Self-Administered, Home-Based SMART (Sensorimotor Active Rehabilitation Training) Arm Training: A Single-Case Report

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MeSH TERMS
- electrical stimulation
- home care services
- recovery of function
- self-care
- stroke

This single-case, mixed-method study explored the feasibility of self-administered, home-based SMART (sensorimotor active rehabilitation training) Arm training for a 57-yr-old man with severe upper-limb disability after a right frontoparietal hemorrhagic stroke 9 mo earlier. Over 4 wk of self-administered, home-based SMART Arm training, the participant completed 2,100 repetitions unassisted. His wife provided support for equipment set-up and training progressions. Clinically meaningful improvements in arm impairment (strength), activity (arm and hand tasks), and participation (use of arm in everyday tasks) occurred after training (at 4 wk) and at follow-up (at 16 wk). Areas for refinement of SMART Arm training derived from thematic analysis of the participant’s and researchers’ journals focused on enabling independence, ensuring home and user friendliness, maintaining the motivation to persevere, progressing toward everyday tasks, and integrating practice into daily routine. These findings suggest that further investigation of self-administered, home-based SMART Arm training is warranted for people with stroke who have severe upper-limb disability.


Recovery of upper-limb function after stroke remains poor. Estimates indicate that between 50% and 70% of people with stroke in the chronic stage of recovery have little or no dexterous function of their upper limb 18 mo post-stroke (Houwink, Nijland, Geurts, & Kwakkel, 2013; Kong, Chua, & Lee, 2011; Welmer, Holmqvist, & Sommerfeld, 2008), and nearly 70% continue to report disuse or nonuse 4 yr after stroke (Broeks, Lankhorst, Rumping, & Prevo, 1999). Although the best available evidence indicates that recovery of upper-limb function requires intensive task-oriented training (Bell, Wolke, Ortez, Jones, & Kerr, 2014; Bosch, O’Donnell, Barreca, Thabane, & Wishart, 2014; Lohse, Lang, & Boyd, 2014; Waddell, Birkenmeier, Moore, Hornby, & Lang, 2014), the challenge for people with stroke is to actively engage in such training (Hayward, Barker, & Brauer, 2010). This challenge is particularly relevant for people with severe disability, who have limited underlying movement to engage in task-oriented training (Barker, Gill, & Brauer, 2007) and require training over a long period of time (Dam et al., 1993). Because cost and access to rehabilitation generally prohibit long-term therapy (Barker & Brauer, 2005; U.K. Department of Health, 2007), people with stroke who have severe upper-limb disability need to be able to drive their own recovery.

Home-based training offers one avenue for people with stroke to engage in intensive task-oriented training in addition to hospital and community rehabilitation services and for when those services cease. A systematic review, however, found no evidence that home-based training promotes recovery of...
function for people with stroke who have severe upper-limb disability (Coupar, Pollock, Legg, Sackley, & van Vliet, 2012). Furthermore, interventions included in this review were therapist-administered, the cost of which could limit long-term sustainability. Hence, a need exists for both self-administered, home-based interventions and interventions appropriate for people with severe disability.

The SMART (Sensorimotor Active Rehabilitation Training) Arm is a nonrobotic device specifically designed to enable people who have severe upper-limb paresis after stroke to actively participate in task-oriented training. To date, SMART Arm training has been shown to promote upper-limb recovery in this population when therapist-administered in both home (Barker, Brauer, & Carson, 2008) and hospital (Hayward et al., 2013) settings. However, it is not known whether self-administered, home-based SMART Arm training is feasible for people with stroke who have severe upper-limb disability. The primary aim of this study, therefore, was to explore the feasibility of self-administered, home-based SMART Arm training for one person with stroke who has severe chronic upper-limb disability.

We proposed that self-administered, home-based SMART Arm training, according to the standard SMART Arm training protocol, would be possible for this person. We also proposed that the addition of SMART Arm training to this person’s established rehabilitation program would result in functional improvement comparable to therapist-administered home-based SMART Arm training. The secondary aim of this study was to identify areas for refinement of SMART Arm training for self-administered, home-based use.

Method

A pretest–posttest follow-up, single-case, mixed-method study was conducted after approval by the local hospital human research ethics committees. Occupational therapists and physiotherapists screened people with stroke undergoing outpatient rehabilitation at the local hospital. Inclusion criteria were adult with stroke (≥ age 18); diagnosis of first stroke more than 6 mo earlier; persistent severe upper-limb disability (less than Grade 3 on the Manual Muscle Test [MMT; Medical Research Council, 1978] for the lateral head of triceps and less than 4 points on the Motor Assessment Scale [MAS; Loewen & Anderson 1988 Item 6 [Upper-Arm Function]]); and resident in the local health service catchment area in an accessible home, with sufficient space for use and storage of the SMART Arm device (60 × 120 × 170 cm [2 × 4 × 5.5 ft]; 90 kg [200 lb]).

Exclusion criteria were upper-limb comorbidities that limited functional improvement, for example, substantial arthritis; other neurological conditions, such as Parkinson’s disease; elbow contracture greater than 15˚; and intolerance of or contraindication to cutaneous electrical stimulation. Three people with stroke were identified, of whom two were excluded because of inaccessible homes (i.e., mobile home, elevated home). The third person who met the eligibility criteria was provided with a full explanation of the trial and invited to participate, and subsequently he provided informed consent.

Participant

JT was a 57-yr-old man who had a right frontoparietal hemorrhagic stroke 9 mo earlier. Before the stroke, JT had no adverse medical history, was independent in all daily activities, and worked full time as a handyman. JT had not returned to work since his stroke.

JT received all stroke care at the local public hospital. Immediately after the stroke, JT was admitted to the Acute Stroke Unit with a dense hemiparetic left upper- and lower-limb hemisensory loss and left-sided perceptual neglect. Thirteen days later, JT was transferred to the Inpatient Rehabilitation Service for a total of 95 days. After discharge from the Inpatient Rehabilitation Service, JT attended the Outpatient Rehabilitation Service daily. Within all three services, JT participated in 2–5 hr of daily therapy that focused on recovery of upper- and lower-limb function and activities of daily living.

Throughout the current study, JT was advised to continue his established daily program at the Outpatient Rehabilitation Service. He was medicated with 330 mg of phenytoin to prevent seizures and 5 mg of ramipril and reported taking herbal supplements to improve general health and well-being.

Intervention

In preparation for SMART Arm training, the researchers (a physiotherapist and physiotherapy student) provided JT and his wife with two coaching sessions in their home. The first session (2 hr) focused on SMART Arm set-up, operation, and training according to the standard protocol. They also provided a manual containing this information. The second coaching session (1.5 hr) occurred 1 day later, after JT, with his wife’s support, had completed one training session without a therapist present. The researchers assessed JT’s competency in set-up, operation, and training and gave him feedback. They also coached him on how and when to incrementally progress
SMART Arm training. To guide JT’s progress, the researchers subsequently provided three in-home and three telephone coaching sessions. During coaching sessions, the researchers also engaged in discussion with JT and his wife regarding potential refinements to SMART Arm training. Skype sessions were planned but not conducted because of unreliable Internet connections.

The standard protocol used in previous therapist-assisted SMART Arm research was used (Barker et al., 2008; Brauer, Hayward, Carson, Cresswell, & Barker, 2013; Hayward et al., 2013). JT sat beside the SMART Arm (Figure 1) with his hand held in a customized splint attached to a linear track and his trunk restrained by a harness to minimize compensatory trunk movements (Woodbury et al., 2009). The researchers or his wife applied electrodes to JT’s lateral head of triceps to provide electrical stimulation to augment reaching. They set training parameters for the computer-training program before each session by electronically recording JT’s start position (90° elbow flexion), personal best (active reach distance, i.e., how far JT could reach down the track on his own), and goal for movement (passive reach distance, i.e., how far JT could reach down the track with assistance).

On the sounding of a tone and the appearance of a line (goal for movement) on the computer screen, JT reached as far as possible along the track toward the line. Once JT reached his personal best, electrical stimulation was automatically triggered to augment elbow extension to reach the goal for movement. Real-time auditory and visual feedback were provided through the interactive computer-training program. Feedback included distance reached and repetitions achieved. JT was instructed to undertake SMART Arm training 5 days a week for 4 wk, for a total of 20 sessions. He was instructed to achieve a minimum of 60 repetitions per session in Week 1, progressing to a minimum of 80 repetitions per session in Weeks 2–4.

Automatic progression of the goal for movement and threshold for electrical stimulation occurred within sessions through a predetermined progressive task algorithm (based on distance reached and speed of movement). JT and his wife were required to progress the remaining training parameters by manually adjusting rest time, hand position (splint to hand piece), track elevation and orientation, load, and computer feedback.

JT was required to keep a written record of training sessions in a journal. This record included training parameters (e.g., repetitions, track elevation) and self-reflection (What was good about training? What wasn’t good? How could it have been better?). JT was prompted to consider personal, mechanical, technical, and operational aspects of the device and training protocol and to record adverse events (e.g., pain, falls). Researchers completed a journal entry for each coaching session that included session content and self-reflection according to the questions and prompts provided to JT. Refinements for SMART Arm training occurred during the study (e.g., foot restraint) or were planned for the future (e.g., design changes).

**Measurement**

Several outcome measures were used to assess JT’s arm function. Table 1 lists these measures and provides supporting evidence of validity and reliability for each. JT’s arm function was assessed by the researchers at three time points: 1 day before training, within 3 days of training completion, and 3 mo after training completion. Assessors, order of assessment, and time of day were consistent across time points. Clinical and self-report measures were used to assess arm function in terms of impairment, activity, participation, and the impact of stroke on health and life (Table 2), consistent with previous SMART Arm research (Barker et al., 2008; Brauer et al., 2013; Hayward et al., 2013).

**Data Analysis**

To determine whether training was possible, we investigated whether training occurred according to the training protocol by extracting data from the participant’s journal. These data included dose, training content, assistance provided, and number and content of researcher in-home and telephone coaching sessions. Adverse events were also described and tallied. To determine whether the training provided any clinical benefit, we calculated change scores for clinical and self-report measures between time points.
points. Clinical benefit was defined as a 10% or 1-point change (Van der Lee, Beckerman, Knol, de Vet, & Bouter, 2004; Van der Lee et al., 2001).

To identify areas for refinement of SMART Arm training, we undertook thematic analysis of the participant’s and researchers’ journal entries at the end of the follow-up period. By reading and rereading the journal entries, we (Barker and Neibling) identified key areas for refinement, data coded these key areas, and defined the properties and dimensions of each area (Green & Thorogood, 2009). To verify each key area, we conducted a member check with JT and his wife.

Results

This study used a single-case mixed method to determine the feasibility of self-administered, home-based SMART Arm training; whether adding it to the participant’s outpatient rehabilitation program had clinical benefits; and ways to refine the training. Overall, JT considered his SMART Arm training to be both feasible and effective. He stated,

I’ve had people ask me, did the SMART Arm do you any good? And I say bloody oath it did. It got my arm moving and in turn got my confidence going, which started to allow me to do things that I hadn’t been able to do in a long time.

Table 1. Outcome Measures Used and Supporting Evidence of Validity and Reliability

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Validity</th>
<th>Reliability</th>
<th>Reference for Outcome Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Muscle Test: strength through full range, lateral head triceps, ± indicates range</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Ritchie Articular Index: shoulder pain on passive external rotation</td>
<td>✓</td>
<td>✓</td>
<td>Bohannon &amp; Andrews (1990), Gustafsson &amp; McKenna (2003)</td>
</tr>
<tr>
<td>Motor Assessment Scale: upper-limb function items</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper-Arm Function</td>
<td>✓</td>
<td>✓</td>
<td>Poole &amp; Whitney (1988)</td>
</tr>
<tr>
<td>Hand Movement</td>
<td>✓</td>
<td>✓</td>
<td>Loewen &amp; Anderson (1988)</td>
</tr>
<tr>
<td>Advanced Hand Movement</td>
<td>✓</td>
<td>✓</td>
<td>Kjendahl, Jahnse, &amp; Aarnodt (2005)</td>
</tr>
<tr>
<td>Motor Activity Log–28: how much and how well affected arm is used in everyday tasks</td>
<td>✓</td>
<td>✓</td>
<td>Uswatte, Taub, Morris, Light, &amp; Thompson (2006)</td>
</tr>
<tr>
<td>Stroke Impact Scale: percentage of recovery</td>
<td></td>
<td></td>
<td>Duncan et al. (1999)</td>
</tr>
</tbody>
</table>

Table 2. Upper-Limb Function at Pre- and Posttraining and Follow-Up

<table>
<thead>
<tr>
<th>Measure and Scale</th>
<th>Pretraining (0 wk)</th>
<th>Posttraining (4 wk)</th>
<th>Follow-Up (12 wk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impairment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual Muscle Test: triceps muscle strength, Grade 0–5</td>
<td>3–</td>
<td>4–</td>
<td>4–</td>
</tr>
<tr>
<td>Modified Ashworth Scale (Bohannon &amp; Smith, 1987): resistance to passive elbow extension, 0–4</td>
<td>3</td>
<td>1+</td>
<td>1</td>
</tr>
<tr>
<td>Tardieu Scale: spasticity of biceps, 0–4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ritchie Articular Index: shoulder pain, 0–4</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Activity: Motor Assessment Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item 6 Upper-Arm Function, 0–6</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Item 7 Hand Movements, 0–6</td>
<td>0</td>
<td>1, 3</td>
<td>1, 3, 6</td>
</tr>
<tr>
<td>Item 8 Advanced Hand Movements, 0–6</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Participation: Motor Activity Log–28: 0–5</td>
<td>0</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Stroke Impact Scale on Health and Life, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke Impact Scale: impairment</td>
<td>64</td>
<td>66</td>
<td>67</td>
</tr>
<tr>
<td>Stroke Impact Scale: activity</td>
<td>48</td>
<td>56</td>
<td>60</td>
</tr>
<tr>
<td>Stroke Impact Scale: participation</td>
<td>45</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>Stroke Impact Scale: recovery</td>
<td>40</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Stroke Impact Scale: arm recovery</td>
<td>15</td>
<td>25</td>
<td>65</td>
</tr>
</tbody>
</table>

Note: — = not applicable; ✓ = has supporting evidence.
Feasibility

JT completed 2,100 repetitions during 28 training sessions over 4 wk without hands-on assistance from a therapist or from his wife. JT’s wife provided support for physical aspects of set-up (electrode and trunk-restraint application, foot placement), computer use, and manual adjustment (e.g., adding load). The researchers provided three in-home and three telephone coaching sessions during the training period, as planned. No adverse events were reported.

Training progressed across the 4-wk program. Improvements included increased goal for movement, track elevation (from –7° to 17°), load (from 0 kg to 5 kg), time per session (from 60 min to 25 min), and number of training sessions per day (from one to two sessions); reduced use of electrical stimulation; and change in hand restraint from a splint to a free position.

Clinical Benefits

Before SMART Arm training, JT had moderate upper-limb impairment (triceps strength: Grade 3 on the MMT) but severe activity limitations (0/18 for upper-limb items on the MAS) and participation restrictions (0/5 on the Motor Activity Log–28 [MAL–28; Uswatte, Taub, Morris, Light, & Thompson, 2006]; Table 2). At the completion of SMART Arm training, JT demonstrated a clinically meaningful improvement in arm impairment (triceps strength: MMT Grade 4), activity (5/18 for upper-limb items on the MAS), and participation (1/5 on the MAL–28; see Table 2). At follow-up, upper-limb impairment gains were maintained, and further improvement in arm activity (7/18 for upper-limb items on the MAS) and participation (1.5/5 on the MAL–28) was demonstrated. JT’s perception of his overall arm recovery improved from 15% at baseline to 65% of full recovery at follow-up.

Areas for Refinement

After thematic analysis of journal entries, we identified several areas for refinement. These areas focused on enabling independence, ensuring home and user friendliness, maintaining motivation to persevere, progressing toward everyday tasks, and integrating practice into daily routine.

Enabling Independence. Self-administered, home-based training requires that the person with stroke practice and progress without therapist assistance. According to JT and his wife, factors that enabled them to train independently included coaching sessions and the corresponding manual and automated training progressions. Conversely, JT’s dependence on his wife for set-up and manual progressions meant opportunities for practice were missed. Therefore, recommended refinements included designing one-handed set-up (e.g., electrode cuff), adding a user-friendly touch screen for set-up of the training program, and providing automatic progression across more training parameters.

Ensuring Home and User Friendliness. To be acceptable for self-administered home use, the SMART Arm device and training protocol must harmonize well with the home and the user. JT’s home had adequate physical access and a suitable working space in which the brightly colored device was regarded as an appealing addition. JT and his wife expressed that the training program was user-friendly and foolproof. However, the device size and weight prevented transportation in a standard car. Attachment of hand pieces was time consuming, making set-up and progression slow. Therefore, recommended refinements included reducing device size and weight for transportation, home access, and storage and providing quick-release hand pieces for ease of set-up and progression.

Maintaining Motivation to Persevere. Without people with stroke receiving constant therapist supervision, their compliance with SMART Arm training is dependent on their motivation to persevere. JT was motivated by the 4-wk time period that the SMART Arm was available, on-screen feedback and automatic progressions in response to his success, and in-home coaching sessions during which his progress was reviewed and guidance was gained to progress further. JT’s motivation waned when he had to wait for assistance; when he was unsuccessful because he had progressed a training parameter too quickly (added too much weight); and when he saw little carryover in arm use from training to everyday activities. Therefore, recommended refinements included goal setting and review from coaching session to coaching session, video link-up for out-of-home sessions, and automation or prompting of progressions across all training parameters to enhance carryover to use of his arm for everyday activities.

Progressing Toward Everyday Tasks. The purpose of SMART Arm training is to bridge the gap between no arm function and use of the arm in everyday tasks. JT focused on progressing in reaching distance, repetitions, and load, but he did not initially try to progress in other training parameters (e.g., elevation, feedback, hand pieces). Later, in an effort to generate carryover to everyday tasks, JT practiced tasks of importance to him on, and then off, the SMART Arm (e.g., reaching for bolts and screws). Therefore, recommended refinements included a comprehensive training program consisting of activities on and off the SMART Arm that reflect everyday tasks of importance to the person with stroke and a plan for progression to achieve those tasks.
Integrating Practice Into Daily Routine. To drive recovery over the long term, training must be part of the lifestyle of the person with stroke rather than an addition to, or replacement of, his or her lifestyle. Having the SMART Arm in the home allowed JT to integrate practice into his daily routine. Although unexpected life events disrupted his daily routine and hence his SMART Arm training routine, JT found that once his daily routine was restored, so too was his SMART Arm routine. Therefore, recommended refinements included compiling a daily timetable that reflects the usual routine of the person with stroke and then identifying opportunities for practice within that routine.

Discussion

This study demonstrated that JT, a 57-yr-old man with persistent and severe upper-limb disability after a stroke 9 mo earlier, was able to complete 4 wk of self-administered, home-based SMART Arm training and achieve clinically meaningful improvements in upper-limb function that were maintained at follow-up. Training was performed without hands-on assistance and exceeded the prescribed dose. JT’s wife provided support for set-up and manual progressions, and the researchers provided weekly in-home and telephone coaching sessions. Recommended areas for refinement of SMART Arm training focused on enabling independence, ensuring home and user friendliness, maintaining motivation to persevere, progressing toward everyday tasks, and integrating practice into daily routine. These findings provide support for further development of SMART Arm training as a self-administered, home-based intervention for people with stroke with severe upper-limb disability.

Consistent with our proposition, self-administered, home-based SMART Arm training conducted according to the standard training protocol was possible for a person with stroke. The need for assistance with set-up and manual progressions, however, meant opportunities for training were missed. Nonetheless, compliance with the training protocol was high when compared with other home-based upper-limb training interventions, which have reported as little as 67% compliance with the protocol (Cordo et al., 2009).

Before SMART Arm training, JT had minimal upper-limb function at the impairment level and no measurable function at the activity or participation level, despite having participated in 9 mo of therapist-assisted rehabilitation. When JT undertook self-administered, home-based SMART Arm training in combination with therapist-assisted outpatient rehabilitation, he demonstrated improvements in arm function after training and at follow-up, with the magnitude of change consistent with previous therapist-administered SMART Arm trials in both home (Barker et al., 2008) and hospital (Hayward et al., 2013) settings.

It is possible that JT’s extra practice led to the improvement in function because additional practice results in greater improvements in upper-limb function (Veerbeek et al., 2014). It is also possible that the improvements occurred because the Smart Arm device enabled JT to actively participate in highly repetitive and task-oriented practice, which had not been previously possible for him. Further trials would be required to determine the effect of self-administered, home-based SMART Arm training with and without therapist-assisted outpatient rehabilitation on persons with stroke.

Recommended areas for refinement of SMART Arm training reflected factors previously reported for robotic therapy devices, such as a user-friendly computer interface and independent set-up (Hughes et al., 2011; Lu et al., 2011). However, the most important factor was the participant’s need for training to be integrated into his or her daily routine. Therefore, it is critical for therapists to understand the daily routine of the person with stroke (and his or her support networks) for successful home-based training. This understanding allows training to be efficiently integrated into otherwise competing life roles and responsibilities.

This study demonstrates how a single case study can be used to explore the application of an intervention within a new environment. Purposive sampling enabled selection of a person with stroke from whom we believed most could be learned and who could be closely monitored.

To increase generalizability of the findings, the next step is to undertake further case studies to ensure maximum variation in the sample with respect to the impact of personal and environmental factors (e.g., small home environment, living alone) on the person with stroke. In addition, the effect of self-administered SMART Arm training with and without therapist-assisted outpatient rehabilitation must be studied. Independent assessment and phase repetition either by measurement over several time points (multiple baseline) or a four-phase design (i.e., ABAB; Tate, Aird, & Taylor, 2012) could provide a suitably robust study design.

Implications for Occupational Therapy Practice

This case report has the following implications for occupational therapy practice:

- SMART Arm training may offer a feasible option for people with stroke with severe paresis to undertake self-
administered upper-limb rehabilitation within the home, once recommended changes have been implemented.

- The feasibility of home-based, self-administered training may be influenced by the extent to which training fits into the daily routine of the person with stroke and the availability of coaching sessions to refine and make progress on task practice.

Conclusion

This case report demonstrated that self-administered, home-based SMART Arm training was feasible for one person with severe and chronic upper-limb disability after stroke who had some help with set-up from a support person and minimal coaching by a therapist. In addition, this case demonstrated that improvements in upper-limb function could be made when self-administered, home-based SMART Arm training occurred in combination with therapist-assisted outpatient rehabilitation. Identified areas for refinement of SMART Arm training could be used to guide translation of other interventions to be self-administered and home based. After implementation of refinements to the SMART Arm device and training protocol, robust investigation of self-administered, home-based SMART Arm training is warranted. ▲

References


