Arm Ability Training for Stroke and Traumatic Brain Injury Patients With Mild Arm Paresis: A Single-Blind, Randomized, Controlled Trial

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ABSTRACT. Platz T, Winter T, Müller N, Pinkowski C, Eickhof C, Mauritz K-H. Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: a single-blind, randomized, controlled trial. Arch Phys Med Rehabil 2001;82:961-8.

Objective: To test the efficacy of the arm ability training (AAT) on a sample of patients with central arm paresis after traumatic brain injury (TBI) or stroke.

Design: Single-blind, randomized, controlled trial.

Setting: Inpatient rehabilitation center.

Patients: Consecutive sample of 74 patients of whom 60 (45 with stroke, 15 with TBI) completed the study; 37 patients received a 1-year follow-up.

Intervention: Daily AAT with ($n = 20$) or without ($n = 20$) knowledge of results, or no AAT ($n = 20$) during a 3-week intervention period.

Main Outcome Measures: Summary time scores of the Test Evaluant les Membres superieurs des Personnes Agees (TEMPA)—a test of upper extremity function with daily function–like activities (focal disability)—and kinematic analysis of aimed movements.

Results: Patients with AAT realized superior improvement as compared with controls. Mean improvement in the time needed to perform (1) all TEMPA tasks was 41.4 versus 12.8 seconds ($p = .0012$); (2) unilateral TEMPA tasks, 16.5 versus 4.2 seconds ($p = .0036$); and (3) the ballistic component of aimed movements, 96 versus 20ms ($p = .0115$). Knowledge of result did not substantially modify these effects. A functional benefit existed at 1-year follow-up.

Conclusion: The AAT reduces focal disability among stroke and TBI patients with mild central arm paresis.

Key Words: Activities of daily living; Arm; Brain injuries; Cerebrovascular accident; Paresis; Rehabilitation.

OUTCOME STUDIES have provided clear evidence of the effectiveness of stroke rehabilitation in the achievement of independence in activities of daily living (ADLs).[1] However, controlled trials comparing different, widely used treatment methods for motor rehabilitation of stroke victims (conventional therapy, proprioceptive neuromuscular facilitation, the Brunnstrom, Rood, or Bobath techniques, electromyographic biofeedback) have failed to document their differential therapeutic effects in terms of arm function, gait, and ADL competence.[2-7] As a consequence, their specific efficacy, and any effects of spontaneous recovery, are difficult to determine; further evaluation of the efficacy of specific interventions in motor rehabilitation with clinical trials seems warranted.

In recent years, some treatment approaches have clearly been shown to be efficacious. In patients with moderate to severe central arm paralysis and inability to activate individual muscles selectively, training techniques that permit repetitive, selective, muscular activation have been especially useful. Examples of such techniques are repetitive hand training,[8] electromyography-initiated electric stimulation,[9] and a sensorimotor stimulation technique.[10] Also, several studies[11-13] have shown that arm function in chronic stroke patients with moderate paresis, who develop a learned nonuse of the affected arm, can be improved by constraint-induced movement therapy. These examples suggest that motor rehabilitation therapies might best be designed to focus on specific functional problems such as selective innervation or learned nonuse of recovered function.

At present there is no specific arm rehabilitation technique with proven efficacy for patients with stroke or traumatic brain injury (TBI) who have mild central arm paresis and who already have had good recovery of arm function. Patients who have regained considerable strength and selective innervation can perform most everyday motor tasks, but nevertheless have quantitative limitations such as reduced speed and accuracy with various motor tasks.[14,15] As a consequence, their motor performance appears clinically clumsy and slowed. Further, these patients are the ones who are most likely to live independently and to resume previous activities, including their occupations. In that situation, even minor motor deficits may be a considerable handicap to these patients because of the everyday demands on their motor abilities. Thus, there is a need to develop and evaluate therapeutic interventions.

Arm ability training (AAT) for stroke and TBI patients with mild central arm paresis has been developed by one of the authors (TP). The training was designed to address this specific patient group's deficits; it incorporates training strategies believed to enhance transfer from the training situation to everyday life.

The term *motor abilities* refers to different independent sensorimotor capabilities that together support a wide range of arm activities. Examples of abilities that have been established by factorial analysis among healthy subjects are manual and finger dexterity, arm-hand steadiness, aiming, and wrist-finger

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speed.[16-18] It has been shown that stroke patients with good clinical recovery still have limitations with all of these motor abilities.[14,15] Therefore, the training was structured to address these different abilities, offering the potential that any improvement of motor abilities would translate into improved motor performance in different circumstances.

Other factors incorporated in the AAT that were thought to improve motor learning were the repetitive structure of training,[8,19,20] and the variation of task difficulty.[21] Further, improvement in speed and accuracy of execution (as opposed to pattern of joint motion) was continuously emphasized, both as a general training concept made explicit to the patient and by verbal instructions during training. The explicit behavioral goal is a more efficient motor performance through accuracy and speed; merely repeating training tasks at a given performance level is not considered an optimal stimulus for further recovery in the AAT approach.

Knowledge of results is feedback about the outcome of movement in terms of the environmental goal (eg, accuracy and speed of movement), whereas knowledge of performance relates to movement pattern.[21] Because ATT's behavioral goal is improved outcome of the movement rather than movement pattern (which is a lesser problem with the target population), knowledge of results is conceptually related to the AAT. This type of augmented feedback is a key factor in promoting motor learning among healthy individuals.[22] Thus, its efficacy has potential for patients; it could promote training effects by increasing motivation to achieve the intended behavioral goal, or guide the selection of movement strategies.

It was hypothesized that the AAT improves arm function in terms of more efficient motor performance among patients with mild central arm paresis after stroke or TBI and that telling patients about their results during training sessions can further enhance the AAT's effect. Accordingly, the objective of this single-blind, randomized, controlled trial was to investigate (1) the efficacy of the AAT on arm motor function (focal disability), and (2) the effect on the study sample of additional knowledge of results.

METHODS

Subjects

Sixty patients (45 with stroke, 15 with TBI) with mild central paresis completed the study. All admissions to the Department of Neurological Rehabilitation at the Free University, Berlin, between June 1996 and December 1998 were screened to determine their eligibility for the study. Admission criteria were (1) a first unilateral supratentorial stroke (localized intracerebral hemorrhage or ischemic stroke) in the subacute phase from 3 weeks to 6 months poststroke or a TBI in the subacute or early chronic phase from 3 weeks to 24 months postinjury and (2) mild central arm paresis (Motricity Index[23] arm score $<$ 100; shoulder abduction and elbow flexion muscle strength $>$ 3/5, thumb-index finger-opposition strength $>$ 2/5 using Medical Research Council criteria[24]; selective finger movements and precision grip preserved; no major somatosensory disturbance, ie, no or slight reduction of sensation to light touch and no position sense deficit).

Stroke and TBI patients were selected because cerebrovascular accident and brain injury are the most common causes of acute onset central arm paresis that have a good potential for consecutive recovery. In case of bilateral motor impairment with TBI patients, the more affected arm was trained.

In selecting patients for the study, it was necessary that they have some residual weakness (Motricity Index below full score). Also, as a prerequisite for the AAT, patients had to be able to move their arms against gravity and some resistance (shoulder and elbow flexion strength of 4/5), to move their fingers, and be able to grip objects (finger opposition strength at least 3/5). Patients with severe somatosensory deficits were ineligible because their motor control deficits and the effects of training differ from motor stroke patients.[25]

Patients were excluded if they were older than 80 years; had peripheral nerve damage of the trained arm; had musculoskeletal disease affecting arm mobility; or had any cognitive dysfunction of a severity that was incompatible with training participation (ie, severe behavioral disturbances or speech comprehension deficits incompatible with a structured motor training). As possible baseline indicators of an individual's potential for spontaneous recovery and general learning abilities, we documented duration of disease and estimated premorbid intelligence quotient based on sociodemographic data[26] at baseline and compared between experimental groups. The study was approved by the local ethics committee. All participants gave written informed consent.

Design

We used a single-blind, randomized block design. Subjects were blocked according to their diagnosis and randomly assigned to each level of the experimental factor by software based on a computerized random number generator (no AAT, $n = 20$; AAT, $n = 20$; AT+KR [knowledge of results], $n = 20$). Sealed envelopes were used to achieve blinding for study recruitment personnel.

Treatment Conditions

Arm ability training. Patients receiving the AAT had—in addition to routine inpatient rehabilitation therapy—15 training units, 1 per weekday for 3 consecutive weeks. Training was provided on an individual basis by an author (NM) and supervised by the principal investigator (TP).

Arm abilities had been established based on factorial analysis of motor performance among healthy subjects and denote independent motor abilities that in various combinations account for arm motor performance in varying circumstances.[16-18] They are arm-hand steadiness, the ability to keep the arm steady; tracking, the ability to move precisely under continuous visual control; aiming, the ability to perform rapid goal-orientated movements; wrist-finger speed, the ability to make quick isolated alternating movements of wrist and fingers; finger dexterity, the ability to manipulate small objects, primarily with the fingers; and manual dexterity, the ability to grip and manipulate larger objects, primarily with the hands and arms. As a whole, not on an individual basis, AAT training tasks were chosen to involve, and thereby to train, different abilities. Thereby, training task selection has a chance to be comprehensive in terms of task relevance for motor performance in the many different circumstances encountered in daily life (ie, if different motor abilities could be promoted by the training, this should transfer to a wide range of everyday motor behavior).

The training consisted of 8 different tasks (table 1). Within each task a variation of task difficulty was implemented (ie, various sizes of targets for aiming). Workload was individually standardized; before starting AAT, each patient was assessed to determine the level of difficulty with which he/she could cope with each task and how many repetitions he/she could perform within 1 minute. Accordingly, individual workloads were determined for the remainder of the training period. The workload and repetitions for each type of task that could be performed within 1 minute was considered 1 block. Each day, 4 blocks of every type of task were consecutively practiced.

Table 1: AAT Tasks

1. AIMING: hitting targets with a stylus (distance 18–23cm, target width 3–25mm, on table surface and 30cm above table surface) requires fast and accurate arm movements
2. TAPPING: fast, repetitive alternating movements of index and middle finger
3. CANCELLATION of circles of various sizes with a pen involves small and precise finger/hand movements while stabilizing the upper arm
4. TURNING COINS: requires finger dexterity and forearm pro- and supination
5. MAZE TRACKING: involves precision of slow, continuous, visually guided movements
6. BOLT and NUT: picking up bolts (diameter, 2, 5, 10mm) (nonaffected arm) and nuts (affected arm) and screwing nuts on bolts (affected arm) requires finger dexterity, aiming, and steadiness
7. PLACING SMALL OBJECTS: small wooden objects (width, 25, 10, 5mm) have to be placed on top of each other at different positions in the workspace involving finger dexterity, aiming, steadiness, and partially forearm pro- and supination
8. PLACING LARGER OBJECTS: water-filled jam glasses (diameter, 8, 6.5, 5.5cm) have to be transported across the workspace (20cm) and put on top of each other affording manual dexterity, aiming with different weights, and endurance

Thus, at the beginning, absolute training time (exclusive of rests and workspace restructuring time) was 32 minutes; training time was decreased when patients were able to complete their workloads more quickly. During the training, patients were encouraged to complete their workloads in even less time but without compromising the individual tasks' accuracy demands. Independent of the type of task, any improvement would thus translate into a reduced time demand for the standardized workload.

Knowledge of results. Patients who received average knowledge of results were shown bar diagrams on a computer screen during training that indicated their individual progress: results were provided separately for each type of task. After each block of training, the time needed to complete that block was shown on the screen; after 4 blocks had been completed, the average time needed to complete them was shown for the current day and for all previous training days. Because patients were not allowed to compromise the accuracy demands of training tasks, any improved efficiency of motor performance was reflected in a reduced time demand. Hence, time needed to complete blocks of training tasks served as global performance score that patients easily understood.

Assessment

Patients were assessed twice in 3 weeks, once before and once after treatment (pre- and posttest). Assessment involved measures of focal disability and of motor performance. Side effects were documented at the second assessment. In addition, patients were invited to participate in a follow-up assessment of focal disability 1-year posttest.

Assessment of focal disability. The primary purpose of the study was to investigate AATs: efficacy (and knowledge of results) in improving the efficiency of motor performance, especially with ADLs (focal disability). The Test Evaluant les Membres superieurs des Personnes Agees[27] (TEMPA) is currently the only commercially available, thoroughly validated, timed test of upper extremity performance of tasks representing ADLs and consequently was chosen for the trial.

TEMPA involves 9 unilateral and bilateral tasks related to routine ADLs in a fixed order, with standardized material and test positions. Subjects are (1) to pick up and move a coffee jar from an upper to a lower shelf (unilateral task); (2) to open a jar, take a spoonful of coffee, and put it into a cup (bilateral task); (3) to pick up a pitcher containing 500mL of water from an upper shelf and pour water into a glass (unilateral task); (4) to take a key, unlock a locker containing a pillbox, open it, and get 2 placebo pills in 1 hand (bilateral task); (5) to write "Belle Canada" on an envelope and affix a postage stamp (bilateral task); (6) to take a folded scarf and tie it around his/her neck (bilateral task); (7) to take a deck of cards, shuffle it 3 times, and deal 5 cards (bilateral task); (8) to handle 4 different coins and insert them in a slot near the top shelf (unilateral task); and (9) to pick up different small objects and release them into a small jar (unilateral task). Each task is measured according to 3 criteria: length of execution, functional rating, and task analysis. For length of execution, each task is timed to the nearest tenth of a second, beginning as soon as the subject's hand leaves the table and ending the moment the task is completed.

Test-retest and interrater reliability had originally been established with a sample of 29 subjects aged between 62 and 82 years with neurologic or orthopedic conditions affecting the upper limb (including stroke); intraclass correlation coefficients (ICCs) ranged from moderate to high (.70–1.0).[27] In another study[28] of 104 subjects aged 60 to 94 years, concurrent validity was shown by estimating the correlation between TEMPA and 2 tests measuring similar constructs, the Action Research Arm Test (ARAT) ($r = .90$–.95) and the Box and Block Test ($r = .73$–.78); further, TEMPA was shown to correlate more strongly with an ADL test ($r = .69$–.71) than the ARAT ($r = .55$–.60). We assessed interrater reliability of a German version[29] with the 60 patients in the current trial (ICC $> .98$ for summary time scores, $\rho > .83$ for summary scores of functional rating and tasks analysis) and test-retest reliability (ICC $> .88$ for summary time scores, $\rho > .88$ for summary scores of functional rating and tasks analysis). We also assessed various validity aspects with a sample of 26 patients (including stroke and TBI patients) aged 14 to 86 years with neurologic upper extremity impairment and with a sample of 32 control subjects aged 15 to 83 years.

The primary dependent variables of the trial and measures of focal disability were (1) the summary time score needed to complete the unilateral tasks of TEMPA when performed with the affected arm, and (2) the summary time score needed to complete all tasks of TEMPA. Length of time needed to execute tasks was selected rather than its qualitative aspects (ie, movement pattern), because the AAT aims primarily at improving efficiency of motor performance. Qualitative assessment criteria of TEMPA, ie, functional rating and task analysis scores, were therefore not selected as dependent variables; in addition, suspected ceiling effects and limited sensitivity to change with these ordinal scales could have limited their usefulness if used with patients with only mild disability.

Assessment of motor performance. Using a standardized procedure, aiming movements were kinematically analyzed with a digitizing tablet (sampled at 100Hz).[a] Twenty, single, standardized, fast and accurate aiming movements were performed with a stylus on a table by seated subjects. The home position was located near the body, the target at a distance of 200mm from the home position in midline with a target width of 12.5mm. Movements were started after a warning and "go" signal with interstimulus intervals that varied randomly from 1 to 3 seconds. Aimed movements involving shoulder flexion and elbow extension were to be performed as quickly as possible within the accuracy demands of the task (the target had to be hit with the tip of the stylus). The kinematic analysis was of total movement time for each aimed movement and its 2 constituents: a largely ballistic component (phase 1), from movement onset to maximal deceleration, covering the major proportion of movement distance; and a final homing in component (phase 2), from maximal deceleration to the end of the movement, covering the final paths of the movement, guaranteeing endpoint accuracy, and depending more on feedback during the movement. Accuracy measured as absolute error (vectorial distance from center of target at movement termination) was intended to be held constant across subjects and time of assessment so that the performance level could be interpreted based on movement time data. Test-retest reliability, the test's ability to discriminate between motor stroke patients with good recovery and healthy controls, and its sensitivity to change was shown.[15]

Secondary, dependent variables for pre- and posttest included each patient's mean total movement time and accuracy for aiming movements, and time of the first and second phase of aiming movements.

Blinded evaluation. The primary clinical evaluator (CP) was blinded to the patient assignment in the 3 groups and to the pre- and posttest status of assessments. This was achieved by randomly assigning identification numbers to each assessment, by videotaping (TEMPA) or digitizing (aiming) performance, and by evaluating results in a random order after each patient had completed pre- and posttesting. Test results of TEMPA were exclusively based on videotapes. The primary clinical evaluator assessed length of execution for TEMPA tasks using videotapes and assessed offline whether the automated kinematic analysis for aimed movements was appropriate.

TEMPA scores from a second clinical evaluator (NM), also based on videotapes, were used to calculate interrater reliability coefficients. The interrater reliability was very high for the summary time score needed to complete all TEMPA tasks and these were performed with the affected arm only (unilateral and bilateral, ICC = .997; unilateral tasks, ICC = .997).

Side effects. At the posttests, all patients receiving the AAT were asked to complete a form about the side effects of the training at the time. They were asked whether they experienced any side effects of the experimental arm training. Control subjects were not asked.

Sample Size Calculation

Sample size calculation was based on the secondary dependent variable (aiming) because of a lack of information about the expected effects with the primary dependent variable (TEMPA). A sample of 20 patients per group was necessary to achieve an 80% chance (power = .80) to observe a statistically significant ($\alpha = .05$, 2-sided test) differential effect of the experimental levels (ie, AAT) of similar magnitude, as reported in a sensitivity to change analysis.[15] It was predetermined that any enrolled patient lost during the 3-week observation period would be replaced to ensure statistical power of the efficacy trial.

Statistical Analysis

Potential differences of characteristics of experimental and control groups were assessed by analysis of variance (ANOVA) (continuous data) and chi-square tests (nominal data). General linear models were used to test differences in improvement over time between levels of experimental factors. These models included multiple regressions within a repeated-measures ANOVA design.[30] Repeated measures were pre- and posttest scores of dependent variables (factor time). Independent (between-subjects) variables were the experimental factors (AAT vs no AAT = factor AT; KR vs no KR = factor KR), and the factor diagnosis (stroke or TBI). Of main interest were the time × experimental interactions. Diagnosis was included in the model as potential modifier. In a subsequent analysis, the potential modifying effect of the affected side was evaluated by adding the factor arm (right or left) in the model.

The AAT's efficacy[31] was assessed with data from 60 patients completing the intervention pre- and posttest. The effect of the AAT was tested by comparing the 20 patients who had no AAT with the 40 patients who did (KR and no KR). The effect of knowing one's results was tested by comparing the 20 AAT patients who were not shown their results with the 20 AAT patients who were.

Further, long-term efficacy of the AAT was assessed by comparing the subjects' pretest scores and 1-year follow-up scores.

Partial sums of squares were used to test hypotheses. Adjusted F tests were used based on the Huynh-Feldt epsilon, when indicated. Cook's distance was estimated as a measure of influence of individual observations on the regression analysis. It was assumed that values greater than 1.0 indicate that the observation is extreme in the predictor space, or has a large Studentized residual and thus questions the model's correctness. For all analyses, Cook's distance was less than 1.0. A 2-tailed significance level of .05 was chosen. All statistical procedures were performed with the SAS system.[b]

RESULTS

Subjects

Seventy-four patients were enrolled in the study, of whom 14 were lost during the intervention period because of personal, organizational, or medical reasons. Five of the lost subjects had been assigned to the no AAT group, 4 to the AAT group, and 5 to the AAT+KR group. Characteristics of the 60 patients completing the study are shown in table 2. All patients were right-handed.[32]

Groups were comparable in age, gender, diagnosis, affected arm, degree of paresis, estimated premorbid intelligence quotient,[27] and concomitant nonexperimental motor therapy (physical and occupational therapy). Numeric differences in duration of disease were attributed to a single outlier, a TBI patient assigned to the control group who was 91 weeks postinjury. In the main, stroke patients had ischemic stroke; a few patients with intracranial bleeding (ICB) met eligibility criteria and were included (no AAT group: 2 patients; AAT group: 2 patients; AT+KR group: 1 patient with ICB).

One year posttest, the 60 study participants were invited for a follow-up assessment. Follow-up data were obtained from 37 patients including 23 who had received the AAT—14 from the AAT group, 9 from the AAT+KR group, and 14 from the no AAT group.

Efficacy of the AAT

Results are summarized in figure 1, which shows the primary dependent variables, the summary time score needed to com-

Table 2: Patient Characteristics of the Control (n = 20) and 2 Experimental Groups (n = 20 each)

Characteristic	Experimental Groups AAT	Experimental Groups AAT+KR	Control Group No AAT	p
Age (yr) (mean ± SD)	49 ± 17.9	54 ± 18.0	58.0 ± 15.3	.473 (F)
Gender (men/women)	11/9	14/6	11/9	.535 (χ^2)
Diagnosis (stroke/TBI)	16/4	14/6	15/5	.766 (χ^2)
Side of paresis (left/right)	12/8	14/6	11/9	.610 (χ^2)
Motricity Index: paretic arm (mean ± SD)	87 ± 6.3	83 ± 8.2	86 ± 7.2	.1457 (F)
Disease duration (wk) (mean ± SD)	6.1 ± 3.6	6.2 ± 7.1	10.3 ± 19.9	.298 (F)
Premorbid IQ (mean ± SD)	98 ± 6	98 ± 7	99 ± 7	.449
Motor therapy units (PT+OT) (mean ± SD)	28.6 ± 10.3	27.8 ± 8.4	32.3 ± 8.2	.114 (F)

Abbreviations: F, F test (with model: dependent variable = intercept + group + error); Motor therapy units, number of units received during 3-week interval from pre- to post-test; PT, physical therapy; OT, occupational therapy.

plete TEMPA tasks (unilateral and bilateral, fig 1A; unilateral tasks, fig 1B). Table 3 presents the main results of the statistical analysis of the efficacy of the AAT and table 4 presents results of the (additional) efficacy of intermittent average knowledge of result.

No statistically significant differences were observed between patients who did or did not recieve the AAT in the baseline scores of TEMPA or the kinematic analysis of aiming movements ($p > .10$). Similarly, baseline differences between the AAT and AAT+KR groups were not statistically significant for dependent variables.

The ANOVA for the primary outcome variables shown in figure 1 and table 3 indicates a similar picture for both immediate training effects and long-term effects. TEMPA task summary time scores at posttest and 1-year follow-up of patients who received AAT improved by 41.4 and 51.3 seconds, respectively, over pretest scores. Scores of patients who did not have AAT improved by only 16.5 and 26.3 seconds. The average change in scores on TEMPA's unilateral tasks by AAT patients was 12.8 seconds immediately after training and 20.1 seconds at 1-year follow-up. Scores for the control group were 4.2 and 10.8 seconds, respectively. Statistically, there was evidence of improvement over time (factor time). The AAT clearly resulted in a pronounced improvement after training (table 3, Immediate Training Effects, time × AAT). A differential benefit for patients with AAT could still be documented 1 year later; statistically, the effect was substantiated for TEMPA unilateral tasks (table 3, Long-Term Effects, time × AAT). Because partial sums of squares were used to test hypotheses, AAT's effect can be considered a relevant factor on its own. Changes over time were not modified (stroke or TBI) (time × diagnosis; not significant [NS]). Equally, changes over time were not related to the area that was paretic (time × arm; NS).

Efficacy of Knowledge of Result

Intermittent average knowledge of result was not associated with a statistically significant differential effect on improvement for any of the above dependent variables (compare table 4, time × KR). While numerically, knowledge of result was associated with the biggest long-term improvement of TEMPA scores (compare fig 1, AAT+KR), low values for the F statistics indicate the lack of any substantial effect of knowledge of result.

Side Effects

Patients receiving AAT were asked to complete a form on which they could record any side effects from the AAT. While not a blinded assessment, this self-report form served to alert

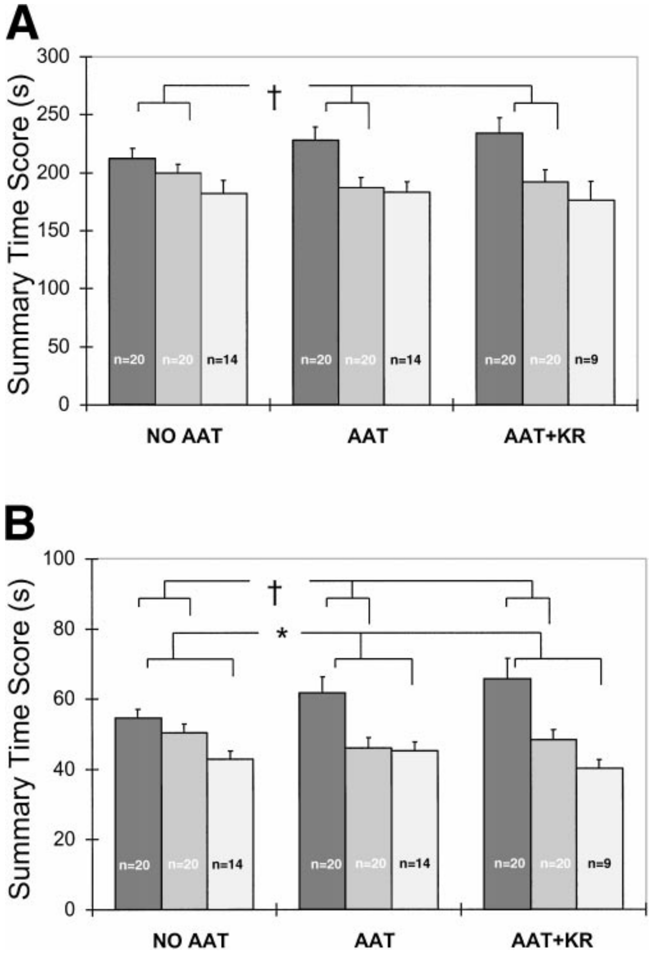

Fig 1. Group data of TEMPA scores for (A) all TEMPA tasks and (B) unilateral TEMPA tasks when performed with the affected arm for patients receiving either no AAT (NO AAT), arm ability training (AAT), or AAT and intermittent average knowledge of results (AAT+KR). Data are shown for pretest (dark gray), posttest (middle dark gray), and 1-year follow up (light gray). Group data are shown for 60 patients completing pre- and posttests and the subgroup of 37 patients who completed the 1-year follow-up assessment. Bars indicate group mean scores and their standard error. * $p < .05$, † $p < .01$.

Table 3: AAT Versus No AAT Group Results of Repeated-Measures ANOVA

	Immediate Training Effects (n = 60) Pretest vs Posttest			Long-Term Effects (n = 37) Pretest vs Follow-up (1yr)		
Parameter	ANOVA Factor	$F_{1,57}$	p	ANOVA Factor	$F_{1,34}$	p
TEMPA: all tasks	Time	36.27	.0001	Time	46.12	.0001
	Time × AAT	11.69	.0012	Time × AAT	3.17	.0838
	Time × diagnosis	.38	.5419	Time × diagnosis	3.18	.0835
TEMPA: unilateral tasks	Time	16.35	.0002	Time	33.57	.0001
	Time × AAT	9.20	.0036	Time × AAT	5.42	.0260
	Time × diagnosis	.40	.5272	Time × diagnosis	.00	.9517

the investigators to any areas of concern. Five of 40 patients receiving AAT reported shoulder discomfort or pain during training sessions.

Kinematic Motion Analysis

The kinematic analysis of aiming movements permitted a more detailed investigation of motor behavior. We separately analyzed the first more ballistic movement phase, and then the a second homing-in phase of aimed movements. This information was available from 59 of 60 patients who completed pre- and posttests (1 patient from the AAT+KR group could not be tested for technical reasons).

As intended, accuracy was fairly stable across groups and assessments. Absolute error that was comparable across groups (factor AAT, $F_{1,56} = 1.94$, $p = .1690$), improved somewhat from pre- to posttest (absolute error, total average: pretest 3.4mm, posttest 3.2mm; factor time, $F_{1,56} = 7.17$, $p = .0097$; time × AAT, $F_{1,56} = .31$, $p = .5774$).

Regarding movement time, a differential effect of the AAT was noted for the first more ballistic movement phase that covers most of the distance to be moved (compare fig 2). The AAT led to a bigger reduction of movement time in the first movement phase (average reduction of movement time/first phase: AAT 96ms, no AAT 20ms; time × AAT, $F_{1,56} = 6.83$, $p = .0115$). No differential effects of the AAT were noted on the second homing-in phase of aiming movements (average reduction of movement time/second phase: AAT, 46ms; no AAT, 49ms; time × AAT, $F_{1,56} = 0.0$, $p = .9972$). As a consequence, total movement time showed a tendency toward a greater improvement among patients who had received the AAT (movement time: time × AAT, $F_{1,56} = 3.53$, $p = .0656$).

DISCUSSION

Our results indicate that focal disability of the upper limb in stroke and TBI patients with mild central arm paresis can be significantly improved by the AAT. On average, control subjects showed an 8% reduction in the time needed to perform the TEMPA tasks from pre- to posttest; patients receiving the AAT improved 18%, indicating a clinically relevant 10% improvement attributable to AAT. A differential functional benefit for patients who had AAT was also suggested for a subgroup of AAT patients whose 1-year follow-up data were compared with their pretest scores. The effect was statistically significant when the affected arm was assessed.

The AAT's efficacy was similar for both stroke and TBI patients. This is an important finding, especially because information about efficacy of interventions for TBI patients is even more limited than it is for stroke patients.[33] We demonstrated that focal disability related to the target impairment mild central arm paresis could be improved, independent of the underlying pathologic condition. Equally, whether patients' left or right arms were affected had no significant influence on improvement.

The kinematic analysis of aiming movements provided the opportunity to investigate issues of motor control. Even though the test was unlike TEMPA, strikingly similar results emerged and provided further confirmation of the AAT's efficacy (compare fig 2). More detailed motion analysis revealed that the first more ballistic movement phase of aiming movements was differentially affected by the AAT, whereas the more feedback-guided late movement phase was not. Movement time spent in the first phase by patients with AAT was reduced. Therefore, an advantage of the AAT could be that it improves ballistic motor behavior in hemiparetic subjects.

Shoulder pain was the only self-reported complaint during the training period. Mild pain during training sessions occurred in 12.5% of the patients; in addition, 2 patients (~5%) discontinued the training because of shoulder pain. Shoulder pain is common in stroke patients[34] and, therefore, it seems unlikely to have been caused solely by the experimental training. Rather, the training might have worsened symptoms of a preexisting condition (ie, poststroke glenohumeral joint changes, shoulder-hand syndrome).[35,36] Nevertheless, the development of shoulder pain should be closely monitored during AAT.

Intermittent knowledge of result has the potential to enhance motor learning.[22] Knowing whether performance improves

Table 4: AAT+KR Versus AAT Group Results of the Repeated-Measures ANOVA

	Immediate Training Effects (n = 40) Pretest vs Posttest			Long-Term Effects (n = 23) Pretest vs Follow-up (1yr)		
Parameter	ANOVA Factor	$F_{1,37}$	p	ANOVA Factor	$F_{1,20}$	p
TEMPA: all tasks	Time	53.64	.0001	Time	45.73	.0001
	Time × KR	.02	.8820	Time × KR	.74	.3985
	Time × diagnosis	.59	.4472	Time × dagnosis	2.14	.1591
TEMPA: unilateral tasks	Time	23.84	.0001	Time	41.74	.0001
	Time × KR	.05	.8219	Time × KR	.11	.7427
	Time × diagnosis	.48	.4948	Time × diagnosis	.00	.9768

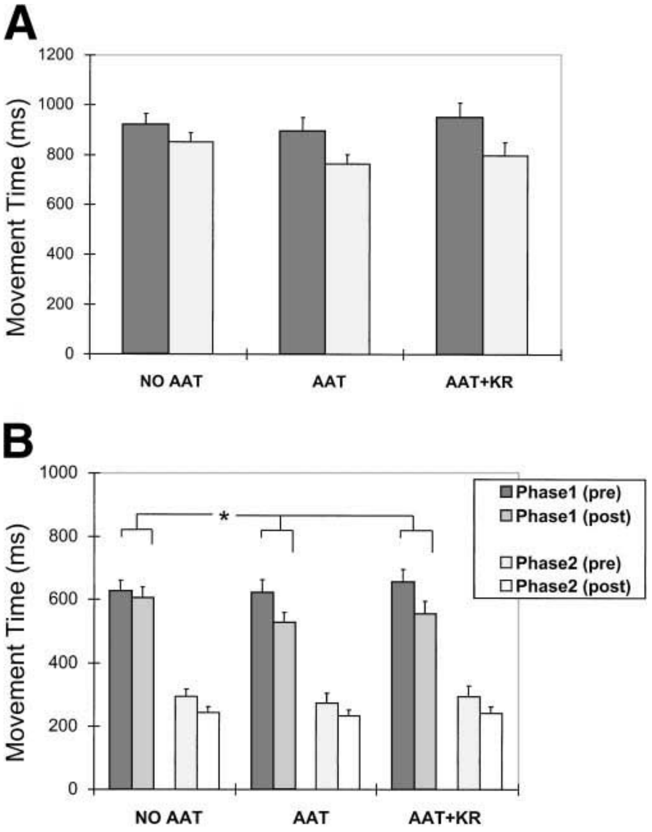

Fig 2. Group data of kinematic analysis of aiming movements. (A) Total movement time is presented; (B) movement time of the first and second movement phase (before and after maximal deceleration). Patients received either no AAT ($n = 20$; NO AAT), AAT ($n = 20$; AAT), or AAT and intermittent average knowledge of results ($n = 19$; AAT+KR). Data are shown for pre- (darker gray) and posttest (lighter gray). $* p < .05$.

during a period of training may facilitate motivation, and it may also help an individual explore the effect of any consciously or subconsciously selected training strategy. In this study, subjects receiving AAT were randomly assigned to receive or not receive intermittent average knowledge of results separately for each type of task, presented as bar diagrams on a computer screen. Surprisingly, knowledge of result had no statistically significant effect on either immediate or long-term outcomes (table 4). This fact may indicate that patients were aware of their actual performances and progress independent of augmented feedback. Or, knowing the actual level of performance through immediate feedback may not have implications for selecting movement strategies in a highly structured and standardized training situation.

The study has the following limitations. The AAT's efficacy, but not its potential superiority above other therapeutic techniques, was demonstrated. Superiority would have to be demonstrated in trials comparing all appropriate therapies. Long-term results could be affected by a sample distortion bias, because only 62% of the original study population could be reassessed after 1 year; this could have led to a lack of statistical power to substantiate long-term effects (ie, length of execution for all TEMPA tasks). The incidence of shoulder pain attributable to the AAT could not be estimated, because related information was not obtained from controls and data collection related to side effects was unblinded.

CONCLUSION

The study demonstrates the AAT's efficacy for patients with mild central arm paresis after stroke and TBI. This is the first clinical therapeutic study to show promotion of arm motor recovery for these specific patient groups. Therefore, the AAT can be recommended as part of a rehabilitation program for this patient population. Together with clinical trials with stroke patients with more pronounced arm paresis,[8-10] the results suggest that central arm paresis is amenable to specific therapeutic intervention when the training specifically addresses relevant functional limitations.

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