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ORIGINAL ARTICLE

Postural control in subjects with visual impairment

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Purpose. *To investigate the effect of long-term, not experimentally induced visual impairment on balance, and to clarify which means are used to compensate for this sensory deficit.*
Methods. *Posturography was examined in 50 visually impaired subjects (11 with congenital blindness and 39 with acquired visual impairment) and 50 healthy controls. Examination was performed in 4 testing conditions: while standing on firm surface or foam pads (which decreases the somatosensory input) and with open or closed eyes (manipulating visual input).*
Results. *Subjects with acquired visual impairment were significantly less stable than controls when tested with open eyes, especially when standing on foam pads, but equal to controls when eyes were closed. Congenitally blind subjects performed equally to normal controls in all test conditions when tested with eyes open, and performed significantly better than controls with eyes closed. In comparison to subjects with acquired visual impairment, the congenitally blind were significantly more stable in all test conditions. Fourier analysis revealed that the visually impaired subjects showed decreased intensity values within the lowest frequency range of 0.1 Hz and below, a range believed to be sensitive to the function of the visual system.*
Conclusions. *We have found that vision impairment influenced postural control, especially if acquired and not congenital. The somatosensory and vestibular systems serve as compensatory mechanisms, which is utilized most effectively by the congenitally blind.*

Key Words. *Balance, Postural control, Visual impairment*

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INTRODUCTION

Vision is one of the 3 basic sensory systems regulating postural control, together with the vestibular and somatosensory systems (1), and therefore deprivation of vision should affect static balance. Several studies showed that acquired impairment of vision, such as due to cataract, can impair balance and lead to high risk of falls (2-4). Other studies, however, demonstrated that the majority of visually impaired people are able to control their balance normally in spite of their visual impairment (1, 5). A possible explanation is that the other postural control systems, vestibular and somatosensory, are mobilized effectively as compensatory mechanisms (5), as these subsystems were shown to interact and integrate (6, 7).
Posturography of visually impaired subjects has been extensively investigated by conducting experiments on restriction of visual input in laboratory settings in healthy subjects (2), or examination of subjects with acquired visual impairment (4). Results of posturographic examina-

tion of the congenitally blind are relatively scarce and none used computerized posturography (8, 9).

The main objective of this study was to investigate the effect of long-term, not experimentally induced visual impairment on balance, and to clarify which means are used to compensate for this sensory deficit. Our hypothesis was that visually impaired subjects can mobilize their somatosensory and vestibular systems to compensate for the impairment of balance caused by the hypofunction of the visual system.

METHODS

The study included 50 subjects with visual impairment and 50 healthy controls matched for gender. Mean age was 34.4±12 years (range 21.9-68.8) and 37.1±7.9 years (range 21.1-50.4) in the control and study group, respectively (p=0.8).

The visually impaired group included patients with opacity of the optical media (i.e., cataract, n=24), damage to the visual sensory tract (retina or optic nerve, n=4), combinations of the above (n=11), and congenital blindness (n=11). All subjects were recruited from attendants of the Vocational Service Institute for Visually Impaired, Halle, Germany.

The healthy subjects were selected from personnel of the Service Institute, family members of the visually impaired subjects, and students of the Martin Luther University, Halle. Inclusion criteria were as follows: visual acuity using optical correction better than or equal to 6/7.5; normal results on slit-lamp, intraocular pressure, and fundus examination; no inherited eye disease in a first-degree family member; refraction of ≤5 diopters sphere and/or 2 diopters cylinder; no neurologic, orthopedic, or vestibular pathology or diabetes mellitus; and no consumption of any medications 24 hours before the test.

All subjects underwent optometric evaluation which included visual acuity test using the Landholt C visual acuity test. Visually impaired subjects with a visual acuity better than 6/18 as well as subjects who found the study too stressful were excluded. All participants received written information, which was read to the visually impaired subjects, explaining the goals and contents of the study and gave written consent to participate. The study was approved by the Martin Luther University Research Ethics Committee and conformed to the Helsinki Declaration for studies in human subjects.

Instruments

Postural control was assessed by the Tetrax Interactive Balance System (Sunlight-BeamMed, Petah Tikva, Israel). This device measures the vertical pressure fluctuations on 4 independent force plates (dimensions: length 25 cm, width 13 cm, height 8 cm each), each supporting the heel and toe parts of each foot. The plates are equipped with a strain gauge, which output consists of fluctuations of voltage. This output is transformed by an A-D Device into a digital signal, which is analyzed by the Tetrax Software. The weight of the examinee is automatically controlled by the software while height does not interfere with the Tetrax parameters, as shown by systematic examinations (10).

The device software yields 4 basic posturographic measures; however, for the purpose of this study, only 2 were analyzed: Stability Index and Fourier Spectral Analysis.

The Stability Index. The Stability Index is calculated as the square root of the sum of squared differences between adjacent pressure fluctuation signals, transmitted by the A-D device and sampled at a rate of 32 Hz for each of the 4 platforms. The higher the Stability Index, the greater the sway. This parameter, besides being a measure of stability, is also an indicator of effective compensatory postural control mechanisms (11, 12).

Fourier Spectrum of Postural Sway. The Tetrax software evaluates the intensities of sway within 8 frequency ranges. It was shown in a number of studies that the different frequency ranges of the postural Fourier Spectrum are sensitive to disturbances of the postural control (1, 13, 14). Excessive high intensities at a certain frequency range will indicate that the respective system is overstimulated or mobilized for the purpose of compensation, whereas abnormally low scores will reflect functional deficiency (5, 15). A detailed description of the Tetrax Interactive Balance System and its parameters is presented elsewhere (1, 11-13, 16).

Recording procedure

Subjects were asked to stand erect and focus as much as they could on a 6/60 Snellen letter placed 3 meters in front of them. Each recording session lasted 32 seconds. Posturography was examined in 4 test conditions, 3 of which were designed to impair the input from 1 of the 3 basic sensory systems regulating postural control:

1. Unimpaired sensory input: standing with eyes open on solid surface, with information from all sensory channels available. The performance in this position can be used as reference value, to calculate a sensory preference score, to be described later.
2. Selectively impaired sensory input: a) standing with eyes closed on solid surface, which induces stress mainly on the somatosensory and the vestibular systems, vision being restricted; b) standing with eyes open on foam pads (dimensions: length 25 cm, width 13 cm, height 8 cm each, one for each foot, placed on top of the platforms), hence reducing the somatosensory feedback from the lower extremities, leaving the vestibular and visual systems as the main channels that maintain equilibrium.
3. Standing on foam pads with eyes closed, a test condition which leaves the vestibular system as the only unimpaired source of sensory information.

A sensory preference score was calculated by dividing the performance in each of the perturbation test conditions [2 (1), 2 (2), 2 (3)] by the normal baseline position (1). Thus, a high score in a certain test condition reflects the mobilization of this system due to impaired input from the other systems, as described by Allum and Shepard (6).

Statistical elaboration was carried out in 2 stages. Stage 1 focused on the assessment of differences between the visually impaired subjects versus the healthy controls. After testing the normality of the distribution with the Kolmogorov-Smirnov test, regular t tests between the group means were performed. At the second stage, the sample was trichotomized, by subdividing the group of the visually impaired subjects into congenitally blind and acquired visual impairment. The new data sets were analyzed using analysis of variance, computing the statistical significance of differences between the subgroups by means of Scheffé post hoc test. The critical level of significance was adjusted using the Bonferroni correction.

RESULTS

As evident by the Stability Index values, visually impaired subjects were less stable than controls when tested with open eyes. On the other hand, when eyes were closed, visually impaired subjects performed on an equal level; also in the relatively most stressful test condition, i.e., standing on foam pads (Tab. I). Comparison of sensory preference scores (Tab. II), which represent the degree of compensatory mobilization of the visual, somatosensory, and vestibular subsystems when one or more of the other sensory inputs is impaired, shows that visually impaired subjects are significantly superior in controlling their stability when the somatosensory and vestibular systems are the main active systems (when eyes are closed). On the other hand, when they have to rely more on the visual system and less on the somatosensory system (while standing on foam pads with eyes open), their performance drops significantly below the level of the controls.

In Figures 1-3, a comparison of spectral analysis of postural sway is presented. With eyes open (Fig. 1), visually impaired subjects show an overall higher level of intensity throughout the spectrum, which is statistically significant ($p=0.001$) within the medium low and medium high ranges (0.1 Hz to 3 Hz). With eyes closed (Fig. 2), it is the normal group which shows higher intensities throughout the spectrum, which are statistically significant at the lower and upper ends of the spectrum. Figure 3 plots the increment of sway intensification induced by closure of the eyes, i.e., the

TABLE I - STABILITY IN 4 TEST CONDITIONS IN HEALTHY AND VISUALLY IMPAIRED GROUPS

	Eyes open, solid surface, no visual impairment		Eyes closed, solid surface, visual impairment		Eyes closed, foam pads, somatosensory visual impairment		Eyes open, foam pads, somatosensory impairment	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Healthy	1.01	0.28	1.48	0.34	1.96	0.45	1.29	0.23
Visually impaired	1.10	0.33	1.14*	0.24	1.62*	0.42	1.45	0.32
p value	0.01		<0.001		0.001		0.004	

Bonferroni correction, critical level of $p=0.02$.

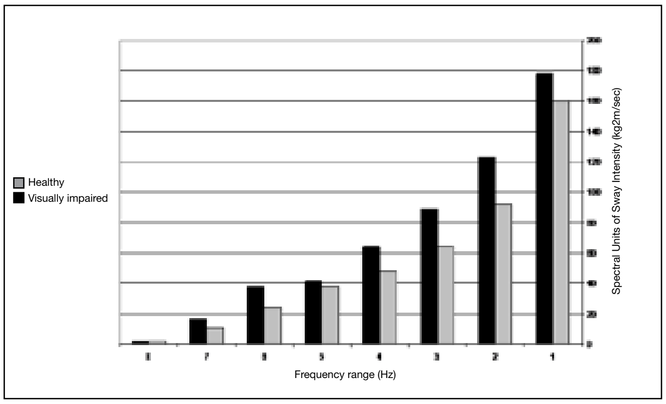

Fig. 1 - *Fourier Spectrum of Postural Sway in healthy and visually impaired subjects tested with eyes open on solid surface.*

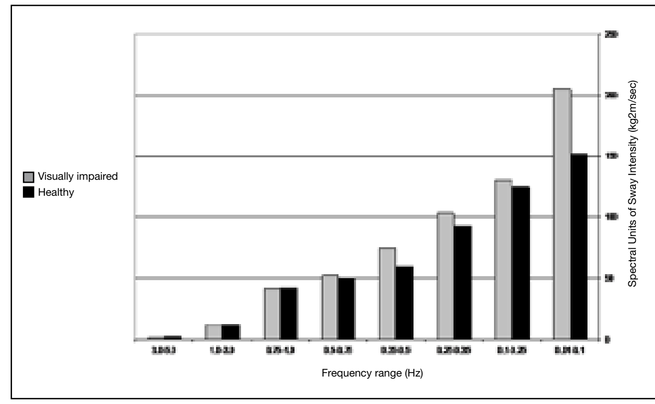

Fig. 2 - *Fourier Spectrum of Postural Sway in healthy and visually impaired subjects tested with eyes closed on solid surface.*

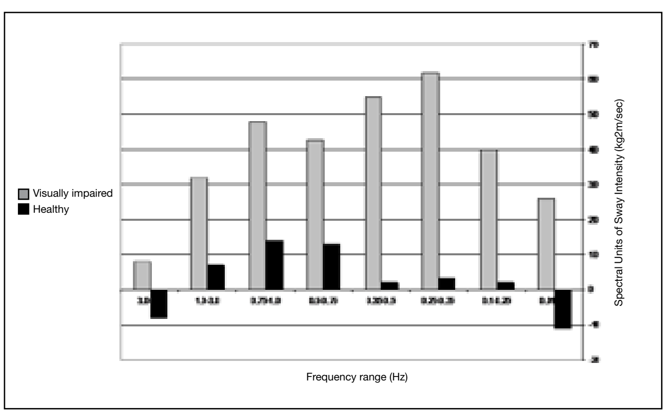

Fig. 3 - *The effect of visual occlusion on sway intensity.*

difference of performance with closed versus open eyes, divided by the performance with open eyes, which served as baseline. It is evident that with closed eyes the healthy subjects show a conspicuous intensification throughout the spectrum, especially in the medium range, with a peak at the frequencies which represent the vestibular system (0.1-0.5 Hz). In visually impaired subjects, eye closure does not affect the vestibular related range, but induces a moderate increment of intensity at the somatosensory related range (0.5-1.00 Hz), while at the low and high end of the spectrum sway intensity decreases.

We further subdivided the visually impaired group into 2 categories: congenitally blind and acquired visual impair-

TABLE II - SENSORY PREFERENCES SCORES IN HEALTHY AND VISUALLY IMPAIRED SUBJECTS

	Eyes open, solid surface		Eyes open, foam pads		Eyes closed, solid surface		Eyes closed, foam pads	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Healthy (n=52)	15.5	3.49	19.7	5.51	22.5	5.50	29.7	7.00
Acquired visual impairment (n=41)	20.6	5.33	29.2	7.91	23.2	6.29	31.7	8.09
Congenital visual impairment (n=11)	15.3	2.23	22.2	4.59	16.4	7.29	25.3	12.2
F test p	<0.001		<0.001		0.022		0.107	

Bonferroni correction, critical level of p=0.02.

ment (Tab. III). Congenitally blind subjects were more stable in all test conditions than subjects with acquired impairment. When tested with eyes open, the performance of congenitally blind subjects was statistically similar to that of the control group, and with eyes closed, their stability was even superior to normal (although this difference reached statistical significance only when tested on a solid surface). Interestingly, the congenitally blind subjects performed equally with eyes open or closed when tested on a solid surface.

DISCUSSION

This study demonstrates clearly that persistent visual impairment induces changes in the interaction between the postural control subsystems. In visually impaired subjects, the vestibular and somatosensory systems seem to assume a more prominent role in maintaining balance and thus compensate for the weak or absent visual input. On the other hand, visually impaired subjects, having learned to use the vestibular and somatosensory functions as a reliable source of information for maintaining balance, rely less on their vision, as evidenced by their normal posturographic performance when eyes are closed. This finding is supported by an fMRI study which demonstrated that activation of the vestibular system causes deactivation of the visual cortex and vice versa (14).

This pattern is even more evident when evaluating the performance of the congenitally blind subjects. We have found that this compensatory mechanism, when initiated at birth, may lead to superior to normal balance in situations where visual input is not available. These findings are in part similar to the results of a study conducted by De Oliveira and Barreto (17), who compared a small number of subjects (n=11) with acquired blindness to normal controls. They found that lateral but not anteposterior sway was significantly greater (worse stability) in the blind and was related to the duration of visual loss. It should be noted that in this study balance was tested only while the subject's eyes were open, as the authors may have considered eye closure an experimental intervention not necessary in blind subjects. However, MRI studies have shown that in healthy subjects tested in complete darkness the closure of the eyelids per se induces changes in the activation and interaction of the visual, somatosensory, vestibular, and auditory systems (18, 19).

Comparing the 2 populations by spectral analysis of their postural sway (Figs. 1-3), the differential effect of presence versus absence of visual input on the postural control dynamics can be observed from a different angle. With eyes open (Fig. 1), the significantly higher intensities within the range of 0.2 to 1.00 Hz in the visually impaired subjects confirm the compensatory mobilization of vestibular and somatosensory functions. When the eyes are closed (Fig. 2), the pattern is inverse, and throughout the entire spectrum the visually impaired subjects show lower intensity

TABLE III - STABILITY MEASURED IN 4 TEST CONDITIONS IN THE CONGENITALLY BLIND GROUP, ACQUIRED VISUAL IMPAIRMENT GROUP, AND NORMAL CONTROLS

	Eyes open, solid surface, no visual impairment		Eyes closed, solid surface, visual impairment		Eyes open, foam pads, somatosensory impairment		Eyes closed, foam pads, somatosensory visual impairment	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Healthy	1.01	0.28	1.48	0.34	1.28	0.23	1.97	0.455
Acquired visual impairment	1.13	0.33	1.15	0.24	1.45	0.324	1.59	0.419
Congenital visual impairment	1.07	0.4	1.11	0.587	1.46	0.295	1.70	0.943
p value	0.01		<0.000		0.010		0.001	

Scheffé post hoc test: eyes open, pads: healthy vs acquired visual impairment: p=0.02; acquired visual impairment vs congenital visual impairment: NS; congenital visual impairment vs healthy: p=0.05. Eyes closed, solid surface: healthy vs acquired visual impairment: p=0.001; acquired visual impairment vs congenital visual impairment: not significant; congenital visual impairment vs healthy: p=0.02. Eye closed, pads: healthy vs acquired visual impairment: p=0.001; acquired visual impairment vs congenital visual impairment: not significant; congenital visual impairment vs healthy: not significant. Bonferroni correction, critical level of p=0.02.

scores than the healthy subjects. We believe that the absence of visual input is compensated by the healthy subjects with vestibular and somatosensory overactivation, while the visually impaired subjects, who already use this strategy, do not need to or cannot use it under such circumstances.

Figure 3 demonstrates the differences in postural strategy induced by visual occlusion in better contrast and greater detail. In the control group, eye closure causes a pronounced increase in vestibular-related frequencies (0.1-0.5 Hz), but this effect is not seen at all in the visually impaired subjects. On the other hand, eye closure causes intensification in the somatosensory related sway (0.5-1.00 Hz) in both groups. These results confirm the findings of Fukuoka et al (20), who demonstrated that low-frequency sway is controlled by the visual system, as well as recent results reported by Friedrich et al (5), who observed significant changes in the extremely-low-frequency sway caused by experimental restriction of the visual field in normal subjects. The findings in relation to the highest frequency band are difficult to explain. It is possible that the increase in sway at this frequency band can be considered a manifestation of postural tremor (7), which in neurologically normal subjects can be produced by muscular stress (12). The slightly increased high-frequency sway induced in situations when postural steadiness has to be maintained in absence of visual input may be better controlled by the visually impaired subjects, who use somatosensory control to a greater extent than healthy subjects.

Postural control is influenced differently by central versus peripheral visual loss. In this study, we examined central vision only in all subjects, thus the different effect of peripheral versus central visual loss was not studied.

In conclusion, from the point of view of basic research, the results of the present study help to explain the hitherto poorly investigated functional role of the lower end of the postural sway spectrum, and support the research of Friedrich et al (5) and Fukuoka et al (20). From a clinical perspective, the important role of somatosensory and vestibular functions as compensatory strategies in visually impaired subjects, highlighted in this study, would indicate that the training of these functions as described in the study of Kollmitzer et al (21) would contribute to the rehabilitation of postural deficit in these subjects, especially with aging, and reduce the risk of falls.

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