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Trunk Restraint Therapy: The Continuous Use of the Harness Could Promote Feedback Dependence in Poststroke Patients

A Randomized Trial

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Abstract: The objective of this study was to evaluate the long-term effects of the task-specific training with trunk restraint compared with the free one in poststroke reaching movements.

The design was randomized trial.

The setting was University of Campinas (Unicamp).

Twenty hemiparetic chronic stroke patients were selected and randomized into 2 training groups: trunk restraint group (TRG) (reaching training with trunk restraint) and trunk free group (TFG) (unrestraint reaching).

Twenty sessions with 45 minutes of training were accomplished. The patients were evaluated in pretreatment (PRE), posttreatment (POST) and 3 months after the completed training (RET) (follow-up).

Main outcome measures were modified Ashworth scale, Barthel index, Fugl–Meyer scale, and kinematic analysis (movement trajectory, velocity, angles).

A significant improvement, which maintained in the RET test, was found in the motor ($P < 0.001$) and functional ($P = 0.001$) clinical assessments for both groups. For trunk displacement, only TFG obtained a reduction statistical significance from PRE to the POST test ($P = 0.002$), supporting this result in the RET test. Despite both groups presenting a significant increase in the shoulder horizontal adduction ($P = 0.003$), only TRG showed a significant improvement in the shoulder ($P = 0.001$ – PRE to POST and RET) and elbow ($P = 0.038$ – PRE to RET) flexion extension, and in the velocity rate ($P = 0.03$ – PRE to RET).

The trunk restraint therapy showed to be a long-term effective treatment in the enhancement of shoulder and elbow active joint range and velocity rate but not in the maintenance of trunk retention.

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Abbreviations: ANOVA = analysis of variance, BI = Barthel index, FM = Fugl–Meyer scale, HS = healthy subjects, MAS = modified Ashworth scale, mCIMT = modified constraint-induced movement therapy, POST = posttreatment, PRE = pretreatment, RET = retention test/follow-up, TFG = trunk free group, TRG = trunk restraint group.

INTRODUCTION

After stroke, reaching movements are characterized by a great temporal and spatial segmentation, with reduced active range of motion of shoulder and elbow movements, disrupted interjoint coordination, and increased trunk displacement.[1]

A given task can be executed in different ways through the different combinations of individual joint movements (degrees of freedom). This ability of the musculoskeletal system is called ‘‘motor redundancy’’, which is an important aspect of the normal voluntary movement.[2] During the stroke recovery process, the central nervous system seems to retain the capacity to explore this motor redundancy through the use of the trunk recruitment (additional degrees of freedom) as a substitute of the lost motor elements (deficits in the upper limb joint range).[3] In the Cirstea and Levin study,[1] the trunk recruitment was justified for the need to overcome the upper limb joint ranges limitation. However, the motor persistence compensation can lead to a limitation to the long-term poststroke recovery.

Michaelsen et al[4] proposed a trunk restraint technique associated with a task-specific reaching training program. The loss of interjoint coordination between elbow and shoulder limits the harmonic reaching movement, which is compensated by the recruitment of additional degrees of freedom; mainly of trunk and shoulder girdle movements.[5] The restraint aims to avoid compensatory trunk movement and to facilitate the development of normal motor patterns in the affected upper limb.

Task-specific training is based on therapeutic exercises focusing on the motor impairment and offers function specificity to the rehabilitation program.[6] It is important to emphasize the tasks needed to be transferred to the real environment to guarantee an efficient learning, which is proved by the retention tests. The retention of motor learning occurs, in a more significant way, if there is variability and specificity of the tasks performed.[7]

Other studies also show that trunk restraint therapy can improve the shoulder and elbow range of motion and also decrease compensatory trunk strategies.[3,8] These changes were also kept in the retention tests. Thus, the objective of this investigation was to evaluate the retention effects 3 months after the task-specific training with trunk restraint compared with the free one in poststroke reaching movements.

METHODS

Twenty stroke patients were recruited from the Physiotherapy and Occupational Therapy Outpatient Unit of the University Hospital at Campinas – UNICAMP, and all of them signed informed consent forms previously approved by the Research Ethics Committee of the University (#110/2004). Ten healthy patients were also selected to obtain normal reference parameters of kinematic assessment.

Patients had sustained a single and chronic (>6-month postevent) unilateral stroke of nontraumatic origin, with hemiparetic sequel in the upper limb, could understand simple instructions, perform community gait, and had a good sitting balance. Those with shoulder pain or other neurological and orthopedic conditions affecting the reaching movement ability or trunk, hemispatial neglect, or apraxia were excluded.

The patients who met the inclusion criteria were stratified to 1 of 2 groups. A sealed opaque envelope, containing a single cheat of paper marked with number 1 (group 1) or 2 (group 2), was used to allocate the patient. This procedure was made by an external assessor. The patients were not informed about the different treatment groups, and therefore they were blind for the type of intervention applied.

The muscle tone (shoulder and elbow flexors) was evaluated using the modified Ashworth scale;[9] motor impairment was evaluated using the upper limb section of the Fugl–Meyer[10,11] assessment scale and activities of daily living were assessed by the Barthel index.[12,13]

Kinematic data were recorded by an infrared system of motion analysis (Qualisys Motion Capture System – 2.57 Sweden) with a sample frequency of 240 Hz during 8 seconds. The coordinated data were low-pass filtered using a 6-Hz, finite impulse response filter with order 26 using the Matlab software.

Five infrared reflexive markers were used (Figure 1). For the kinematic capture, the patients were seated in a chair and invited to fit a cone in a target placed within arm's length (measured on the nonaffected arm from the medial border of axilla to the distal wrist crease). The target was placed so that only the arm movement was required to reach the target. The initial hand position of the affected arm was on the lateral trunk, with the shoulder in a neutral position and the elbow close to the side of the body (90°). Three trials of 6–8 seconds' time were recorded, and a media was used to calculate the evaluated data.

From the collected dates, values concerning sagittal (YZ), horizontal (XY), and 3-dimensional (XYZ) planes were computed.

Trunk displacement was verified in millimeters as sagittal movement of marker 3.

Index of curvature was measured from marker 5. This index shows the straightness of the wrist trajectory from the initial position to the goal, resulting in a ratio of actual end point path to a straight line [index = 1, whereas a semicircle has an index of 1.57 (π/2)].

Shoulder angles were calculated using 2 vectors formed from marker 1 to marker 2, and from marker 2 to marker 4, with flexion/extension movements in the sagittal plane and adduction/abduction movement in the horizontal plane. Full horizontal abduction and the anatomical position were considered at 0°. Flexion/extension elbow angles were measured using 2 vectors formed from markers 2 to 4 and from markers 4 to 5, using the sagittal and horizontal planes. The elbow full extension was considered at 180°.

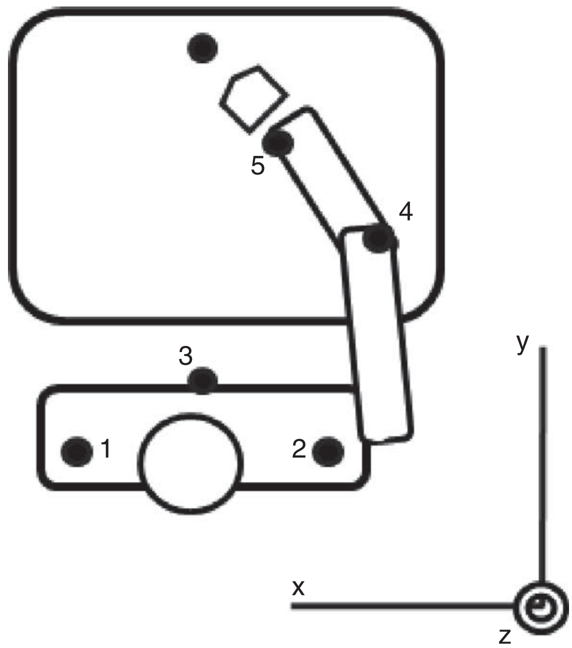

FIGURE 1. Horizontal plane showing the 5 markers; 1, contralateral acromion; 2, ipsilateral acromion; 3, midsternum; 4, lateral humeral epicondyle; 5, wrist radial styloide process.

Movement time was defined as differences between movement onsets and offsets that tangential velocity rose above and fell below at 5% of its peak value.

The maximum tangential velocity of the arm was computed from the velocity vector expressed by a numerical differentiation from wrist and sternum markers in the 3-dimensional plane. Numbers of peaks and the percentage of movement time at the maximum peak velocity (rate, %) were extracted from tangential velocity traces.

The evaluations were performed by a blind researcher, in admission time (PRE), after the end of the 20 treatment sessions (POST) and 3 months after the training was completed (retention test – RET).

The selected patients were randomized individually into 2 training groups (Figure 2):

1. Trunk restraint group – TRG (n = 10): reaching training with trunk restraint by a harness that limited the trunk movements.
2. Trunk free group – TFG (n = 10): unrestraint reaching training, only with verbal feedback to maintain the trunk right position.

Forty-five training minutes, twice a week, totaling 20 sessions, were performed. The training was based in the motor-learning concepts including repetitive and task-specific practice. The training task consisted of grasping a cone (3.5-cm diameter base, 13-cm high) and fitting random targets as requested by the therapist in a training platform (54-cm length, 64-cm extent, 1.5-cm high) with 9 targets (6.5-cm diameter) placed 10–13 cm apart, along 3 lines. The targets were ordered in a way that stimulated the complete range of motion of shoulder and elbow and had pictures, colors, letters and

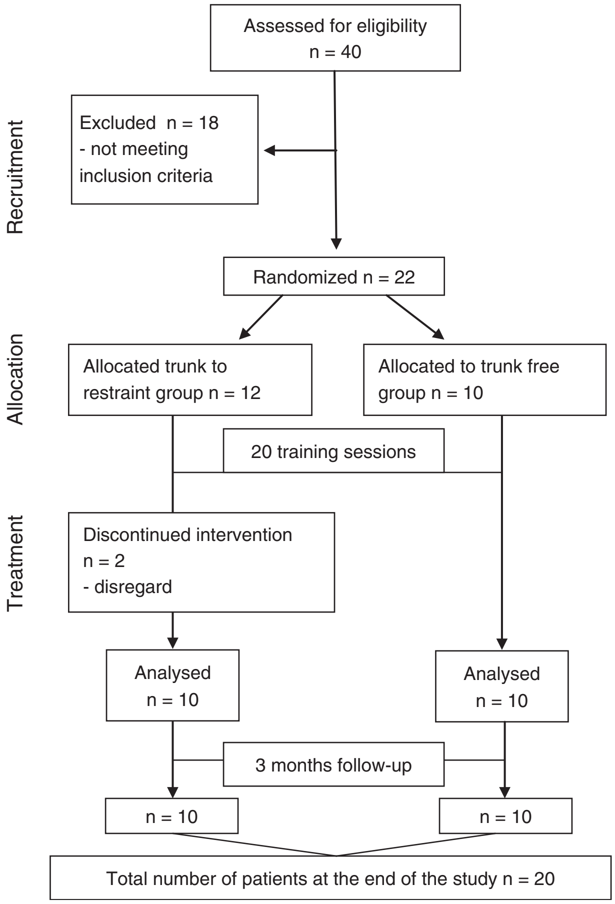

FIGURE 2. Flowchart of patient randomization on follow-up.

numbers on them yielding variability and feedback to the performing tasks (Figure 3).

Chi-squared, or Fisher tests, was used to compare the categorical variables (ie, sex) between the 3 groups (HS, TRG, TFG). Mann–Whitney (for 2 groups) and Kruskal–Wallis (for 3 groups) tests were used to compare the ratio dates (ie, age, years since stroke) measured at a single instant. Repeated-measure analysis of variance (ANOVA) and appropriate post-hoc tests (Bonferroni) were applied to compare the numerical variables (ie, kinematics dates) between groups and

FIGURE 3. Harness and training platform. (A) Stroke patient performing a reaching training with trunk restraint by a harness. The numbers in the targets were used to perform cognitive tasks. (B) Posterior custom-designed harness.

TABLE 1. Demographic Data of Healthy and Hemiparetic Patients

	HS (n = 10) Mean/SD	TRG (n = 10) Mean/SD	TFG (n = 10) Mean/SD	*P* Value
Sex, %				
Male	50	80	60	
Female	50	20	40	$P = 0.510^*$
Age, y	38.0/12.32	47.40/11.46	55.60/11.85	$P = 0.037^\dagger$
Type of lesion, %				
Ischemic		60	70	$P = 1.000^*$
Hemorrhagic		40	30	
Impairment side, %				
Right		60	50	$P = 1.000^*$
Left		40	50	
Years after onset		4.32/4.03	3.44/3.12	$P = 0.496^\ddagger$
FM – upper limb (66)		32.80/18.62	34.90/17.93	$P = 0.825^\S$
Barthel index (100)		91.50/3.37	89.00/8.43	$P = 0.890^\S$

FM = Fugl–Meyer scale, HS = healthy subjects, RET = retention test, SD = standard deviation, TFG = trunk free group, TRG = trunk restraint group.
* Fisher test.
† Kruskal–Wallis test/post-hoc Dunn (HS < TFG).
‡ Mann–Whitney test.
§ ANOVA repeated measure.

instants. The normality of the kinematic variables was detected by Shapiro–Francia test and for variables that were not normal were proposed Box–Cox transformation. The significance level adopted for the statistical tests was 5% ($P < 0.05$).

RESULTS

The demographic and clinical data of the participants are shown in Table 1. All stroke individuals had the territory of middle cerebral artery as a predominant injury site. A total of 18 of the 20 participants with stroke had hypertension like a risk factor.

Clinical Results

A significant improvement for both groups was detected in the motor impairment ($P < 0.001$) and the function ($P = 0.001$) assessments from PRE to the POST and RET tests (Table 2).

Kinematic Results

Kinematic data analyses from healthy and hemiparetic patients are described in Table 3.

The HS was better than hemiparetic for the most kinematic variables, except for elbow horizontal flexion/extension ($P = 0.083$) (HS = TRG and TFG) and shoulder flexion/extension ($P = 0.064$) (HS = TFG).

TRG had no statistical improvement for the trunk displacement variable. However, it has been noticed, by the mean analyses, a reduction in the trunk excursion from PRE to POST test that was not maintained in the RET test. In contrast, TFG obtained a significant result from PRE to POST test ($P = 0.002$) and maintained those values in the RET test, although, in this situation, with no statistical significance. There was no significant difference between groups ($P = 0.497$).

In the baseline, TFG already used more shoulder horizontal adduction joint range than TRG ($P = 0.015$). Statistical significance was found in both groups from the PRE to the POST and RET tests ($P = 0.003$).

The improvement in the shoulder flexion/extension joint range was statistically significant from PRE to POST and RET tests ($P = 0.001$) only for TRG. Before the intervention, TFG already demonstrated to be better than the TRG group ($P = 0.012$).

TABLE 2. Clinical Measures of Hemiparetic Groups

	TRG			TFG			
Variable	PRE Mean/SD	POST Mean/SD	RET Mean/SD	PRE Mean/SD	POST Mean/SD	RET Mean/SD	*P* Value
Shoulder flexors	0.10/0.32	0.00	0.00	0.10/0.32	0.10/0.32	0.00	$P = 0.238$
Elbow flexors	0.80/0.59	0.95/0.90	0.90/0.88	1.00/0.75	0.75/0.72	0.60/0.66	$P = 0.131$
FM – upper limb (66)	32.80/18.62	35.70/20.13	35.80/19.78	34.90/17.93	38.30/19.59	37.60/19.13	$P < 0.001^*$
Barthel index (100)	91.50/3.37	93.50/5.30	94.0/5.16	89.0/8.43	93.50/5.80	96.0/4.59	$P = 0.001^*$

FM = Fugl–Meyer scale, POST = posttreatment evaluation, PRE = pretreatment evaluation, RET = retention test, SD = standard deviation, TFG = trunk free group, TRG = trunk restraint group.
* ANOVA repeated measure: PRE≠POST and RET for both groups.

TABLE 3. Mean Values of Kinematic Variables

Kinematic Variable	HS Mean/SD	TRG PRE Mean/SD	TRG POST Mean/SD	TRG RET Mean/SD	TFG PRE Mean/SD	TFG POST Mean/SD	TFG RET Mean/SD
Trunk displacement, mm	18.6/10.0	85.1/86.0	42.1/29.9	79.9/79.5	97.7/83.1	25.2/10.2†	33.9/20.7
Index of curvature	1.25/0.06	1.58/0.28	1.55/0.22	1.51/0.24	1.42/0.15	1.41/0.20	1.40/0.21
Shoulder horizontal adduction, degree	70.3/16.5	33.7/12.7	45.2/18.3	45.2/15.6‡	53.3/17.5	60.6/8.9	59.9/18.3‡
Shoulder flexion/extension, degree	47.6/9.1	22.1/7.2	32.5/12.4	32.7/10.3§	38.9/12.9	43.4/11.6	42.8/12.3
Elbow horizontal flexion/extension, degree	44.7/7.2	38.8/4.3	47.7/0.2	47.2/11.9‖	46.8/10.1	45.3/8.7	45.5/9.4
Elbow sagital flexion/extension, degree	64.9/11.3	26.6/9.3	36.718.3	33.2/15.0	49.5/22.8	46.2/26.2	42.9/20.4
Movement time, s	0.74/0.23	1.79/0.77	1.67/0.68	1.44/0.41	1.51/0.42	1.37/0.48	1.42/0.46
Wrist Peak velocity, mm/s	1007/209	497/185	537/163	595/160	580/191	715/197	622/183
Velocity rate, %	42.3/7.6	22.6/14.4	32.4/11.7	37.8/14.0¶	33.9/11.6	43.2/13.5	37.4/8.9
Velocity peaks, n	1.69/0.5	12.41/9.5	10.11/5.1	9.13/5.7	9.34/4.9	7.48/5.1	7.48/4.2

FM = Fugl–Meyer scale, HS = health subjects, POST = posttreatment evaluation, PRE = pretreatment evaluation, RET = retention test, SD = standard deviation, TFG = trunk free group, TRG = trunk restraint group.
* ANOVA repeated-measure and post-hoc Bonferroni.
† TFG – $P = 0.002$ (PRE≠POST).
‡ TRG and TFG – $P = 0.003$ (PRE ≠ POST and RET).
§ TRG – $P = 0.001$ (PRE ≠ POST and RET).
‖ TRG – $P = 0.038$ (PRE ≠ RET).
¶ TRG – $P = 0.030$ (PRE ≠ RET).

Before the intervention, both groups were similar to the HS and TFG showing more elbow horizontal flexion/extension joint range than the TRG group ($P = 0.038$). Statistical improvement posttreatment was found only for TRG from PRE to RET test ($P = 0.038$).

In contrast to healthy patients, the hemiparetic patients had a slower movement evidenced by a decrease in the wrist peak velocity ($P < 0.01$) and a major movement time ($P < 0.01$) (pretreatment values). From both groups, after the training period, there was an improvement with no statistical significance.

The rate of maximum peak velocity presented a significant difference in the instant pretreatment between the hemiparetic groups, showing that the TRG had lower scores than the TFG ($P = 0.043$). This variable did show a significant improvement from PRE to RET test ($P = 0.030$) only for the TRG.

No statistical improvements were found in the elbow sagital flexion extension, index of curvature, and number of peaks for both groups.

DISCUSSION

In the present study, the task-specific training with trunk restraint (TRG) was able to provide an improvement in the shoulder and elbow active joint ranges and in the rate of maximum peak velocity, thus offering more chances in the intensive use of the affected arm. However, the results showed that there was no improvement in the retention of the trunk. Therefore, the free trunk training developed more attention in the abnormal recruitment of the additional degrees of freedom and did not explore, in an efficient way, the multijoint combinations presented in the upper limb.

Although the clinical measures do not focus on the trunk and shoulder girdle compensatory strategies, as well as on the joint range movement during the performed tasks,[6] both groups showed an improvement in the upper limb motor and functional impairment (measured by Fugl–Meyer and Barthel index). These data corroborate with the Oliveira et al[14] study that observed a great clinical improvement in reaching movements in trunk restraint hemiparetic patients. Another study demonstrated functional and motor improvements for 2 training groups after modified constraint-induced movement therapy, plus trunk restraint or only modified constraint-induced movement therapy.[15] The therapeutic intervention based on the restriction of the trunk compensatory movements aims at decreasing the use of additional degrees of freedom while promoting the facilitation of upper limb normal motor patterns.[16]

In this study, TFG showed an effective reduction in the trunk compensatory recruitment, retaining the gains on follow-up tests. TRG had improvements from PRE to POST evaluations but with no statistical significance and with no maintenance in the RET. It suggested that the continuous use of the trunk physical restraint in TRG may have produced an intense dependence, leading the patient to miss the intrinsic information that is responsible for the ability of error detection and correction.[17]

On the contrary, this group (TRG) acquired higher improvements in the shoulder and elbow active joint range and used less deceleration phase to perform the reaching (improvement in the rate of maximum peak velocity), when compared with the TFG group.

Reaching training only with verbal guidance (TFG), despite having been shown to be more effective in the trunk recruitment retention, did not offer an improvement in shoulder and elbow joint ranges, except for the elbow adduction range, which can be explained by the facilitation that occurs naturally in adduction movements owing to the characteristic flexor pattern of stroke.[18] Roby-Brami et al[19] reported that during nonrestraint tasks, patients use a limited range of motion of shoulder and elbow, consistent with the injured volunteer motion range. Thus, the patient fixes the shoulder girdle to the trunk and reduces the number of degrees of freedom associated with the arm, giving the system an additional stability.[20]

Thus, the use of proprioceptive information and the intrinsic (corrective) and extrinsic (verbal) feedback in the TFG seem to have contributed for the better trunk restraint. However, the use of cutaneous and proprioceptive information giving to the TRG by the trunk restraint has a crucial role in motor recovery of patients with brain damage, also fundamental to the beginning of motor training.[14,21]

Another factor that may have led to an improvement in the active joint range only in the TRG is that TFG had better kinematic values in the PRE test assessment. Therefore, we can infer that the TRG still had a subclinical potential to be explored, unlike the control group that already had values very close to those considered regular (motor recovery plateau). Any physical activity causes neuromuscular adjustments, leading to a stabilization of motor performance, but this plateau is not indicative that the person has lost the capacity to improve.[22,23] Unrestraint therapy was not favorable to explore the possibilities of improvement of the TFG affected arm.

Regardless of the applied protocol, both groups showed positive results in values for the movement velocity. All patients reduced the task execution time, increased the velocity of movement, and performed more harmonic trajectories (less velocity peaks).

The hemiparetics spent more time in the phase after the maximum peak velocity, because this is the period in which feedback is more likely to be used to adjust the movement in a way to compensate for the higher movement variability and thus to improve accuracy.[24,25] The increase in the deceleration time is indicative of an increase in the control of corrective feedback happened.[26] In the pretreatment period, the patients presented early velocity peaks because they depended on long deceleration phases to make the correction of the movement.

The use of physical feedback, provided by the harness associated with the practice of repetitive tasks, was able to provide an increase in the maximum velocity rate (ie, the maximum velocity peak occurred more lately). This suggests that the patients had less time to make the movement correction, which may have led to the improvement in the internal planning.

In conclusion, the trunk restraint therapy could be able to improve the upper limb active joint range and the internal planning of the movement, but not retained the trunk excessive displacement because it offers an excessive and continuous feedback. The use of restraint could be beneficial, but the authors suggested that is important to planning a harness weaning protocol to avoid the information dependence by the patient.

REFERENCES

1. Cirstea MC, Levin MF. Compensatory strategies for reaching in stroke. *Brain.* 2000;123:940–953.
2. Archambault P, Pigeon P, Feldman AG, et al. Recruitment and sequencing of different degrees of freedom during pointing movements involving the trunk in healthy and hemiparetic subjects. *Exp Brain Res.* 1999;126:55–67.
3. Michaelsen SM, Levin MF. Short-term effects of practice with trunk restraint on reaching movements in patients with chronic stroke. *Stroke.* 2004;35:1914–1919.
4. Michaelsen SM, Luta A, Roby-Brami A, et al. Effect of trunk restraint on the recovery of reaching movements in hemiparetic patients. *Stroke.* 2001;32:1875–1883.
5. Levin MF. Interjoint coordination during pointing movements is disrupted in spastic hemiparesis. *Brain.* 1996;119:281–294.
6. Kwakkel G. Impact of intensity of practice after stroke: issues for consideration. *Disabil Rehabil.* 2006;28:823–830.
7. Kalra L, Ratan R. Recent advances in stroke rehabilitation 2006. *Stroke.* 2007;38:235–237.
8. Michaelsen SM, Dannenbaum R, Levin MF. Task-specific training with trunk restraint on arm recovery in stroke. *Stroke.* 2006;37:186–192.
9. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther.* 1987;67:206–207.
10. Fugl-Meyer AR, Jaasko L, Leyman L, et al. The post-stroke hemiparetic patients. A method for evaluation of physical performance. *Scand J Rehabil Med.* 1975;7:13–31.
11. Maki T, Quagliato EMAB, Cacho EWA, et al. Reliability study on the application of the Fugl-Meyer scale in Brazil. *Rev Bras Fisioter.* 2006;10:177–183.
12. Mahoney FI, Barthel D. Functional evaluation: the Barthel index. *Maryland St Med J.* 1965;14:56–61.
13. Oliveira R, Cacho EWA, Borges G. Post-stroke motor and functional evaluations: a clinical correlation using Fugl–Meyer assessment scale, Berg balance scale and Barthel index. *Arq Neuropsiquiatr.* 2006;64:731–735.
14. Oliveira R, Cacho EWA, Borges G. Improvements in the upper limb of hemiparetic patients after reaching movements training. *Int J Rehabil Res.* 2007;30:67–70.
15. Woodbury ML, Howland DR, McGuirk TE, et al. Effects of trunk restraint combined with intensive task practice on poststroke upper extremity reach and function: a pilot study. *Neurorehabil Neural Repair.* 2009;23:78–91.
16. Wu C, Chen Y, Chen H, et al. Pilot trial of distributed constraint induced therapy with trunk restraint to improve poststroke reach to grasp and trunk kinematics. *Neurorehab Neural Repair.* 2012;26:247–255.
17. Wulf G, Chiviacowsky S, Schiller E, et al. Frequent external-focus feedback enhances motor learning. *Front Psychol.* 2010;1:1–7.
18. Zackowski KM, Dromerick AW, Sahrmann SA, et al. How do strength, sensation, spasticity and joint individuation relate to the reaching deficits of people with chronic hemiparesis? *Brain.* 2004;127:1035–1046.
19. Roby-Brami A, Feydy A, Combeaud M, et al. Motor compensation and recovery for reaching in stroke patients. *Acta Neurol Scand.* 2003;107:369–381.
20. Carr JH, Shepherd RB. A motor relearning model for stroke rehabilitation. *Physiotherapy.* 1989;75:372–380.
21. Woldag H, Hummelshein H. Evidence-based physiotherapeutic concepts for improving arm and hand function in stroke patients: a review. *J Neurol.* 2002;249:518–528.
22. Kwakkel G, Kollen BJ. Predicting activities after stroke: what is clinically relevant? *Int J Stroke.* 2013;8:25–32.
23. Ullbert T, Zia E, Petersson J, et al. Changes in functional outcome over the first year after stroke. An observational study from the Swedish Stroke Register. *Stroke.* 2015;46:389–394.
24. Van Vliet PM, Sheridan MR. Coordination between reaching and grasping in patients with hemiparesis and healthy subjects. *Arch Phys Med Rehabil.* 2007;88:1325–1331.
25. Stewart JC, Gordon J, Winstein CJ. Planning and adjustments for the control of reach extent in a virtual environment. *J Neuroeng Rehabil.* 2013;10:27.
26. Stewart JC, Gordon J, Winstein CJ. Control of reach extent with the paretic and nonparetic arms after unilateral sensorimotor stroke: kinematic differences based on side of brain damage. *Exp Brain Res.* 2014;232:2407–2419.