II. *Change scores in subscales for measurement scales overtime*

Scales	T0 Baseline Median (IQR)	T1 Post-intervention Median (IQR)	z score[a]	*p*-value	Effect size[b]
ArmA (*n* = 88)					
Caring for affected arm	9 (5, 15)	3 (1, 7)	–6.43	**<0.000**	0.7
Completing tasks/activities	44 (32.3, 48)	30.5 (13.3, 44)	–6.63	**<0.001**	0.7
Impact on participation	6 (5, 8)	4 (2, 6)	–6.33	**<0.001**	0.7
Symptoms	9 (6.3, 12)	6 (3.3, 9)	–5.15	**<0.001**	0.5
MAS (*n* = 92)					
Shoulder – adductors	2 (0, 3)	1 (0, 2)	–3.96	**<0.001**	0.4
Elbow – flexors	2 (1, 3)	1 (0, 2)	–2.86	**0.003**	0.3
Fore arm – pronators	2 (1, 3)	1 (0, 2)	–3.65	**0.001**	0.4
Wrist – flexors	2 (0, 3)	1 (0, 2)	–3.25	**0.001**	0.3
Finger – flexors	2 (0.3, 3)	1 (0, 3)	–3.23	**0.001**	0.3
Others	1 (0, 2)	0 (0, 2)	–3.15	**<0.001**	0.3
Total	12 (4.3, 16)	7.5 (1, 12)	–4.16	**<0.001**	0.4
EQ-5D (*n* = 92)					
Mobility	3 (2, 4)	2 (2, 3)	–5.57	**<0.001**	0.6
Self-care	3 (2, 4)	2 (1, 3)	–4.93	**<0.001**	0.5
Usual activities	4 (3, 4)	3 (2, 3)	–5.71	**<0.001**	0.6
Pain/discomfort	2 (1, 3)	1 (1, 2)	–3.63	**<0.001**	0.4
Anxiety/depression	2 (1, 3)	2 (1, 2)	–3.32	**<0.001**	0.3
Overall health	50 (40, 70)	75 (60, 85)	–6.01	**0.001**	0.6
Index value (UK)[c]	0.49 (0.22, 0.61)	0.66 (0.50, 0.75)	–5.70	**<0.001**	0.6
AMT (total) (*n* = 83)	9 (9, 10)	9 (9, 10)	–0.93	0.354	0.1
FIM Motor (*n* = 81)	75 (72, 85.6)	81 (70.5, 87.5)	–0.66	0.512	0.1
Self-care	33 (31, 40.6)	36 (29.5, 40.5)	–1.00	0.316	0.1
Sphincter	13 (12, 14)	14 (13, 14)	–2.26	0.24	0.3
Locomotion	12 (8, 12)	12 (9.5, 13)	–2.12	**0.035**	0.2
Mobility	18 (15, 19.6)	19 (18, 21)	–2.74	**0.006**	0.3
FIM cognition (*n* = 81)	32.5 (29, 34)	33 (30, 35)	–1.77	0.076	0.2
Communication	14 (12, 14)	14 (12.5, 14)	–0.56	0.577	0.1
Psychosocial	6 (6, 7)	7 (6, 7)	–3.00	**0.003**	0.3
Cognition	12 (11, 14)	13 (12, 14)	–1.63	0.104	0.2

[a]A Wilcoxon signed-ranks test was conducted to evaluate the impact of the interventions.
[b]Effect size statistics (r) Cohen's criteria: (0.1 = small, 0.3 = medium, 0.5 = large effect).
[c]EQ-5D index-based summary score (UK).
Significant values are shown in bold.
ArmA: Arm Activity Measure; AMT: Abbreviated Mental Test; DASS: Depression Anxiety, Stress Scale; EQ-5D: Euro-Quality of life scale; ES: effect size; FIM: Functional Independent Measure; IQR: interquartile range; MAS: Modified Ashworth Scale; *n*: total number.

Table III. *Change scores in the streamlined Wolf Motor Function Test over time (*n = *75)*

Scales	T0 Baseline Median (IQR)	T1 Post-intervention Median (IQR)	Z value	*p*-value	Effect size[a]
Extend elbow (weight)	3.0 (3.0, 4.0)	3 (3.0, 4.0)	–2.39	**0.017**	0.3
Time (s)	2.2 (1.2, 4.8)	1.6 (0.9, 5.0)	–2.03	**0.043**	0.2
Hand to box (front)	3.0 (1.0, 4.0)	3.0 (1.0, 4.0)	–2.09	**0.037**	0.2
Time (s)	2.3 (1.1, 6.6)	1.8 (0.9, 9.9)	–0.75	0.940	0.1
Lift can	3.0 (1.0, 4.0)	3.0 (1.0, 4.0)	–2.28	**0.023**	0.3
Time (s)	5.4 (2.5, 35.0)	4.2 (2.0, 35.6)	–0.97	0.330	0.1
Lift pencil	2.0 (1.0, 3.5)	3.0 (1.0, 4.0)	–3.04	**0.002**	0.4
Time (s)	8.8 (2.5, 43.0)	5.0 (2.0, 24.4)	–2.33	**0.023**	0.3
Turn key in lock	3.0 (2.0, 4.0)	4.0 (3.0, 5.0)	–2.33	**0.020**	0.3
Time (s)	3.6 (1.8, 8.3)	2.8 (1.2, 6.2)	–1.61	0.108	0.2
Fold towel	3.0 (1.0, 4.0)	3.0 (1.0, 4.0)	–3.04	**0.002**	0.4
Time (s)	18.8 (9.0, 49.5)	15.7 (7.4, 38.0)	–1.85	0.065	0.2
Grip left	15.0 (0.8, 27.7)	19.7 (1.2, 30.4)	–1.89	0.059	0.2
Grip right	15.8 (3.0, 25.4)	19.4 (4.2)	–2.68	**0.007**	0.3
Pinch left	0.7 (0.0, 3.5)	2.9 (0.0, 4.5)	–2.36	**0.018**	0.3
Pinch right	0.9 (0.0, 3.7)	3.1 (0.7, 4.9)	–3.66	**<0.001**	0.4

[a]A Wilcoxon signed-ranks test was conducted to evaluate the impact of the interventions. Effect size statistics (r) Cohen's criteria: (0.1 = small, 0.3 = medium, 0.5 = large effect).
Significant values are shown in bold. IQR: interquartile range.

bility and good clinical outcomes of an innovative 6-week programme designed to enhance upper limb function, and to improve cognitive function and participation in persons with stroke and other neurological conditions. Improvement in motor and cognitive function and QoL was independent of diagnosis and, importantly, was achieved irrespective of the variability, type or intensity of the "Hand Hub" programme. This suggests that engagement of these patients in such activities post-treatment may underpin improvement in QoL. The "Hand Hub" provided a platform for patients to regain lost skills and routines that enhance their daily functional activities, psychological gain and participation. For a significant proportion of patients, the Hand Hub provided their only experience of rehabilitation for the upper limb. There were no negative effects of the "Hand Hub" programme. These findings are relevant for long-term planning and management of patient population with upper limb dysfunction.

Previous studies have reported that stroke survivors perceive their loss of arm and hand function to be of equal or greater seriousness than limitations in their walking abilities (38, 39). Loss of upper limb function contributes in a substantial way to stroke-related disability and many experience ongoing transient and/or persistent physical and psychosocial morbidity due to upper limb impairments (12, 14). The participants in this study were similar to those in other studies conducted in similar contexts with respect to demographic and clinical characteristics (12, 14). Our findings are consistent with earlier studies reporting that increased task-specific activities and practice of upper limb improved arm and hand function after stroke (1, 10, 12, 14).

This pragmatic clinical observational study was conducted using a CPI approach in a busy clinical practice. Such an approach is appropriate for the implementation of changes to a service using the Plan-Do-Study-Act quality improvement framework (20). The Hand Hub not only improved patient outcomes, but also built capacity in the provision of subacute rehabilitation services and enhanced the quality of the rehabilitation by addressing problems of critical importance to patients. Strategic use of technology, as used in this programme, improved access to rehabilitation for the arm and hand that was not possible with existing resources. The Hand Hub typically enabled 5 patients to be treated at the same time, supervised by 1 therapist and an allied health assistant. This improved the response of the rehabilitation service to the waiting list by providing a way of streaming patients towards intensive therapy for upper limb dysfunction. The Able-X and Able-M devices cost less than AUD$1000 each, and are therefore affordable within the public health sector. The Hand Hub exposed patients to games that were interesting and challenging, as opposed to pure physical repetition of tasks in traditional therapy programmes, thus providing enjoyment and variety, and sustaining interest in continuing to practice. Wood et al. reported that, with repetitive practice, patients cease to think of arm movements and begin to think in terms of accomplishing the goal (40). Moreover, the devices provided immediate visual feedback on performance, which encouraged the patients to continue the intensive exercise. These elements have long been recognized as being critical for motor learning.

This study has some limitations. First, this is an observational study (without a control group), which reduces the ability to draw casual relationships between the Hand Hub programme and improved patient outcomes. Furthermore, the improved outcomes might be due to unmeasured confounding variables and not the Hand Hub programme itself. However, the implementation of this intervention occurred within a complex clinical environment, and included a mechanism for referral and evaluation of patients with upper limb dysfunction that recognized the current clinical deficit. A traditional

randomized controlled trial might not be the most appropriate research design for evaluation of a multi-component intervention. The treating therapists were unaware of the study purpose or outcomes to prevent any "Hawthorne" effect, or alteration in their behaviour due to involvement in the study. Secondly, participants were a selective cohort referred to single tertiary institution with strict inclusion criteria and who volunteered to participate, which may limit the generalizability of findings. The study cohort, however, covered a wide geographical population in Victoria, and represents a broad sample of neurological patients. Participants in this study were complex in terms of disease severity, symptoms and comorbidities (reflective of clinical practice). These factors influenced the type and intensity of the intervention provided; however, this study did not attempt to control these factors. The therapists worked individually with each participant to set goals and selected an appropriate tailored programme. Compliance and attendance in sessions was challenging due to therapy being centre-based, but most patients attended more than 90% of sessions. Participants were predominantly from within the Melbourne Health catchment area (50 km^2), although the distances travelled for treatment ranged from 1 to 550 km. This study was conducted in a real-life setting in busy tertiary public hospital with limited funding. Thirdly, there were limitations in some of the outcome measures used. Although the FIM is widely used to measure burden of care, participants with higher scores may still have significant residual impairment of upper limb function. The ArmA is a relatively new self-report scale, comprising both passive and active function subscales, and has been used in the context of evaluation of spasticity. In order to reduce the burden of assessment, we chose to use the streamlined Wolf Motor Function Test rather than the whole test. This subset has been tested for reliability and construct validity in stroke patients (27), though not for patients with other neurological conditions; however, our participants showed improvement on these items. Although our participants reported significant improvements in their ability to use the affected upper limb in everyday life, the lack of a formal assessment of this aspect of upper limb function was a shortcoming of this study. Another limitation was the fact that the participants were chronic patients who may not have received therapy for some time, so that the benefits from the Hand Hub programme may have been through recovery of function previously gained, but lost through lack of practice. The lack of a follow-up assessment in this study did not permit evaluation of whether gains in function in the Hand Hub were maintained. Several studies have shown that gains in function are lost when therapy stops (40–42). Future studies could include an evaluation of delivery of intervention via tele-rehabilitation to reduce the burden of travel, and a multi-site observational study, which includes follow-up assessments at 3 and 6 months post-intervention.

In conclusion, this single-site before–after prospective intervention study shows that regular and repetitive hand exercise using computer-based games improved hand function, cognitive function and overall QoL in persons with stroke and other neurological disorders. This information has implications for the future planning of clinical service delivery models and the Hand Hub model could be considered for routine inclusion in the management of patients with stroke and other neurological disorders. However, the findings need to be further confirmed in a larger study sample, with a longer follow-up in this complex patient population.

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