

Short-Term Effects of Practice With Trunk Restraint on Reaching Movements in Patients With Chronic Stroke

A Controlled Trial

Stella M. Michaelsen, DEA; Mindy F. Levin, PhD

Background and Purpose—In prehension tasks with objects placed within arm's reach, patients with hemiparesis caused by stroke use excessive trunk movement to compensate for arm motor impairments. Compensatory trunk movements may improve motor function in the short term but may limit arm recovery in the long term. Previous studies showed that restriction of trunk movements during reach-to-grasp movements results in immediate increases in active arm joint ranges and improvement in interjoint coordination. To evaluate the potential of this technique as a therapeutic intervention, we compared the effects of short-term reach-to-grasp training (60-trial training session) with and without physical trunk restraint on arm movement patterns in patients with chronic hemiparesis.

Methods—A total of 28 patients with hemiparesis were assigned to 2 groups: 1 group practiced reach-to-grasp movements during which compensatory movement of the trunk was prevented by a harness (trunk restraint), and the second group practiced the same task while verbally instructed not to move the trunk (control). Kinematics of reaching and grasping an object placed within arm's length were recorded before, immediately after, and 24 hours after training.

Results—The trunk restraint group used more elbow extension, less anterior trunk displacement, and had better interjoint coordination than the control group after training, and range of motion was maintained 24 hours later in only the trunk restraint group.

Conclusion—Restriction of compensatory trunk movements during practice may lead to greater improvements in reach-to-grasp movements in patients with chronic stroke than practice alone, and longer-term effects of this intervention should be evaluated. (*Stroke*. 2004;35:000-000.)

Key Words: hemiplegia ■ rehabilitation ■ recovery of function

Arm and hand movement problems are major contributors to disability in patients after stroke.¹ In the months after stroke, function of the paretic arm can improve as reaching, grasping, and manipulating ability is regained. Improvements in function can occur in 2 ways. In some cases, premorbid movement patterns may be regained because of true motor recovery. However, because of the redundancy in the number of degrees of freedom (DFs) of the body,² actions can be accomplished by substitution of other DFs for movements of impaired joints. These alternative movements or motor compensations³ are also observed in animals recovering from experimental stroke.^{4,5} In man after stroke, when reaching for objects placed within arm's length, in particular, excessive trunk movements may assist in smooth hand transport^{6,7} or in hand positioning and orientation for grasping.^{8,9}

In patients with hemiparesis, the unrestricted and unguided repetition of a motor task may reinforce compensatory movements.¹⁰ Patients with severe impairment tend to improve performance (defined as movement speed, precision,

and smoothness) of a pointing movement after 1 day of intensive training by incorporating trunk anterior displacement, a movement not normally needed for the task. Thus, in the short term, although compensatory movements may improve performance of the paretic arm, in the long term, these may be maladaptive by preventing recovery or reappearance of more efficient arm movement patterns.¹¹

Restriction of compensatory trunk movements may encourage recovery of "normal" reaching patterns in the hemiparetic arm when reaching for objects placed within arm's length. Michaelsen et al⁶ evaluated movement patterns of the hemiparetic arm made with or without restriction of compensatory trunk movements during reach-to-grasp tasks. During trunk restraint, patients improved active elbow extension, shoulder ranges, and interjoint coordination when reaching. Trunk restraint thus allowed patients to use joint ranges that were present but not recruited during unrestrained reaching. It is not known how long these changes may persist and whether, with training, patients can decrease the amount of

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TABLE 1. Summary Demographic Data for Each Group

Characteristic	Trunk Restraint (n=14)	Control (n=14)
Gender		
Male	8 (57%)	10 (71%)
Female	6 (43%)	4 (29%)
Age, y	54 (17)	60 (20)
Lesion side		
Left	11 (79%)	8 (57%)
Right	3 (21%)	6 (43%)
Handedness		
Left	1 (7%)	3 (21%)
Right	13 (93%)	11 (79%)
Time since stroke, mo	36 (28)	22 (15)
Fugl-Meyer scale (66)	50 (11)	49 (13)
TEMPA	-44 (25)	-50 (33)
Spasticity (16)	8 (2)	7 (2)

Values represent the No. (%) or the mean (SD).

compensatory movement used in reach-to-grasp tasks. Thus, as a first step in the study of the longer-term efficacy of this training approach, we evaluated whether a single day of repetitive reach-to-grasp training with physical trunk restraint led to better retention of improvements in arm kinematics than practice with only verbal instruction to minimize trunk motion. Preliminary results have appeared in abstract form.¹²

Methods

Subjects

Potential participants were identified from discharge lists of Montreal area rehabilitation centers. Of 518 medical charts screened, 112 patients met eligibility requirements according to study inclusion and exclusion criteria. Patients were included if they were <80 years old, had sustained a single, nontraumatic unilateral stroke, and had arm paresis. Patients were excluded if they had cerebellar or brain stem lesions, shoulder pain, or other neurological/orthopedic conditions affecting reaching ability, or severe perceptuocognitive deficits

(hemineglect, ataxia, receptive aphasia). Of these 112 individuals, 54 were contacted, and 35 expressed willingness to participate. After obtaining informed consent, they were assessed by a physical therapist, and 7 individuals were excluded because of inability to perform the task.

Participants consisted of 28 patients (57 ± 18 years) having had sustained a stroke 7 to 94 months previously (29 ± 24 months). Patients were stratified on arm motor impairment according to Fugl-Meyer scores¹³ (moderate to severe 26 to 50; mild 51 to 66), and randomly allocated in blocks of 4 to either a physical trunk restraint group (TR) or a control group (C; Table 1).

Clinical Evaluation

Clinical testing included arm impairment and functional ability. Aside from the impairment assessment (Fugl-Meyer scale)¹³ that included sensation and proprioception, arm function was evaluated with TEMPA (Upper Extremity Performance Test for the Elderly).¹⁴ TEMPA assesses unimanual and bimanual tasks, with lower scores indicating better function (normal function=0). Elbow spasticity was assessed with the Composite Spasticity Index (CSI)¹⁵ measuring biceps tendon jerks, resistance to full-range passive elbow extension, and wrist clonus. A CSI score of 4 indicates normal tonus, and 16 corresponds to severe spasticity.

Reaching Task

Participants reached and grasped a cylinder in response to an auditory signal (Figure 1). Arm and trunk kinematic data during unrestrained reaching (10 trials) were recorded before (pretest trials [PRE]) and after (post-test trials [POST]) a 60-trial training period on day 1 and in a single session on day 2 (retention test [RET]). TR practiced reaching-to-grasping, with trunk movement restricted by an electromagnet. For C, the magnet was not activated. Both groups were instructed not to move the trunk and to use as much elbow extension as possible so that effects of physical restraint versus self-restraint could be compared. To minimize fatigue, a 2- to 5-minute rest period was permitted after every 10 trials.

Data Acquisition and Analysis

Kinematic data were recorded by an optical motion analysis system (Optotrak 3010; Northern Digital) for 2 to 7 s at 120 Hz. Eight infrared-emitting diodes (IREDs) were placed on bony landmarks of the arm and trunk: (1) index, (2) thumb, (3) head of first metacarpal, (4) radial styloid, (5) lateral epicondyle, (6) ipsilateral acromion, (7) contralateral acromion, and (8) midsternum.

Temporal characteristics of arm trajectory were considered indicators of performance outcome. These included number of velocity

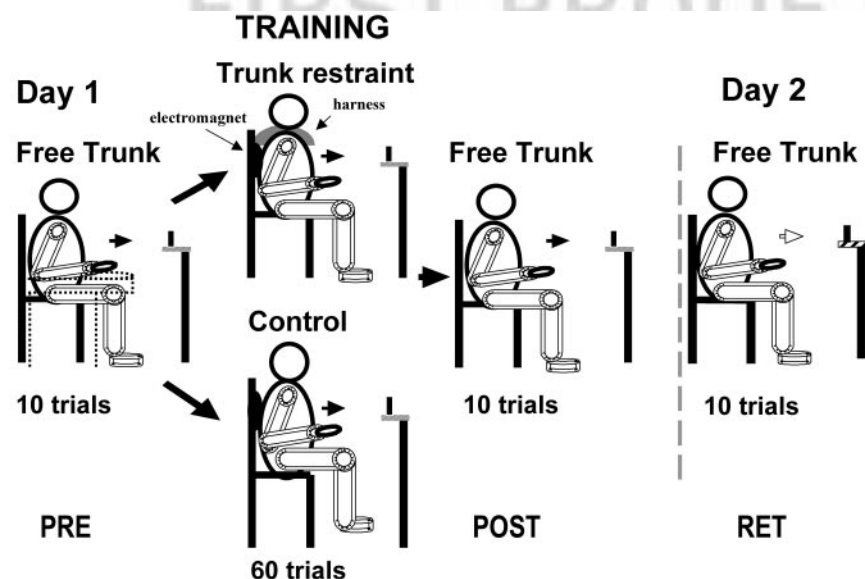


Figure 1. Experimental design. Patients sat with hip and knee joints flexed to 90° and feet supported. At task onset, the arm was close to the body, with the elbow flexed to $\approx 70^\circ$ and the hand on a support (left, dotted lines). The contralateral arm was beside the body. Participants wore a harness consisting of breast and back plates connected by adjustable straps. An electromagnet attached to the wall was locked to the back electromagnetic plate at the interscapular level. A cylinder (35-mm diameter \times 95-mm height) was placed in the sagittal midline at a distance of 90% of maximal arm length (determined for each subject according to his/her arm's length with full passive elbow extension) at the height of the sternal xiphoid process. Arm and trunk kinematic data were recorded on day 1 before and after a 60-trial training period with or without trunk restraint, and on day 2. All recording sessions (10 trials) were done without trunk restraint.

TABLE 2. Kinematic Data of Reach-to-Grasp Movements

	Trunk Restraint					Control				
	PRE	POST	Change	RET	Change	PRE	POST	Change	RET	Change
Performance outcome measures										
Velocity peaks, n	5.6 (2.3)	6.2 (3.0)	+0.6	6.5 (2.7)	+1.0	5.1 (1.8)	6.1 (2.9)	+1.0	6.0 (3.2)	+0.8
Movement time, s	1.78 (0.49)	1.93 (0.66)	+0.15	1.80 (0.54)	+0.02	1.82 (0.61)	1.92 (0.70)	+0.10	1.93 (0.74)	+0.11
Wrist peak velocity, mm/s	717 (219)	661 (190)	-56	680 (178)	-37	624 (184)	634 (167)	+10	633 (167)	+9
Time to peak velocity, ms	486 (153)	514 (188)	+28	460 (214)	-27	452 (159)	438 (153)	-14	471 (193)	+19
Movement variables										
Trunk displacement, mm	166 (101)	114 (68)	-52*	133 (104)	-32*	190 (124)	171 (128)	-19	188 (134)	-2
Trunk rotation, °	12 (3)	11 (3)	-1	11 (4)	-1	12 (5)	11 (4)	-1	12 (4)	0
Elbow extension, °	96 (24)	106 (24)	+10	109 (24)	+12*	91 (26)	99 (26)	+8	95 (28)	+4
Shoulder horizontal adduction, °	43 (23)	50 (25)	+7	50 (27)	+7	33 (29)	42 (26)	+9	38 (28)	+5
Shoulder flexion, °	31 (21)	37 (21)	+7	38 (21)	+7	24 (21)	31 (19)	+6	28 (20)	+4

Values are mean (SD). *Significant differences between groups.

peaks, movement time (MT), peak tangential velocity (V_{max}), and time to peak velocity (TPV) of the wrist marker. Arm tangential velocity was computed from the magnitude of the velocity vector obtained by 3-point central difference numerical differentiation of the x , y , and z marker positions. MT was the time between movement beginning and end, defined as times at which tangential velocity rose above or fell and remained below, respectively 5% of the trial V_{max} . Movement end time corresponded to the moment of hand contact with the cylinder.

We also measured movement variables (5 DFs and interjoint coordination) that could contribute to motor performance improvement. DFs were (1) trunk anterior displacement, (2) trunk rotation, (3) elbow extension, (4) shoulder flexion, and (5) shoulder horizontal adduction. Trunk displacement was computed in millimeters as movement of the sternal marker in the sagittal plane. Trunk rotation was the angle between the vector joining the 2 shoulder markers (IREDS 6 to 7) and the frontal axis in the horizontal plane (where 0° corresponds to a straight line). Elbow flexion/extension was the angle between vectors formed by IREDS 4 to 5 and 5 to 6 where full extension equaled 180°. Shoulder horizontal adduction/abduction was the horizontal projection of the angle between vectors defined by IREDS 5 to 6 and 6 to 7. Full horizontal abduction (0°) coincided with a shoulder position in line with the vector defined by shoulder markers. Shoulder flexion/extension was the angle between vectors defined by IREDS 5 to 6 and the sagittal plane through the vertical axis of the ipsilateral shoulder joint with 0° defined as the arm alongside the body.

Maximal joint excursions and final arm postures (END, defined above) were computed for each time period (PRE, POST, RET) and expressed as normalized differences between POST and RET with respect to PRE. No change, increases, or decreases in a parameter measured in POST or RET compared with PRE were denoted as 0, negative or positive values, respectively.

Interjoint coordination between elbow extension and shoulder horizontal adduction was analyzed with the Temporal Coordination Index (TCI).¹⁶ Briefly, TCI represents the difference between the elbow and shoulder phase angles at each moment in time throughout the movement. On the basis of our preliminary analysis in 10 healthy age-matched subjects performing the same reach-to-grasp task, TCI was characterized by a single-peaked function with an amplitude of $-45.9^\circ \pm 15.1^\circ$ and a duration of 0.348 ± 0.059 ms. For this comparison, we used data from arms of healthy subjects instead of patients' ipsilesional arm because this arm has been shown to have coordination deficits between adjacent joints.¹⁷ TCI amplitude and duration were considered to deviate from normal when values fell outside of the mean ± 1 SD of the values in healthy subjects. Because TCI profiles in some patients consisted of multiple peaks, it was not possible to compare them statistically with those of healthy subjects

in whom there was a single peak. Thus, improvements in interjoint coordination were identified qualitatively as changes in TCI meeting 1 of the following criteria: (1) appearance of a single peak in the TCI curve where there were previously multiple peaks, (2) a change in TCI duration, or (3) a change in TCI amplitude previously outside of and then falling within the range of the mean ± 1 SD of the healthy group.

Statistical Analysis

Student t tests were used to evaluate whether clinical status and arm and trunk movement patterns were similar between groups in PRE.

We tested the hypothesis that training with trunk restraint would improve movement quality by increasing active arm joint ranges and reducing compensatory trunk movement. We compared normalized differences (change scores) of temporal parameters of reaching (V_{max} , TPV, MT) and 5 DFs with 2-way repeated-measures ANOVAs (factors: group [2 levels]; time [2 levels]) using a significance level of $P < 0.05$.

Results

Before training, both groups were similar in age, chronicity, arm impairment, and arm function (Table 1), and had similar arm and trunk kinematics (Table 2, PRE).

Effect of Training on Arm Kinematics

Training did not influence any performance outcome measures in either group (Table 2).

In terms of movement variables, TR but not C patients used less trunk movement after training (Table 2). Although there were no differences in rotation, anterior displacement decreased significantly more (by 52 mm) in TR than in C (by 19 mm; group main effect $F_{1,26}=5.14$; $P < 0.05$), and this reduction was retained only in TR (Figure 2A, top). Individual analysis showed that 6 of 14 TR subjects decreased trunk anterior displacement by 40 mm or more in RET, whereas only 2 C subjects showed a similar decrease (Figure 2B, top).

Elbow extension at the end of movement increased with practice in both groups (time main effect $F_{2,52}=15.94$; $P < 0.001$). There was a larger increase in elbow extension in TR, and this difference was significant in RET (2-way interaction $F_{2,52}=3.11$; $P < 0.05$; Figure 2A, bottom). Individual analysis showed an increase of $\geq 10^\circ$ between PRE and

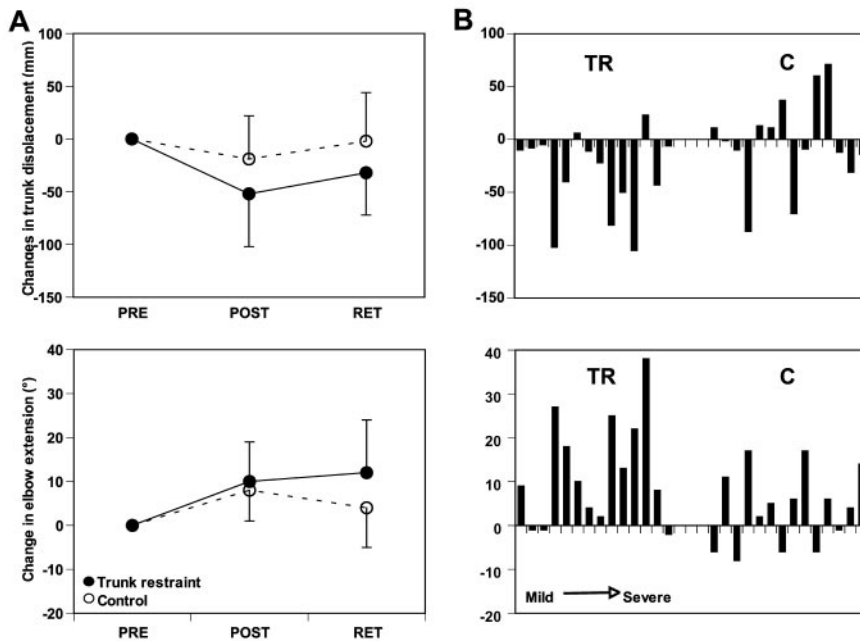


Figure 2. A, Mean changes and SDs for TR (filled circles) and C (open circles) in trunk anterior displacement (top) and elbow extension (bottom) in POST and RET. B, Changes in trunk anterior displacement (top) and elbow extension (bottom) for individual subjects between PRE and RET. In each panel, individual patients are arranged according to clinical severity.

RET in 7 of 14 TR patients compared with 4 of 14 C patients (Figure 2B, bottom).

Both groups showed small increases ($\approx 7^\circ$) in shoulder horizontal adduction (time main effect $F_{2,52}=9.40$; $P<0.001$; post hoc $P<0.005$) and shoulder flexion (time main effect $F_{2,52}=13.03$; $P<0.001$) after training, with no significant between-group differences (Table 2).

Compared with healthy subjects, disruption in temporal coordination between shoulder and elbow movements was evidenced by the presence of multiple small peaks in TCI (17 patients). In cases in which a single peak in TCI was present (11 patients), disruption in coordination was evidenced by an increased amplitude or duration compared with the normal range (mean \pm SD) as defined above. The increase in amplitude was caused by 1 joint accelerating while the other decelerated or by both joints accelerating in opposite directions (eg, initiation of reach by elbow flexion instead of extension during shoulder horizontal adduction). Specifically, in patients, TCI amplitude was significantly correlated with arm motor impairment (Fugl-Meyer scale $r=0.51$; $P<0.01$). Examples of TCI analysis in 1 healthy subject (Figure 3A through 3C) and 1 participant with hemiparesis (Figure 3D and 3E) are shown in Figure 3. For the patient, TCI shape, amplitude, and duration approached normal values after training (Figure 3F and 3G). The number of participants showing some improvement in TCI was greater in TR (8 of 14) than in C (5 of 14; $\chi^2=5.2$; $P=0.02$).

Discussion

A single session of repetitive reach-to-grasp training to objects within arm's reach during physical restriction of trunk compensatory movements led to greater gains in elbow extension, greater decreases in trunk involvement, and improved temporal interjoint coordination compared with instructed practice alone. Of particular clinical interest is that these improvements were maintained 24 hours after training

only in TR. Results combined with the finding that some patients in C also improved imply that patients with chronic hemiparesis retain the capacity to relearn premorbid movement patterns in the affected arm with appropriate practice.

In a previous study,⁶ reaching patterns (arm ranges of motion and interjoint coordination) changed during the period of trunk restraint. However, from that study, we were unable to determine whether improvements were a result of the stabilizing effect of the external trunk support or to a reorganization of the arm DFs by the central nervous system (CNS) to accomplish the task. Results of the present study, showing an improvement of interjoint coordination for a short time after restraint removal, supports the latter mechanism. Supposing that motor patterns chosen by the CNS are those that best accomplish the task according to the patient's capability,¹⁸ trunk restraint may be used to "force" the patient to use the "full" but unexploited capacity of the arm. This is similar to the strategy of constraining the unaffected arm¹⁹ to force the patient to make more use of the affected arm with the added feature that reduction of compensatory movement patterns is also targeted.

In healthy subjects, beneficial effects of training with physical restriction occur in the initial learning stage to prevent development of "bad habits."²⁰ It has long been recognized by clinicians^{2,11} that once a compensation has been learned, it is very difficult to modify. Indeed, prolonged use of compensatory trunk movements to reach targets placed within arm's length may result in the system learning not to use arm joints for reaching and grasping ("learned nonuse")¹⁹ so that recovery of independent use of these joints would be discouraged. In our study, physical trunk restraint can be considered similar to "manual guidance,"²¹ in which spatial constraints are used to promote use of more optimal movement patterns.

Repetitive practice of reach-to-grasp tasks with limitation of compensatory trunk movement may be superior to training

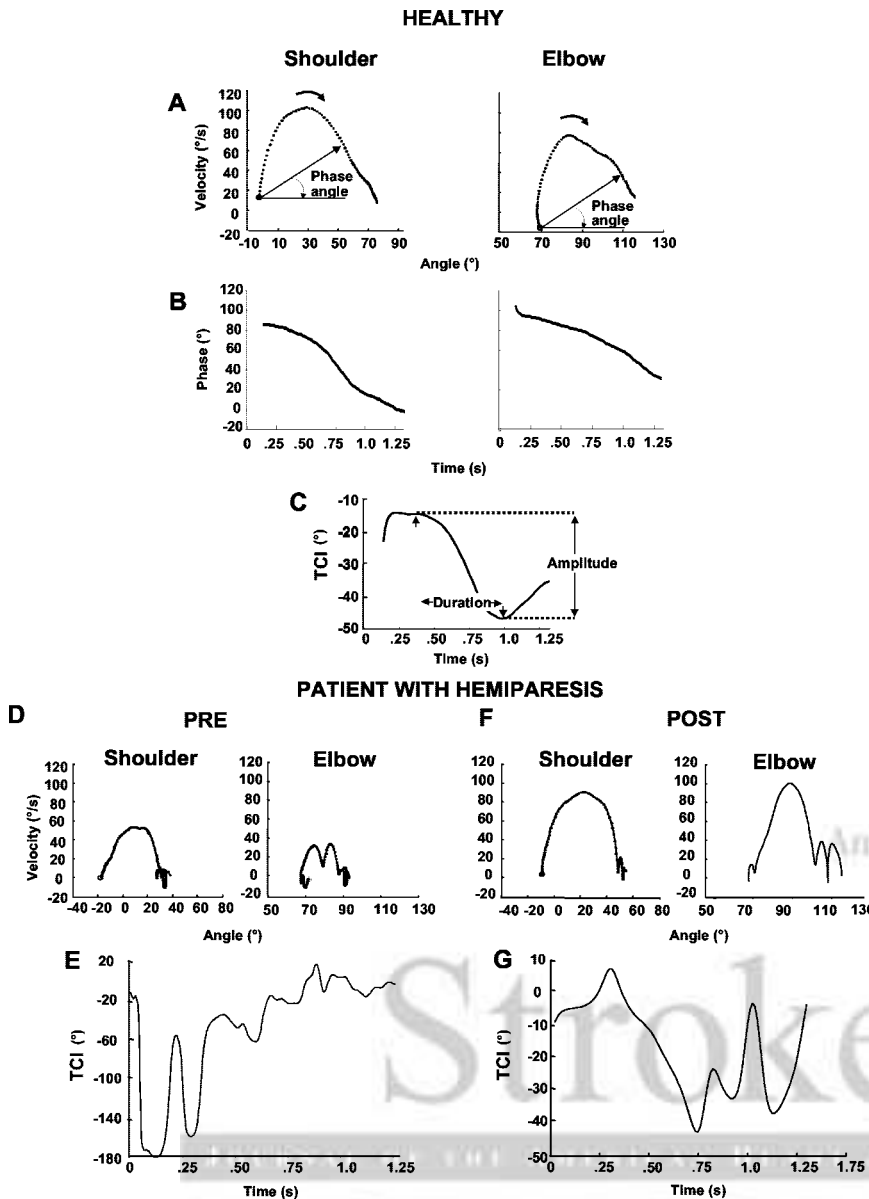


Figure 3. Determination of TCI in a typical healthy subject (A through C) and before (D and E) and after (F and G) training in 1 participant with hemiparesis. Velocity/angle plots (A, D and F) are shown for both subjects. Phase angles (shown only for the healthy subject in B) were calculated between the horizontal line and a line from the origin (placed at the initial position) to successive data points along phase plots shown in A. Thick curved arrows indicate movement direction. C, E, and G, TCI is the difference between elbow and shoulder phases and describes temporal coordination between joints throughout the movement. Note that there are multiple peaks in TCI of the patient before training (PRE) and that after training, the number of peaks is reduced.

arm movement alone, which has failed to show any additional improvement in arm kinematics.²² Short-term benefits of a simple reach-to-grasp training with physical trunk restraint provides a strong argument for applying this training in clinical settings. The implication for therapy is that restriction of trunk use should be used even in patients with chronic hemiparesis to encourage maximal use of available DFs. Trunk restraint may also be a useful technique in the acute phase of stroke to promote maximal arm motor recovery. We specifically did not address whether our intervention improved functional capacity of the arm because it was expected that longer-term practice would be necessary to affect change in this dimension. Further studies, using randomized controlled trials, are necessary to assess the longer-term effects of trunk restraint during arm training on recovery of arm function after stroke.

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