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VISUAL CONTRAST THRESHOLDS DURING SINGLE-AXIS AND DUAL-AXIS WHOLE-BODY VIBRATIONS (5 HZ, 1.2 MS^{-2})

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ABSTRACT

The hypothesis was proved that whole body vibrations transmitted through the seat impair spatial retinal resolution and oculomotor alignment parallel to the vibration axis. More specifically, it was assumed that the decrement increases gradually from single-axis lateral via single-axis vertical and dual-axis linear to dual-axis circular motions.

20 subjects (19-26 yrs, 14 men, 6 women) with good vision participated in the study where in separate experimental sessions either fixation disparity or contrast threshold for vertically and horizontally oriented test patterns were determined during 5 conditions. The latter comprized a control ($a_z = a_y = 0$) and 4 conditions where 5 Hz sinusoidal vibrations of 1.2 ms^{-2} r.m.s. were applied separately, either in the vertical or in the lateral direction or simultaneously in both directions, once without and once with a phase shift of 90° thus causing dual-axis linear or circular motions.

The variability of vertical fixation disparity and contrast thresholds for horizontal gratings increased significantly whenever the subjects were exposed to vertical motions (alone or combined with lateral motions). These results indicate an increased difficulty to recognize properly characters and graphic patterns that contain horizontal lines. This may lead to the development of asthenopic complaints.

1 INTRODUCTION AND OBJECTIVES

Visual performance may be degraded if a display and an observer move relatively to each other. Meddick and Griffin (1976) reported that circular motions of a display cause greater decrements than either vertical or lateral motions. Whether this applies as well to the opposite situation where the observer moves and the display is stationary was studied in the present experiment where 5 Hz sinusoidal motions of 1.2 ms^{-2} r.m.s. were applied separately in the vertical or in the lateral direction or simultaneously in both directions with phase shifts of 0° or 90° thus producing dual-axis linear or circular motions, respectively. Taking in account extended studies on the transmissibility of vibrations from the seat to the head (Paddan & Griffin 1988a, b) the least decrements of visual performance were expected for single-axis lateral motions, the greatest for dual-axis circular motions.

2 MATERIAL, METHODS AND EXPERIMENTAL DESIGN

Technical equipment and environmental conditions: Vertical and lateral motions were transmitted to an aluminium platform on which a slightly contoured rigid metal seat with a short backrest was mounted. A 17“ monitor in front of the seat was adjusted to the head level of the subjects and used for the visual tasks. The distance between the screen and the prolongation of the seat tube was 3.2 m. Air temperature was 23 ± 0.1°C, velocity 0.2 ± 0.05 m/s; humidity varied between 40 and 50 %.

Vibration measurements: Translational vibrations in the 3 orthogonal axes were measured during each task between seat and ischial tuberosities according to ISO 2631 and at the scull-pan where the accelerometers were fixed with bands (pressure ≈ 7 N/3 cm^2). Unweighted tri-axial background accelerations were < 0.1 ms^{-2} r.m.s. at the seat, its frequency weighted magnitudes were < 0.02 ms^{-2} r.m.s.. Acceleration distortions of the 5 Hz sinusoidal motions varied from 7 to 10 % or 17 to 23 % for vertical or horizontal vibrations, respectively.

Visual tasks: According to the 2 vibration axes each test was applied with 2 perpendicular orientations either vertically or horizontally using a PC-controlled conventional VDU screen. The central quadratic area (21 x 21 cm^2) of the screen was surrounded by a quadratic white card board (1.1 x 1.1 m^2) that was illuminated by halogen luminaires to about 7 cd/m^2. The test room had a mean illumination of 2 lx. Each test lasted about 3 to 4 minutes.

Fixation disparity: Binocular vision is optimal when a fixated target is imaged onto the center of the fovea in each eye, so that the principle visual directions intersect at the fixation point. But even subjects with normal binocular vision may have slight deviations from this state, typically a few minutes of arc. This is measured using a test where 2 visual test targets (nonius bars) are presented dichoptically, i.e. separately, one to each eye.

The subject observes a CRT monitor, wearing a spectacle frame with perpendicular polarizing filters. The screen is divided into three parts. The central part is visible to both eyes and includes the fusion stimulus, i.e. the letters XOX. Above and below the central character O are the two vertical nonius bars. As the upper and the lower areas of the screen are covered by perpendicular polarizing foils the upper nonius bar is only visible to the right and the lower bar only to the left eye. The nonius bars are presented as bright lines on a dark background in a series of 100 short exposures (100 ms) with 2 s intervals. While the fusion stimulus remains stationary, the amount of the horizontal distances between both nonius bars (offset) is varied in small steps. After each presentation the subject responds to whether the upper nonius bar was perceived to the right or to the left of the lower nonius bar. Using probit analysis a sigmoidal psychometric function is calculated from these data. The 50%-point corresponds to the offset at which the nonius targets are perceived to be vertically aligned and represents the mean fixation disparity. There is no offset in case of optimal binocular vision (the nonius bars are physically and subjectively aligned), fixation disparity is indicated by a physical offset though the nonius bars are perceived in line. The slope of the function quantifies the temporal variability of fixation disparity. The probability that the instantaneous fixation disparity will be within one standard deviation is 68 % (labelled as variability). To measure the vertical fixation disparity the test was changed to have horizontal nonius lines.

Contrast threshold was measured with a quadratic grating pattern (4 x 4 deg) with stripes in either horizontal (y-axis) or vertical orientation (z-axis). For the vertical grating the luminance profile varies sinusoidally along the horizontal axis but remains constant in the vertical direction. The parameters of the grating are the contrast and the spatial frequency which is the number of grating cycles per degree of visual angle. Only one spacial frequency was applied in the present study, namely 13.3 and 10.3 cycles/deg for vertical and horizontal gratings, respectively. The difference resulted from a computer error.

The Békésy tracking method was used to find the contrast threshold. Initially, at zero contrast, the screen is blank. The contrast of the grating is then continuously increased. As soon as it becomes visible the subject presses a button which causes the contrast to decrease. The button is pressed until the grating just disappears, whereafter the contrast increases again and so on. The first 5 contrast reversals were discarded and the median of the last 25 reversals for appearance was taken for the threshold and used for statistical calculations.

Design and procedure: The experimental sessions were preceded by a training session which served to familiarize the subjects with the procedure, the vibrations and their tasks. Individual viewing distances which varied due to a slightly kyphotic posture were then measured and readjusted in the following experimental sessions.

Fixation disparity and contrast threshold were measured in separate experimental sessions on different days. Each session started with the appropriate 2 task orientations without vibration stress. They were followed by 10 different tests (2 orientations, 5 experimental conditions) which were systematically permuted so that each test occurred equally often in each position. The 5 experimental conditions comprized a control ($a_z = a_y = 0$) and 4 conditions where 5 Hz sinusoidal motions of 1.2 ms^{-2} r.m.s. were applied separately, either in the vertical or in the lateral direction or simultaneously in both directions, once without and once with a phase shift of 90° thus causing dual-axis linear (yz0: right down to left up) or circular motions (yz90: anticlockwise).

Vibrations started after a rest period of 3 minutes with an acceleration of 1.2 ms^{-2} r.m.s. during the entire test period of 3 to 4 minutes. The additional rise-decay times were 2 seconds. The visual tasks started 3 seconds after vibration onsets.

Subjects: 20 subjects (14 men, 6 women, 19-26 yrs) with good monocular and binocular vision participated in the experiments, which were approved by the local ethic committee. Medical contra-indications and safety aspects listed in ISO/DIS 13090-1 were taken into account.

Statistics: A repeated measurement analysis of variance and the Friedman test were computed for each task. Differences to the control condition (no vibration) were examined by calculating the respective contrasts. Correlations were calculated between the accelerations measured at the scullpan and the parameters of the visual tasks.

3 RESULTS AND DISCUSSION

3.1 Visual tasks during the control situation

Due to the number of experimental situations the determination of contrast thresholds was restricted to a single spatial frequency, which is - according to Moseley and Griffin (1987) - sensitive to the influence of vibrations. Slight esophoric fixation disparities as determined during the control situation were expected as they are typical for long viewing distances (Jaschinski 1997).

3.2 Visual performance during the sessions, sequence

The slightly kyphotic posture of the subjects caused some interindividually varying viewing distances (308 - 322 cm) which proofed to have no significant influence on the results ($p > 0.05$).

The 10 various tests (2 task orientations, 5 experimental conditions) were equally distributed over the sessions. The sequence was regarded in the analysis but proofed to be significant for none of the tasks ($p > 0.05$), meaning that neither learning nor fatigue had occurred. Following Moseley and Griffin (1987) fatigue was probably avoided by the intermittent short-term exposures achieved by alternating short tasks and pauses. Whereas fixation disparity was reported to remain constant during experimental sessions (Jaschinski-Kruza 1993) controversial reports exist on learning effects for contrast thresholds. Davies and Griffin (1989) who used the method of increasing contrasts registered gradually decreasing thresholds over 5 sessions, where Methling and Jaschinski (1996) who applied the same technique used here found no improvements over 5 sessions.

3.3 Biomechanical behavior

Vibrations of the eye-balls were assumed to impair oculomotor alignment and to degrade spatial vision by blurring the retinal image. Vertical motions were assumed to impair the alignment and spatial resolution of horizontal lines, while lateral vibrations impair the alignment and the spatial resolution of vertical lines. A simple relation, however, was not expected as several authors have shown that any, even single-axis seat motions evoke complex translational and rotational motions of the head and of the eyes in the 3 orthogonal axes (e.g. Hartung 1982, Paddan & Griffin 1988a,b).

As actually available methods are not suitable for the routinely registration of eye motions, translational vibrations in the 3 orthogonal axes were measured at the scullpan during visual tasks. According to figure 1 vertical seat motions were most decisive. Whether applied separately or simultaneously with lateral motions of the same frequency and magnitude, the accelerations at the head were always the same. Related to seat accelerations (transmission, seat-to-head ratio) vertical motions were reduced at the head (≈ 0.7) but coupled with horizontal motions. Cross-axis coupling was greatest for fore-and-aft motions (≈ 1.9), lateral motions were similar as during single-axis lateral seat vibrations (≈ 0.5).

The transmission of vertical accelerations seems to contradict other studies where the respective ratios exceeded unity (Paddan & Griffin 1988a). But Paddan and Griffin (1996) have shown that vertical accelerations increase considerably from the back towards the front of the head. This justifies the assumption that vertical accelerations near the eyes are much greater and most likely greater than at the seat. Additionally, vertical seat motions caused strong fore-and-aft motions of the head (≈ 1.9) and moderate lateral motions were rather low but still as large as during lateral seat motions (≈ 0.5). Similar cross-axis couplings were already described by Paddan and Griffin (1988a,b).

When separately applied, lateral seat motions were attenuated (ratio: 0.6). They neither caused cross-axis coupling nor contributed to vertical motions during simultaneous presentation.

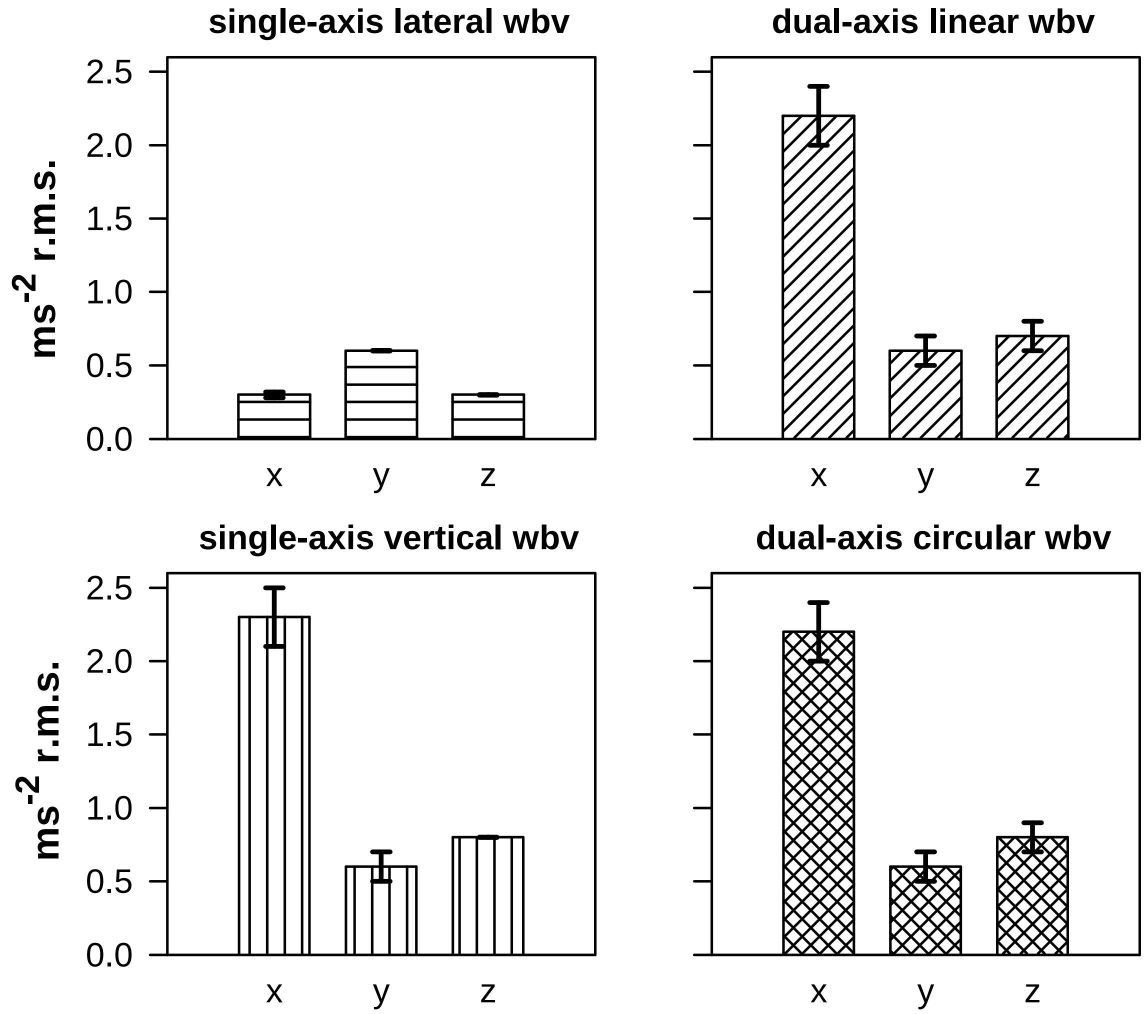

Figure 1: Accelerations at the scullpan (means and standard errors) and sinusoidal whole-body vibrations (y: lateral motions, z: vertical, yz: dual-axis motions [0: linear, 90: circular]).

So, the 4 vibration conditions at the seat were virtually reduced to 2 conditions at the head determined by the presence and absence of vertical motions (figure 1).

3.4 Vibration conditions, decrements of visual performance and their significance

As the resonance frequencies of the eyeballs range from 20 to 25 Hz (Hartung 1982), the motions of the scullpan and of the eyeballs are probably similar if the seat vibrates sinusoidally with 5 Hz. Accordingly, the motions of the eyeballs must be greater in the vertical than in the lateral direction. But due to their anatomical features, their size, and weight, the surrounding tissue etc. their motions must differ to some extent, which is more important for the oculomotor alignment than for contrast thresholds.

According to the biomechanical behavior contrast thresholds for horizontal gratings and the variability of vertical fixation disparity increased whenever the subjects were exposed to vertical vibrations alone or simultaneously with lateral motions. Compared to the control situation the values increased significantly during single-axis vertical, dual-axis linear, and circular motions and these effects were significant on the 1 %-level (fig. 2, $p < 0.003$, $p < 0.018$). Lateral vibrations, however, neither contributed to vertical vibrations nor affected visual performance if applied separately. The greater significance of vertical motions is supported by

Lewis and Griffin (1980a,b) who observed a decrement of reading performance during whole-body vibrations.

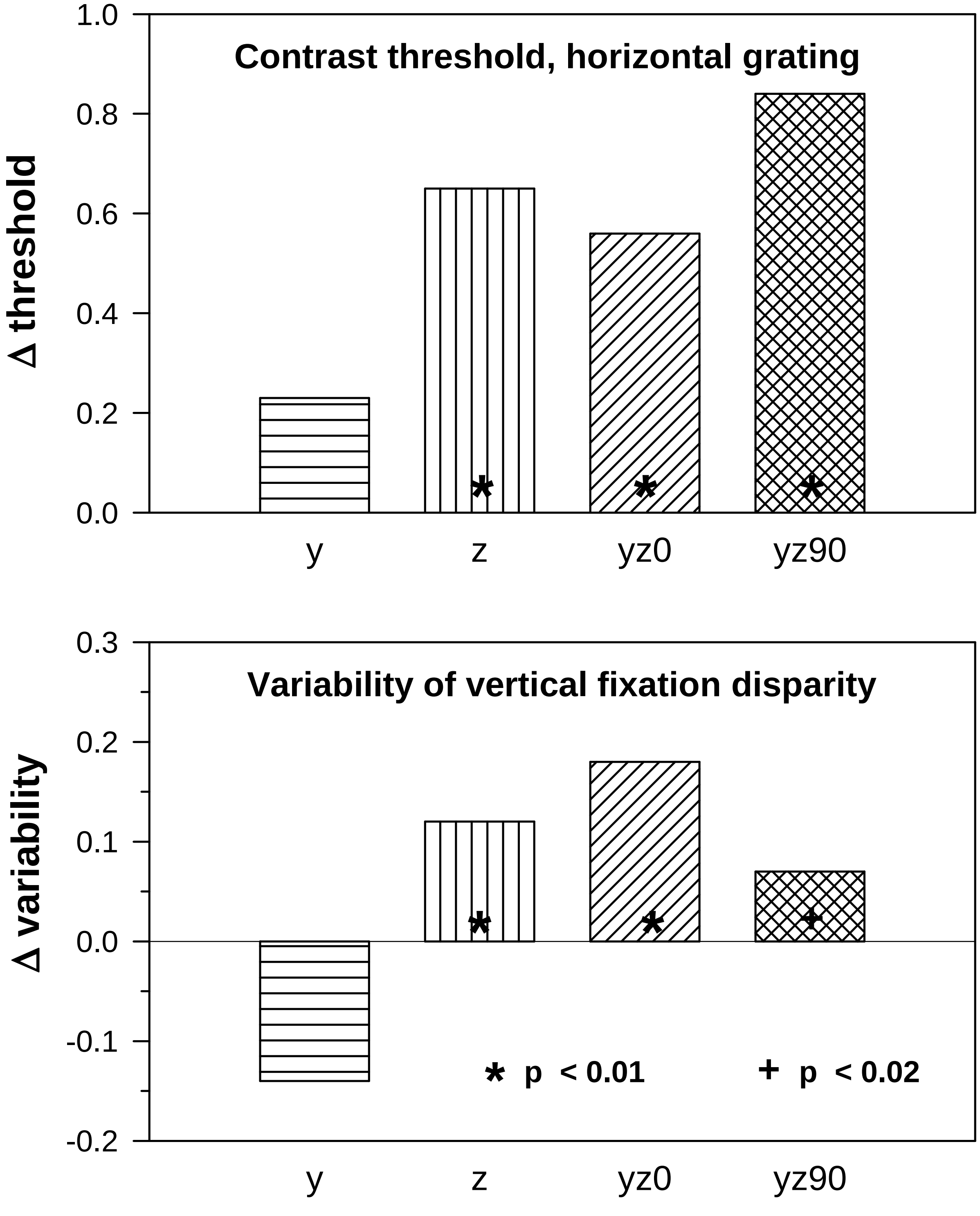

Figure 3: Mean differences between vibrations and control condi-tions of contrast thresholds for horizontal gratings and variability of vertical fixation disparity (y: lateral, z: vertical, yz: dual-axis motions [0: linear, 90: circular],* $p < 0.01$, + $p < 0.02$ for contrast to control).

Unimpaired mean fixation disparity indicates that the ability of binocular vision was not affected by vibrations. This confirms the results of Hartung (1982) who failed to determine an effect on stereovision.

The effects on the variability of vertical fixation disparity suggests that the vertical alignment between the two eyes was more variable and unstable, whenever vertical vibrations were applied. This evidently greater difficulty to align the eyes is plausible since the motions of both eyes are - as explained above - not necessarily the same.

The effects on contrast thresholds which are supported by Moseley and Griffin (1987) indicate that exposure to vertical vibrations make it more difficult to recognize properly characters and graphic patterns with high spatial complexity in the vertical axis (horizontal lines) where the vertical oscillations of the retinal image cause frequent overlappings of bright and dark horizontal bars and thereby a blur of the target image.

Table 1 presents the correlation coefficients between the results of the visual tasks and simultaneously registered translational motions at the scullpan. Significance (p<0.02) was determined only between vertical head motions and contrast thresholds for horizontal gratings. Subjects with greater vertical head motions revealed greater decrements of contrast thresholds. But there was no correlation with the variability of vertical fixation disparity.

Increased contrast thresholds correspond to an equivalent decrease in visual acuity of 6 %. The overall rather small effects in this study are probably related to the following facts.

Frequency: The foveal image is stabilized to some degree by the visually driven pursuit reflex and by the vestibulo-ocular reflex (Barnes 1983).

Viewing distance: Lewis and Griffin (1980b) have shown that the movements of the retinal image due to translational head motions are rather negligible above about 1 meter. The distance chosen here was about 3 m and applies to many working conditions.

Table 1: Correlations between visual tasks and vibration accelerations during 5 experimental conditions ($^+$/* p ≤ 2/1 %)

	Vibrations at the scullpan					
	fore & aft	lateral	vertical	fore & aft	lateral	vertical
Vibration conditions at the seat	Contrast thresholds					
	vertical grating			horizontal grating		
Lateral (y)	-0.01	-0.01	0.10	-0.06	0.12	0.45
Vertical (z)	0.31	-0.13	0.24	0.00	0.21	0.54$^+$
Dual-axis, linear	0.07	-0.27	-0.09	-0.12	0.07	0.68*
Dual-axis, circular	0.15	-0.38	0.09	-0.09	-0.07	0.54$^+$
	Fixation disparity					
	horizontal			vertical		
Lateral (y)	0.32	-0.33	0.11	0.18	0.13	-0.13
Vertical (z)	-0.10	0.58*	0.15	0.00	0.16	-0.27
Dual-axis, linear	-0.19	0.52	-0.12	-0.08	0.49	-0.12
Dual-axis, circular	-0.19	-0.19	0.33	-0.15	0.41	-0.15

Backrest: Backrests usually force the transmission of vibrations particularly of higher frequencies and this effect increases with the height of the backrest. So, the effect of the short lumbar support used in this study was certainly rather small.

Binocular vision: Regarding contrast thresholds the effects might have been greater if one eye would have been occluded as in the study executed by Moseley and Griffin (1986, 1987). So, there might be some compensation due to binocular vision which is undoubtedly a more realistic situation.

4 CONCLUSION

In this study visual performance was solely affected by vertical vibrations, where concomitant lateral motions of the same frequency and magnitude did not contribute to. The increased threshold for horizontal gratings indicate a reduced ability to recognize properly characters and graphic patterns of high vertical complexity. Additionally, the vertical vibrations make it more difficult to stabilize the binocular vertical alignment which can lead to asthenopic complaints (Mallett 1974, Pickwell 1989).

5 REFERENCES

1. Barnes GR, 1983: Physiology of visuo-vestibular interactions: discussion paper. J Roy Soc Med 76:747-754
2. Davies AD, Griffin MJ, 1989: Modelling the effects of vibration on visual performance. ISVR Technical Report 171
3. Hartung E, 1982: Beeinflussung der visuellen Leistung des Menschen unter Einwirkung mechanischer Schwingungen. [Doctoral thesis, Bremen 1982]
4. ISO 13090-1, 1996: Mechanical vibration and shock - Guide to the safety of tests and experiments with people - Part 1: Exposure to mechanical vibration and repeated shock
5. Jaschinski W, 1997: Fixation disparity and accommodation as a function of viewing distance and prism load. Ophthal Physiol Opt (in press)
6. Jaschinski-Kruza W, 1993: Precision of convergence of the eyes while viewing a visual display unit. In: Luczak H, Çakir A, Çakir G (eds): Work with display units 92. [Elsevier Science Publishers BV]
7. Lewis CH, Griffin MJ, 1980a: Predicting the effects of vertical vibration frequency, combinations of frequencies and viewing distance on the reading of numeric displays. J Sound Vib 70:355-377
8. Lewis CH, Griffin MJ, 1980b: Predicting the effects of vibration frequency and axis, and seating conditions on the reading of numeric displays. Ergonomics 23:485-501
9. Mallett RFJ, 1974: Fixation disparity - its genesis and relation to asthenopia. Ophthal Optician 14:1159-1168.
10. Meddick RDL, Griffin MJ, 1976: The effect of two-axis vibration on the legibility of reading material. Ergonomics 19:21-33
11. Methling D, Jaschinski W, 1996: Contrast sensitivity after wearing prisms to correct for heterophoria. Ophthal Physiol Opt 16:211-215
12. Moseley MJ, Griffin MJ, 1986: Effects of display vibration and whole-body vibration on visual performance. Ergonomics 29:977-983
13. Moseley MJ, Griffin MJ, 1987: Whole-body vibration and visual performance: an examination of spatial filtering and time-dependency. Ergonomics 30:613-626
14. Paddan GS, Griffin MJ, 1988a: The transmission of translational seat vibration to the head - I. vertical seat vibration. J Biomechanics 21:191-197
15. Paddan GS, Griffin MJ, 1988b: The transmission of translational seat vibration to the head - II. horizontal seat vibration. J Biomechanics 21:199-206
16. Paddan GS, Griffin MJ, 1996: Transmission of mechanical vibration through the human body to the head. ISVR Technical Report No 260
17. Pickwell D, 1989: Binocular Vision Anomalies: Investigation and Treatment. Butterworth, London, UK