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VERTICAL GROUND REACTION FORCE FEEDBACK TO ENHANCE STROKE PATIENTS' SYMMETRICAL BODY-WEIGHT DISTRIBUTION WHILE RISING/SITTING DOWN

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ABSTRACT. A force platform with an auditory output consisting of two electronic balances was used to reinforce symmetrical body-weight distribution in stroke patients. Forty patients randomly assigned to an experimental group or a control group practised rising and sitting down for 15 min, thrice daily, 5 days a week for 6 weeks. The experimental group but not the control group received ground reaction force feedback through the auditory output. Vertical ground reaction forces under each foot were measured with two force plates. Mean difference in improvement of body weight distribution on the paretic leg was 13.2 ± 10.7 (M, SD) per cent total body weight in the experimental group and 5.1 ± 6·7 per cent in the control group in rising ($p < 0.01$) and 12.7 ± 7.5 per cent total body weight and 4.6 ± 6.6 per cent in sitting down tests ($p < 0.001$). The patients in the experimental group achieved in average close to a symmetrical body-weight distribution while rising and sitting down. Improvements in physical performance and sit-stand tests were greater in the experimental group ($p < 0.05$ and $p < 0.01$, respectively). No differences were seen in improvement in performance of activities of daily living. Symmetry in body-weight distribution in rising and sitting down correlated with high scores in physical performance, motor function in rising, and with functional ability.

Key words: vertical ground reaction force feedback, auditory output, stroke, hemiplegia, rising, sitting down, body-weight distribution, symmetry.

When a healthy person rises or sits down, the body-weight is usually distributed nearly symmetrically on the two legs but may be borne more on the right or the left leg, depending on whether the person intends to move to the right or to the left after standing up (7). In contrast, following early recovery after stroke some patients spontaneously and constantly weight-bear on the non-paretic leg when getting up from and sitting down on a chair (4, 7).

Immediately after the occurrence of a stroke, patients use the non-paretic side and learn how to manage in activities of daily life, compensating with the intact side of the body. Although they may be able to weight-bear on the previously paretic leg, while rising and sitting down (12) some patients continue to distribute body-weight unevenly. This learning phenomenon, termed 'learned non-use' (27), may result in secondary complications such as reduced mobility of the ankle joint (7), low muscle force, shortened triceps surae muscles, hypertonus (22) and osteoporosis (28) of the unloaded leg. If the patient fails to relearn a motor behaviour aiming at weight bearing on the affected leg, an asymmetrical pattern of body-weight distribution may become habitual due to an acquired, no longer adequate, pre-programmed motor plan (6) for rising and sitting down. Difficulties arise when balancing on the non-paretic leg without relevant support from the affected leg.

Learning new motor tasks depends heavily upon sensory information. After learning when the skill has been acquired, the skill depends largely on preprogrammed commands that require little or no feed-back (6). Augmented feedback to reinforce relearning of daily motor tasks in the initial cognitive stage has been studied by Gentile (15) who advised the use of knowledge of performance (KP) during the fixation phase in the training of motor tasks of a closed type, i.e., movements performed under stationary environmental conditions (25). Wallace & Hagler (29) also concluded that KP is a strong feedback source in the acquisition of a closed motor skill.

In stroke patients the intrinsic feedback may be compromised, resulting in inadequate relearning of

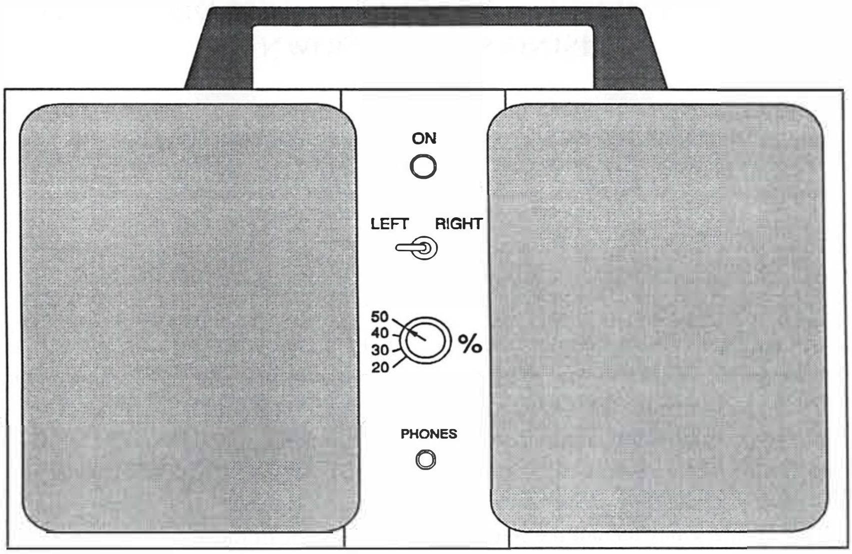

Fig. 1. The training device; a force platform consisting of two electronic balances, sensing vertical ground reaction forces under each foot.

motor skills (18). Augmented visual and/or auditory feedback from EMG, vertical force or joint position has thus been used since the beginning of the 1960's to facilitate relearning of motor activities. Studies have shown the beneficial effects of different devices for auditory feedback to achieve symmetrical weight-bearing in standing and in walking (2, 9, 20, 21, 30). No study, to our knowledge, has concerned the effects of auditory feedback to achieve symmetrical weight-bearing while rising and sitting down.

A vertical ground reaction force feedback device with an auditory output was therefore constructed* (Fig. 1). The purpose of the study was to evaluate the effect of training with this device (*a*) to reduce the asymmetric weight-bearing on the legs in rising and sitting down and (*b*) to enhance the physical performance in patients with stroke. The aim was furthermore to find out whether there was a correlation between symmetry of body-weight distribution on the lower extremities while rising/sitting down and high scores in physical performance, motor function and independence in activities of daily living in patients with hemiparesis after stroke.

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PATIENTS AND METHODS

Forty-two stroke patients were studied one week to three months after a cerebrovascular insult. The patients should be able to understand and follow instructions, have adequate hearing and be able to stand up independently. Patients with normal motor function in the lower extremities, who stood up with ataxia or who had severe cognitive deficits were excluded. Forty-two stroke patients, with informed consent, all in-patients from Rehabilitation departments in Stockholm were randomly assigned, decided by lot, to an experimental group or a control group, equally large. Forty patients completed the study. Patient characteristics of the two groups are shown in Table 1.

Body-weight distribution measurements

The vertical floor reaction forces under each foot were determined with two strain-gauge force transducers attached to two platforms (23).

The patient sat in a standardised position on an adjustable, armless chair with a back support. The seat height was set to

Table I. *Characteristics of the stroke patients (mean and SD) and number (No) in the experimental (n = 20) and the control group (n = 20)*

	Experimental	Control
Age (Mean, SD)	64.6±6.7	65.1±9.0
Weight	70.4±19.9	69.5±11.8
Height	173.8±7.8	167.3±9.9
Female (No)	4	11
Male	16	9
Cerebral haemorrhage	3	3
Cerebral infarction	15	17
Unspecified	2	
Involved side, left/right	12/8	8/12
Hemianopia	4	2
Sensory deficits	5	8
Sensory loss	5	1
Cognitive deficits		
time		1
space	3	5
body image	4	4
visual perception	5	4
Muscular hypertonus	4	6
Days since stroke incidence	38±18	38±22

the patient's knee height, determined as the distance from the lateral knee joint line to the floor, with the tibia perpendicular to the floor. The trunk was upright and the thighs supported for 3/4 of the femoral length. The patient placed one foot firmly on each platform right above the strain gauge force transducers. The patients were instructed to stand up, to stand for one minute and to sit down again. The instructions were: "Please stand up, as you usually do" and after one minute of standing "Please sit down, as you usually do". A few pretest trials were allowed, for the patients to become accustomed to the testing procedure.

The recordings from the two strain-gauge force transducers were analysed with a specially designed computer program called KI-Raise. The time integral of the vertical forces under each foot in rising and sitting down was measured (Fig. 2). Body-weight distribution was computed as the ratio between the time integrals of the vertical forces of the paretic leg and the non-paretic leg, where 1.0 equals symmetrical body-weight distribution (12). The means from three tests of rising and of sitting down were calculated. Both groups were tested before and after a training period of 6 weeks. No differences in vertical floor reaction forces, measured before the training, were seen between the groups.

Clinical assessments

Activities of daily living were assessed using the Barthel Index (19, 17), scoring 10 items (self-care and mobility) with a maximum score of 100.

Physical performance of the lower extremities was rated using the Fugl-Meyer Assessment, a three-point ordinal scale (13, 11), including motor function, balance, light touch and position sense, passive range of motion and occurrence of joint pain in the lower extremities. Scoring is cumulative from 0 to 100 points.

Motor function in sit-stand was tested using the Motor Assessment Scale (MAS) (1–6 points), designed by Carr et al. (8, 24).

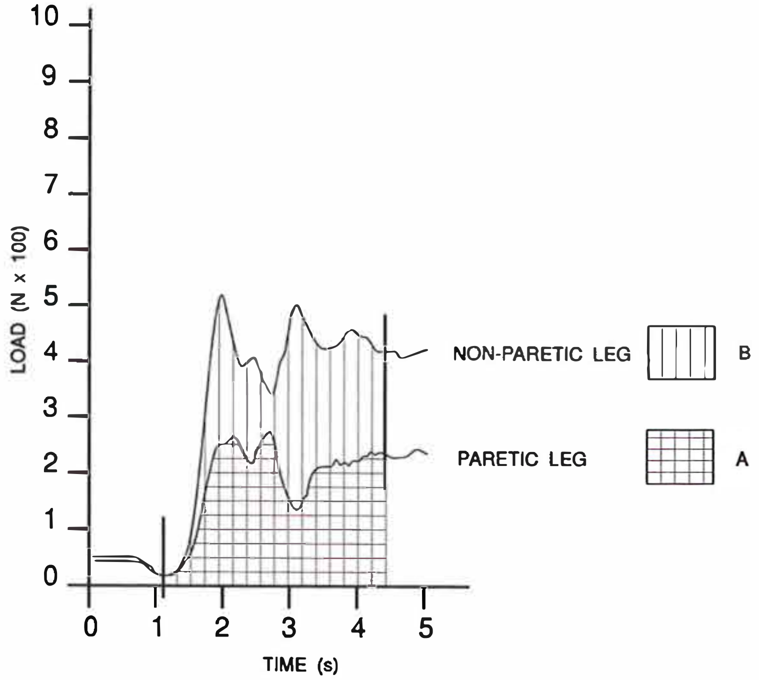

Fig. 2. The time integral of the vertical forces of the paretic (A) and the non-paretic leg (B).

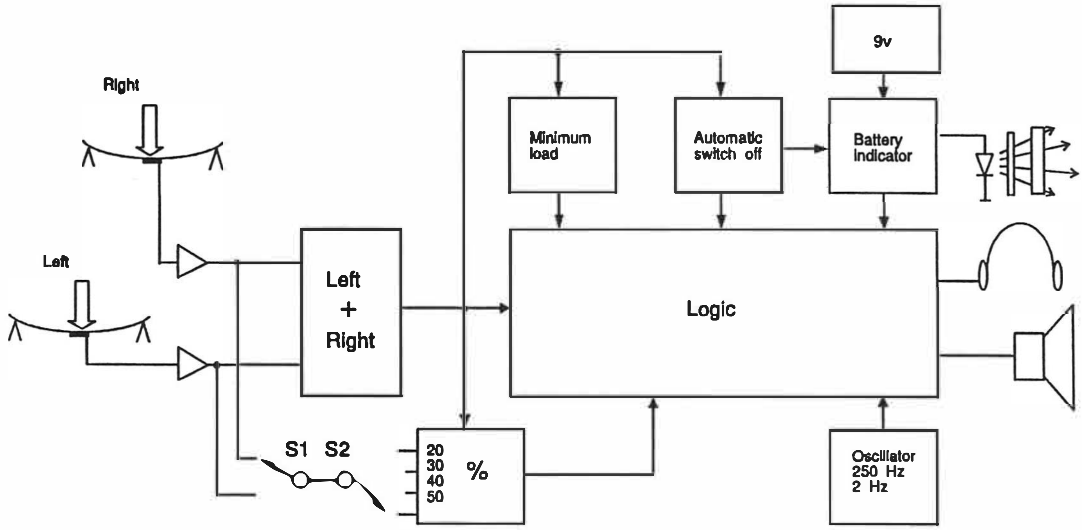

Fig. 3. Electronic circuit, registering the difference in loading of the two balances of the training device.

Orientation in time and space, body image and visual perception as considered aspects of basic cognitive level, was assessed according to Bernspång (3), using a three-point ordinal scale with a maximum score of 12 points. Muscular tonus of the quadriceps, hamstrings, adductors and triceps surae was estimated from the resistance to manual passive joint movements using a five-point rating scale with 0 indicating normal muscular tonus and 4 severe hypertonus (extremity fixed in flexion or extension (1)).

The median scores of the clinical assessments were not different in the two groups before the start of the training.

Training device and training procedure

The force feedback platform (Fig. 1) consisted of two electronic balances, sensing vertical forces separately from each foot. To allow easy use at home it was of small size (0.6*0.3 m), light weight (5 kg) and could be run with a battery. The two balances were connected to an electronic circuit (Fig. 3), which registered the difference of load on the two balances. It was supplied with an auditory output that delivered a signal when the load on the paretic leg was above a threshold ratio corresponding to 20, 30, 40 or 50 per cent of total body-weight. The level was selected according to the patient's ability of weight distribution and was increased stepwise until the patient could load 50 per cent of the total body-weight on the paretic leg.

All patients carried out their individual conventional physiotherapy according to the motor relearning program of rehabilitation (7, 16) during the course of the study. Added to this was a training programme of rising and sitting down with vertical ground reaction force feedback in the experimental group and without such feedback in the control group. The patients in the experimental group, as well as in the control group rose up from sitting, stood quietly for a while and sat down from standing. All patients were instructed to put equal weight on both feet during the exercises. The training comprised 15-minute sessions, three times a day, 5 days a week for 6 weeks. The patients in the experimental group trained with feedback from the platform and the patients in the control group without feedback, otherwise similar. Hence the patients in the experimental group, supported by the auditory bio-feedback signal, received knowledge of performance immediately when the load of the paretic leg reached the preset body-weight distribution.

Relationships between symmetrical body-weight distribution and physical performance and independence in activities of daily living

After 6 weeks' training with and without vertical ground reaction force feedback, all the patients ($n = 40$) had clinical assessments with measurements of the body-weight distribution while rising and sitting down.

Statistical methods

The results from vertical floor reaction forces were tested with Student's paired and un-paired t-tests, where the level for significance chosen was 1%.

The results from the clinical assessments were tested with the Wilcoxon's signed rank test and the Mann-Whitney U test, where the level for significance chosen was 5%. Spearman Rank correlation coefficient was used to calculate the relationships between symmetry of body-weight distribution on the lower extremities while rising/sitting down and scores in physical performance and independence in activities of daily living respectively, where the level for significance chosen was 1%. The study was approved by the Karolinska Hospital Ethics Committee.

RESULTS

Body-weight distribution while rising

Before training, the average loading of the paretic leg was 34.7 per cent body-weight (ratio = 0.55) in the

Table II. *Ratio of body-weight distribution in rising and sitting down tests within and between groups. Mean and SD are given*

	Rising				Sitting down			
	Pre	Post		Diff.	Pre	Post		Diff.
Experimental group	0.55±0.18	0.95±0.25	$p<0.001$	0.4±0.34	0.57±0.17	0.95±0.21	$p<0.001$	0.38±0.23
				$p<0.01$				$p<0.001$
Control group	0.66±0.17	0.81±0.18	$p<0.01$	0.15±0.19	0.68±0.25	0.8±0.21	n.s.	0.12±0.21

experimental group and 39.0 per cent body-weight (ratio = 0.66) in the control group. After training, the average loadings were 47.8 and 44.1 per cent body-weight, (ratio = 0.95 and 0.81), respectively (Table II and Fig. 4). There were significant improvements towards symmetrical weight distribution on the legs in both groups. Mean differences of improvement of body-weight distribution on the paretic leg were 13.2

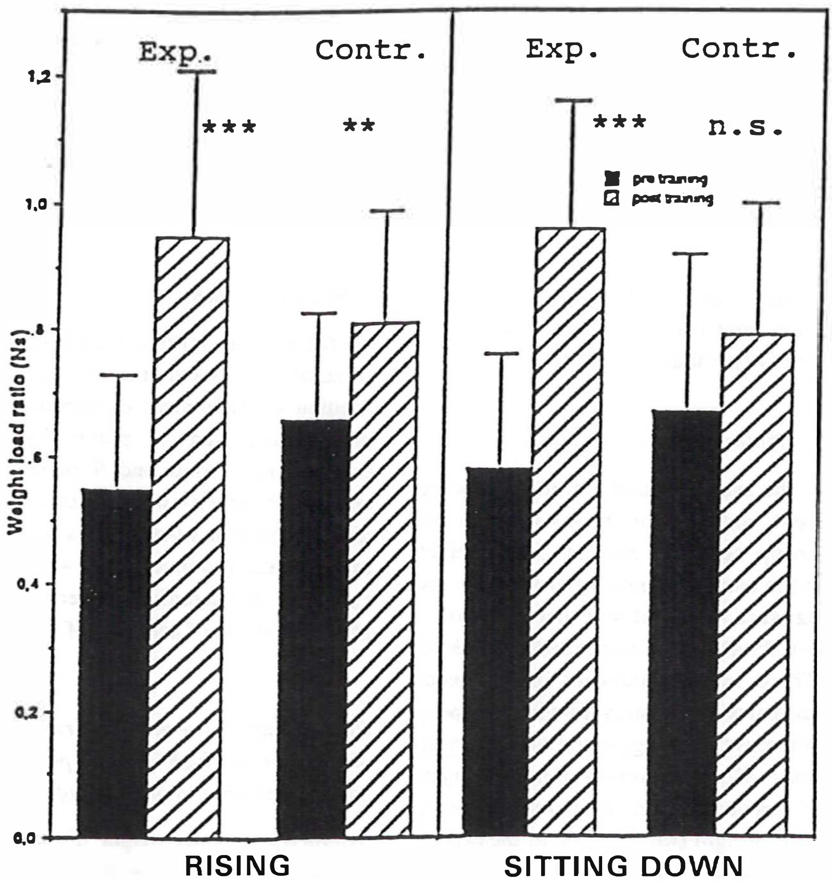

Fig. 4. Body-weight distribution ratio while rising/sitting down in the experimental and the control group, pre and post training. Mean and SD are given. *** = $p<0.001$, ** = $p<0.01$, n.s. = non significant

Table III. *Physical performance, sit-stand and activities of daily living within and between groups. Median and range are given.*

	Physical performance			
	Pre	Post		Diff.
Experimental group	70 (51–90)	87 (55–97)	$p<0.001$	12 (1–23)
				$p<0.05$
Control group	75 (64–88)	86 (65–93)	$p<0.001$	9 (−2–18)
	Sit-Stand			
Experimental group	2 (2)	6 (2–6)	$p<0.001$	4 (0–4)
				$p<0.01$
Control group	2 (2)	4 (2–6)	$p<0.001$	2 (0–4)
	Activities of daily living			
Experimental group	70 (40–95)	95 (70–100)	$p<0.001$	22.5 (5–55)
				n.s.
Control group	65 (45–90)	90 (60–100)	$p<0.001$	22.5 (5–50)

per cent body-weight (ratio = 0.4) in the experimental group and 5.1 per cent (ratio = 0.15) in the control group in rising tests ($p<0.01$) (Table II).

Body-weight distribution while sitting down

Before training, the average loading of the paretic leg was 35.6 per cent body-weight (ratio = 0.57) in the experimental group and 39.1 per cent body-weight (ratio = 0.68) in the control group. After training, the average loading were 48.3 and 43.6 per cent body-weight, (ratio = 0.95 and 0.8), respectively (Table II and Fig. 4). There was a significant improvement towards symmetrical weight distribution in the experimental group whereas the change in the control group was not significant. Mean differences of improvement of body-weight distribution on the paretic leg were 12.7 per cent body-weight (ratio = 0.38) in the experimental and 4.6 per cent body-weight (ratio = 0.12) in the control group in sitting down tests ($p<0.001$) (Table II).

Clinical assessments

All the patients improved in physical performance, in sit-stand and in activities of daily living (Table III). Median of differences of improvement of physical performance were 12 points (range 1–23) in the experimental group and 9 points (−2–18) in the control group ($p<0.05$). Median of differences of improvement in sit-stand was 4 points (0–4) in the experimental group and 2 (0–4) in the control group ($p<0.01$). No significant differences in improvement in scores of test of activities of daily living were seen.

Relationships between symmetrical body-weight distribution and high scores in physical performance and independence in activities of daily living

Symmetry of body-weight distribution while rising and sitting down, respectively, correlated with high scores in all rated parameters ($n=40$), as shown in Table IV.

Table IV. *Correlations coefficients (S_r) between body weight distribution while rising (BWD up)/sitting down (BWD down) and physical performance (F-M), motor function in rising (MAS sit) and functional ability (BI)*

	F-M	MAS sit	BI
BWD up	0.54***	0.73***	0.53***
BWD down	0.5**	0.53**	0.6***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

DISCUSSION

When the patients are physically trained after a stroke occurrence, it is difficult to judge the extent to which improvement in motor function is due to the training or to spontaneous recovery. Stroke patients from rehabilitation departments with uniform treatment strategies were therefore selected for the study and randomly assigned to either an experimental group with the specific type of biofeedback training or to a control group without biofeedback, but otherwise similar training.

The results showed that the patients in the experimental group with biofeedback training achieved a symmetrical or close to a symmetrical distribution of body-weight in rising and sitting down tests. The most marked difference between the groups was in the sitting down tests, in which the patients in the experimental group improved markedly whereas the patients in the control group showed no significant change in their asymmetric body-weight distribution. The quadriceps muscles responsible for the normal eccentric actions in sitting down appeared difficult to activate in the affected leg, which may be due to the habitual non-use, learned during the early phase of the hemiparesis. In the experimental group where training was supported by biofeedback, this non-use was markedly diminished. The study thus indicates that the spontaneous reluctance to activate muscles for adequate eccentric work in a previously paretic leg may be corrected through biofeedback training. The difference between the groups might be due to the encouragement which the patients in the experimental group received from the auditory signal, that they were capable of more movement or more motor control than they thought (27, 12). The biofeedback thus assisted the patients to better use their capacity to distribute body-weight symmetrically in rising as well as in sitting down. This might be of importance as rising to standing and sitting down is a frequent activity in daily life.

The results of this study confirmed that knowledge of performance (15) through vertical ground reaction force feedback was essential for the stroke patients in the cognitive phase, when learning to load the previous paretic leg while rising and especially while sitting down. Whether the almost symmetrical body-weight distribution, as shown in the experimental group, is carried over in an open task situation of rising and sitting down needs though to be studied further.

The patients in the experimental as well as in the control group improved in activities of daily living and in physical performance, as could be expected since the patients were in an early phase after stroke, where spontaneous recovery is relatively fast. The patients in the control group were instructed to put equal weight on both feet during their frequent practice. Their improvement in activities of daily living confirms the findings by Gallistel (14) that repetitive training plays an important role in tuning motor activity to become effective and more reliable. However, the improvements were greater in rising to standing and in physical performance in the experimental group, when testing differences between the two groups (Table III). It thus seems that training in keeping symmetrical body-weight distribution through biofeedback decreases the disability level and improves the motor activity, coordination, sensory function and balance. This may prevent secondary impairments in the lower extremities.

Finally we found that the more the stroke patients loaded the paretic leg while rising/sitting down, the better they scored on assessments of physical performance, motor function in rising and activities of daily living. These results agree with the findings that the more body-weight a stroke patient puts on the paretic leg while standing quitely, the better he/she scores on motor function and A.D.L. (10, 26) and the more body-weight he/she puts on the paretic leg while walking the better he/she scores on appearance and cadence in gait (5). Thus it seems that there is reason to continue teaching the stroke patient to concentrate on weight-bearing on the paretic leg already while rising and sitting down in order to reach motor recovery and functional independence.

CONCLUSION

Training with feedback from vertical ground reaction forces by the use of an auditory signal facilitated relearning symmetrical body-weight distribution, when rising and sitting down. Physical performance of the affected leg and motor function in sit-stand in patients with stroke were likewise promoted. Symmetrical body-weight distribution while rising/sitting down correlated positively with high scores in physical performance, motor function in rising and functional ability.

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REFERENCES

1. Ashworth, B.: Preliminary trial of carisoprodol in multiple sclerosis. Practioner *192:* 540–542, 1964.
2. Basmajian, J.V.: Biofeedback in rehabilitation; A review of principles and practices. Arch Phys Med Rehabil *62:* 469–475, 1981.
3. Bernspång, B., Asplund, K., Eriksson, S. & Fugl-Meyer, A.R.: Motor and perceptual impairments in acute stroke patients: Effects on self-care ability. Stroke *18:* 1081–1086, 1987.
4. Bobath, B.: Adult hemiplegia: Evaluation and treatment. Heinemann Medical Books Ltd, London, 1978.
5. Bohannon, R.W.: Gait performance of hemiparetic stroke patients: Selected variables. Arch Phys Med Rehabil *68:* 777–781, 1987.
6. Brooks, V.B.: The neural basis of motor control, pp. 11–17. Oxford University Press, Inc., New York, 1986.
7. Carr, J.H. & Shepherd, R.B.: A motor relearning programme for stroke. 2nd ed. Aspen Systems, pp. 100–111. Rockville, Maryland, 1987.
8. Carr, J.H., Shepherd, R.B., Nordholm, L. & Lynne, D.: Investigation of a new motor assessment scale for stroke patients. Phys Ther *65:* 175–180, 1985.
9. Conrad, L. & Bleck, E.E.: Augmented auditory feedback in the treatment of equinus gait in children. Dev Med Child Neurol *22:* 713–718, 1980.
10. Dettmann, M.A., Linder, M.T. & Sepic, S.B.: Relationships among walking performance, postural stability and functional assessments of the hemiplegic patient. Am J Phys Med Rehabil *66:* 77–90, 1987.
11. Duncan, P.W., Propst, M. & Nelson, S.G.: Reliability of the Fugl-Meyer Assessment of sensorimotor function following cerebrovascular accident. Phys Ther *63:* 1606–1610, 1983.
12. Engardt, M. & Olsson, E.: Body-weight bearing while rising and sitting down in patients with stroke. Scand J Rehab Med. Accepted for publication, 1991.
13. Fugl-Meyer, A.R., Jääskö, L., Leyman, I., Olsson, S. & Steglind, S.: The post-stroke hemiplegic patient. I. A method for evaluation of physical performance. Scand J Rehab Med *7:* 13–31, 1975.
14. Gallistel, C.R.: The organization of action: A New Synthesis Lawrence Erlbaum Associates, Hillsdale, 1980.
15. Gentile, A.M.: A working model of skill acquisition with application to teaching. Quest *17:* 3–23, 1972.
16. Gentile, A.M.: Skill acquisition. *In*: Movement Science, Foundations for Physical Therapy in Rehabilitation (ed. J. H. Carr & R. B. Shepherd), Heinemann Physiotherapy, London, 1987.
17. Granger, C.B., Albrecht, G.L. & Hamilton, B.B.: Outcome of comprehensive medical rehabilitation: Measurement by PULSES Profile and the Barthel Index. Arch Phys Med Rehabil *60:* 145–154, 1979.
18. Herman, R., Cook, T., Cozzens, B. & Freedman, W.: Control of postural reactions in man: The initiation of gait. Plenum Publishing Corporation, New York, 1973.
19. Mahoney, F.I. & Barthel, D.W.: Functional evaluation: The Barthel Index. Md Med J *14:* 61–65, 1965.
20. Miyazaki, S., Ishida, A., Iwakura, H.: Portable limb-load monitor utilizing a thin capacitive transducer. J Biomed Eng *8:* 67–71, 1986.
21. Moore, A.J. & Byers, J.L.: A miniaturized load cell for lower extremity amputees. Arch Phys Med Rehab *57:* 294–296, 1976.
22. Odéen, I.K. & Knutsson, E.: Evaluation of the effects of muscle stretch and weight load in patients with spastic paraplegia. Scand J Rehab Med *13:* 117–121, 1981.
23. Olsson, E., Öberg, K. & Ribbe, T.: A computerized method for clinical gait analysis of floor reaction forces and joint angular motion. Scand J Rehab Med *18:* 93–99, 1986.
24. Poole, J.L. & Whitney, S.L.: Motor assessment scale for stroke patients: Concurrent validity and interrater reliability. Arch Phys Med Rehabil *69:* 195–197, 1988.
25. Poulton, E.C.: On prediction in skilled movements. Psychol Bull *54:* 467, 1957.
26. Sackley, C.M.: The relationships between weight-bearing asymmetry after stroke, motor function and activities of daily living. Physiotherapy Theory and Practice *6:* 179–185, 1990.
27. Taub, E.: Somato-sensory deafferentation research with monkeys: Implications for rehabilitation medicine. *In*: Behavioral Psychology in Rehabilitation Medicine: Clinical Implications (ed. L.P. Ince), pp. 371–401. Williams and Wilkins, Baltimore, 1980.
28. Van Ouwenaller, C., Uebelhart, D. & Chantraine, A.: Bone metabolism in hemiplegic patients. Scand J Rehab Med *21:* 165–170, 1989.
29. Wallace, S.A. & Hagler, R.W.: Knowledge of performance and the learning of a closed motor skill. Res Quart *50:* 265–71, 1979.
30. Wannstedt, G.T., Herman R.M.: Use of augmented sensory feedback to achieve symmetrical standing. Phys Ther *58:* 553–559, 1978.

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