ORIGINAL REPORT

ARM STUDIO TO INTENSIFY UPPER LIMB REHABILITATION AFTER STROKE: CONCEPT, ACCEPTANCE, UTILIZATION AND PRELIMINARY CLINICAL RESULTS

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Objectives: To assess the acceptance, utilization and clinical results of an arm studio designed to intensify treatment of the severely to moderately affected arm after stroke. In line with a distal bilateral approach, the equipment comprised 4 workstations, 1 finger trainer, and 3 machines for bilateral training of selected distal and proximal movements.

Design: Open study.

Subjects: Of 119 treated patients after subacute stroke, 30 completed a questionnaire and 24 were assessed.

Methods: All patients completed 15 sessions, each of 30–45 min duration, on each of 2 workstations. Based on the patients' impairment level they were divided into 3 groups, as follows: group A, plegic; group B, proximal and distal movements but hand non-functional; and group C, able to grasp and release an object. Motor functions were assessed with the Fugl-Meyer Score (FM, 0–66) for groups A ($n=6$) and B ($n=6$), and the Action Arm Research Test (ARAT, 0–57) for group C ($n=12$).

Results: No side-effects occurred. The patients regarded the training positively. The initial FM was 8.5 (standard deviation (SD) 3.3) and final FM 21.2 (SD 4.4) for group A, initial FM 25.3 (SD 6.9) and final FM 44.3 (SD 9.1) for group B, and initial ARAT 33.3 (SD 11.2) and final ARAT 43.5 (SD 10.7) for group C.

Conclusion: The use of the arm studio to intensify upper limb rehabilitation after stroke is promising, and a controlled study is warranted.

INTRODUCTION

Stroke affects 180 persons per 100,000 population in the industrialized world annually (1). Of the surviving patients, approximately 80% exhibit arm paresis, the severity of which is bimodally distributed (2). In severe paresis the upper extremity (UE) is non-functional and the grip force of the paretic hand is absent or minimal. The prognosis of regaining meaningful hand activity 6 months later is poor (3); furthermore, early rehabilitation emphasizes the compensatory use of the non-affected hand to regain independence in basic activities of daily living (ADL), which may result in insufficient treatment intensity for the severely affected UE. However, an early intensive treatment approach is advocated in the case of the severely affected UE (4).

Equipment- or robot-mediated therapy is a recent option for intensifying rehabilitation of the UE. Starting from the pioneering work of the MIT-Manus (5), numerous devices have been designed and positively evaluated (see review (6, 7)). Broader clinical application has been hampered not only by cost, but also by the fact that no current machine can substitute the multiple degrees of freedom of the different upper limb segments.

In order to overcome these problems, the authors designed an arm studio comprising several workstations of relatively inexpensive machines to enable the repetitive practice of different movements and tasks, including those of the fingers. The arm studio should allow the cost-effective provision of impairment-oriented treatment without requiring an increase in staffing. The approach is very similar to the Zander Institutes of the early 20th century, which provided mechanized Swedish gymnastics (8), or to modern task-oriented circle class training for the lower limbs (9). The aim of the current study was to examine the use of the arm studio for the non- or minimally functional UE, including its acceptance, and utilization in a consecutive sample of patients after stroke who were admitted for inpatient rehabilitation, and the first clinical results in selected patients after stroke.

MATERIALS AND METHODS

Patient selection

The therapeutic team assessed all acute and chronic stroke patients within 8 months of stroke, for admission to a comprehensive inpatient rehabilitation of 6–10 weeks. Criteria for participation in the arm studio were:

- non-functional or minimally functional UE, according to clinical observation on the ward while dressing, performing personal hygiene and eating in the morning;
- no severe upper limb spasticity, i.e.<3 on the modified Ashworth Scale (0–5, 0 = normal tone, 5 = joint in fixed posture) when tested for passive hand and finger extension while supine;

- no hemiparetic shoulder pain requiring physical therapy or medication for pain;
- no swollen hand impeding closing the fist;
- no other neurological or orthopaedic impairments of the UE requiring physical therapy or medication for pain;
- mobilized in a wheelchair;
- able to follow therapists' instructions;
- a positive single test session in the arm studio;
- informed consent to participate in the open study, approved by the ethics committee.

Arm studio

The studio compromised 6 devices: a computerized arm trainer Bi-Manu-Track (BMT); an electromechanical finger trainer Reha-Digit (RD); and 2 each of the mechanical arm trainers Reha-Slide (RS) and Reha-Slide Duo (RSD) (Fig. 1).

The BMT follows a bilateral distal approach (for a comprehensive description see (10)). It is an end-effector based machine. The patient grasps 2 handles connected to the axes of the 2 drives. In a sitting position, they perform 2 movements in a mirror-like or parallel fashion; a forearm pro-supination and a wrist flexion extension. The drives enable 3 treatment modes: passive–passive, active–passive with the non-affected hand driving the affected hand, and active–active, whereby the patient has to overcome an initial isometric resistance to free the bilateral movement. Within 20 min, the patient practises 400 repetitions each of the 2 movement cycles, totalling 800 repetitions with the 3 modes evenly distributed.

The finger trainer, RD, enables the passive movement and vibration of the fingers II–V (for a comprehensive description see (11)). It consists of 4 mutually independent plastic rolls, each fixed eccentrically to the powered axle of the device, forming a cam-shaft. The surface of each finger roll is concave, forming a gutter to maximize the contact area between finger and roll. Two smaller locking rollers, also concave, hold each finger against the larger finger roll. A 24 V direct current motor rotates the drive axle up to 30 times a minute through a clutch mechanism, which allows the axle to stop rotating if the hand goes into a powerful spasm. A vibration engine, situated under the base plate, provides small amplitude (2 mm) stimulation at a frequency that can be set at between 0 and 30 Hz. A session lasts 15 min corresponding to 300 rotations at a frequency of 20 Hz, which was found to be convenient for most patients.

The arm trainer, RS, is positioned on a height-adjustable table. It consists of 2 yoked grips, which the patients can move in 3 dimensions: forwards–backwards, sideways, and in a rotational manner comparable

Fig. 1. Arm studio for severely affected patients after stroke. Patients practising on several devices. Front to back, and left to right: Bi-Manu-Track, Reha-Digit, Reha-Slide duo and Reha-Slide.

to that of a motorbike accelerator (for a comprehensive description see (12)). Computer biofeedback, via a wireless mouse connected to the combining rod, is optional. Within a period of 15–20 min, the patient practises 400 movements; 200 forward–backward movements, 100 circles clockwise, and 100 anticlockwise. The patient then plays a computer-based, individually adjusted game, requiring bimanual co-ordination for approximately 5 min.

The arm trainer, RSD, which is akin to the custom-made BATRAC (bilateral arm training with rhythmic auditory cueing; commercialised as Tailwind by Anatomical Concept UK Ltd, Clydeland, Scotland), is positioned on a height-adjustable table. It comprises 2 unyoked grips, which the patient can move forwards and backwards in a parallel or alternate fashion. A stool harness prevents compensatory trunk movements. Resistance to the movement can be set individually on either side. The grips can be adjusted so that the patient can practise while sitting or standing. Within a period of 20 min the patient practises 5 blocks of 5 min of either a parallel or alternate movement execution. A total of 100–300 repetitions is common.

Treatment algorithm

The selected patients participated in an additional 3-week programme in the arm studio, for 30–45 min each weekday; a total of 15 sessions. The choice and number of workstations used depended on the severity of paresis of the UE. Three groups were formed. In group A ($n=6$) the hand was plegic with no palpable movement of the wrist and finger extensors, the patients could at most move the shoulder and/or the elbow in a synergistic manner. In group B ($n=6$), starting selective movements proximal and/or distal, for shoulder elevation and abduction a visible movement with gravity eliminated, corresponding to a Medical Research Council Scale (MRC) grade of 2 (MRC 0–5, 0=plegic, 5=normal strength), was required. In group C ($n=12$), patients were able to grasp, reposition and release a tennis ball placed on a table in a therapeutic situation.

For those patients whose group assignment was a matter of debate within the therapeutic team, the Fugl-Meyer motor score (FM, 0–66, see below) served as a further criterion: with group A FM 14, group B FM > 14, and group C FM ≥ 34.

For every session, group A practised with the BMT and the RD, group B with the BMT and the RS, and group C with the RS and RSD. One therapist and one helper were responsible for setting up and supervising of the 6 workstations in the studio, following thorough instruction in their use.

The conventional rehabilitation programme was continued for all patients, with a mean of 4 individual sessions of physiotherapy and 3 individual sessions of occupational therapy, of 30 min each, every week. The underlying concept was a functional approach to the restoration of mobility and competence in ADL as primary goals. Whenever possible, the therapists tried to incorporate the paretic hand into functional tasks, such as dressing, eating or combing the hair.

Outcomes measured

The therapeutic team checked for any side-effects, such as shoulder pain (for RS and RSD), blisters on the fingers and palm (for BMT and RD) and soft tissue pain (for all devices).

A questionnaire was used to assess the patients' subjective impressions of the arm studio rehabilitation programme. The questionnaire comprised 7 questions (Table I), which patients answered on a 5-step ordinal scale (++, +, 0, –, and – –, corresponding to yes absolutely/excellent, yes/good, do not know/no change, no/bad, not at all/very bad). In addition, patients and their relatives were able to comment freely.

An experienced rater assessed the motor function of the upper limb with the help of internationally known scales at the beginning and end of the 3-week course. The rater was aware of the fact that the patients had trained in the arm studio. In groups A and B, the FM score, and in group C the ARAT, were applied. FM provides a valid and reliable assessment of reflexes and motor tasks according to presumed stages of recovery, with each motor subtest comprising 1–7 items. All items are
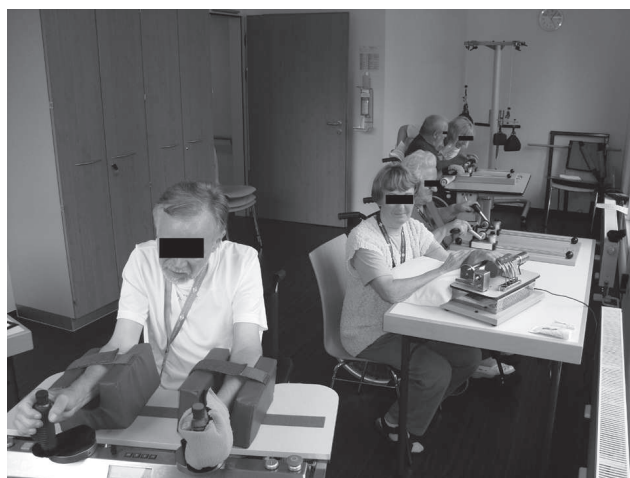
Table I. *Results of questionnaires of 30 patients at the end of the study*

| | ++ | + | 0 | – | – – |
	n	*n*	*n*	*n*	*n*
How content were you with the additional therapy opportunity in the arm studio?	18	11	0	1	0
Did you enjoy the training with the devices?	17	12	0	1	0
Did the training increase your motivation?	15	13	1	1	0
Did the devices enable you to exercise independently?	6	13	8	3	0
Were the therapeutic support and instructions sufficient?	13	11	4	2	0
Do you think that this kind of training may enhance the motor functions of your upper limb?	9	10	10	1	0
Would you recommend the arm studio as an additional training?	12	16	1	1	0

++: best validation; +: positive validation; 0: neutral validation; –: negative validation; – –: worst validation.

scored according to a 3-point ordinal scale, except for reflex activities (which are dichotomous). The scores represent no function (0), partial function (1) and perfect function (2). The maximum FM score is 66.

The ARAT monitors UE function, related to ADL. The complex movements of the UE are reduced to certain patterns, i.e. grasp, grip, pinch and gross movements. There are 19 items divided into 4 subtests (grasp, grip, pinch and gross movement). The subtests are structured hierarchically, with an ordinal 4-point scale applied to each item. A score of "0" is given if the patient is not able to perform any part of the task, a score of "1" if the patient is able to lift the object completely from the platform, a score of "2" if the function can be performed fully but clumsy, and a score of "3" if the item is performed normally. The maximum ARAT score is 57.

Effect sizes for the dependent variables in each group were calculated.

RESULTS

Within 8 months, 159 patients after stroke, admitted for in-patient rehabilitation, were screened. Of these, 119 met the study inclusion criteria, and were enrolled in the 3-week programme in the arm studio. The 3 main reasons for refusal were: (*i*) UE less impaired, (*ii*) patients did not regain wheelchair mobility at all or not early enough to be enrolled in the 3-week programme, and (*iii*) a too severely impaired cognition.

Of the 119 participating patients, 65 were men and 54 women, their mean age was 75.0 years, mean stroke interval 4.3 weeks, and 62 patients had right hemiparesis and 57 left hemiparesis. Ninety-eight patients were in the subacute stage and 21 in the chronic stage after stroke.

All but 6 patients completed the 3-week course. The reasons for non-completion were: acute worsening of the health condition (4 cases), and refusal (2 cases) as the patients did not perceive any benefit for themselves of the demanding programme.

In addition to other in- and out-patients with various aetiologies other than stroke, a mean of 22.2 patients were treated every weekday.

No side-effects, interrupting the treatment for one day or more, occurred.

Every fourth patient (*n* = 30) completed the questionnaire. Most of the patients answered the questions with ++ or +; – or – – answers were not given. All patients were content (Table I); 18 patients reported that they had very much liked (++, *n* = 11) or liked (+, *n* = 7) participating in the programme. Nineteen patients agreed that they could have practised independently, 24 patients rated the therapeutic supervision positively, and with the exception of 2 subjects, all patients would recommend

the treatment to other patients. Nineteen patients reported an improvement in their condition with respect to the affected UE. On request patients in group A mainly reported a reduction in increased muscle tone, whereas patients in groups B and C experienced improvements to various extents in their affected hand function in daily life, ranging from helping with dressing to turning the cap of a toothpaste tube, for example.

In 24 consecutive patients the motor functioning of the UE was assessed. (This did not include all patients as an experienced external assessor was available for only a limited time). Of these, 6 patients were from groups A and B, and 12 patients from group C (Table II).

The mean (SD) initial FM of the 6 patients in group A was 8.5 (SD 3.3), and the mean final FM was 21.2 (SD 4.4). All 6 patients were in the subacute phase (Table II).

The mean (SD) initial FM of the 6 patients in group B was 25.3 (SD 6.9), and the mean final FM was 44.3 (SD 9.1). Of these, 1 patient was in a chronic phase with a stroke interval of 2 years prior to onset of treatment. His initial FM score was 18 and final FM score 31 (Table II).

The mean (SD) initial ARAT of the 12 patients in group C was 33.3 (SD 11.2), and their mean final ARAT was 43.5 (SD 10.7). Two patients were in the chronic phase; their initial scores were 18 and 49, and final scores 27 and 55, respectively.

The effect sizes (Table II) were 3.2 (FM, group A), 2.3 (FM, group B), and 0.9 (ARAT, group C).

DISCUSSION

This paper presents the concept, treatment algorithm, and first clinical results of an arm studio to intensify rehabilitation of the upper limb after stroke. The results do not lead to any conclusion on its effectiveness.

The arm studio, which provides high-intensity impairment-oriented training, may, however, have great potential for the rehabilitation of the upper limb of severely affected patients after stroke. First, the studio may be more cost-effective than additional individual physical therapy sessions; as only 1 therapist and 1 helper are necessary to run each group session for up to 6 patients, a mean of 22.2 patients could be treated every day. Secondly, the arm studio workstations can be customized to the individual status of each participant, including the intensity, frequency, and duration of the exercise. Thirdly, the majority of the patients regarded the training positivelyabout the additional training; only 6 of 119 patients dropped out. With the

Table II. *Clinical data and initial and final assessment values for upper limb motor control at admission and discharge from the arm studio. The Fugl-Meyer score (FM, 0–66) was used in groups A and B, and the Action Research Arm Test (ARAT, 0–57) in group C*

Patient number	Sex/age, years	Hemi	Time from stroke (weeks)	Assessment value	
				Admission to arm studio	Discharge from arm studio
Group A					
1	M/66	Right	3	5	20
2	F/78	Right	6	7	20
3	M/75	Left	4	7	20
4	M/83	Right	5	8	23
5	F/84	Left	3	12	19
6	M/76	Left	6	13	29
Mean (SD)	77 (6.5)		4.5 (1.4)	FM 8.5 (3.3)	FM 21.2 (4.4)
				Effect size: 3.2	
Group B					
1	M/62	Right	96	18	31
2	M/80	Left	4	19	50
3	F/61	Left	3	22	44
4	F/72	Right	3	26	41
5	M/74	Right	3	33	42
6	M/68	Left	3	34	58
Mean (SD)	69.5 (7.3)		18.7 (37.9)	FM 25.3 (6.9)	FM 44.3 (9.1)
				Effect size: 2.3	
Group C					
1	M/70	Left	8	14	30
2	F/81	Left	74	18	27
3	F/88	Right	3	25	36
4*	M/80	Right	3	29	38
5	M/68	Left	5	29	38
6*	F/67	Right	6	35	40
7	F/77	Right	4	36	57
8	M/70	Left	3	37	57
9	F/86	Left	3	37	43
10	M/79	Left	3	38	44
11	M/74	Left	80	49	55
12	F/81	Left	3	52	57
Mean (SD)	16.3 (28.4)		16.3 (28.4)	ARAT 33.3 (11.2)	ARAT 43.5 (10.7)
				Effect size: 0.9	

*Patient had a haemorrhagic stroke, whereas others had ischaemic strokes.

use of the arm studio, the rehabilitation of the patient's paretic UE was more effective, the impairment-oriented approach of the studio reinforced the individual therapy, which aimed to incorporate the paretic hand into daily activities, and the group dynamic between patients using the studio, particularly when comparing individual results obtained for the computer games with the RD, was considered stimulating.

Regarding the selection of workstations, the reader is referred to the potential conflict of interest of the senior author (SH), described below. The selection of alternative workstations would be possible, and a preceding positive randomized controlled trial (RCT) would be valuable. For the workstations described in the current paper, positive RCTs have been reported for the BMT ($n=44$) (10), the RS ($n=56$) (12), and the BATRAC ($n=21$) (23), akin to the RSD.

The underlying theory of the workstations selected were passive mobilization, repetitive training of isolated movements, a distal approach to upper limb rehabilitation in severely affected patients, and a bilateral approach, except in the case of the RD.

The bilateral training aims to facilitate rehabilitation of the paretic side through stimulation of the intercallosal fibres, as shown by Renner et al. (13), given that the non-affected hand reached at least 10% of its maximum grip force. Furthermore, for single patients in the subacute phase, Staines et al. (14) showed that a bilateral approach was superior to a unilateral one with respect to clinical effectiveness and brain activation of the primary motor area of the lesioned hemisphere.

A larger cortical representation of the hand compared with the shoulder, and the discussed competition between proximal and distal segments for plastic brain territory after stroke, are arguments in favour of a distal approach to rehabilitation, as used in the BMT and RD (15).

The repetitive training of isolated movements is supported by the repetitive wrist paradigm of Bütefisch et al. (16), which proved superior to Bobath therapy in subacute patients after stroke. Nevertheless, many therapists would argue that a more functional and goal-oriented approach might yield better results than the repetitive and potentially boring training of isolated movements. However, Higgins et al. (17) failed to show any superior effect of a functionally-oriented upper limb training (3 times per week over a period of 6 weeks) in a study of 91 mildly affected patients within 1 year after first-time stroke. In this study the control group practised gait only.

The passive joint mobilization aimed to prevent the immobilization-related risk of changes in soft tissue and joint compliance associated with developing contractures. In healthy subjects, positron emission tomography has shown that active and passive elbow movements result in identical strong increases in regional blood flow in the sensorimotor cortex (18). Similarly magnetencephalography has revealed dipolar sources within 1 cm of the central sulcus following passive finger movement (19).

No side-effects occurred. Those patients with pre-existing hand or shoulder pain, arthritis or soft tissue problems were not included in the study population, as they were most likely to develop problems. It remains to be seen whether arthritis, which is common among people of the same age range as those who experience strokes, is aggravated or helped by repetitive gentle movement in the arm studio. As stated previously, the results of this pilot study do not allow any conclusions to be drawn about the effectiveness of the arm studio rehabilitation. Additional limitations of this study are the small number of patients assessed before and after the intervention, the potential bias in the selection of workstations, and the lack of validity of the questionnaire of the questionnaire about patients´ perception of the studio rehabilitation. Group A predominantly reported a reduction in elevated muscle tone, whereas single patients in groups B and C reported substantial improvements in activities of the paretic hand. These impressions were reflected in the results obtained in randomly selected patients. Six randomly selected patients in group A and 6 in group B had improved their FM score by a mean of 12.7 (SD 3.5) and

19.0 (SD 8.1) points, respectively, even though 2 of the 6 patients in group B were in the chronic stage. In the BMT and RS trials, subacute patients after stroke with an initial mean FM score of less than 10 in both studies improved their FM by a comparable mean of 11.8 and 10.4 points, respectively, but the treatment schedule in those 2 studies was 6 weeks of daily training. The effect sizes of the dependent variables of group B and C corresponded to sample sizes of 12 randomized controlled trials (see (17), Fig. 2, p. 305), whereas in group A, the most severely affected patients, the effect (3.2) was stronger. Despite the limited validity of an effect size calculated for dependent variables, this result warrants further investigation of the potential of the arm studio in that subgroup of patients. Based on the FM, Duncan et al. (20) distinguished 3 groups of patients who were treated conventionally. The most severely affected subjects had an initial mean FM score (0–66) of less than 10 one month after stroke (comparable to patients in group A), 3 months later their mean FM score was 13 (values derived from ref 20, Fig. 2, p. 838).

In conclusion, the arm studio may be a cost-effective option to increase the intensity of impairment-oriented training for severely affected patients after stroke. The patients' acceptance of the training, and the preliminary results described here, justify setting up a controlled trial to investigate the effectiveness and efficiency of this treatment.

ACKNOWLEDGEMENTS

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