AUDITORY FEEDBACK REGULATION OF PERTURBED STANCE IN STROKE PATIENTS

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ABSTRACT. The effect of auditory input on impaired postural control perturbations was evaluated in two groups of stroke patients participating in a rehabilitation programme after a recent (<12 months) and single episode of stroke, or less recent (>12 months), and multiple episodes of stroke. Auditory input took the form of feedback signals generated by the forces actuated by the feet on a force platform in response to the patient's postural movements. Vibratory stimuli applied to the calf muscles induced sudden perturbations which the patients had to counteract to maintain an upright stance. The effect of auditory feedback in facilitating the maintenance of stance was measured in terms of sagittal torque variance (body sway) recorded on a force platform. In the presence of auditory feedback, body torque variance in response to perturbed posture was significantly reduced in the recent stroke group, whereas in the less recent stroke group the auditory feedback did not prove effective. Moreover, learning seems essential to utilize the auditory feedback.

Key words: audio, feedback, human, posture, stroke, vestibular.

INTRODUCTION

Stroke is the third leading cause of death and an important cause of long-term disability in the elderly. One-third of stroke patients survive the acute event but are left with considerable residual disability (22). Although stroke may present with any combination of motor, sensory and cognitive deficits, motor dysfunction is the single most common type of impairment (1). Rehabilitation of gait and stance is one of the major goals in the aftercare of stroke patients, and a variety of treatment programmes have been devised for the purpose (24).

Ability to maintain an upright stance and to stabilize the body is a prerequisite for motor performances in the activities of daily living (ADL) (7). It is based on complex feedback and feedforward control, as well as on the integrity of several networks in the central nervous system (CNS) acting in response to afferent visual, vestibular and somatosensory information (26). Together with hearing (19), the various sources of sensory information provide a basis for orientation in space.

Biofeedback is already widely used in physiotherapy and rehabilitation (2, 12). The feedback loop is usually based on body movements, and may be further amplified by auditory or visual information to augment such different motor performances as symmetrical stance (10, 25) or gait (6, 18) in hemiparetic stroke patients. Afferent sensory stimulation with acupuncture needles in hemiparetic patients has also proved useful (17). We recently reported that auditory feedback input may stabilize perturbed stance in healthy subjects (20), and hence, that auditory feedback could be used to supplement afferent information and thus improve impaired postural control.

It is not known whether patients with impaired postural control after stroke can use auditory feedback as an external source of information to augment not only quiet stance but also perturbed stance. Coping with perturbations in stance may be compared to the everyday task of maintaining upright posture in response to sudden and unanticipated disturbances to posture and gait. The aim of this study was to investigate whether patients could benefit from feedback auditory input to enhance motor control of posture during repeated perturbations of stance, thus indicating a possible use of auditory biofeedback training in rehabilitation.

MATERIALS AND METHODS

Patients

We investigated 15 patients (3 women and 12 men; median age 61 years, range 31–81) with previous stroke and persisting

Table I. *Summary of the patients' baseline characteristics initial signs and localization of cerebral lesions. Group I = recent (<12 months) single episode of stroke; group II = both older (>12 months) as well as bilateral and more frequent episodes of stroke. ACA = arteria cerebri anterior: MCA = arteria cerebri media; PCA = arteria cerebri posterior. Art. = artery; No. = Case number*

Group	No.	Sex	Age	Signs	Art.	Infarct site at CT/MRI
I	2	F	50	Left side hemiparesis and sensory loss	MCA	Right parietal lobe
I	3	M	81	Left side hemiparesis	MCA	Right frontoparietal lobe
I	4	M	55	Left side hemiparesis	MCA	Right internal capsule
I	6	M	68	Ataxia. Left side visual field defect	PCA MCA	Left cerebellum, internal capsule and occipital lobe
I	9	M	61	Right side hemiparesis	MCA	Left internal capsule
I	10	M	67	Left side hemiparesis	MCA	Right frontoparietal lobe
I	12	M	46	Left side hemiparesis	MCA	No lesion visible
II	1	M	61	Left side hemiparesis	MCA	Right parietal lobe
II	5	M	57	Right side hemiparesis	MCA	Bilateral capsular infarctions
II	7	M	61	Aphasia	MCA	Bilateral old ischaemic lesions
II	8	F	31	Right side hemiparesis	MCA	Left frontoparietal lobe. Old right-sided lesion
II	11	F	48	Left side hemiparesis Agnosia. Agraphia	MCA	Multiple cerebral infarctions
II	13	M	63	Aphasia. Right neglect. Right side hemiparesis	ACA	Left frontoparietal lobe
II	14	M	70	Right side hemiparesis	MCA	Left parietal lobe

impairment of motor function of stance and gait. All patients were currently active in or had previously participated in a similar rehabilitation programme, as they were recruited from the same rehabilitation centre, at Orup in Sweden. Inclusion criteria were any previous stroke, a diagnosis verified with computerized tomography (CT) and/or magnetic resonance imaging (MRI). Based on the duration and recurrence of the illness (stroke) the patients were divided into two groups: Group I, with a recent (< 12 months) single episode of stroke; Group II, with less recent (> 12 months) as well as bilateral and/or multiple episodes of strokes. Baseline characteristics, clinical symptoms, arterial territory involved, and CT or MRI findings are given in Table 1.

Methods

Other than the presence of clinically diagnosed stroke, the only inclusion criteria were that the patients should be able to stand erect with the eyes open for about 5 min and be able to understand and follow verbal instructions. One patient was excluded because of impaired vision (confirmed at ophthalmic examination). Ear, nose and throat examination as well as pure tone audiometry were performed prior to the experiment. A pure tone average (0.5 kHz, 1 kHz, 2 kHz) was calculated, median 11.5 dB (range −2 dB to 40 dB) for the right ear and median 10.5 dB (range −3 dB to 40 dB) for the left ear.

The auditory feedback took the form of a sound signal derived from sagittal body movements, and its stabilizing effect on perturbed body posture was investigated. Body sway in the sagittal plane was recorded with a force platform. The changes in the centre point of force (CPF) actuated by the feet on the platform being digitized and samples at 10 Hz by computer (COMPAQ 486/25). The auditory feedback sound signal was derived from the force platform signal as follows. After computer recording, the platform signal was transformed by a voltage-controlled signal generator (Wavetec, model 164) to a sinusoidal tone the frequency of which changed in response to the movement of the body in the sagittal plane, i.e., increasing in pitch when the patient leaned forward and decreasing in pitch when the patient leaned backward. The baseline tone of 1500 Hz representing eased upright stance was thus increased and decreased by 56 Hz/Nm in concert with body movements, and relayed to the patient as a feedback signal through earphones (Fig. 1).

The intensity of the auditory feedback signal was 85 dB SPL (sound pressure level) when measured at ear level (Brüel and Kjaer, Sound Level Meter, 2218). In control tests with no auditory feedback, the patients' earphones relayed music (Haffner serenade by Mozart) instead, to obscure possible orientation cues from environmental noise. All tests were performed in a normally reverberate and illuminated room.

Vibratory stimulus pseudo-randomly applied with vibrators attached on the belly of the right and left gastrocnemius and soleus muscles was used to elicit perturbation of the patient's posture by disturbing proprioception, i.e. vibration-induced body sway (8, 9). Low intensity (120 mW, amplitude 0.4 mm, frequency 60 Hz) vibrators were used to elicit perturbations. The design and calibration of this vibratory stimulus system has been described in detail elsewhere (20).

The patients were instructed to stand erect but relaxed on the force platform, heels together not touching and feet at an angle of thirty degrees, arms crossed over the chest, with the eyes open and focused on a mark on the wall at a distance of 1.5 m. The experiment consisted of four test sequences scheduled according to a Latin square design. In tests A
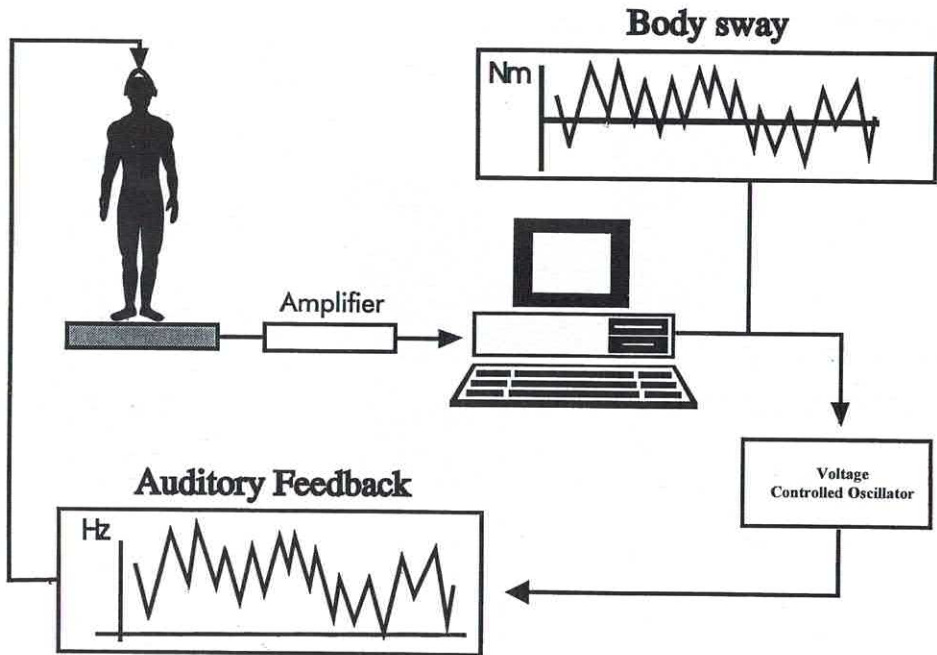
Fig. 1. Diagram of experimental set-up and feedback sound signal generation from body sway.

and B patients were provided with music, but in tests C and D they were provided with auditory feedback either without (A and C) or with (B and D) vibratory stimulus. Each test was divided into two periods, period 1 (0–64 s) and period 2 (64–148 s), in order to check for any learning effects. The patients were informed in advance about the different test routines and they were allowed to become adept with the stimulus and practise for about 2 min before the test commenced.

Statistics

Torque variance representing the body sway in the sagittal plane was calculated and evaluated with the Matlab 4.2 program (Mathworks Inc, USA). As calculated values for torque variance within each test tended to be skewed, according to the Shapiro-Wilk test, a non-parametric test, the Wilcoxon/Krusal-Wallis rank sum test was used to evaluate the difference p-values <0.05 being considered statistically significant. All statistical computation was performed with a statistical software package (JMP 2.0; SAS Institute Inc. USA).

RESULTS

The patients stood on the force platform with their eyes open in all tests. The results for all patients are given in Fig. 2. Sagittal torque variance (body sway) increased significantly during vibratory stimulation when the patients' earphones relayed music, but when they relayed auditory feedback the vibratory

stimulus did not cause a significant increase of the torque variance (Fig. 2).

In patients with recent stroke (group I), auditory feedback (test D) significantly reduced the torque variance (body sway) in the second half of the experiment (period 2), as compared to test B when the earphones relayed music, whereas in the first half of the experiment (period 1) the torque variance was not significantly reduced (Fig. 3).

In patients with less recent stroke (group II) the availability of auditory feedback (test D) did not alter the torque variance, as compared to test B (Fig. 4).

DISCUSSION

Auditory feedback of sagittal movements of the centre point of force reduced torque variance (body sway) during perturbations of posture in patients with a recent (<12 months) isolated episode of stroke (group I). Patients with less recent (>12 months) and/or multiple stroke episodes (group II) did not benefit from the auditory feedback input. In patients with recent stroke the beneficial effect became significant in the second test period (64–148 s), a finding which emphasizes the importance of learning and training in postural rehabilitation (11, 24). This
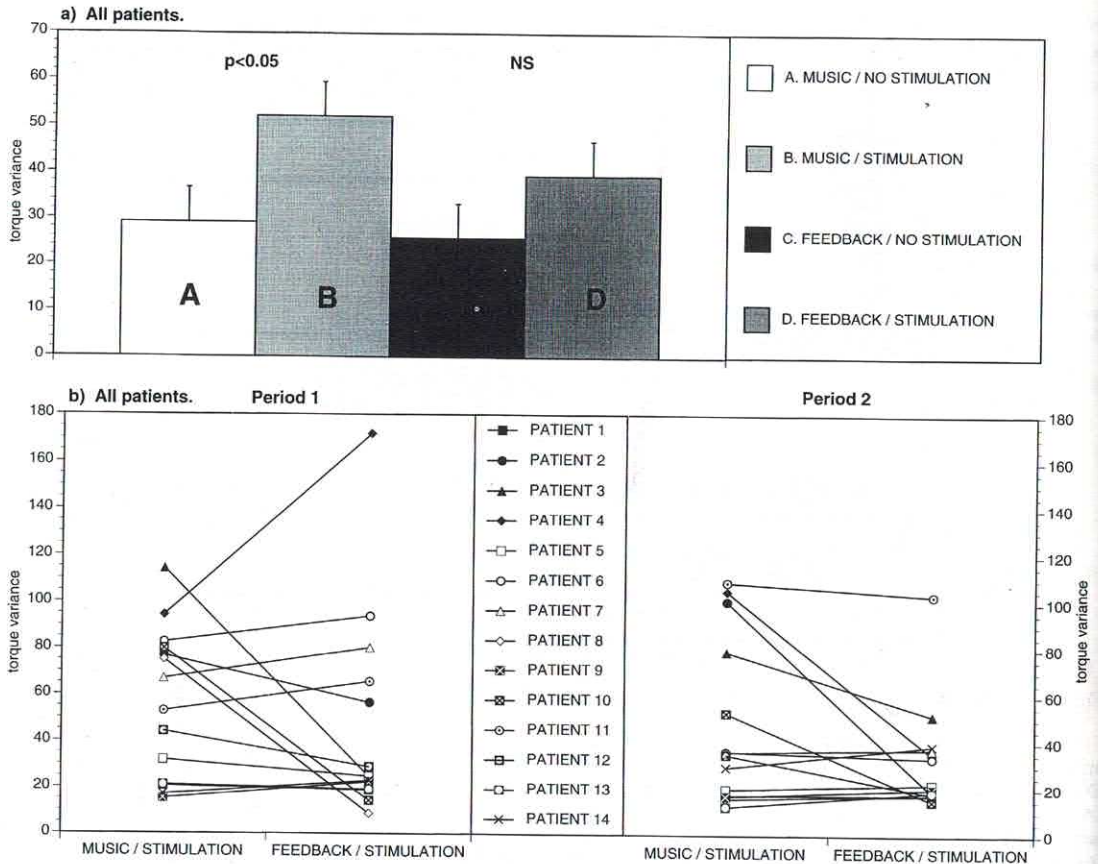
Fig. 2. (a) Mean and SEM of sagittal torque variance (body sway) are given for all patients. NS = not significant. A, B, C and D are the four different tests. (b) Evaluation of the sagittal torque variance (body sway) for each patient is given.

breaking point between the test periods (64 s) corresponds to that of the so-called postural adaptation time constant recently described (15).

In all patients, postural impairment was a prominent sequel of hemispheric stroke. In no patient was vertigo the main initial symptom, as is often the case in stroke involving the vertebrobasilar territory (23) and also reported in cases of stroke involving the middle cerebral artery territory (5). No patient had any manifest neuropathy, although one patient in group II (less recent stroke) had a history of diabetes mellitus type I.

Vibration applied to the calf muscles activates proprioceptive receptors (muscle spindles) and induces body sway (8). Vibration-induced body sway has been found useful in several studies of postural control, both in healthy subjects (16), and in patients with peripheral or central vestibular lesions (21). Vibration of sufficient intensity can cause manifest disturbance of posture, and may induce falls even in normal subjects (9). The vibration-induced body sway

reaction seems to be stable from about 15 years to at least 75 years of age (13). In the present study, the patients were of late middle age (median 61 years).

In the present experiment, a low intensity vibration (120 mW) was used, known to cause less pronounced body movements (20), resulting in slower frequency changes of the auditory feedback input. The auditory feedback input reflects the changes in forces actuated by the feet on the platform during body movements, but does not directly reflect head movements. This may explain why auditory feedback was more effective in reducing slower body perturbations, where the use of the so-called ankle strategy may be expected (14), and hence the feedback pattern would be simpler than it would be in a dynamic multisegmental response. These slow vibration-induced body movements and the auditory feedback input generated from them, acting upon a patient with postural deficit, are augmented to effectively enhance postural stability in a circuit manner.
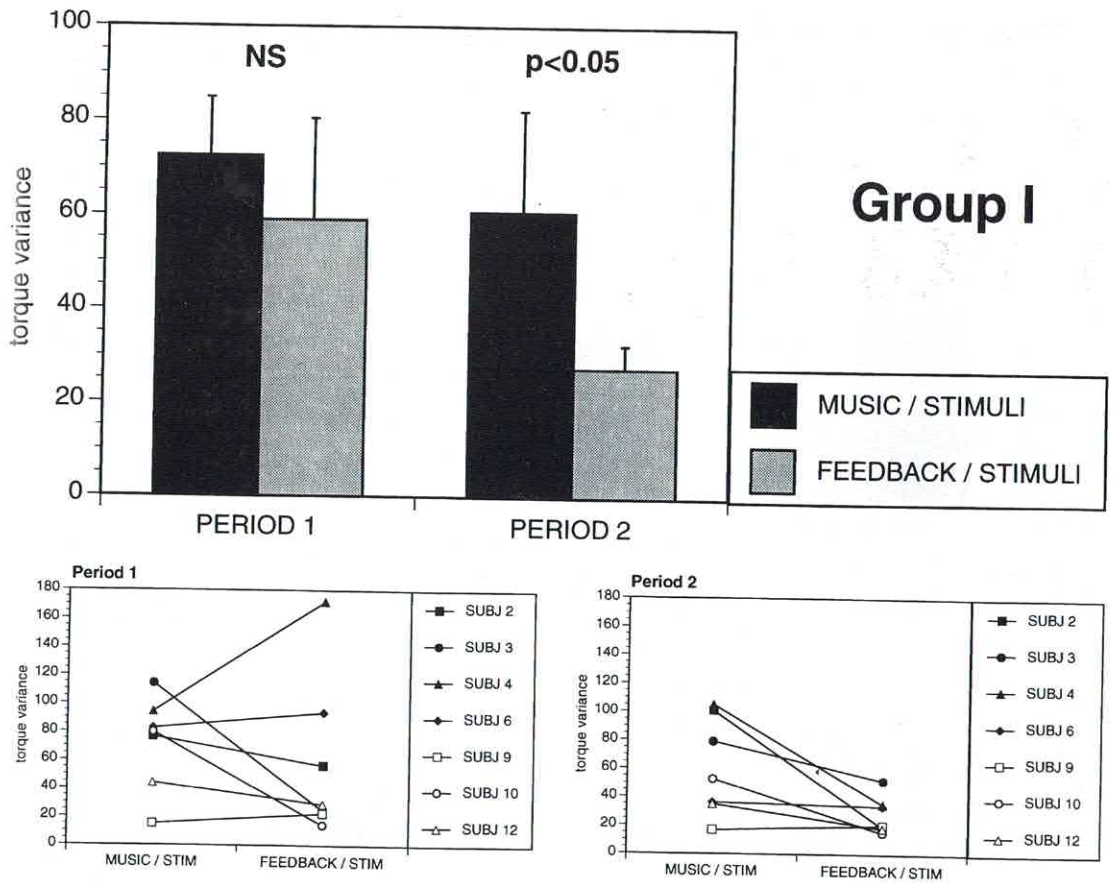
Fig. 3. Mean values and SEM for sagittal torque variance (body sway) in group I (recent (< 1 year) one or more episode of CVI). The difference between music/stimuli (test B) and feedback/stimuli (test D) is given for periods 1 and 2. Changes in sagittal torque variance are also given for each patient NS = not significant.

All tests were performed with the patient's eyes open as stabilizing effect of the availability of visual information is of great help in healthy elderly subjects (3), and because stroke patients perform most of their rehabilitation training with the eyes open (4). Although an even more pronounced stabilizing effect of the auditory feedback would have been expected under visually deprived conditions, as the present findings suggest auditory feedback provides useful information supplementing visual input; that is, the availability of auditory feedback would have had little or no effect had it not provided information beyond that derived visually from the surroundings.

Patient number four reported that "I was afraid to use the changing sound [auditory feedback] in the beginning but when I became familiar with it, it helped" (see Fig. 2; patient 4; period 1 and 2). After the experiments, all patients rated the effect of the auditory feedback on a visual analogue scale (VAS), ranging from 0 (no help) to 5 (excellent help). VAS ratings were significantly higher in group I (recent stroke) than in group II (less recent stroke) ($p < 0.05$; Wilcoxon/Kruskal-Wallis test). Although the values for postural variables obtained in test sequences where music was relayed by the earphones instead of auditory feedback suggest this form of auditory input to have had a certain placebo effect, no VAS ratings were made for these tests as the primary aim was to investigate the possibility of using auditory feedback in a rehabilitation context as an aid in counteracting sudden perturbations of posture, and not to compare subjective assessment of different treatments.

The present findings suggest that the stabilizing effect of auditory feedback may contribute to minimizing response to sudden perturbations, and that as this effect becomes gradually apparent it may represent a learning effect. As sudden perturbations need to be coped with in everyday life, auditory feedback
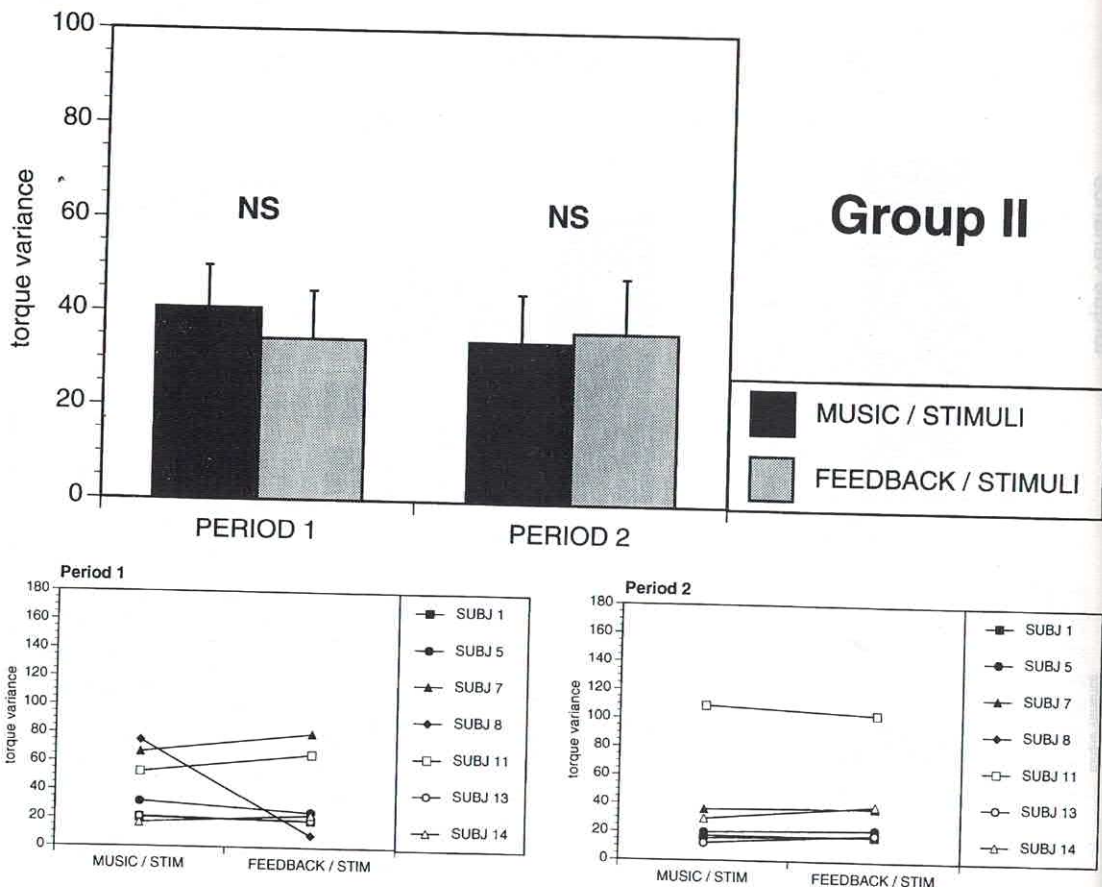
Fig. 4. Mean values and SEM for sagittal torque variance (body sway) in group II (older (> 1 year) as well as bilateral and more frequent episodes of CVI). The difference between music/stimuli (test B) and feedback/stimuli (test D) is given for periods 1 and 2. Changes in sagittal torque variance are also given for each patient. NS = not significant.

might prove useful in rehabilitation training programmes aimed at augmenting postural skills.

The finding that the effect of auditory feedback was more marked in group I (recent stroke) suggests auditory feedback to be better suited for use in the early phase of stroke rehabilitation programmes, or as an additional procedure supplementing other methods in studies of postural control. Early stroke patients and healthy subjects standing with eyes closed (20) appear to be better able to utilize auditory feedback as a means of enhancing perturbed postural control. In the present test set-up the auditory feedback reflects the changes in force required for body postural movements, information supplementary to the one of the vestibular receptors signalling the angular velocity of the same postural movements. Initially through cognition and later with sufficient training in synchronizing vestibular and audible

information, a modulation of the amplitude of the postural response may be achieved; an ability mediated by remaining cortical structures and/or subcortically (27). Already being involved in rehabilitation using postural training mainly based on visual and proprioceptive augmentation, patients suffering from remote stroke have already reached their very best in postural performance standing with eyes open, not further enhanced with auditory feedback. Whether auditory feedback may be used to enhance upright stance with eyes closed in this group of remote stroke patients is a matter for further investigations.

Finally, it should be borne in mind that the present study group comprised 14 unselected patients with CNS (stroke) lesions varying in site and magnitude, and that ability to benefit from auditory feedback may vary according to the site and magnitude of the lesion. However, the present unselected study group

is naturally more representative of the clientele at most rehabilitation centers. The present finding that this heterogeneous group of stroke patients manifest a significant effect of the auditory feedback procedure suggests that it might prove useful in postural control training in coping with the kind of sudden perturbations encountered in everyday life.

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