ABSTRACT. The effect of auditory input on postural control was evaluated in separate experiments performed in three groups of healthy volunteers. Auditory input took the form either of feedback signals generated by a force platform in response to the subject's postural control movements, or of field orientation (frame of reference) input provided by repeated clicks emitted by loudspeakers in a normally reverberant environment. The effect of these acoustic cues was measured in terms of body sway vectors recorded on a force platform during stance perturbations induced by vibratory stimuli applied to the calf muscles either at low (120 mN) or high (850 mN) intensity, the subject standing with eyes closed or open, as instructed. In the presence of feedback auditory input, body sway in response to low intensity vibratory stimulation was significantly reduced, but not in response to high intensity stimulation. This may be due to the fact that the head and body movements induced by high intensity vibratory stimulation are so rapid and powerful that they override the information available or to the subject using other strategies for postural control in which auditory feedback, at least in the form used here, does not contribute useful information. The availability of field orientation input did not reduce body sway in response to vibratory stimulation at low intensity. This was probably due to the cognitive lag which precluded use being made of the input before the fast proprioceptive responses to vibratory stimulation had already occurred.

Key words: vestibular, audio, posture, vibration, human.

INTRODUCTION

The ability of humans to stand upright, stabilise the body and simultaneously perform motor tasks is based upon complex feedback and feedforward mechanisms of the central nervous system (CNS) in response to afferent visual, vestibular and proprioceptive information as well as information from the pressure receptors of the soles of the feet (22). Together with hearing (14), thisafferent sensory information provides a basis for orientation in space.

Several animal species are capable of using auditory information, both in feedback and feedforward loops, for orientation purposes and to facilitate the performance of motor tasks essential for survival (18). Humans with normal hearing can locate sound sources with good precision, which is the basis for the use of diverse sounds in daily life as warning signals or to facilitate orientation in space (14, 17). Moreover, humans exposed to rotating sound fields, where visual information has been eliminated, experience an illusion of self-rotation, and may even manifest nystagmus (11). Biofeedback using auditory input to augment motor performance has also been used in physiotherapy to facilitate weight bearing on one leg in amputees (21), as well as in flight simulators to enhance instrumental flight skills (12).

Whether humans can use auditory input as an exteroceptive source of information only, or whether information useful to postural control can be obtained from auditory feedback input is not known. The aim of this study was to ascertain whether humans could use auditory input in a feedforward or feedback manner to enhance motor control of posture during quiet or perturbed stance.

MATERIAL AND METHOD

Three different experiments were performed on healthy paid volunteers with normal pure tone audiograms and no history of neurological or CNS disease or head trauma. The subjects were naive inasmuch as they were not previously informed about the test routine and they were not allowed to become acquainted with the equipment or practice. The subjects abstained from any drugs or alcohol during the 24-hour period preceding the tests (Table 1).

Two types of auditory input were used: feedback sound signals deriving from body movements, and sound from
Table I. Number and age of subjects in each experiment

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Number</th>
<th>Female</th>
<th>Male</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>12</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>17</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>6</td>
<td>6</td>
<td></td>
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</table>

Frequencies, both in anechoic and in reverberative chambers. The present set-up was chosen as providing a three-dimensional frame of reference (i.e., field orientation), while avoiding the possibility of harmonics from the two sound sources, confusing the subject.

The intensity of the auditory input was 85 dB SPL (sound pressure level) when measured at ear level, for both feedback and frame of reference signals (Briel and Kjaer, Sound Level Meter, 1988).

In control tests when subjects were provided with neither auditory feedback or feedforward input, they were provided with monophonic music (the Haffner symphony by Mozart) to mask possible orientational cues from environmental noise. All tests were performed in a normally reverberative chamber.

Vibratory stimulation applied through vibrators attached with elastic strips on the belly of the right and left gastrocnemius muscles were used to elicit perturbation of posture by disturbing proprioception—i.e., vibration-induced body sway (6, 7). For detailed description of this vibratory system, see Eklund (5). In experiments using feedback auditory input, both high intensity (85 dB, amplitude 1.0 mm, frequency 60 Hz) and low intensity (128 dB, amplitude 0.4 mm, frequency 60 Hz) vibrators were used to elicit stronger or weaker perturbations, respectively. The power supply to the vibrator’s DC motor (Escap, Switzerland) was provided by a custom-built generator and the vibratory stimulus was switched on/off according to a PRBS schedule.

All experiments consisted of three test sequences: A: eyes open; B: eyes closed; and C: eyes closed, and feedback, or feedforward auditory input scheduled according to a Latin square (Table II).

Sway variance in the sagittal plane was calculated and evaluated with the 8th-Mat lab software (Mathworks Inc., USA). As calculated values for sway variance within each experimental group tended to be skewed, they were log-transformed (natural log) for normal distribution to allow the use of parametric tests performed with statistical

Table II. Test set-up regarding eye status, auditory input and vibratory stimuli

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Test sequence</th>
<th>Eye status</th>
<th>Sound</th>
<th>Vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>204 sec PRBS stimulus preceded by 30 sec rest</td>
<td>A: Open</td>
<td>Music</td>
<td>60 Hz freq.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B: Closed</td>
<td></td>
<td>60 Hz amp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: Closed</td>
<td></td>
<td>120 mW effect</td>
</tr>
<tr>
<td>II</td>
<td>216 sec PRBS stimulus preceded by 30 sec rest</td>
<td>A: Open</td>
<td>Music</td>
<td>60 Hz freq.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B: Closed</td>
<td></td>
<td>60 Hz amp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: Closed</td>
<td></td>
<td>120 mW effect</td>
</tr>
<tr>
<td>III</td>
<td>204 sec PRBS stimulus preceded by 30 sec rest</td>
<td>A: Open</td>
<td>Music</td>
<td>60 Hz freq.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B: Closed</td>
<td></td>
<td>120 mW effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C: Closed</td>
<td></td>
<td>7.0 g High</td>
</tr>
</tbody>
</table>

The availability of an auditory frame of reference did not differ between conditions (experiment I). With stronger perturbation of posture, and hence more rapid movements, (i.e., during stimulation with high intensity vibration, experiment III), the feedback auditory input did not succeed in reducing the body sway (Fig. 5).

Fig. 2. Field orientation (frame of reference) set-up. L1 and L2 are loudspeakers, and V the force platform.

Fig. 1. Diagram of feedback sound signal generation from body sway.

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Fig. 3. Mathematical model for the three-way analysis of variance.

Log Variance

\[ \log(\text{Variance}) = \text{Subject} + \text{Test} + \text{Order} + \text{Test x Order} \]

<table>
<thead>
<tr>
<th>Subject experiment</th>
<th>Test</th>
<th>Order</th>
<th>Test x Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1,24</td>
<td>1,24</td>
<td>1,24</td>
</tr>
<tr>
<td>II</td>
<td>1,24</td>
<td>1,24</td>
<td>1,24</td>
</tr>
<tr>
<td>III</td>
<td>1,24</td>
<td>1,24</td>
<td>1,24</td>
</tr>
</tbody>
</table>

Test A = Eyes open, music
Test B = Eyes closed, music
Test C = Eyes closed, auditory input feedback or frame of reference

Order or test sequence A B C designed according to Latin square schedule

k = 1,3

Scand J Rehab Med 27
Table I. Number and age of subjects in each experiment

<table>
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<th>Male</th>
<th>Age</th>
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<tbody>
<tr>
<td>I</td>
<td>12</td>
<td>12</td>
<td>Range 20–44</td>
</tr>
<tr>
<td>II</td>
<td>17</td>
<td>7</td>
<td>Mean 30</td>
</tr>
<tr>
<td>III</td>
<td>6</td>
<td>6</td>
<td>Range 21–41</td>
</tr>
</tbody>
</table>

Field orientation (frame of reference) set-up. L1 and L2 are loudspeakers, and V the force platform.

Table II. Test set-up regarding eye status, auditory input and vibratory stimuli

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Time</th>
<th>Eye status</th>
<th>Sound</th>
<th>Vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Open</td>
<td>Music</td>
<td>60 Hz, breq.</td>
<td>5.5 g, Low</td>
</tr>
<tr>
<td>II</td>
<td>Closed</td>
<td>Music</td>
<td>60 Hz, breq.</td>
<td>5.5 g, Low</td>
</tr>
<tr>
<td>III</td>
<td>Closed</td>
<td>Music</td>
<td>5.5 g, Low</td>
<td>5.5 g, Low</td>
</tr>
</tbody>
</table>

Field orientation (frame of reference) set-up. L1 and L2 are loudspeakers, and V the force platform.

RESULTS

In all three experiments (I, II, III), variance of sagittal body sway increased significantly when visual cues were eliminated (i.e., the subject standing with eyes closed; test B), as compared to the eyes open condition (test A) without simultaneous auditory input (Fig. 4 and 5).

The availability of feedback auditory input (test C) significantly reduced the variance of body sway in subjects standing with eyes closed during perturbations at low intensity vibration (Experiment III), whereas the availability of an auditory frame of reference did not (Experiment II). With stronger perturbation of posture, and hence more rapid movements (i.e., during stimulation with high intensity vibration, experiment III), the feedback auditory input did not succeed in reducing the body sway (Fig. 5).

DISCUSSION

Auditory feedback input deriving from the antero-posterior movement of the centre point of force actuated by the feet, reduced body sway in healthy subjects during perturbation of posture by vibration at low intensity (120 mW), but not during vibration at high intensity (850 mW) causing stronger perturbation. The availability of an auditory frame of reference...
(i.e., field orientation) did not reduce the body sway, even though the postural perturbations were of low intensity. The availability of visual information (i.e., the eyes open test condition) reduced body sway significantly, as compared to the eyes closed test condition, irrespective of whether the intensity of vestibular stimulation was high or low, a finding consistent with those obtained previously (8).

Vibration to the calf muscles activates proprioceptive receptors and induces the body sway (6, 7, 9). Vibration-induced body sway has been found useful in studies of postural control, and in standing subjects during hyperthermally reduced pressure (somatosensory) input from the foot (13), as well as in studies of patients with peripheral or central vestibular lesions (16). Vibration of sufficient intensity can cause manifest disturbance of posture, and may induce falls even in normal subjects (7). In the present experiments, two different intensities of calf muscle vibration were used to elicit perturbations: low intensity vibration (120 m/s²), or high intensity vibration (850 m/s²) inducing faster and more pronounced body sway.

In the present study, the subjects were less than 45 years of age. This may have effect on the results. However, vibration induced body sway seems to be stable from 15 years to at least 75 years of age, and even a slight decrease of sway velocities may be observed in subjects between 75–90 years (9). The reduction of the low intensity vibration-induced body sway during auditory feedback might thus be improved further in older subjects.

The low intensity vibration (120 m/s²) causes less manifest body movements, resulting in slower frequency changes of the auditory feedback input. The auditory feedback input reflects the changes in forces actuated by the feet during body movements, but does not directly reflect changes due to head movements. This may explain why feedback auditory input was more effective in reducing slower body perturbations, where the use of a so-called ankle strategy may be expected (10), and the audio reaction time of the feedback sound above 500 ms (2) is not a limiting factor. These slow vibration-induced body movements and the auditory feedback input generated from them may also interact to reduce body sway as the other receptor systems (vestibular and somatosensory) required for postural control are intact and contribute effectively to the stabilisation of posture. Experiments using an auditory input feedback system based on major excursions of body posture during quiet stance based on major excursions of body posture during quiet stance have yielded similar results (i.e., has shown the effectiveness of feedback auditory input in reducing body excursions (19)).

In experiment I, the field orientation or reference frame auditory input was not effective in reducing vibration-induced body sway, even though the perturbations were of low intensity. However, this does not rule out the possibility that the control of body posture might be facilitated by auditory input from a fixed external frame of reference, although this seems to be a less important input for postural control than vestibular and somatosensory input during proprioceptive perturbation of normal subjects. In animals, the topographic representation of auditory space in the central nervous system is well known (1, 15), and provides a basis for orientation and monitoring of body movements as well as movements of the environment when integrated with information from other receptor systems (i.e., the visual, vestibular and proprioceptive information required for postural control). Environmental sound providing an auditory frame of reference, field orientation input, is known to be effective in the spatial orientation of the blind, for instance (20) although in daily life the non-visually handicapped human uses visually determined frames of reference for spatial orientation, auditory input constituting a supplementary frame of reference requiring adequate training to become effective. In experiment II, untrained subjects, apparently unable to utilise the field orientation input (i.e., the sound shift between the two loudspeakers) in their efforts to maintain postural control, manifested increased body sway.

In experiment III, body posture was perturbed with high intensity vibration (850 m/s²) causing fast and prominent changes in the centre point of force, and hence in the feedback auditory input. Owing to cognitive lag (2), feedback auditory input can not be interpreted quickly enough to permit the fast and intensive changes in body posture to be compensated, and the potential stabilising effect of the feedback auditory input is thus negated. The vibration and intensive changes in body posture caused by high intensity vibration (850 m/s²) may also require another postural strategy (10) which does not take into account the delicate and time-dependent effect of the feedback auditory input required to reduce body sway significantly. Fast angular movements at the ankle may also evoke activity in the antagonistic muscles so as to diminish the initial compensatory reaction to the test perturbations (3, 4) caused by high intensity vibration (850 m/s²) and thus further increase the frequency shift in the auditory feedback input.

The effect of auditory feedback was stabilisation or vibration-induced body sway may be useful in rehabilitation contexts as well as in training programmes aimed at augmenting human skills. The present results suggest that auditory feedback may be better suited for training where position deviations are present (as in stroke patients) than to supplement recognition of and response to fast movements.

REFERENCES
Fig. 4. Results for one subject during experiment I. The body sway in the antero-posterior plane is given for all three tests performed together with a graphic illustration of the auditory input. Note the same shape of the curves in test C and auditory feedback input, only different amplitude.

Effect of auditory input on postural control

In experiment II, untrained subjects, apparently unable to utilise the field orientation input (i.e., the sound shift between the two loudspeakers) in their efforts to maintain postural control, manifested increased body sway.

In experiment III, body posture was perturbed with high intensity vibration (850 mW) causing fast and prominent changes in the centre point of force, and hence in the feedback auditory input. Owing to cognitive lag (2), feedback auditory input can not be interpreted quickly enough to permit the fast and intensive changes in body posture to be compensated, and the potential stabilising effect of the feedback auditory input is thus negated. The vibration and changes in body posture caused by high intensity vibration (850 mW) may also require another postural strategy (10) which does not take into account the delicate and time-dependent effect of the feedback auditory input required to reduce body sway significantly. Fast angular movements at the ankle may also evoke activity in the antagonistic muscles so as to diminish the initial compensatory reaction to the test perturbations (3, 4) caused by high intensity vibration (850 mW) and thus further increase the frequency shift in the auditory feedback input.

The effect of auditory feedback stabilization to vibration-induced body sway may be useful in rehabilitation contexts as well as in training programmes aimed at augmenting human skills. The present results suggest that auditory feedback may be better suited for training where position deviations are present (as in stroke patients) than to supplement recognition of and response to fast movements.

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Fig. 5. Log-transformed torque versus. The mean, SEM and level of significance are given in each experiment.
PULSED ULTRASOUND TREATMENT OF THE PAINFUL SHOULDER
A RANDOMIZED, DOUBLE-BLIND, PLACEBO-CONTROLLED STUDY

Matth Nykänen
From the Pulkaharju Rehabilitation Hospital, Pulkaharju, Finland

ABSTRACT. To study the effect of pulsed ultrasound in shoulder pain, 35 patients were treated with pulsed ultrasound and 37 patients with placebo ultrasound in a double-blind design. The therapy was given during in-patient rehabilitation, 10–12 treatments over 3–4 weeks. Treatment time was 10 minutes, frequency 1.0 MHz, on-off ratio 1:4 and intensity 1.0 mW/cm². Follow-ups were done after 4–12 months. No differences (p < 0.05) in outcomes were found between the groups after the treatment period or at follow-ups. These results discourage the adding of pulsed ultrasound therapy with the variables used to the conservative treatment of the painful shoulder.

Key words: shoulder pain, pulsed ultrasound, controlled clinical trial.

INTRODUCTION

Ultrasound has been used in the treatment of shoulder pain for decades. Some reports have claimed the value of continuous ultrasound in this condition (7, 11, 5), but the failure to randomize treatment and the lack of controls have cast doubt on their conclusions. Other studies which used control groups failed to prove any beneficial results (3, 5, 14).

Ultrasound can influence blood flow, the mediation of inflammation, eucytotic function, angiogenesis, collagen synthesis and collagen maturation, as recently reviewed (13). Many of these effects are due to the temperature elevation, but with the introduction of pulsed ultrasound, non-thermal effects are also shown to be present (4). However, the clinical significance of these non-thermal effects is unclear (10). Controlled clinical trials using pulsed ultrasound in treating lateral epicondylitis (epicondylitidis) have produced diverging results (1, 6, 12, 18). In this study, pulsed ultrasound was used to treat patients with painful rotator cuff in a double-blind placebo-controlled study design.

MATERIAL AND METHODS

The source population consisted of in-patient rehabilitation clients coming for a treatment period of 3–4 weeks from April 1987 to April 1989. Included in study were 73 patients (11 women, 62 men; aged 37–67 years) suffering from shoulder trouble of at least 2 months’ duration and with a painful arc between 0–130° of abduction, or with other painful movement plus pain in supraspinatus area (patient upright, shoulder 90° of abduction, 30° of horizontal abduction, and full internal rotation. Patient maintains position against downward resistance) (9). Fifty-eight patients were war cripples or veterans whose rehabilitation was financed by the State Accident Office. The rest were people suffering from musculoskeletal problems to whom the Finnish Social Insurance Institute had decided to finance an institutional rehabilitation period.

Patients with suspected biceps-tendinopathy (prominent tenderness on biceps-sulcus and pain during resisted elbow flexion), with prominent local tenderness over the acromioclavicular joint, with frozen shoulder (adhesive capsulitis) (restricted active and passive external rotation), with apparent rupture of rotator cuff (marked weakness or inability of active abduction not due to pain) were excluded. Likewise excluded were patients with shoulder problems associated with hemiplegia, or cases of altered anatomy or function like posttraumatic states with bone or nerve lesions. Patients with inflammatory rheumatic diseases, and patients with unsolved compensation claims were also excluded.

All the patients found to fulfill the study criteria were willing to participate, and after giving informed consent, the subjects were randomly assigned to groups A or B. The responsible physician made a clinical assessment including:

1) a gonometric measurement of abduction with recording of the starting point of possible painful arc, and 2) pain according to the supraspinatus test (9) (0 = no pain, 1 = mild pain, 2 = moderate pain, 3 = severe pain). This assessment was repeated at discharge.

Treatment was given with a EST300-machine (Elecit Co., Oslo, Finland) using Ultra-Phone ultrasonic coupling medium (Pharmaceutical Innovations Inc., Newark, New Jersey, USA). Before treatment the therapist chose a transducer plug labeled either A or B according to the respective group of patients. A technician, also responsible for the regular checking of the ultrasonic output of the machine, had made the other plug non-functioning. Apart from him, no other person knew which plug was manipulated.