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Visual Control of Human Stance On a Narrow and Soft Support Surface

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Summary

The influence of additional visual feedback (VF) on stance control was studied under conditions of changed afferent information from the foot sole and ankle joint due to different support surfaces. The changes of body sway amplitudes were analyzed and their frequency spectrum was established. The effect of visual feedback on the amplitude and frequency characteristics of human stance was manifested as: a) a decrease of the mean amplitude of body sway during visual feedback, corresponding to the decrease of power spectrum density (PSD) of stabilograms in the frequency range below 0.05 Hz, b) an increase of mean velocity of body sway corresponding to the increase of PSD of stabilograms in the frequency range of 0.4–1.5 Hz. The results showed that the improvement of the upright stance by additional visual feedback is mainly mediated through activation of postural muscles at the ankle level, or ankle strategy. The stabilization effect of VF on stance control is slight or negligible if the performance part in ankle joint (narrow support) was reduced.

Key Words

Visual feedback – Posture control – Afferent control of stance

Introduction

Visual feedback provides information about body movements in relation to a static environment and plays an important role in stance control (Dichgans and Brandt 1978). If the visible surroundings are moving, the subject tries to stabilize body sway in relation to the visual space reference and a compensatory reaction is started by means of body deviation (Lishman and Lee 1973). The postural readjustments induced by linear motion of the visual scene and characterized by an inclination of the subject in the same direction as the movement of visual field have been described (Lestienne *et al.* 1977).

Another control mechanism of postural activity using visual input was introduced by means of additional visual feedback. Signals from a force platform presented as a movable point on the screen, with decay of one second providing the actual information about the body sway magnitude and direction for postural control during standing. The optimum coefficient of amplification for visual feedback gain were in the range of multiplier from 2 to 4 (Hlavačka and Litvinenková 1973, Litvinenková and Hlavačka 1973). An additional visual feedback loop in processing the subject's stance on a hard surface resulted in the activation of the voluntary component of posture control thus stabilizing posture and this was manifested by smaller excursions and higher velocity of body sway (Hlavačka and Križková 1979). Effective compensation of deteriorating of posture control (altered support-surface, body weight changes) was obtained only when the performance of the efferent-action part of the postural system remained unchanged (Hlavačka and Šaling 1986).

Moreover, additional visual feedback in human stance control significantly minimized body sway evoked by galvanic labyrinthine stimulation (Križková *et al.* 1983), or vibration of the Achilles tendon (Šaling and Hlavačka 1981). Several studies have investigated the influence of visual feedback (force platform signals on the screen) on the research of posture, rehabilitation and vestibular training (Gantchev *et al.* 1978, Clarke *et al.* 1990).

The main goal of this paper was to study the influence of additional visual feedback on stance control and the quality of the support surface. The changes of body sway amplitudes were analyzed and their frequency spectrum was established.

Methods

The study was performed on 16 healthy subjects (9 men and 7 women) between the ages of 20 and 55 years. A force platform (surface area 45 x 45 cm) with three strain gauges was used for the registration of the centre of foot pressure. During the test, subjects were standing on the force platform, their hands were hanging loosely along the body and their heels were close together with the feet forming an open angle of 30 degrees. The following experimental situations were used:

- standing on a hard support surface (control)
- standing on a soft support surface (10 cm thick foam rubber, density 30 g/dm^3).
- standing on a 8 cm wooden rail (support surface narrowed in the antero-posterior direction).

In all experimental situations the subjects with open eyes were tested with and without additional visual feedback. On-line visual feedback (VF) was realized by watching an oscilloscope screen (22 x 18 cm) placed 1.0 m in front of the subject's eyes. Subjects were informed about their body tilts as a moving light point on the screen controlled by force platform output signals. Up and down motions of the point on the screen represented antero-posterior (AP) body sway. Lateral deviations of the light point represented body sway in the left-right (LR) direction. The subject's task was to minimize deviations of the light point and to maintain it within a encircled area (diameter 4 cm) on the screen by voluntary effort of postural activity. One stabilometric measurement in every experimental situation lasted 50 s. Five minutes' rest time followed each experimental measurement to avoid fatigue.

The stability of stance was characterized by five amplitude parameters. Their values were obtained by processing of LR and AP stabilometric signals on a computer PC/AT. Both analog platform output signals (stabilograms) at intervals of 50 s were digitized (sample frequency 40 Hz). The following stabilometric parameters were assessed:

- amplitude of lateral Ax and antero-posterior Ay stabilograms (4. SD - four times the value of the standard deviation of the stabilogram) characterizing the magnitude of body sway in both directions,
- velocity index of lateral Ix and antero-posterior Iy stabilogramns (mean values of the first derivative of stabilograms) reflecting the activity of postural muscles,
- root mean square of stabilograms, RMS = $\mathrm{sqrt}(Ax^2 + Ay^2)$ characterizing the dynamics of tilting around a mean position.

The frequency spectrum of the recorded AP and LR stabilograms were analyzed by FFT (power spectrum density, normalized by the stabilogram's variance - $PSD/(SD)^2$). For statistical evaluation Student's t-test for paired observations was used. A difference of $p<0.05$ was considered significant.

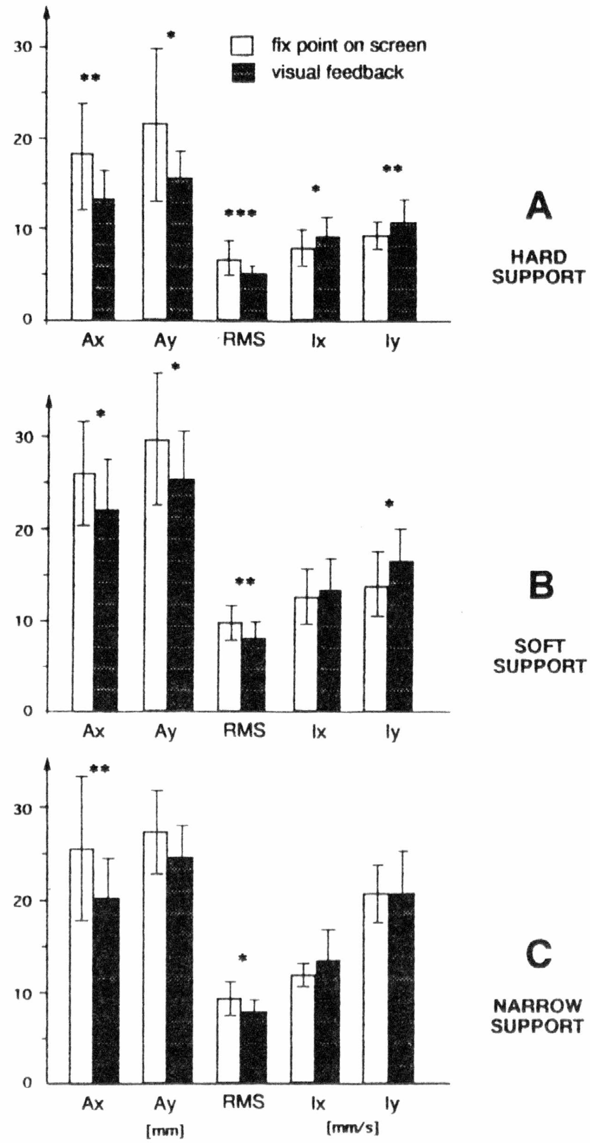

Fig. 1
The influence of additional visual feedback and of the quality of support surface upon the stabilometric parameters: Mean values (± S.D.), Ax, Ay – lateral and fore-aft amplitudes, RMS-root mean square, Ix, Iy – lateral and fore-aft velocity indexes, $^*p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$ (n=16). Striped bars mean visual feedback condition.

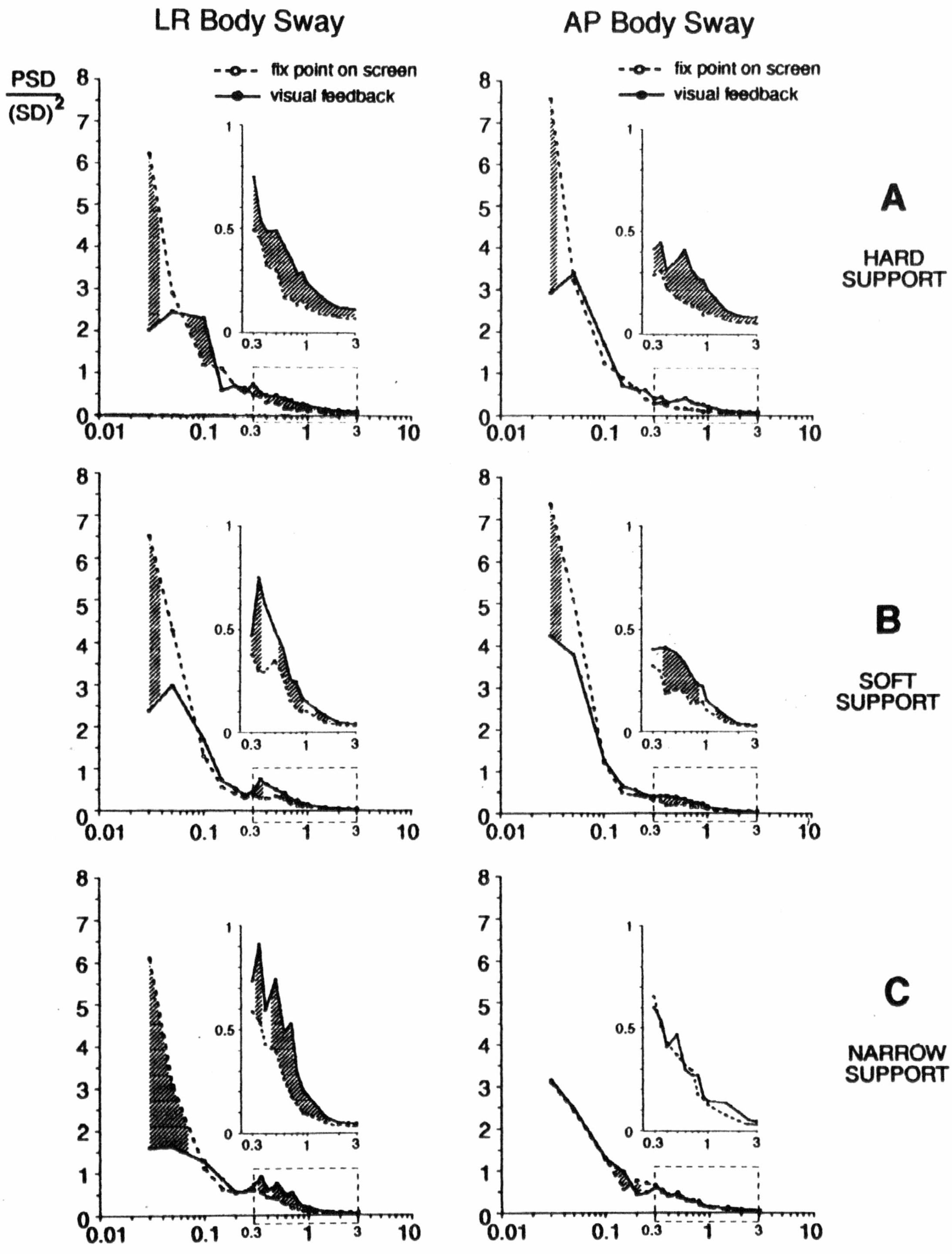

Fig. 2
The influence of visual feedback on mean values of power spectra of body sway in three qualitatively different support surfaces. LR-lateral and AP-anteroposterior directions. Striped area means the statistically significant difference $p<0.05$ (mean values, $n=16$).

Results

The results of amplitude analysis of the stabilograms are shown in Fig. 1. (A,B,C). The erect stance stability on the hard support surface was improved during VF (Fig. 1A). It was manifested by a significant decrease of the stabilogram amplitude in antero-posterior (Ay) and lateral (Ax) directions and the values of parameter RMS. On the contrary, values of the velocity index of stabilogramns Ix and Iy were increased.

When the subjects stood on the soft support surface (Fig. 1B), the VF decreased the values of parameters Ax, Ay and RMS, but with a lower significance than on the hard support. A significant increase was observed in the values of parameter Iy during this experimental situation.

When the subjects stood on the surface narrowed in the AP direction (Fig. 1C), the VF significantly reduced the amplitude only in LR body sway - Ax and consequently the value of parameter RMS. The changes of values Ix and Iy induced by VF were not significant.

The frequency analysis of AP and LR stabilograms in the control situation with VF during stance on the hard support surface showed a decrease of the PSD of stabilograms in the lower frequncy 0.03 Hz (Fig. 2A). A significant increase of the PSD of stabilograms at frequencies above 0.3 Hz was observed in both AP and LR directions.

When the subjects stood on the soft support, the PSD of lateral sway in the frequency ranges of 0.35–0.40 and 0.60–0.90 Hz, and the PSD of antero-posterior sway in the frequency range 0.40 to 0.80 Hz significantly increased with VF (Fig. 2B). The reduction of PSD of sway at the low frequency (0.03 Hz) was significant in both directions.

The frequency analysis of stabilograms revealed that the influence of VF on the AP and LR body sway during stance on the narrow support (Fig. 2C) differed. An increase of PSD of lateral sway in the frequency range of 0.5–1.5 Hz and a decrease of PSD of sway at the lowest frequency (0.03–0.05 Hz) were shown. The effect of VF during stance on the support narrowed in the antero-posterior direction was negligible on the PSD of antero-posterior sway.

Discussion

The present results have confirmed and extended information about the stabilizing effect of additional visual feedback in stance control (Hlavačka and Šaling 1986). The improved posture control is manifested by the amplitude and frequency characteristics of stabilograms especially in two basic indicators. First, the decrease of mean sway amplitude, corresponding with the decrease of stabilogram PSD in the frequency range below 0.05 Hz. Second, the increase of sway mean velocity, corresponding with the increase of PSD in the frequency range of 0.4-1.5 Hz.

The first finding can be considered as a manifestation of visual feedback loop – body sway – movements of a light point on the screen – compensatory activity of postural muscles – body balance stabilization. It is interesting that the decreasing amplitude was observed in very slow body sways, during visual feedback conditions in the frequency range of 0.03-0.1 Hz. Converting these values to the duration of one sway cycle, one body tilt lasted approximately from 10 to 30 s. It can be assumed that the visual feedback did not operate in each body tilt. The feedback influence probably reduced the slow drift of body position by intermittent single action of postural muscles, thus optimalizing the body centre of gravity over the base support. This idea is in agreement with previous findings that the visual system is mainly involved in discontinuous adjustment as a trigger for programmed postural strategies and patterns of muscular activation (Paulus *et al.* 1987).

The second finding reflects the increased activity of postural muscles in the ankle joint induced by additional visual feedback. The experimental conditions of soft and narrow support provide limited or misleading sensory information or impaired motor component in balance control. In this case, the central nervous system increases the activity of leg and trunk postural muscles (Horak and Nashner 1986). In situations B and C, the increased muscle effort was documented by increased velocity of body sway expressed by higher values of velocity indexes Ix, Iy (Fig. 1).

The afferent information from the sole and biomechanical contact with the sole-support surface in our experimental situation can be characterized as follows:

A - standing on the firm support surface represents normal somatosensory afferentation.

B - standing on soft support surface represents a reduction of tactile information from the sole and a limiting condition for realizing the stabilization actions of stance, because of support elasticity.

C - standing on the support surface narrowed in the antero-posterior direction means limitation of tactile information from the sole, reduction of proprioceptive inputs and marked mechanical constrains on ankle sway.

In experimental situations A and B - hard and soft support surfaces - the stabilization of stance is accompanied by a decrease of body sway amplitude. Similar results were obtained during compensation of artificially increased body weight in stance (Hlavačka and Šaling 1986). In case B, the changed afferent inputs in stance control can be compensated by additional visual feedback. In case C - the negative effect of short support on stance stability can not be compensated by additional visual feedback.

In cases B and C in which the visual and proprioceptive information were reduced and the drastic mechanical contraints were involved (case C), the visual feedback had a declining effect on postural stabilization. The statistical analysis of body sway amplitude and body sway velocity demonstrated the improvement of all five stabilometric parameters for situation A, four parameters in situation B, and only two parameters in situation C (Fig. 1A,B,C). Moreover, the velocity index Iy in situation C was maximal and its values were the same independently of the presence of visual feedback. This observed phenomenon may be caused by the fact that stance on the narrow surface is near to the limiting condition of balance control due to mechanical constraints of the support (Nashner *et al.* 1989) and it requires maximal activation of the locomotor system. It is interesting that the stabilizing effect in posture control is not affected by shortening of the support surface in the lateral direction (Fig. 1C - Ax). The frequency analysis in situation C showed a decrease of PSD values of lateral body sway in the low frequency range (0.03-0.05 Hz) and the increase in frequency range 0.4-1.5 Hz. For antero-posterior body sway in situation C, the PSD curves were practically the same regardless of the presence or absence of visual feedback, but were also very similar to the PSD curve in situation A - the stance on the hard support with visual feedback. This means that the mechanical configuration of the support surface limits the ability to move the body centre of gravity in the low frequency range similarly as the influence of additional visual feedback (Fig. 2 A,C).

The automatic postural movements supporting upright stance are organized using one or a combination of two basic patterns (Horak and Nashner, 1986). The "ankle" pattern relies on large torsional moments about ankle joints and the centre of gravity movements are constrained to low frequencies (0.01-0.5 Hz) because the moment of body inertia about the ankles is large (Nashner *et al.* 1989). The "hip" pattern relies on torsion movements about the hips to rotate the ankle and hip joints in opposite directions. Hip movements, however, move the centre gravity rapidly (frequency about 1 Hz) and they are effective when standing on small support surface areas (Nashner *et al.* 1989).

The results of our previous work showed that the EMG activity of m. triceps surae in visual feedback during stance on a hard support surface is increased (Podivinský *et al.* 1985). According to the above mentioned facts and our findings, we conclude that the improvement of upright stance by additional visual feedback is mainly realized in the low frequency range below 0.1 Hz through activation of postural muscles at the ankle level *via* ankle strategy. When the performance part in the ankle joint (narrow support) was reduced, the stabilization effect of VF on stance control was slight or negligible.

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