Disability and Rehabilitation

ISSN: 0963-8288 (Print) 1464-5165 (Online) Journal homepage: http://www.tandfonline.com/loi/idre20

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To cite this article: Rachel Kizony, Patrice L. Weiss, Sharon Harel, Yoram Feldman, Alexei Obuhov, Gabi Zeilig & Mordechai Shani (2016): Tele-rehabilitation service delivery journey from prototype to robust in-home use, Disability and Rehabilitation, DOI: 10.1080/09638288.2016.1250827

To link to this article: http://dx.doi.org/10.1080/09638288.2016.1250827

Published online: 22 Dec 2016.

http://dx.doi.org/10.1080/09638288.2016.1250827

ORIGINAL ARTICLE

Tele-rehabilitation service delivery journey from prototype to robust in-home use

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ABSTRACT

Purpose: The purpose of this study is to present a retrospective study on clients with Acquired Brain Injury (ABI) enrolled in a tele-motion-rehabilitation service program for two or more months.
Methods: Data from 82 clients (46 males; 74 with ABI), aged 22–85 years, are reported. The Kinect-based CogniMotion System (ReAbility Online, Gertner Institute, Tel Hashomer, Israel) provided services that included 30-min biweekly sessions. Participants were evaluated prior to and 2 months following the commencement of service with clinical assessments that measured movements and function of the weaker upper extremity and cognitive abilities.
Results: Clients enrolled in the service had intact or mild cognitive impairment, mild-moderate motor impairment but little use of their weak upper extremity for daily activities. They were satisfied with the service and reported high levels of system usability. Post-intervention clinical assessments were performed on about half of the participants after 2 months; significant improvements in active movements of the weak upper extremity, shoulder flexion range of motion and in the Trail Making Test were found ($p < 0.05$).
Conclusions: The service appears to be feasible for people with ABI and effective in important clinical outcomes related to improvements in upper extremity function.

ARTICLE HISTORY
Received 4 March 2016
Revised 7 August 2016
Accepted 17 October 2016

KEYWORDS
Tele-rehabilitation; acquired brain Injury; remote intervention; virtual-reality

➤ **IMPLICATIONS FOR REHABILITATION**

- Tele-rehabilitation provided with Microsoft Kinect 3D sensor virtual reality tracking system is feasible for people with Acquired Brain Injury.
- People with Acquired Brain Injury in the chronic stage were satisfied with the tele-rehabilitation service and perceived it as beneficial to improve their motor and cognitive abilities
- The CogniMotion System service appears to be effective in important clinical outcomes related to improvements in upper extremity function.

Introduction

Tele-rehabilitation refers to the use of information and communication technologies to provide rehabilitation services to people remotely in their homes or other environments.[1] The goal is to improve client access to care by receiving therapy beyond the physical walls of a traditional healthcare facility, thus expanding the continuity of rehabilitation care.[2] The need to expand the delivery of rehabilitation services and incorporate aspects of self-care and remote monitoring is important in light of the shift in global demographics to an older population and the increasing prevalence of chronic health conditions (i.e. living with the consequences of an acquired injury or event or with a disease for many years).[3] In addition, studies have demonstrated that, for example, the function of the weak upper extremity can be improved even in the chronic stage post-stroke [4] when rehabilitation services are minimal. Moreover, there is evidence that higher movement repetitions improve brain plasticity [5] but this intensity of exercise is not usually achieved during regular rehabilitation.[6] Tele-health in general, and tele-rehabilitation, in particular, hold significant potential to meet these needs by providing professional long-term services that are accessible to more people, and offer a more affordable level of care,[7] although its adoption requires consideration of issues related to health care policy (e.g., reimbursement, licensure portability).[8]

The recent development of advanced sensor and remote monitoring technologies has enabled an increasing number of tele-rehabilitation applications to be deployed into the home,[9] in schools,[10] and in work settings.[11] While early telecare services looked to provide basic follow-up care and caregiver support, more recent work has developed and deployed systems to provide home-based exercise monitoring, diet and medication compliance tracking, and other more dynamic interventions.[12] Current telehealth systems range from synchronous, single client–single clinician interactions (e.g.,[13]) to multi-user asynchronous platforms wherein clients engage in activities offline which is later retrieved and evaluated by a clinician ("store and forward"). More recently, hybrid systems that combine synchronous and asynchronous interactions have been gaining popularity due to the flexibility of their service model. Hybrid systems offer

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the benefit of inexpensive, high intensity self-training that is accompanied by professional treatment where direct online feedback is given.[14] This may help in facilitating learning and the transfer of skills trained in the system to everyday activities.

The feasibility and effectiveness of tele-rehabilitation for people with Acquired Brain Injury (ABI) was investigated by Huijgen et al. [15] and Piron et al. [16] who showed the feasibility of a tele-rehabilitation intervention for arm/hand function training provided by hospital-based therapists to clients at home using technologies based on tracking devices and teleconferencing. Chumbler et al. [17] used a single-blinded RCT to investigate the effect of a tele-rehabilitation intervention on physical function and disability in veterans who had a stroke. The tele-rehabilitation group improved significantly in their physical function, with improvements persisting after the intervention. Langan et al. [18] tested a computer-based activities tele-rehabilitation to improve upper limb performance in seven adults with chronic stroke who were trained for a period of six weeks, concluding that a supervised, home-based tele-rehabilitation program is feasible for the chronic stages of stroke. A different approach was taken by Nijenhuis et al. [19] who investigated the use of a dynamic wrist and hand orthosis in a home-based gaming environment to support a high dose of self-administered arm and hand exercises for post-stroke training. They demonstrated the usability of the system and reported an improvement in active movements of the weaker upper extremity and in the score of the Stroke Impact Scale.[20]

Other researchers have focused on the use of tele-rehabilitation for orthopedic conditions. Tousignant et al. [21–24] studied clients with proximal fractures of the humerus who were provided with tele-rehabilitation treatment via a videoconferencing system in their homes. They were evaluated for pain, range of motion, and health care satisfaction prior to and immediately following the intervention. All the clinical outcomes improved post-intervention and participant satisfaction was high. Moffet et al. [25] used an RCT to compare an in-home tele-rehabilitation program to a face-to-face home visit approach of clients following a total knee arthroplasty. Their results demonstrated the non-inferiority of in-home tele-rehabilitation and supported its use as an effective alternative to face-to-face service delivery after hospital discharge of clients following a total knee arthroplasty.

Several meta-analyses on the use of tele-rehabilitation for a range of therapeutic objectives have been performed recently. Agostini et al. [26] examined 12 studies to determine whether tele-rehabilitation was more effective than other modes of delivering rehabilitation to regain motor function, in different populations of clients (neurological, total knee arthroplasty, and cardiac). Whereas the results of interventions for cardiac and orthopedic clients favored tele-rehabilitation, the effect of tele-rehabilitation for neurological clients has not been conclusively demonstrated. Chen et al. [27] performed a meta-analysis of seven studies to determine whether tele-rehabilitation leads to an improvement in abilities required for activities of daily living (ADL, such as dressing and grooming) for stroke clients. They concluded that there is moderate evidence that tele-rehabilitation is as effective as conventional rehabilitation in improving ADL and motor function for stroke survivors. As in previous reports (e.g., Laver et al. [28]), the main conclusion from these meta-analysis studies is the need for continued research in this field that should aim to decrease the heterogeneity of the investigated population (i.e., the various motor and cognitive deficits that impact the ability of clients regain functional ability), to increase the number of study participants and to report data concerning the economic differences between conventional and tele-rehabilitation.

In comparison with the studies presented above, there are very few reports on tele-rehabilitation service delivery supported by objective outcome data, i.e., they tend to be reported via anecdotal case studies describing the client's experience rather than present data from clinical measures. Levy et al. [29] performed a retrospective study that examined functional outcomes, health-related quality of life (HRQoL), and satisfaction in a group of veterans who received physical therapy via an in-home video-based tele-rehabilitation program. Significant improvement was shown in the participants' Functional Independence Measure,[30] Montreal Cognitive Assessment, two Minute Walk Test,[31] and Veterans RAND 12-Item Health Survey.[32] In addition, all veterans reported satisfaction with their tele-rehabilitation experience. This is a clinical demonstration of a project that delivered real-time, client-centered rehabilitation therapies such as occupational, physical, and recreational therapy, as well as psychological and nursing care directly to veterans in their homes. However, although the participants received the majority of therapy sessions via in-home telehealth, approximately a quarter of therapy sessions were completed in a traditional, face-to-face format. Therefore, this investigation more accurately reflects a mixed-method approach to rehabilitation rather than pure tele-rehabilitation. Moreover, most of the clients had musculoskeletal disorders and not ABI.

Vollenbroek-Hutten et al. [33] reported on clients in four different diagnosis groups (acute hip, arthritis, cancer, and chronic obstructive pulmonary disease (COPD)) who used a multimodal service platform for four different types of tele-based intervention (tele-consultation, activity coaching, web-based exercising, and health monitoring). There were considerable variations in interest-to-participate and in treatment duration. All client groups, except for the arthritis group, were highly satisfied with the ICT-supported rehabilitation services and most would recommend it to others. No effectiveness results were reported.

Demonstration of the robustness of a clinical service delivery program under authentic home care usage requires that its usability, validity, effectiveness, and sustainability be established. In the current paper, we report on an active, not-for-profit tele-rehabilitation service (ReAbility Online) that provides training of the weak upper extremity following a neurological event. In this service, the CogniMotion system provided a hybrid (synchronous-asynchronous), home-based tele-rehabilitation program to improve the motor, cognitive, and functional status of people who had ABI. For this purpose, the Microsoft Kinect 3D sensor-based system was adapted to record upper limb and trunk movements to control a variety of tasks and games that simulate daily activities.[34]

The CogniMotion System was adapted to comply with all key rehabilitation intervention principles.[35] This is accomplished by (1) programable control over the level of difficulty so that clients exercise at a suitably challenging level, neither beyond nor below their current capabilities; (2) targeted auditory responses from the virtual tasks provide clear online feedback of results and performance, showing by how much the clients have succeeded or still need to improve; and (3) offline exercise protocols for independent use by the client (with outcome reports transmitted to the clinician). CogniMotion's usability, validity, and the results of a small sample RCT have been previously demonstrated.[36]

The objective of the current paper is to document the service delivery implemented by the CogniMotion System for people with ABI over a 2-year span. This is accomplished by presenting the clients' clinical profiles as well as reporting on a retrospective study of changes in clinical measurements after 2 months of the tele-rehabilitation intervention. In addition, the results of a focus group of long-term service users are reported.

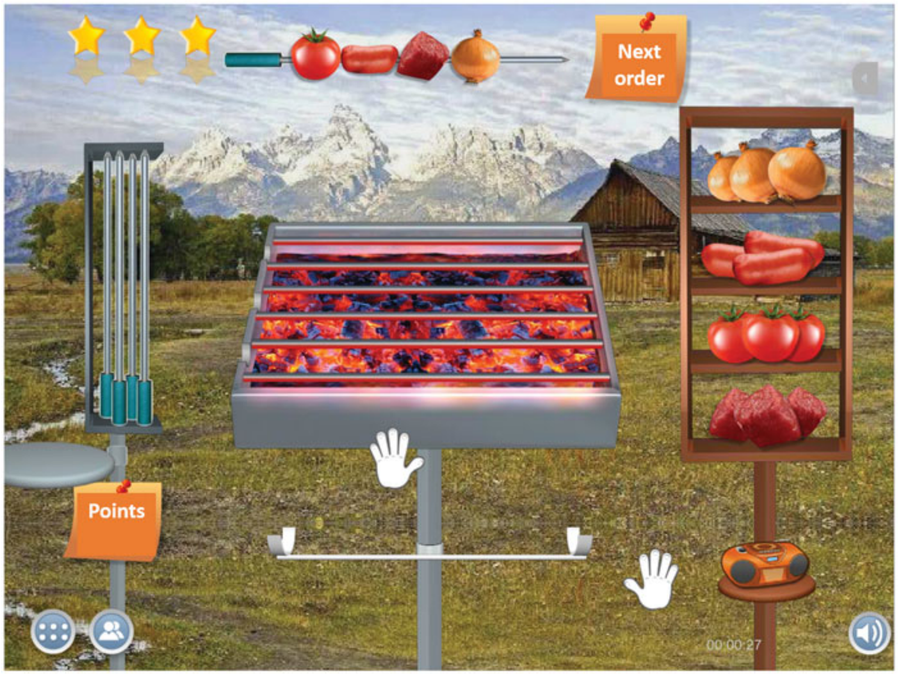

Figure 1. Screen shot of CogniMotion System Grill activity.

Methods

Population

The medical records of clients who were enrolled in the CogniMotion System service from September 2013 to August 2015 were reviewed if they had a diagnosis of ABI or Multiple Sclerosis and were aged 18 years and older. This retrospective study was approved by the Institutional Review Board of the Sheba Medical Center, Tel Hashomer, Israel.

Instruments

CogniMotion system (ReAbility Online, Gertner Institute)

The system consists of a Windows-based personal computer (minimum i3 processor), large television monitor (20–42 in with most clients using 26 in and above), and Microsoft's Kinect 3D sensor (ReAbility Online, Gertner Institute, Haifa, Israel). This equipment is located in the client's home and connected to a clinician's computer setup in a remote Call Center via high speed WiFi. The seated client uses about 20 interactive games and tasks that have been programed with the Kinect Software Developer's Kit, version 1.5 (ReAbility Online, Gertner Institute, Haifa, Israel). Movements of the client's upper extremity and trunk motions and, in some cases, hip flexion, control the action of the customized video games.

Clients were taught to use two simple games during the first session at which time levels of difficulty were adjusted in accordance with upper extremity range of motion, type and extent of compensatory movements, and cognitive limitations. These levels were modified at subsequent sessions as the client's performance improved. Typically, an additional game or task was taught during each session until the client mastered all appropriate activities.

The system itself as well as its feasibility, validity, and effectiveness have been described previously.[34,36] The example screenshot shown in Figure 1 is taken from the Grill activity in which the user prepares kebab skewers in accordance with a displayed 3-item menu. Selection of food items is by virtual "touch" on objects displayed at varying locations on a screen. Levels of difficulty may be adjusted by changing the number of kebabs that need to be prepared, shelf height, and task complexity; i.e., initially the user makes only one kebab but eventually must cope with several simultaneous tasks (preparing a kebab, placing it on the grill, turning it over while preparing the next kebab, removing the first kebab to the plate while turning the second kebab, preparing a third kebab, etc.). This activity has moderate motor and moderate-to-high cognitive requirements. There are more than 15 additional activities (games or simulated daily activities) that span a range of motor and cognitive levels including several that target activity of the lower limb and grasp.

The system provides feedback in the form of "knowledge of results" (e.g., game scores) and "knowledge of performance" (e.g., occurrence of any compensatory movements) to enhance motor learning.

Clinical measures

National Institutes of Health Stroke Scale (NIHSS) (http://www.nihstrokescale.org/) is a 15-item neurologic examination stroke scale used to evaluate the effect of acute cerebral infarction on the levels of consciousness, language, neglect, visual-field loss, extraocular movement, motor strength, ataxia, dysarthria, and sensory loss. Ratings for each item are scored with 3–5 grades with 0 as normal. The NIHSS is valid for predicting lesion size and can serve as a measure of stroke severity and has been shown to be a predictor of both short and long term outcome of stroke clients.

The *Mini-Mental State Exam* (MMSE) [37] for older adults (aged above 65) and the *Montreal Cognitive Assessment* (MOCA) [38] for younger adults (aged below 65) were used as cognitive screening. Both measures are widely used cognitive screening tests with a score that ranges between 0 (severe impairment) and 30 (no impairment).

The *Trail Making Test* (TMT, parts A and B) [39] is a widely used test of visual-motor scanning (Part A), divided attention, cognitive flexibility, and executive functions (Part B). The results are reported in seconds needed to complete each part of the test.

The *Fugl-Meyer Assessment* (FMA) [40] assesses the motor impairment of the upper extremity after stroke. Each movement is graded on a 3-point scale, and the total score for the upper extremity ranges from 0 to 60 points where a higher score represents more active movements. This test is one of the most commonly used instruments in rehabilitation and its validity and reliability have been well established.[40–42] For people with MS, the FMA was administered to their most affected arm and hand.

The *Motor Activity Log* (MAL) [43] consists of a semi-structured interview for the client to assess the use of the weaker arm and hand during activities of daily living such as picking up a glass or brushing teeth. Two scores are given for each activity: one for the amount of use and one for the quality of movement. The questions concern activities performed during the past week or, occasionally, the past month. Possible scores range from 0 (never use the affected arm for this activity) to 5 (always use the affected arm for this activity). The MAL was administered to people with MS concerning their most affected arm.

Feedback on using the system

System Usability Scale (SUS) [44] is a questionnaire which includes 10 items which provide a global view of subjective assessment of a system's usability. Each item is rated on a five-point scale from one (disagree totally) to five (agree totally). Five items are positive statements, such as "I think that I would like to use this system frequently" and "I thought the system was easy to use" and the other five items are negative, for example, "I found the system unnecessarily complex", and "I think that I would need the support of a technical person to be able to use this system." The item scores are calculated to give an overall score ranging from 10 to 100 points. The SUS has been shown to be a robust and reliable evaluation tool [45] but its psychometric properties have not been fully investigated. An additional question that queries about the level of enjoyment from the CogniMotion System was added on a scale of 1 (not at all) to 5 (very much).

Focus group: A focus group of six clients who had used the CogniMotion System for at least 1 year was carried out in order to gain insight into how the target population perceived service delivery and to solicit recommendation regarding improvements in clinician–client interactions. The focus group was recorded and transcribed. In addition, the clients graded their perceptions of how much the service was beneficial to them, from various aspects (e.g., motor, cognitive) on a scale of 1 (not at all) to five (very much). The two questionnaires completed by the focus group as well as the items used to lead the group discussion are provided in an appendix.

Procedures

Clinical protocol

Initial intake was made by telephone to determine a client's potential eligibility for the tele-rehabilitation service, namely whether they had intact sitting balance, mild-moderate impairment of the upper extremity, intact, or mild cognitive impairment and accessibility for Internet and a computer. People who met these criteria were asked to come to the clinic before the start of remote training to be evaluated by a physician who reviewed their medical history. Thereafter, a physical or occupational therapist administered the clinical evaluations mentioned above. In addition, the clinician assessed the ability of the person to interact with the system, i.e., to understand the concept of moving his hands in purposeful movements in order to affect stimulus that appear on the screen. Thereafter, the person received the Kinect, the installation of the software in his home was performed remotely, and the tele-rehabilitation service started within 2 weeks from the in-clinic evaluation.

At the beginning of service, the client received two 30 min online treatment sessions per week for about two months (i.e., 16–20 sessions). During these sessions, the clinician explained how to work with the system, respond to its feedback (of results and performance), and operate the various activities. The clinician also set the level of difficulty in each activity, according to the client's abilities and needs. After this initial phase, that lasted between 8 and 10 sessions (i.e., about 1 month), depending on their abilities and needs, some clients continued independent practice each day supplemented with one online session per week; others continued receiving two online individual sessions or with an additional client per week. After 2 months, the client was asked to return to the clinic for full clinical re-assessment (i.e., clinical evaluations mentioned before except for the cognitive screening). This time, the clinician also administered the System Usability Scale.

At this stage, in accordance with the experience of clinical usage and improvement over the previous 2 months, the client was offered an opportunity to pay a nominal fee to continue training via two alternate modes: (1) independent practice each day supplemented with one online session per week or (2) continue receiving two online sessions per week with or without offline training.

Data analysis

Data were analyzed with IBM SPSS Statistics Version 21.0 (IBM Corporation, Armonk, NY) software. Descriptive statistics were used to describe the clients' profile on the various measures. Comparisons between the first and second evaluations were made with the non-parametric Wilcoxon Signed Ranks test, since according to the Shapiro–Wilk test, the data were not normally distributed. Since this is a retrospective study on a clinical service, some data are missing due to client unavailability (e.g., some could only come for a short evaluation session or were reluctant to undergo some of the evaluations such as questionnaires) or changes of protocol (e.g., the TMT was added only at the middle of the period reported). The actual participant numbers used in the analysis are reported for each variable below.

Results

Report on service

Data from 82 clients (46 males, 36 females), aged 22–85 years, were analyzed. Seventy-four people had a diagnosis of an ABI: 63 (76.8%) with stroke, six with Traumatic Brain Injury (TBI), six with other brain lesions such as arteriovenous malformation (AVM) or removal of a brain tumor. In addition, there were eight clients diagnosed with Multiple Sclerosis (MS). Clinical characteristics of the participants from the ABI and MS groups are presented in Table 1. Clients enrolled in the service have mild-moderate impairment of the weak upper extremity and overall good basic cognitive abilities. There was a large variance in the motor abilities of the upper extremity as well as the extent to which they use it for daily activities. Overall most of the clients do not use their weaker hand for daily activities.

Twenty-two clients completed the System Usability Scale. They found the system to be highly usable for rehabilitation (mean ± SD = 89.1 ± 12.1; median, Inter-Quartile Range (IQR) = 90, 89.4–97.5). In addition, clients reported high level of enjoyment from their experience with the service ($n = 40$) (mean ± SD = 4.1 ± 1.1; median, IQR = 4, 3–5).

Table 1. Description of clients and clinical outcomes of those in ReAbility online service.

	Pathology			
	ABI ($n = 74$)		MS ($n = 8$)	
Gender				
Male	$n = 45$ (60.8%)		$n = 1$ (12.5%)	
Female	$n = 29$ (39.2%)		$n = 7$ (87.5%)	
	n	Mean ± SD (range)	*n*	Mean ± SD (range)
Age (years)	74	59.1 ± 15.5 (22-85)	8	57.4 ± 8.2 (44-68)
Years since event	65	3.4 ± 3.8 (0-16)	4	12.8 ± 7.1 (3-20)
NIHSS (range 0–42)[a]	65	5.5 ± 1.4 (3-9)		NA
MMSE (range 0–30)	30	27.6 ± 1.9 (23-30)	2	29.0 ± 1.4 (28-30)
MOCA (range 0–30)	39	25.8 ± 3.1 (18-30)	6	28.5 ± 1.9 (25-30)
FMA (range 0–60)[a]	65	37.2 ± 11.2 (14-58)	8	48.6 ± 5.2 (37-53)
Shoulder flexion (deg)	65	108.6 ± 38.6 (0-180)	8	135.0 ± 24.6 (80-150)
Shoulder abduction (deg)	65	91.6 ± 31.3 (40-165)	7	119.3 ± 22.8 (90-145)
MAL amount	68	1.7 ± 1.1 (0.21-4.8)	8	2.9 ± 1.5 (1-4.9)
MAL quality	66	1.6 ± 1.1 (0.14-4.9)	8	2.4 ± 1.0 (1.1-3.9)
TMT_A (s)[b]	36	77.7 ± 58.2 (21-235)	5	41.8 ± 10.9 (30-58)
TMT_B (s)[b]	33	164.6 ± 116.1 (41-610)	5	86.4 ± 26.0 (61-116)

NIHSS: National Institutes of Health Stroke Scale; MMSE: Mini-mental State Exam; MOCA: Montreal Cognitive Assessment; TMT: Trail Making Tests; FMA: Fugl-Meyer Assessment; MAL: Motor Activity Log; N/A: Not Applicable.
[a]Although these tests are not normally presented for MS, they are shown here as an indicator of functional performance.
[b]Low scores represent better performance.

Focus group

Overall, the clients were very satisfied with system usage. The main reasons for their satisfaction with the system are shown in Figure 2 and their perceptions of how the system helped them are shown in Figure 3 and provided in greater detail in the appendix. Some example quotes illustrate the impact that the use of this system had on their everyday lives. When asked about how involvement in the service changed their approach to activity, one participant stated, "If I wanted to turn on a faucet or to turn off the light, I hesitated since I would feel some pain or it would be hard. Now I respond more calmly and feel ready to try these activities, and, often, I succeed." Another participant commented, "I very much enjoy using the system and already see results. Knowing how judgmental I am, if I say this, then there really is an improvement. I wait for every session. If I could, I'd use it even more often." A third user wrote, "It has been several years since my stroke. Since then I felt that my left hand was no longer part of my body. For the first time in years [now that I am getting tele-rehabilitation therapy], I have regained the use of my left hand and feel it again! I can now use to hold light objects, eat with a fork and do other daily tasks. Until a few weeks ago, I simply had to avoid these activities."

In addition, an in-depth interview with one of the clients revealed that working with the system enabled her to use the hand in a more natural way without the need to think of each movement. She remarked, "Before I started using the system I had to give direct, conscious commands to my left [affected] arm. When I started working with the system suddenly I did not have to do this. It means that my arm became a part of my body again"

Comparisons between first (pre-intervention) and second evaluations

Significant improvements were found in the score of the FMA ($n = 35$) $z = -3.1$; $p = 0.002$, shoulder flexion ($n = 42$) $z = -3.02$; $p = 0.003$, and TMT-B ($n = 29$) $z = -2.2$; $p = 0.029$ (see Figures 4–6). Paradoxically, the median shoulder abduction ($n = 39$) was significantly higher in the pre-intervention assessment ($z = -2.3$; $p = 0.023$); indeed, the data revealed that only 23% of the clients showed a reduction in shoulder abduction whereas 20% showed no change and 56% showed an increase. No significant changes were found in the MAL Amount or Quality and in the TMT-A (see Table 2).

Discussion

The data presented in this paper document a service delivery program based on a hybrid synchronous–asynchronous tele-rehabilitation system. The service provides long-term therapy aimed at improving upper extremity range of motion, strength, endurance, and functional ability, after clients with ABI have been discharged home. Its successful implementation over a 2-year period demonstrates the feasibility of extending the traditional course of rehabilitation beyond conventional in- and out-patient therapy. Moreover, the significant improvements in the participants' active movements of the weak upper extremity, shoulder flexion range of motion, and scores on the Trail Making Test (entailing visual-motor scanning, divided attention, and cognitive flexibility) point to its effectiveness for a population that does not typically receive intensive therapy. Finally, client reports of their satisfaction with the system and service, their continuing use of the system over the long-term, and their positive feedback regarding its role in maintaining good physical condition provide important social validity for this approach to rehabilitation.

There have been many reports of tele-rehabilitation programs over the past two decades, with most focusing on platform development, feasibility testing, and small trials of clinical effectiveness as described in the Introduction. This approach is in keeping with market analyses such as the Gartner Group's technology "Hype Cycle" that identify different stages of a technology's readiness for deployment.[46] It has taken tele-rehabilitation the previous decade to reach the beginning of the Hype Cycle "plateau" phase, wherein "baby steps" in system design research and development were needed to test the system in a consistent way and determine what improvements should be done. For example, in the early stages of development, performing validation and formative studies to determine the accuracy of the system in measuring range of motion and the ability of the target clients to interact with the system were needed. Thus, the development and feasibility studies have helped to develop a professionally relevant clinical protocol that can be applied in clinics world-wide.

To date, the literature provides modest support for the potential of clinical intervention via remotely situated rehabilitation systems [8–9,23–28] but has not yet addressed many issues related to implementation and monitoring of service programs over significant periods (1 year and more). We have found only Levy et al.'s [29] report on an extended tele-service study, a retrospective, pre–post study design used to analyze the outcomes related to remotely delivered physical therapy for veterans with musculoskeletal disorders or neurological disorders over a 13-month period. It is difficult to directly compare the results from Levy et al. [29] with the current study due to considerable variations in the targeted population (orthopedic versus neurological) and therapeutic objectives, in the type of technologies used (camera monitoring versus motion detection), and in the type of treatment delivery (a synchronous system that provides only one clinician to one client versus a hybrid synchronous–asynchronous system that ranges from one clinician to one or two clients and also has an offline component). However, despite the differences between the

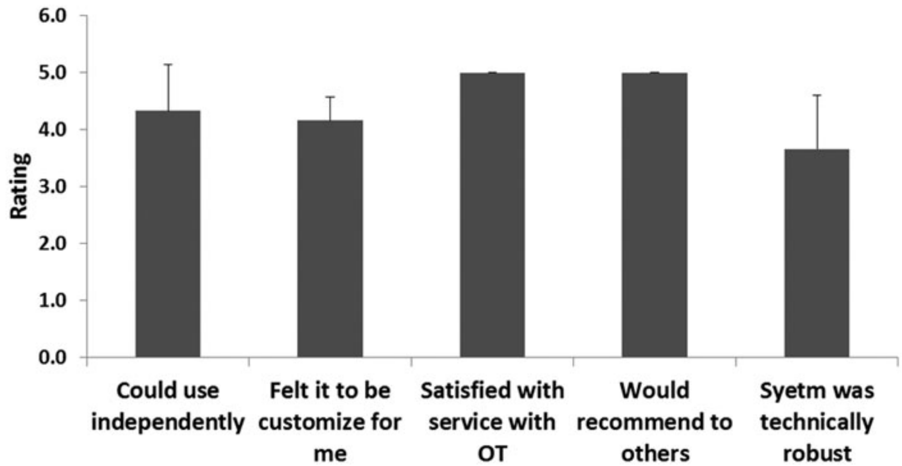

Figure 2. Means and standard deviations for focus group participants' reasons for their satisfaction with the tele-rehabilitation system.

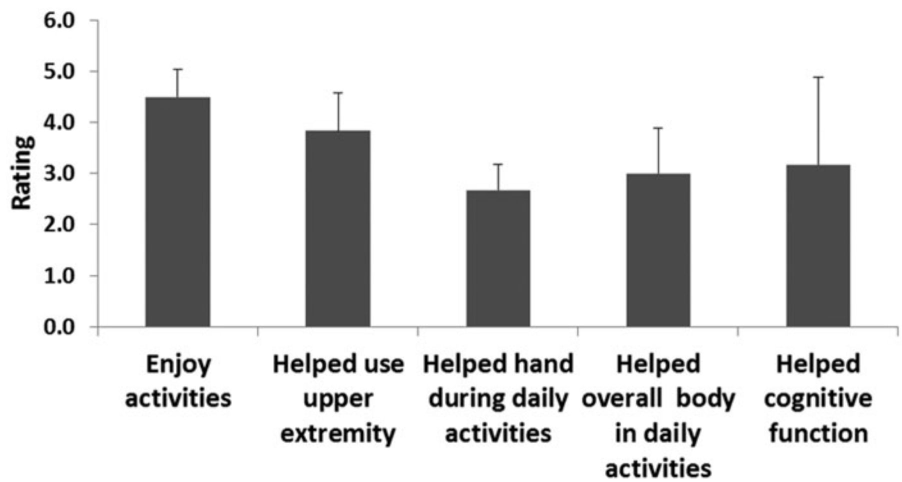

Figure 3. Means and standard deviations for focus group participants' system perceptions of how the tele-rehabilitation system helped them.

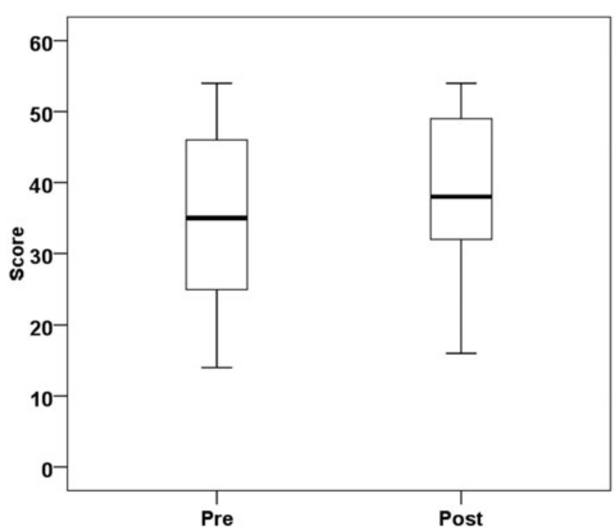

Figure 4. Medians and inter-quartile ranges of Fugl-Meyer Assessment scores ($n = 35$) before and after 2 months of tele-rehabilitation service.

two services, in both studies, clients reported high levels of satisfaction and perceived improvements in their abilities.

The pattern of results in the current study is similar to those reported by Piron et al. [16] who found significant improvements only at the impairment level (i.e., Fugl-Meyer scores) and not at the functional ability of the weaker upper extremity. However, Piron et al. [16] did not report on the subjects' satisfaction or cognitive outcomes.

The lack of a control group in the current retrospective study means that the amount of observed changes in outcome measures between baseline and discharge may be the result of natural recovery (although the clients were at a very chronic stage). Moreover, the relatively small sample size precluded the use of robust, risk-adjusted regression analyses. Nevertheless, the feedback from the service clients point to the importance of also pursuing research designs that go beyond the well documented need for RCT studies. For example, two of the clients who joined the service several years post-stroke stated that they started using their arms only after they enrolled in the tele-rehabilitation service. The reasons for such dramatic effects are not always captured by conventional research outcome measures. Thus, although RCTs are the gold standards for research design, they are not always suited to guiding exploratory technology usage. Research should make use of qualitative as well as quantitative methods and also focus on clients' satisfaction and perceptions to more fully evaluate the added value of non-conventional interventions.

The in-depth interview highlighted an additional point regarding the use of a VR-based gaming environment such as the CogniMotion system for tele-rehabilitation. Such intuitive interactions encourage the user to engage with the activities and use

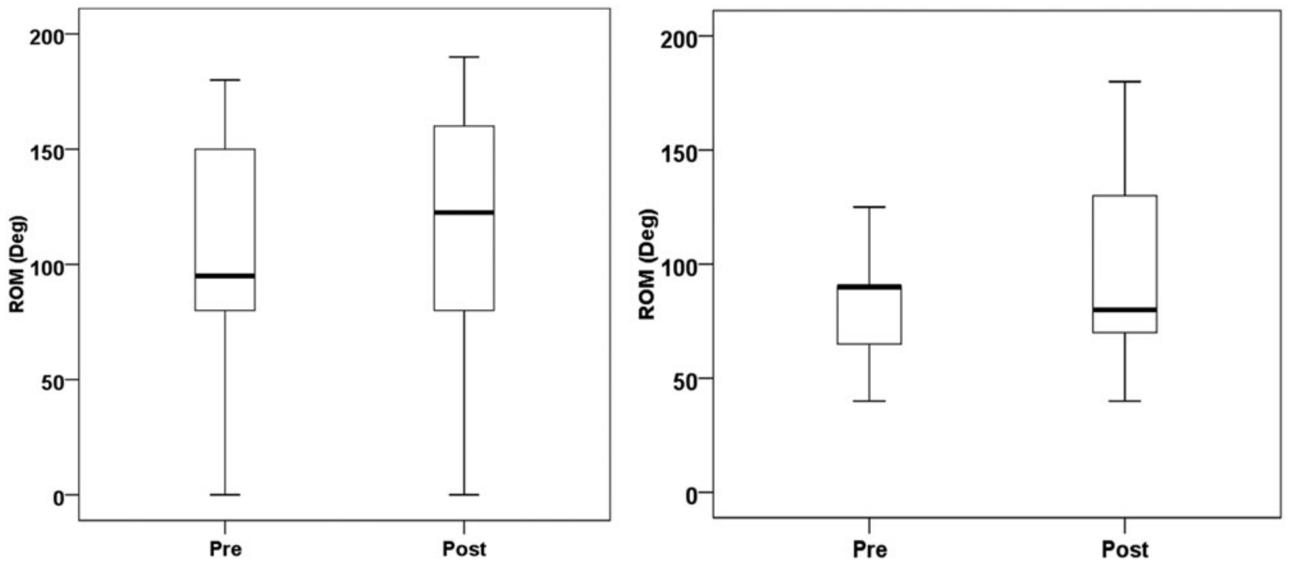

Figure 5. Medians and inter-quartile ranges of shoulder flexion ($n = 42$, on the left) and abduction ($n = 39$, on the right) range of motion before and after 2 months of tele-rehabilitation service.

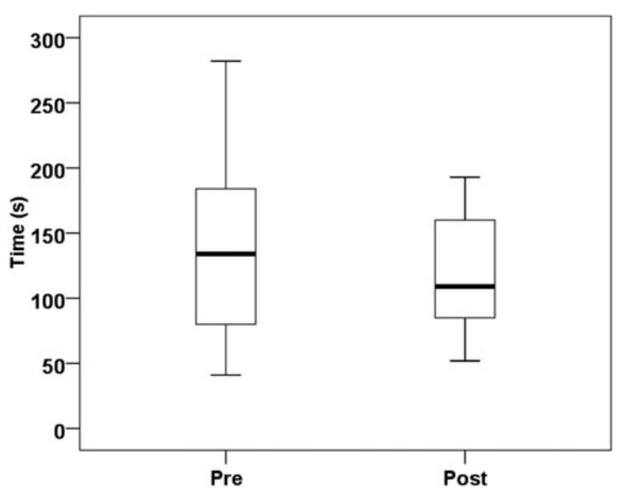

Figure 6. Medians and inter-quartile ranges of Trail Making Test part B times ($n = 29$) before and after 2 months of tele-rehabilitation service.

Table 2. Description of clinical outcomes in the first and second assessments.

	First assessment median (IQR)	After 2 months median (IQR)
Motor activity log (amount) ($n = 39$)	1.14 (0.71–2.36)	1.50 (0.64–2.42)
Motor activity log (quality) ($n = 38$)	1.28 (0.69–1.94)	1.31 (0.74–2.25)
Trail making test A (s) ($n = 29$)	45.0 (33.50–74.50)	44.0 (32.0–60.50)

their limbs in a more natural manner.[47] Chen et al.'s [27] meta-analysis presented a forest plot with a breakdown of VR-based versus non-VR tele-rehabilitation interventions aimed at improving daily function. Although the results favoring tele-rehabilitation were not significant, the forest plot showed a trend in favor of the VR-based services.

A limitation of the extent of client suitability to tele-rehabilitation service offered by the current system is a common consideration for all remotely delivered interventions. Since it is necessary to ensure the client's safety when using the system alone at home, the activities entail exercises that are performed while seated. This excludes those clients, for example, who could benefit from standing balance intervention.

In summary, given the rapid and dynamic development of technology, considerable challenges remain related to the timing for implementing research and the clinical use of technology for rehabilitation purposes.[7] In the rehabilitation domain, too often technology is abandoned after initial research and pilot clinical trials. During the development process of the type of systems described here, it is important to stay "true" to clinical principles and objectives even when tempted by "not-yet-mature" technologies; in the long term, it allows the provision of professional treatment as well as clients' safe self-practice and management. Moreover it provides the basis for covering such services via health care insurance.

It is also important to understand that the system development process is an on-going process that should continue to make use of technology developments so that additional therapeutic objectives can be achieved. The addition of more challenging games, activities, and feedback features is one example of ways to expand system usability. Finally, it is necessary to accompany the service with an on-going study to document clients' profiles, satisfaction with, and responses to the treatment.

Acknowledgements

The authors thank Yuri Fayans, Anat Cohen and Dr. Tal Krasovsky for their programing skills. The authors also thank all our clinicians for their help in the service provision.

Disclosure statement

The CogniMotion System (ReAbility Online, Gertner Institute) is a not-for-profit service in Israel. Plans for marketing the service abroad are now under consideration.

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Appendix

Questions used during the focus group

Questions used to guide the focus group

1. What is the most important aspect of your rehabilitation?
2. Briefly describe how you came to participate in the tele-rehabilitation program? Have you (would you) recommend that others participate as well? Would you suggest its use to your regular therapists?
3. Would you describe yourself as a person who feels comfortable using technology?
4. What challenges did you overcome in order to participate in the program? How could the process have been made easier for you? Give examples.
5. What feedback would you give to the clinicians about what you think are the good and difficult aspects of tele-rehabilitation?
6. How did tele-rehabilitation differ from your experience with conventional rehabilitation? Did you miss having face-to-face contact with your therapist? Why? (Is there anything that could be done with the tele-rehabilitation system in order to make up for this?)
7. Were you anxious or concerned about participating in this program?
8. Did it meet your expectations (how did it differ from what you expected)?

Survey items describing perceptions of CogniMotion Tele-rehabilitation service participants

1. What is important to you when using this therapy system? You can select multiple items:

– It allows me to have therapy more often.
– It keeps me occupied when I don’t have other things to do.
– It increases my comfort with using computer technology.
– It allows me to reduce the amount of my other rehab treatments.
– It makes me more interested in doing therapy
– It allows a large variety of different activities.
– It allows me to do therapy on my own.
– It allows me to have therapy at home.
– It costs less than other therapy.

List any other reasons why you think it is important to use this therapy system.

2. Indicate what should be added to or changed with this therapy system. You can select multiple items.

– Interaction with other people who are having the same therapy.
– More contact with the therapist.
– More frequent face-to- face therapy
– More frequent tele-therapy sessions.
– A greater variety of activities.
– Activities that are more challenging.
– More feedback about how I am performing when doing the activities.
– More feedback about how I am progressing in therapy.
– Activities that are more enjoyable.

List any other items you think should be added to or changed with this therapy system.