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RESEARCH ARTICLE

Influence of pathologic and simulated visual dysfunctions on the postural system

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Abstract Visual control has an influence on postural stability. Whilst vestibular, somatosensoric and cerebellar changes have already been frequency analytically parameterised with posturography, sufficient data regarding the visual system are still missing. The aim of this study was to evaluate the influence of pathologic and simulated visual dysfunctions on the postural system by calculating the frequency analytic representation of the visual system throughout the frequency range F1 (0.03–0.1 Hz) of Fourier analysis. The study was divided into two parts. In the first part, visually handicapped subjects and subjects with normal vision were investigated with posturography regarding postural stability (stability effect, Fourier spectrum of postural sway, etc.) with open and closed eyes. The visually impaired and the normal group differed significantly in the frequency range F1 ($p = 0.002$). Significant differences of the postural stability between both groups were found only in the test position with open eyes (NO). The healthy group showed a significant loss of stability, whereas the impaired group showed an increased stability due to sufficient somatosensoric processes. Visually handicapped persons can compensate the visual information deficit through improved peripheral–vestibular and somatosensoric perception and cerebellar processing. In the second part, subjects with normal vision were examined under simulated visual conditions, e.g., hyperopia (3.0 D), reduced visual acuity (VA = 20/200), yoke prisms (4 cm/m) and pursuits (pendulum). Changes in postural parameters due to simulations have been compared to a standard situation (open eyes [NO], fixation distance 3 m). Visual simulations showed influence on frequency range F1. Compared to the standard situation, significant differences have been found in reduced visual acuity, pursuits and yoke prisms. A loss of stability was measured for simulated hyperopia, pendulum and yoke prisms base down. Stability regulation can be understood as a multi-sensoric process by the visual, vestibular, somatosensoric and cerebellar system. Reduced influence of a single subsystem is compensated by the other subsystems. Obviously the main part of reduced visual input is compensated by the vestibular system. Moreover, the body sway, represented by the stability indicator, increased in this situation.

Keywords Postural stability · Frequency analysis · Visual control · Posturography

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Introduction

The posture and balance regulation is the result of an integration of various multi-sensory processes. In a well-lit environment with a firm base of support, healthy persons rely on somatosensory (70%), vision (10%) and vestibular (20%) information (Peterka 2002). However, when they stand on an unstable surface, they increase sensory weighting to vestibular and vision information as they decrease their dependence on surface somatosensory inputs for postural orientation (Peterka 2002).

About 80% of our sensory perception is gathered by the visual system. Our movements are mainly controlled and coordinated by the eyes. Hence the visual system is not only responsible for cognition of objects, it is also used to give information to the brain about the position of our body. The central vision is benefited for seeing small objects with an excellent visual acuity, for a good spatial resolution, an optimal colour and contrast vision and a large luminance difference sensibility. The peripheral vision is responsible for identifying fast moving objects (better temporal resolution) and for the spatial orientation (Rost 2001; Jendrusch and Brach 2003). For gathering details from a moving object, the fovea has to perform pursuits by coordinated eye and head movements. Eye following movements are used to register floating objects in the fovea with a velocity up to 50–100°/s. If there is a higher velocity, a retinal slip is inserted resulting in saccades (Jendrusch and Brach 2003).

Vision is one of the three basic input channels controlling postural stability and regulation together with the vestibular and the somatosensoric subsystems (Black et al. 1982; Hafstrom et al. 2002; Abdelhafiz and Austin 2003; Stoll et al. 2004; Schwartz et al. 2005). The most important sensory input for keeping balance is the vestibular cue, followed by the somatosensory and the visual cues (Liu et al. 2007). The relative weights placed on each of these inputs are depending on the goals of the movement task, the visual tasks and the environmental context (Peterka 2002; Mergner et al. 2005; Horak 2006; Poulain and Giraudet 2007).

The functional reduction is accordingly large when a visual impairment and/or visual weakness is present (Schwartz et al. 2005). It has been shown that visual deficits are associated with an increased fall risk, particularly in the higher age (Paulus et al. 1984; Brooke-Wavell et al. 2002; Eto 2005; Poulain and Giraudet 2007). The decreased visual efficiency correlates with a loss of postural stability (Manchester et al. 1989; Turano et al. 1994; Anand et al. 2003). In order to parameterize and specify the effects of sensomotoric interventions on the improvement of postural stability and/or for the reduction of the fall risk, the development of suitable assessments is necessary.

It was shown in numerous studies, using different posturographic procedures, that the postural fluctuations are limited to a frequency spectrum of 0.01–4.0 cycles/s (Kapteyn and de Witt 1972; Mauritz and Dietz 1980; Diener et al. 1984; Patat et al. 1985; Ferdjallah et al. 1997; Gagey and Toupet 1998; Kollmitzer et al. 2000; Laughlin and Redfern 2001; Schwesig 2006). Whilst vestibular, somatosensoric and cerebellar disturbances were already frequency analytically parameterized (de Witt 1972; Taguchi 1978; Oppenheim et al. 1999; Schwesig 2006), no evidence was found regarding the visual system.

Up to now only few studies have examined the relationship between the visual and the postural system. By analysing the influence of eye movements on the postural stability it was shown that slow eye movements cause an increase in postural sway (Stoffregen 1985; Guerraz et al. 2000; Strupp et al. 2003; Glasauer et al. 2005).

By measuring the sway intensity with posturography, the results showed that the area of the centre of foot pressure was decreased by presenting the visual stimulus in the periphery (Berencsi et al. 2005). Thus it was shown that the peripheral vision contributes to a stable posture.

To find out how big the feedback from the visual system on the postural system is, two investigations have been made. In the first study, the influence of pathologic visual dysfunctions on the postural system were examined. The primary goal of the first posturographic investigation was the validation of the frequency range F1 (0.03–0.1 cycles/s) of the Fourier analysis as a possible indicator for the visual system. It was furthermore examined, whether persons with visual impairment regulate (compensatorily) their balance via somatosensoric and/or vestibular processes.

In the second study, the influence of simulated visual dysfunctions on the postural system was examined. It was intended to find out if the interactive balance system (IBS) is useful to show the influence of different simulated visual dysfunctions on the postural system.

Methods

Experimental apparatus

Postural stability and regulation was examined using the interactive balance system (IBS; Tetrax Inc., Ramat Gan, Israel) in both sub-studies. In this method of posturography, the vertical pressure fluctuations on four independent force plates, each supporting one heel or the toes of each leg, are recorded. A comprehensive description of the system, including the information regarding reliability and validity of the system, is available elsewhere (Kohen-Raz 1991; Schwesig 2006). Besides stability, it is possible to assess weight distribution, synchronizations as well as the pattern of sway intensities at different frequency ranges, as shown by the fast Fourier analysis of the postural sway waves. Subjects were tested on eight positions as shown in Table 1. In the test positions NO, NC, HR, HL, HB and HF, the subjects were directly standing on the force plates (Fig. 1a). In the test positions PO and PC, the subjects were standing on elastic pillows, which were lying on the force plates (Fig. 1b). The pillows were deteriorating the stand stability and

Table 1 Posturographic testing: test positions (NO–HF)

Identification	Standing position	Head position	Eye position
NO	Without pillows	Head straight	Eyes open
NC			Eyes close
PO	On elastic pillows		Eyes open
PC			Eyes close
HR	Without pillows	Head rotate 45° to the right	Eyes close
HL		Head rotate 45° to the left	
HB		Head up (dorso-flexed)	
HF		Head down (ventro-flexed)	

thus reducing the influence of the somatosensoric system. The measuring period in each case was 32 s.

The main parameters used in this study were: the Fourier spectrum of sway divided into eight frequency bands (F1–F8) (Taguchi 1978; Oppenheim et al. 1999) and the stability indicator (ST).

The ST represents the status of the general postural stability. It is the quotient of the sum of amplitudinal changes (body sway) divided by body weight of the test person. The instability of the test person is greater when the quotient is higher. This value correlates strongly with the values "area of sway", "length of sway" or "amount of sway" of other investigational systems (e.g. Chattecx Balance System, EquiTest, Pro Balance Master, Smart Balance Master, Good Balance, Biodex Stability System).

All parameters used in the IBS are dimensionless values.

In the second study, the visual system was examined with posturography (IBS) too, but now the influence of different visual parameters such as visual acuity, vergence and version on postural stability and regulation was tested.

The eight test positions (NO, NC, PO, PC, HR, HL, HB, HF; compare Table 1) were combined with eight visual situations (A–H), like ametropia, reduced visual acuity or effect of yoke prisms. The visual situations are shown and explained in Table 2.

In all situations, except F, a stable black cross (7 × 7 cm) was presented on a white board (Fig. 1b). In situation F, a moving pendulum was used.

The Fourier spectrum of sway (F1–F8) and the ST were used as parameters. Changes in postural parameters due to simulations have been compared to a standard situation (open eyes [NO], fixation distance 3 m [A]).

Subjects

Study 1: visually handicapped vs. healthy subjects

In the first study, 52 persons with visual impairment and 52 healthy persons were included in the case cohort study ($n = 104$). Those groups were informed about study goals and contents with an information sheet. A written consent was obligatory for study participation. Persons with neurological, vestibular and orthopedic illnesses were excluded.

The study adhered to the tenets of the Declaration of Helsinki.

The sample of the visually impaired ($n = 52$) were recruited from the Vocational Service Institute Halle. The gender distribution of the two groups did not differ significantly (χ^2 after Pearson 0.347; $p = 0.556$) (Table 3).

Study 2: visually simulated dysfunctions

The second study was a prospective study in which 27 subjects (male $n = 8$, female $n = 19$) with normal vision were included. The optometric and posturografic data of these subjects have been collected.

In this study healthy subjects (age range 20–45 years) were included, with a corrected or uncorrected VA ≥ 16/20, independent of the amount of ametropia and of the kind of correction (glasses or contact lenses) and regular stereopsis.

Table 2 Visual situations (A–H) with the used measuring distances and optical corrections for the posturographic measurements

Identification letter	Visual situation	Measuring distance (m)	Optical correction
A	Standard situation with visual acuity$_{cc}$	3	Full correction
B	Visual acuity$_{cc}$ with a longer measuring distance compared to the standard situation	6	Full correction
C	Visual acuity$_{cc}$ with a smaller measuring distance compared to the standard situation	1	Full correction
D	Visual acuity$_{reduced}$ 20/200	3	Full correction with occlusion 20/200
E	Simulated hyperopia (accommodation)	3	Full Correction with –3.0 D
F	Tracking eye movement with a pendulum	3	Full correction
G	Yoke Prisms 4 cm/m basis up	3	Full correction with prisms
H	Yoke prisms 4 cm/m basis down	3	Full correction with prisms

Fig. 1 Measuring system: the subjects were standing on two force plates. They were facing a vertical white board on which a stable black cross was presented at eye level. During the measurement the distribution of the forces on the plates was measured and registered

(a) Test position NO **(b)** Test position PC

Table 3 Subject characteristics

Group	Age (years)		Height (cm)		Weight (kg)		BMI (kg/m^2)	
	MV	SD	MV	SD	MV	SD	MV	SD
Visually impaired	37.7	±7.9	174	±8.3	70.9	±14.2	23.3	±3.3
Healthy group	34.6	±12.0	174	±11.0	81.2	±20.0	26.7	±5.2
Significance (p)	0.121		0.968		0.003		<0.001	

MV mean value, *SD* standard deviation

During the posturografic measurements, the subjects have been wearing the existent correction if regularly worn.

Persons with known postural deformity, medication (except contraceptives) and visual deviations (heterotropia) were excluded.

Statistical analysis

Study 1: visually handicapped vs healthy subjects

Based on our special investigations which were carried out in the course of the first study and using the parameter total score as point of reference, the calculations for the intervention experiment were based on a sample size of $n = 34$ with a power of 80%, α error of 0.05 and an effect size of 0.497 (Schwesig 2006). The sample was $n = 45$, taking into consideration a drop out rate of 30%.

The significant group difference in the parameter body weight was considered to an extent during the statistic evaluation, as this variable was used as co-variant in a general linear model (GLM). Within this univariate, unifactorial covariance analysis, the posturographic parameters (for example stability indicator) acted as dependent variables and the visual impairment (yes vs no was defined) as "firm factor".

The used level of significance $\alpha = 0.05$ was submitted to a Bonferroni correction depending on the number (k) of tests (α/k).

Study 2: visually simulated dysfunctions

Due to a non-normal distribution of data in the second study, the general linear model was not suitable. For that reason the Friedman test was applied. It is a non-parameterized ANOVA. The medians of all results from the test positions (NO–HF) in the frequency ranges F1–F8 and for the stability indicator were compared. It was evaluated whether the medians of a test series (from A to H) were significantly different, in general. The level of significance was $\alpha = 0.05$. In the second step the Conover method was used to find out which specific visual situation (from B to H) showed statistically significant difference compared to the stand position A (normal, eyes open). The method works by comparing the sum of ranks to a critical difference.

Table 4 Body weight adjusted average values (MV) as well as significance examination for all posturo-graphic parameters with GLM

Group	MV	95% Confidence interval		Significance*
		Lower limit	Upper limit	
Dependent variable: F1 (0.03–0.1 Hz) (Part. η^2: 0.091/F: 10.159)				
Visually impaired	15.5	14.2	16.7	0.002
Healthy group	18.4	17.1	19.6	
Dependent variable: F2–4 (0.1–0.5 Hz) (Part. η^2: 0.000/F: 0.025)				
Visually impaired	8.89	8.36	9.42	0.875
Healthy group	8.95	8.42	9.48	
Dependent variable: F5–6 (0.5–1.0 Hz) (Part. η^2: 0.018/F: 1.826)				
Visually impaired	4.16	3.89	4.43	0.180
Healthy group	3.89	3.62	4.16	
Dependent variable: F7–8 (>1.0 Hz) (Part. η^2: 0.012/F: 1.240)				
Visually impaired	0.89	0.83	0.94	0.268
Healthy group	0.84	0.79	0.90	
Dependent variable: ST (Part. η^2: 0.034/F: 3.511)				
Visually impaired	24.9	23.4	26.4	0.064
Healthy group	22.8	21.3	24.3	

df (101; 2; 1), the reported values are mean values of all positions

* Significance level α was adjusted for multiple tests by means of Bonferroni correction (0.05/5 = 0.01)

Results

Study 1: visually handicapped vs healthy subjects

The visually impaired and the normal group differed significantly only in the frequency range F1 of the Fourier spectrum ($p = 0.002$, partial $\eta^2 = 0.091$, Table 4).

Significant differences of the postural stability ($p < 0.001$) between both the groups were found exclusively in the test positions without lids closed (NO and PO, Fig. 2). The healthy group showed a significant loss of stability in the test positions PO and HB, whereas the impaired group showed an increased stability (Fig. 3) due to sufficient somatosensoric processes. The somatosensoric system proved with an empirical variance of 82% (impaired) and 60% (healthy) to be the primary variant for the postural system (test position NO, criterion variable: stability indicator [ST]).

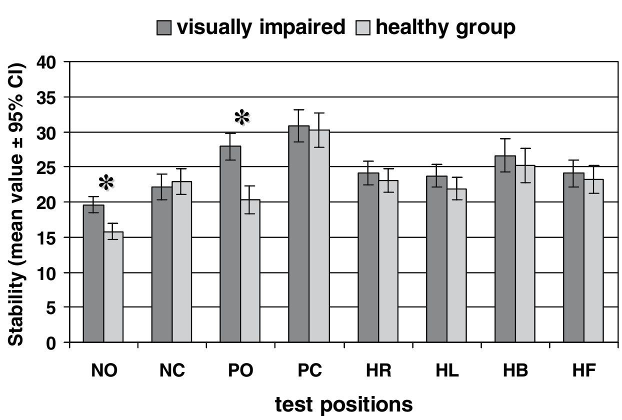

Fig. 2 Postural stability (stability indicator) in the eight test positions. *Significant difference between both groups on the Bonferroni corrected significance level α (0.05/8 = 0.0026)

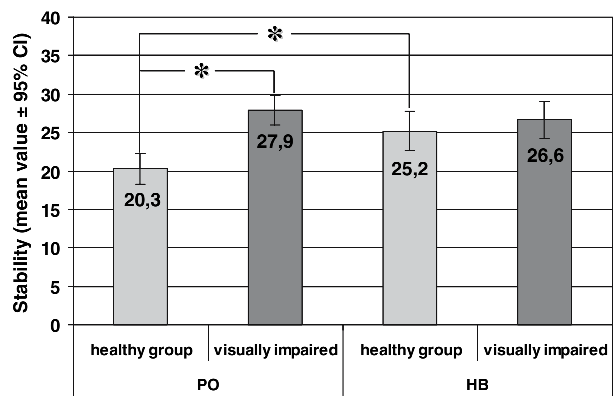

Fig. 3 Comparison of the test positions PO and HB. *Significant difference on the significance level (α = 0.05)

Study 2: visually simulated dysfunctions

The Friedman test showed that diverse visual situations had significant influence on frequency bands F1–F8 and ST in different test positions (NO–HF), (Table 5). The only simulated dysfunctions had an influence on the frequency range F1 (representing the visual system) in the test position NO ($p = 0.005$). This means that in this position with eyes open in a normal stand pose, the result in the frequency analyses showed significantly reduced amplitudes for the frequency range F1 (Fig. 4).

Compared to the standard situation (A) significant differences between the respective visual situations turned out, proven by the Conover method (Figs. 4, 5).

Table 5 Significant posturographic parameters with the Friedmann test in the different frequency bands F1–F8 and the stability indicator in test position NO (normal/eyes open)

Visual situation	Median	Significance (p)
Frequency band F 1 (0.03–0.1 Hz)		
A	18.09	0.005
B, C, D, E, F, G, H	Range 12.84–18.26	
Frequency bands F2–F4 (0.1–0.5 Hz)		
A	5.86	0.006
B, C, D, E, F, G, H	Range 5.67–7.70	
Frequency bands F7–F8 (>1.0 Hz)		
A	0.57	0.003
B, C, D, E, F, G, H	Range 0.59–0.65	
ST		
A	14.59	<0.001
B, C, D, E, F, G, H	Range 14.84–18.09	

The reported values are medians. The normal situation without simulated dysfunction (A) is tested versus all situations with visual simulated dysfunctions (from B to H). The level of significance was $\alpha = 0.05$

The main influence of visual simulations (B–H) was found on the frequency range F1 and on ST. In test position with eyes open (NO), visual situations differed significantly ($p = 0.005$) from the standard situation A concerning frequency range F1. Situations C (smaller measuring distance), D (VA = 20/200), F (pendulum), G (yoke prisms base down) and H (yoke prisms base up) showed significant differences compared to situation A (Fig. 4). The influence of the visual on the postural system is reduced, compared to the standard situation with normal vision.

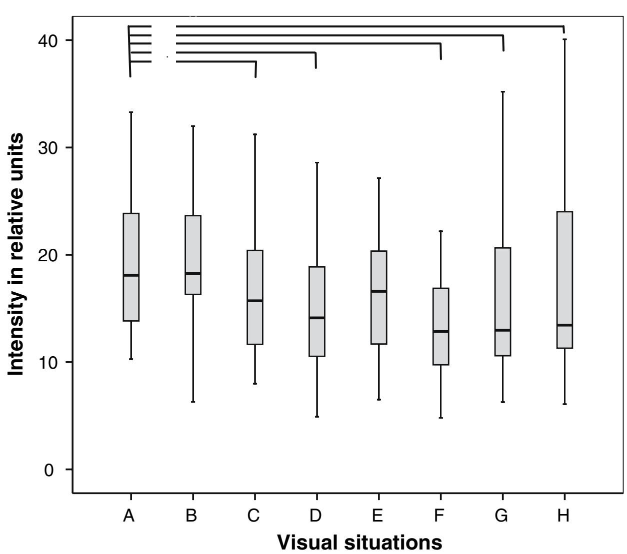

Fig. 4 Comparison of the power proportion (relative units) for the frequency band F1 in the different visual situations (A–H) in the test position with eyes open (NO). Constituted are the medians, the inter-quartile ranges and ranges. *Significant results for different visual situations

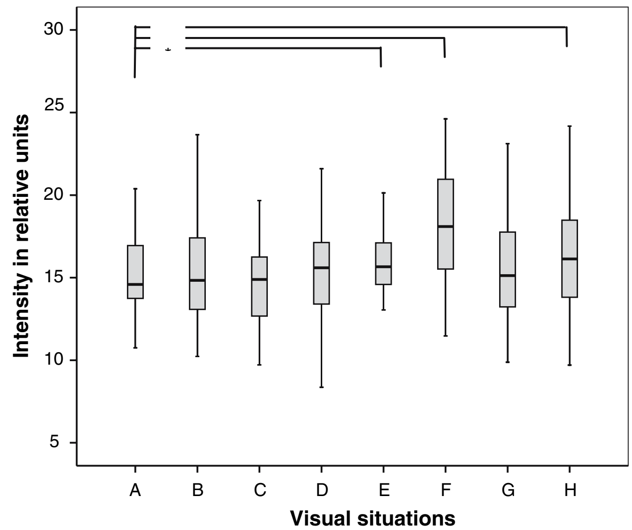

Fig. 5 Comparison of the power proportion (relative units) of the ST in the different visual situations (A–H) in the test position with eyes open (NO). Constituted are the medians, the inter-quartile ranges and ranges. *Significant results for different visual situations

In test position with open eyes (NO), the stability indicator showed significant variance ($p < 0.001$). A loss of stability was significant in situations E (simulated hyperopia), F (pendulum) and G (yoke prisms base down) compared to situation A (Fig. 5).

Decreased visual input due to reduced visual acuity (20/200) scales down the proportion of frequency band F1. In contrast, the proportion of frequency bands F2–F4 ($p = 0.006$) and F7–F8 ($p = 0.003$) increased significantly (Fig. 6).

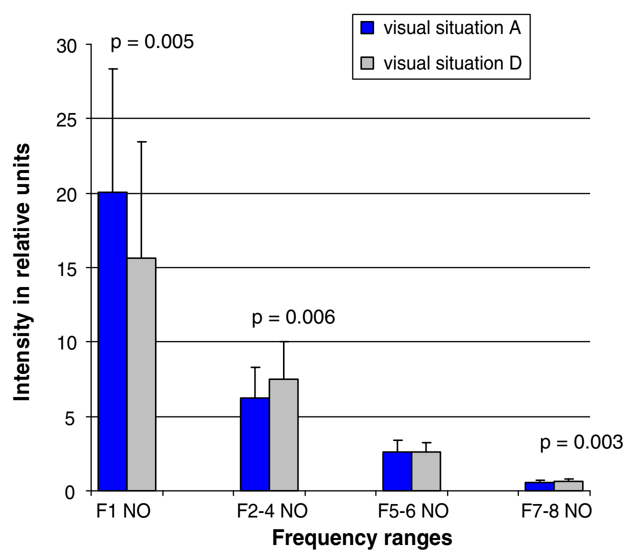

Fig. 6 Significant results for the different frequency bands F1–F8 in the test positions with open eyes (NO) between the visual situations A and D. Constituted are the medians and the standard deviation. The significant differences per series of measurement are marked by the p-value

Discussion

So far, numerous posturographic investigations were described, spotting on the vestibular, the somatosensoric and the cerebellar subsystems (Schwesig 2006). However, investigations on the influence of the visual system were rarely performed. Schwartz et al. (2005) found an increase of postural stability after cataract-operations. Brannan et al. (2003) reported a reduction of the fall frequency of about 80% ($p < 0.001$) after cataract-operations.

The Blue Mountains Eye study showed increased risk of falls with decreased visual acuity, however, there was no linear correlation (Ivers et al. 1998). Other studies have demonstrated that postural stability is caused by contrast sensitivity rather than by visual resolution (Turano et al. 1994; Elliott et al. 1995; Lord and Menz 2000).

The most important result of this investigation is the verification of the frequency range F1 (0.03–0.1 cycles/s) as indicator for the visual system. This can be interpreted from the results of the frequency analysis (Table 4), which showed a significant difference ($p = 0.002$, Part. $\eta^2 = 0.091$) between healthy and visually impaired subjects. The allocation of the frequency range F1 to the visual system is furthermore confirmed by the differentiated frequency-analytic assessment of the individual test positions. It is remarkable that significant differences in the parameters F2–F4, F5–F6 and F7–F8 were found exclusively in the positions without eyes closed (NO and PO). Obviously the visually impaired group compensated its visual deficits with a stronger activation of the other postural subsystems. This success is reflected in the position-specific analysis of the stability indicator (Fig. 2). In this analysis a significant increase of postural instability turned out in the impaired group, only in the positions NO and PO. This can be explained with the dominance of the visual system and the respective advantage of the healthy group. On the other hand the visually impaired group could not use its relevant advantage of compensation of the reduced visual information due to the decreased somatosensoric input in the test conditions of this study (foam mattress).

The inverted results in the comparison of the test positions PO and HB (Fig. 3) are remarkable. Whilst the healthy group exhibited a significant stability loss in the comparison of the test positions PO and HB, the visually impaired group showed an increased stability resulting in a higher stability level in the test position HB than the healthy group. These results can be interpreted as a more efficient integration of somatosensoric information in the central nervous system in the visually impaired group.

It is considered a multisensory reweighting deficit in that there is a failure to “switch” from inaccurate visual information to accurate somatosensory and vestibular information, i.e., to down-weight vision and up-weight somatosensation and vestibular inputs (Allison et al. 2006). Otherwise, Peterka (2002) found that subjects with known bilateral vestibular loss weight vision and proprioceptive cues more highly than do individuals with intact vestibular function. When one sensory channel is downweighted (e.g. vision), it is often thought that other channels (e.g. proprioception, vestibular) may be weighted more heavily (i.e., intermodality reweighting (Ravaioli et al. 2005).

All subjects of the first study had visual impairments. This means that their postural system had months or even years to adopt to this situation. It is questionable, if a short-term simulated visual dysfunction also has an influence on the postural stability in terms of intermodality reweighting? To investigate this relation the IBS was used in a second study to examine healthy subjects with simulated visual dysfunctions. In common with previous investigations (Turano et al. 1994; Elliott et al. 1995; Ivers et al. 1998; Lord and Menz 2000; Brooke-Wavell et al. 2002; Eto 2005; Poulain and Giraudet 2007) it was shown that visual dysfunctions like reduced contrast sensitivity or poor visual conditions like darkness reduce the postural stability and influence the interaction of the visual and the vestibular system (Deshpande and Patla 2007; Liu et al. 2007).

The second study with simulated visual dysfunctions also showed some remarkable results. In test situation D, the visual acuity (VA) was reduced to 20/200 by occlusion. Because of a reduced value of F1 in that situation, it seems that a simulated ametropia has an important influence on the postural control. In different investigations it was found out that the visual system is an important source of information to control postural regulation and stand stability (Previc and Mullen 1990; Bronstein and Buckwell 1997; Kuno et al. 1999; Fushiki et al. 2005; Glasauer et al. 2005). Peripheral vision captures spatial orientation and is co-responsible for the regulation of a stable stand (Gautier et al. 2007; Santangelo and Spenec 2007; Sally and Gurnsey 2007). Former studies indicate that the body sway is more reduced by the stimulation of the peripheral instead of the central visual field (Kawakita et al. 2000; Jendrusch and Brach 2003; Berencsi et al. 2005). In this investigation the central and peripheral vision was reduced by an occlusion (situation D). The decreased amount of F1 showed that the occlusion had an influence on the visual system. As the frequency band F1 is standing for the visual system in general, no determination between the central and peripheral vision is possible. This study could not decide if the deterioration of central or peripheral vision is responsible for the reduction of F1. Discussing the results under the aspect of Berencsi's findings (Berencsi et al. 2005), the peripheral deterioration of vision could have caused the reduction of the visual input to the postural system.

If the central vision would control the main part of the postural regulation, micro movements of the eyes would have a negative effect on the visual input for the postural stability. This should be mapped in smaller amplitudes for F1 and was measured like that in this study (situation D). Saccadic suppression is an argument against the influence of micro movements. During a saccade there is no perception. If the central vision would have an influence on the postural stability, this should result in a higher postural sway (stability indicator). In this study it was not the case (Fig. 5). Thus the theory "the peripheral vision is responsible for spatial orientation and the stability of mass" is supported. The results of situation C are also hints for that. In that situation a shorter measurement distance was used. A significantly decreased amplitude was shown. It can be assumed that the relatively large white board with the fixation target in short distance to the subject blocked peripheral vision and hindered spatial orientation.

In situation F, controversial to all other situations a moving fixation object was presented. The amplitude of F1 in that situation was the least of all. To fixate the moving object, following eye movements are necessary. It could be assumed that a stable perceived object is important for stabilisation of the centre of gravity. This is not the case with the pendulum (situation F). For the fovea, the fixated pendulum remains still, while the peripherally perceived environment is moving. When interpreting the findings showed in situation F, it seems that the always-changing shaky pictures of the environment cannot be used meaningfully for the postural stability. Moving objects instead of unmoving objects cause a reduced visual feedback for a stable stand. The frequency of the moving object seems to be important. The findings of this investigation correspond with the results of other authors (Ravaioli et al. 2005; Jeka et al. 2006; Bobrova et al. 2007) that a moving object with a frequency of more than 0.1 Hz causes stronger movements in the frontal plane of the body.

No statistical difference was shown for situation E (simulated hyperopia) compared to the standard situation, where the subjects had to accommodate to see the fixation object clearly. Obviously the subjects were able to accommodate sufficiently to see the blurred object clearly while the measurement period is 32 s. It cannot be predicted that all subjects really had a clear perception through the whole measuring time. A change between "clear" and "unclear" could have been possible. Nevertheless no negative influence on the information coming from the visual system to the postural regulation was found (no change in F1 compared to situation A). Surprisingly, with accommodation, a higher sway resulted. Obviously accommodation is increasing the instability (higher value of the stability indicator) (Fig. 5).

Applying yoke prisms changes the perception. These prisms (2–4 cm/m) with equal base were introduced to have an influence on the head and body posture (Padula et al. 1994; Kaplan and Carmody 1997; Weissberg et al. 2000; Kapoor and Ciuffreda 2002). The results of this study support this statement. The habitual perception obviously was changed by yoke prisms shown by reduced amplitudes for F1.

Discussing postural regulation, not only the frequency range F1 is of interest. There are also changes in other frequency bands. In this study, decreased amplitude of F1 (visual system) and increased amplitudes in the other frequency bands (F2–F8) were found in the situation with a simulated, reduced visual acuity (Fig. 6). Simulated visual dysfunctions not only have an influence on the visual input of the postural system. They also influence the other subsystems of postural control (vestibular, somatosensory and cerelellar). There is probably a nonlinear correlation between the different subsystems depending on different tasks, vision and movement conditions (Ravaioli et al. 2005; Horak 2006; Liu et al. 2007).

Conclusion

The visual system can be validly illustrated in the frequency range F1 (0.03–0.1 Hz) of the Fourier analysis. So it seems to be a measure for quality of visual feedback in the postural system.

Visually impaired subjects can compensate their visual information deficit by an improved peripheral–vestibular and somatosensoric perception as well as cerebellar processing. This investigation confirms the conclusion, according to which an adequate postural control is considerably depending on the integration of visual, vestibular and somatosensoric information. In case of failure or reduction of a postural subsystem, compensation mechanisms immediately become effective which are posturographically (frequency-analytically) parameterizable and quantifiable.

Stability regulation can be understood as a multi sensoric process by the visual, vestibular, somatosensoric and cerebellar system. Reduced influence of the visual system is compensated by the other subsystems. Moreover, the body sway increased in this situation, represented by the stability indicator. Obviously the main part of reduced visual input is balanced by the vestibular system. Simulated visual dysfunctions reduce the amplitudes of F1 and diminish stand stability.

The IBS is a valid, reliable and practicable assessment tool for specification of sensomotoric intervention effects.

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