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Arm training in standing also improves postural control in participants with chronic stroke

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Abstract

Purpose—To prove the concept that postural control will improve without specific balance control training during arm training in standing with individuals with chronic stroke.

Methods—Nine participants (mean age 64 ± 7) received training involving hand orthotic assisted grasp, reach and release in standing 1 h, 3x/s/week for 6 weeks. Training focused on task completion with no explicit instructions provided for postural alignment, weight shift or balance strategy. Testing consisted of quantified measures using NeuroCom™ Balance Master, Berg Balance Scale (BBS) and Activities-specific Balance Confidence Scale (ABC).

Results—Post training participants demonstrate increased ($p < .05$) composite stability scores for sensory organization testing (mean 71.55 ± 12.7 – 75.55 ± 11). Velocity and directional control of COP weight shift improved for all 9 subjects with 6/9 achieving 100% target acquisition. Directional control improved ($p < .05$) for medial/lateral movements for all speeds and composite score. Anterior/posterior rhythmic weight shifting increased significantly in COP velocity control at moderate and fast velocities and composite score. Increases in mean BBS ($p < .01$) from 41.33 ± 10.1 – 46.88 ± 8.03 exceeded the clinically important cutoff for the scale. Balance confidence improved with ABC mean scores 70.22 ± 14.5 – 79.55 ± 12.86 ($p < .05$). Seven participants demonstrated changes above the minimally important difference for this scale.

Conclusions—Postural control improved following task oriented arm training in standing without explicit postural control goals, instruction or feedback challenging current training paradigms of isolated postural control training with conscious attention directed to center of pressure location and movement.

Keywords

Postural control; Implicit learning; Stroke; Upper extremity training; Standing

1. Introduction

Stroke is the leading cause of long term adult disability in the United States and continues to be a major health care issue with a 40–70 billion dollar yearly economic impact [1]. Permanent disability resulting from stroke affects over 260,000 adults each year with 30,000 requiring nursing-home admission. When considering physical disability post stroke, less than 20% of stroke survivors regain functional use of the their paretic arm [2], almost 50% lack independence in activities of daily living [3] and while 82% regain standing and ambulatory abilities [4], postural instability persists which can lead to falls, injury and

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further disability [5]. Lamb et al. has shown that impaired balance is a predictor of falls for elderly community dwelling women post stroke [6]. Effective rehabilitation interventions to remediate the multifactorial deficits contributing to postural instability and prevent falls is an important challenge for rehabilitation.

Despite the presence of multifactorial deficits, in the literature, the majority of interventions post stroke typically target isolated impairments or functional limitations. For example, arm training approaches are conducted in the seated position [7–9]. Likewise, postural training studies, while conducted in standing, rarely include concurrent functional arm training in reaching or manipulatory tasks [10,11]. To our knowledge, only Combs et al. report a training program that has a component of task oriented skills training in patients post stroke but without specific quantification of postural control outcomes [12]. Training the arm and postural control in isolation, may not restore integrated functional use necessary for independent skilled performance of activities of daily living. For example, activities such as food preparation, bathing and dressing, require integrated postural control, ambulatory skills, reaching, grasping and manipulation of objects in the standing position [13].

When combining reaching for an object in standing, components that contribute to performance of the task include anticipatory postural responses to stabilize posture, weight shift to move the body center of mass (COM) towards the object, visual fixation on the object, as well as the voluntary grasp, reach and release of the object [14,15]. Anticipatory postural control and voluntary arm movement are thought to be controlled by different, but parallel descending pathways [16]. These parallel control mechanisms need to be integrated for effective activity completion [17] without loss of postural control or a fall. Hence, reach training should be carried out in the context of the task demands and may be essential for the implicit engagement of the underlying neural control networks for integration of the different mechanical, sensory, motor and goal oriented systems that contribute to arm function and postural regulation. Combining explicit cues for both arm function as well as postural control, however, would constitute a dual task situation that individuals with stroke would find quite difficult. In this study we propose the use of explicit cues only for the arm during training in standing with no cueing for postural control to facilitate an implicit learning process for the latter (see Pohl et al. [18] for details on implicit learning after stroke).

The purpose of this single cohort study was to provide a proof of concept that combining explicit cues for goal oriented arm training, while standing will result in implicit training of postural control. Such findings would suggest that clinical practice may benefit from this combined explicit/implicit learning approach for more efficient training of both arm function and postural control in a biologically integrated manner.

2. Methods

This study recruited 9 participants with chronic hemiparetic stroke. See Table 1 for subject characteristics. Participants were a sample of convenience recruited consecutively from a larger study. It is unlikely the larger study impacted data reported in this manuscript. All subjects presented with chronic upper extremity hemiparesis determined to be of moderate severity based on the Fugl-Meyer upper extremity test (mean FM 27 ± 10 ; range 0–66). Inclusion criteria included, chronic unilateral ischemic or hemorrhagic stroke, age 50–80, 6 months post stroke having completed all conventional therapy, and ability to stand unsupported for 5 min with contact guard of the trainer. This study was approved by both the University of Maryland and Baltimore VA Medical Center IRB Boards. All subjects signed informed consent.

2.1. Testing methods

Quantitative postural control assessment was conducted using three subtests; sensory organization testing (SOT), limits of stability (LOS) and rhythmic weight shift (RWS), of the NeuroCom™ Smart Balance Master according to standard protocol [19]. The SOT protocol consists of six timed static standing tasks under different sensory conditions for identification of the use of somatosensory, visual and vestibular systems for quiet stance postural control. Test conditions were performed for 2 trials of 20 s each with instructions to “Stand quietly”. The SOT measure was the “composite” stability score which averages the stability across all conditions and trials. The LOS subtest quantifies the maximum distance a person can intentionally displace their center of pressure (COP) from start position of midline COP centered over the base of support to eight targets. Location and movement of the COP was indicated by a cursor display projected on a screen in front of the subject. As targets were highlighted, the subject was to move the COP cursor quickly and accurately as possible towards a target located on the LOS perimeter and hold position as close to the target as possible. The parameters include COP movement velocity and directional control (% to target). If a subject cannot move sufficiently towards a target a no score (NS) is recorded. The RWS quantifies the subject's active weight shift ability by moving the COP cursor to match velocity and direction of a moving visual target in the medial- lateral (ML) and anterior-posterior (AP) directions at three different velocities.

The clinical measures of balance included the Berg Balance Scale (BBS) and the Activities-specific Balance Confidence Scale (ABC). Both tests have been validated for use in the stroke population and have been used to characterize balance deficits [20,21]. No assistive devices or orthoses were used during the quantitative or clinical tests. All tests were performed at baseline and within one week of completion of training. All measures are valid measures of postural control with good to excellent reliability.

2.2. Training methods

Subjects received training 1 h, 3×/s/week, for 6 weeks consisting of 5 upper extremity (UE) tasks involving grasp, reach and release assisted by the Saeboflex® hand training orthosis. Training tasks, performed in standing, included (1) grasp, forward reach and release ball in target buckets, (2) grasp, reach forward through hoop and release ball in bucket targets (simulates a forward reach with emphasis on elbow extension and forearm supination), (3) grasp with pronated forearm and supinate to place hoop ball on horizontal pole (simulates opening a door-holding object while supinating forearm), (4) grasp with palmar grasp, flex and abduct arm to place hoop ball on horizontal pole (simulates holding an object and abduction to place at the side), (5) grasp peg ball with supinated wrist, reach forward and place peg in elevated peg board (simulates holding and placing a glass while maintaining upright position). Subjects completed 30 repetitions of each UE exercise in the order above. Exceptions were made if subjects requested a particular order during any given session. Performance feedback on UE training was provided to address quality of movement including grasp effectiveness, forearm position and shoulder position to limit compensations and specify desired practice kinematics. Assistance/guidance was provided to the arm early on to promote practice of quality movements. UE training was progressed by reducing assistance/guidance and by increasing speed and/or movement extent as tolerated. Targets were placed at distances to promote reach distance and direction and therefore required anterior/posterior as well as medial/lateral weight shift. Distance was determined by ability to complete UE task while also promoting A/P and/or M/L weight shift. Training instruction focused on completion of the upper extremity tasks with no explicit instructions or feedback provided regarding postural control, initial foot position or strategy for postural adjustment. The hand orthosis was used to permit active hand function of grasp and release during arm training tasks given that no subject was able to grasp and release independently at baseline.

All arm training was completed in standing with rests in sitting provided as needed. Average time to complete a given exercise was 8 min with an average standing time of 40 min/session. Nonparetic arm weight bearing for support during the paretic arm training tasks was discouraged.

2.3. Analysis

Composite scores for SOT were compared using one-way repeated measures ANOVA. Directional control and velocity scores were analyzed using a two-way ANOVA comparing speed $\times$ time for each movement direction (ML and AP). Post hoc analyses were completed using the Tukey ($p < .05$). Individual scores for LOS are provided for pre and post training as statistical analyses could not be conducted given the number of “no scores” at baseline testing. A one-way repeated measures analysis of variance was used to compare the pre and post scores for the BBS and the ABC with comparisons to reported minimally detectable/important differences. All subjects were included in all statistical analyses.

3. Results

3.1. NeuroCom™ measures

3.1.1. Sensory organization test—Table 2 shows the composite “stability” score for the SOT testing at pre and post training. Mean scores were significantly increased ($p < .05$) from pre (71.55 ± 12.7) to post training (75.55 ± 11).

3.1.2. Limits of stability—In Table 3, pre and post training individual scores are shown for the velocity and directional control during the limits of stability test. Observational findings were lack of visible ankle strategy to produce a transfer of center of pressure (COP) during weight shift to target in all directions especially posterior and to paretic side. After training, 6 out of 9 (66%) subjects could reach all targets with 3 (subjects 2, 6, 8) reaching 3 out of 4 targets for the major COP movement directions (A/P movements proving to be the most challenging). The changes represent improvements in both velocity and directional control for all 9 participants. Fig. 1 demonstrates pre and post training directional control and movement extent results for the LOS and RWS for one exemplar (subject 4).

3.1.3. Rhythmic weight shift—Group data for the COP velocity and directional control variables are provided in Table 4. Directional control improved significantly ($p < .05$) post training for M/L movements for all speeds and the composite score. Significant increases in COP directional control were noted at moderate and fast velocities and the composite score for A/P weight shifts. Of note, directional control was higher for M/L weight shifts at all speeds compared to A/P weight shifts but we were not powered to detect statistical significance. There were no significant changes in the movement velocity from pre to post training at any speed for ML and AP weight shifts.

3.2. Clinical measures

Significant increases in the mean BBS ($p < .01$) were demonstrated with pre training scores for the group at 41.33 ± 10.1 and 46.88 ± 8.03 post training. On examination of individual baseline scores, 5 out of 9 were below the fall risk score of 45 indicating 55% with risk of falling. Post training, all 9 improved their post training score with 6 out of 9 scoring above the identified fall risk score of 45. All but one subject, who received the maximal score at baseline, demonstrated post training at or gains above the minimally detectable change levels for the BBS reported for elderly across severity levels [22]. The greatest changes were seen for items including alternating foot placement, standing with one foot in front of the other, standing on one foot, reaching forward, and turning.

Mean % ABC scores for the group improved significantly from 70.22 ± 14.5 to 79.55 ± 12.86 at post training ($p < .05$). Post training all 9 subjects reported increased levels of confidence in their ability to balance during the listed tasks with 7 of 9 subjects improving their confidence category. A score below 67% is associated with fall risk in the elderly. Three subjects had baseline ABC scores below 67% with one improving post training above this cutoff. Seven subjects demonstrated post training changes above the minimally important difference (6 pts) for this scale [23].

3.3. Upper extremity measures

Upper extremity outcomes of the larger cohort will be reported in another manuscript. The subset reported here showed improvements pre/post for the Fugl-Meyer upper extremity test (19 ± 8 – 24 ± 6), wolf motor function test times (70 ± 24 – 66 ± 16 s), and the University of Maryland arm questionnaire for stroke (17 ± 5 – 21 ± 8).

4. Discussion

The purpose of this proof of concept study was to demonstrate that focused arm training in standing would result in implicit training of postural control. Our cohort of participants had baseline deficits in postural control consistent with other reports [5,24] and, our primary finding was that postural control improvements were seen following a hemiparetic arm training intervention performed in standing without explicit postural control instruction, suggesting implicit postural learning had occurred.

The capacity for retaining implicit learning of motor skills in individuals post stroke has been demonstrated in a number of studies looking at sequence learning [25,26] and is thought to be in part, due to the distributed nature of the brain regions that support this function. This is the first demonstration of implicit learning of postural control. While the arm training tasks were set up to require postural adjustments prior to and during the execution of the arm task, the instructions and feedback did not focus the subjects' attention on stability, movement of the center of pressure or postural adjustments. We suggest that learning motor skills in this manner, that is, use of implicit learning strategies, may be of particular benefit in the rehabilitation of integrated motor skills. For example, many individuals post stroke demonstrate deficits in both arm function and the normal postural responses that precede and accompany arm movement in a functional task. Asking a patient to focus attention on performance of both their arm function and the control of their balance and weight shift at the same time, a dual task approach, may be too challenging. In addition, training these skills separately would be more time consuming and does not guarantee coordinated function of the two separately trained skills when combined as part of a functional task. Arm training in standing with no explicit cues for balance control can train two tasks at once and is potentially more efficient and effective use of therapist and patient treatment time.

The explicit focus and instruction on arm training also serves as an external attentional focus. Recently a number of researchers have examined the impact of an external attentional focus on postural sway in standing in healthy adults [27,28]. These studies show that the addition of a “supra-postural” task to which the subjects are asked to attend, such as maintaining a finger touch on a curtain in quiet stance, reduced postural sway better than having the participants focus on reducing the sway as an internal attentional focus. These improvements in static postural control are thought to result from the subjects using more “automatic” or unconscious processes for balancing given that their attentional focus is on completion of the finger task. Since postural preparation and control are not typically under conscious voluntary control, challenging postural responses as part of functional tasks (in this case arm training in standing) may engage subcortical neural pathways that are thought

to be active and involved in postural movement preparation, planning and execution and normally work in coordination with cortical pathways that control goal directed arm movement. It has been suggested that training with an attentional focus on postural control may, in fact, be disruptive to the unconscious control processes that subserve these automatic postural actions [29]. Therefore, the significant postural control improvements resulting from training the upper extremity in the standing position, suggest an alternate intervention option for training postural preparation, planning and execution in the post stroke population in contrast to more traditional balance interventions that focus on isolated stability and weight shift training with explicit feedback.

A number of studies in chronic stroke with a conscious focus on postural control have demonstrated improvements in walking speed, endurance and in clinical measures of balance [10,11,30]. Each of the studies included an attentional focus on walking, stepping or sit to stand training demonstrating that explicit attention on postural control activities can result in improvements in gait and clinical measures of balance. Interestingly, these studies report similar gains as we do for the BBS (a measure the studies have in common). However, since the studies do not include task training that requires goal directed reaching of the arm while in standing, the gains in postural control may have limited generalization to activities that engage the arms such as activities of daily living (ADL).

In the community dwelling post stroke population, reduced arm function and ADL disability have been associated with repeat falling [31]. Most activities of daily living performed in standing require arm use in some manner. It is possible that fall risk after stroke may be reduced with task oriented training of an ADL task performed in standing which engages both the systems that control arm movement and those that control anticipatory and reactive postural control. It is plausible that in order to achieve gains in postural preparation in the context of goal directed arm use, an implicit training approach with external focus on the arm task may be preferred and may ultimately result in a reduction of falls in this population. For example, in a study of community dwelling older females by Peeters et al., engagement in regular light and heavy “household activities” resulted in a decrease in risk of recurrent falls [32].

One potential limitation to this study is participants were exposed to a battery of postural outcome tests prior to training. This exposure may have promoted attention to postural control during the UE training. Future research is needed to examine implicit postural control training with explicit arm training in standing in a randomized control trial. We are particularly interested in directly comparing seated arm training to arm training in standing as well as a direct comparison of explicit postural control training in standing reaching activities to our implicit training approach. In addition we recommend future studies to include the specific evaluation of ADL task performance in standing in response to training.

5. Conclusions

Quantitative and clinical measures of postural control improved following task oriented arm training in standing without explicit postural control goals, instruction or feedback. This finding challenges current training paradigms of isolated postural control training that have conscious attention directed to center of pressure location and that promote movement in the absence of integrated arm function.

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Fig. 1.
Graphic representation of RWS (ML/AP) and LOS (exemplar subject #4 w/right sided paresis) pre (top row) and post (bottom row).

Table 1

Subject characteristics.

Subject #	Age	Gender	Side of stroke	Time since stroke (months)	Baseline UE FM
1	65	M	Left	12	13
2	58	M	Left	63	23
3	66	F	Left	33	21
4	78	M	Left	25	5
5	55	F	Right	11	26
6	68	M	Right	12	25
7	66	M	Right	18	29
8	62	F	Left	60	14
9	58	M	Right	26	14
Mean	64 ± 7	6 M 3 F	5 L 4 RT	29 ± 20	19 ± 8

Table 2

Individual scores for sensory organizational composite stability.

	Subject									Mean
	1	2	3	4	5	6	7	8	9	
Pie	84	79	72	59	85	69	77	45	74	71.55
Post	87	81	79	67	88	76	81	54	67	75.55*
Change	3	3	7	8	3	7	4	9	-7	

* $p < .05$.

Table 3

Limits of stability individual data (directional control and velocity).

Direction (% to target)		Subject																	
		1		2		3		4		5		6		7		8		9	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Forward		12	21	79	81	NS	58	NS	30	78	80	NS	39	52	60	NS	NS	NS	24
Back		38	38	NS	NS	NS	60	NS	63	82	89	NS	NS	NS	50	NS	45	NS	57
Paretic side		NS	45	56	62	NS	75	NS	70	84	95	NS	80	NS	70	NS	66	NS	77
NP side		44	69	70	75	63	63	NS	85	89	92	55	81	NS	80	78	79	50	87
Velocity (°/s)		1	2	3	4	5	6	7	8	9									
Forward	0.8	1.1	1.6	2.5	NS	3.6	NS	1.1	2.6	NS	0.9	1.7	2.5	NS	NS	0.8			
Back	2.6	3.3	NS	NS	NS	3.3	NS	1.3	1.3	1.7	NS	NS	1.1	NS	1.5	NS	2.8		
Paretic Side	NS	1.8	1.9	2.3	NS	2.7	NS	1.8	1.4	3.1	NS	1.8	NS	NS	1.7	NS	1.3		
NIP Side	2.5	4.7	3.3	3.8	5.7	6.6	NS	3.5	2.1	2.7	2.1	3.6	NS	3.0	.78	3.8	1.0	2.5	

NS = no score; patient unable to move sufficiently to register a score.

Number present indicates "Full score" which is defined as patient able to reach target.

Table 4

Mean scores for rhythmic weight shift ($n = 9$).

Speed	Directional control (% to target)				Velocity (°/s)			
	M/L pre	M/L post	A/P pre	A/P post	M/L pre	M/L post	A/P Pre	A/P post
Slow	67.80	79.80 *	20.20	23.10	2.55	2.27	1.46	1.45
Moderate	73.60	84.60 *	33.10	46.60 *	4.01	3.81	1.95	2.00
Fast	79.70	89.30 *	34.70	48.00 *	6.21	6.27	2.96	2.77
Composite	73.70	84.60 *	29.30	39.20 *	4.25	4.12	2.11	2.07

* $p < .05$.