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A DESIGN GUIDE FOR VISUAL DISPLAYS AND MANUAL TASKS IN VIBRATION ENVIRONMENTS

PART I: VISUAL DISPLAYS

M.J. Moseley
M.J. Griffin

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A DESIGN GUIDE FOR VISUAL DISPLAYS AND MANUAL TASKS IN VIBRATION ENVIRONMENTS

PART I: VISUAL DISPLAYS

by

M J Moseley and M J Griffin

Human Factors Research Unit
Institute of Sound and Vibration Research
University of Southampton
Southampton SO9 5NH, England

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SUMMARY

Design guidance relevant to the effects of vibration on visual tasks is provided. The information shows how effects are related to characteristics of the vibration, the display and other aspects of the environment. Published experimental studies are used as the basis of a series of design recommendations which may be used to minimise the influence of vibration on visual tasks.

CONTENTS

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1. GENERAL INTRODUCTION

This part of the guide indicates how, and to what extent, vibration degrades the performance of visual tasks. The guide is subdivided into five sections. Section 1 defines the scope of the guide and Section 2 provides an overview of the transmission of vibration from a seat input to the eye of an observer. The third section of the guide summarises the influence of vibration variables upon performance. In the fourth section, display parameters and their influence on visual performance during vibration-degraded viewing conditions are discussed. The final section provides a list of selected references and further information.

Part II of this guide provides similar guidance for manual tasks to be performed in vibration environments (see McLeod and Griffin, 1986).

The guide is based on published experimental studies of the effects of vibration on performance. Some of the experimental data were obtained for the purpose of formulating the guide during a research program conducted over a 10 year period at the University of Southampton (see Griffin et al, 1986).

1.1 Scope of the Guide

This guide concerns tasks in which a seated operator performs a visual task (eg reading from a display) whilst exposed to translational whole-body vibration. Vibration will usually enter the body through the seat and backrest, but additional inputs from the footrest and controls can also occur. (A recommended procedure for measuring and reporting human whole-body vibration exposures is given in the current British Standard (BSI, 1986)).

The variables associated with the effects of vibration on display legibility and visual performance are categorised as follows:-

(i) The vibration stimulus Section 3 summarises the effects of variables associated with vibration (eg frequency, waveform and axis) on visual performance. Visual performance tasks have generally been restricted to those likely to occur within an operational environment (eg alphanumeric reading). However, where data from such tasks are inadequate or unavailable, data derived from more fundamental measures of visual performance (eg grating acuity) are presented.

(ii) Display parameters and legibility   Section 4 describes the variables associated with the presentation of visual information on a display. Several guides that are currently available provide recommendations for parameters such as character size, contrast and symbol definition for displays viewed in static environments (eg. Helander and Rupp, 1984). However, there are no comprehensive guidelines available to assist the designer in specifying parameters for displays viewed in vibration environments. The aim of this section is to provide recommendations which will optimise legibility when viewing conditions might be degraded by vibration.

1.2 Mechanisms

The mechanism by which vibration degrades vision is predominantly the direct movement of the retinal image. In many cases vibration transmitted to the eye or the display results in a blurring of the target image. In addition, image movement (particularly at low frequencies) can produce a perceived overlap of adjacent symbology which may contribute to the perceptual difficulties experienced by the observer.

2. BIODYNAMIC RESPONSE TO WHOLE-BODY VIBRATION

2.1 The Transmission of Vibration from Seat to Head

Vibration input to a seated observer may occur in any of the three translational (x-, y-, z-) axes or three rotational (roll, pitch, yaw) axes. In most operational environments the motion present at the seat interface will be a combination of vibration inputs occurring in more than one axis. The predominant motion will, however, often occur in the vertical (z-) axis. The frequency dependence and other variables known to influence vertical seat-to-head transmissibility are shown in Table 1.

Information concerning head motion in other translational and rotational axes and the effects of seat excitation in other axes may be obtained from the references in Section 5.

2.2 The Transmission of Vibration from Head to Eye

The manner in which vibration is transmitted from the head to the eye of an observer is a function of both simple mechanical transmission and of active physiological control. Head motions in rotational axes have been shown to elicit rotational eye motion due to stimulation of the vestibular system (see Barnes, 1980). These eye movements may be termed 'compensatory' in that they act to reduce image motion arising from movement of the head. Such reflex eye movements are active up to frequencies of approximately 20 Hz and may be highly beneficial to vision when viewing distant images. If the head motion is predominantly translational the vestibulo-ocular reflex is of little value, although some compensatory eye motion may arise from stimulation of otolithic and other non-vestibular proprioceptors. At high frequencies, above approximately 20 Hz, the vestibulo-ocular reflex is ineffective and, in this frequency region, eye resonance may occur.

<table>
<tr><th>Approximate Frequency Range</th><th>Transmissibility</th><th>Variables Influencing Transmission</th></tr>
<tr><td>Below 2 Hz</td><td>~ Unity - no significant body resonances</td><td rowspan="3">Posture seating conditions, head position, headware(eg helmets) and the physical characteristics of subjects have all been shown to influence transmissibility.</td></tr>
<tr><td>2 to 10 Hz</td><td>Frequency region of greatest transmission of vibration due to major body resonances</td></tr>
<tr><td>10 to 20 Hz</td><td>Secondary resonances may occur</td></tr>
<tr><td>Above 20 Hz</td><td>Attenuation of vibration by body structures will reduce translational vibration to less than unity</td><td></td></tr>
</table>

Table 1: The transmission of vertical vibration from seat to head.

In addition to eye motion arising directly or indirectly from vibration of the head, the observer may actively pursue a moving object (the pursuit tracking reflex). This mechanism will be most effective at low frequencies (< 2 Hz) above which tracking accuracy rapidly declines.

3 THE VIBRATION ENVIRONMENT

3.1 Vibration Frequency and Axis

3.1.1 The vertical (z-) axis

The typical frequency dependence of the effects of sinusoidal whole-body vibration on reading performance is illustrated in Figure 1. These data were obtained from three separate experiments and are presented as equal performance contours in the frequency range 2.5 to 63 Hz. The visual task consisted of reading arrays of small numerals subtending 5 min arc (1.1 mm at 0.75 metres). The displays were not vibrated. Subjects sat restrained on a rigid flat seat with backrest and moving footrest. This seat was geometrically similar to that found in a Sea King helicopter. <u>The frequency region in which sensitivity to vibration acceleration is greatest is approximately 5 to 11 Hz</u>. An extension of the observed frequency dependence down to 0.5 Hz is provided in Section 3.3 for whole-body, display and simultaneous whole-body and display vibration.

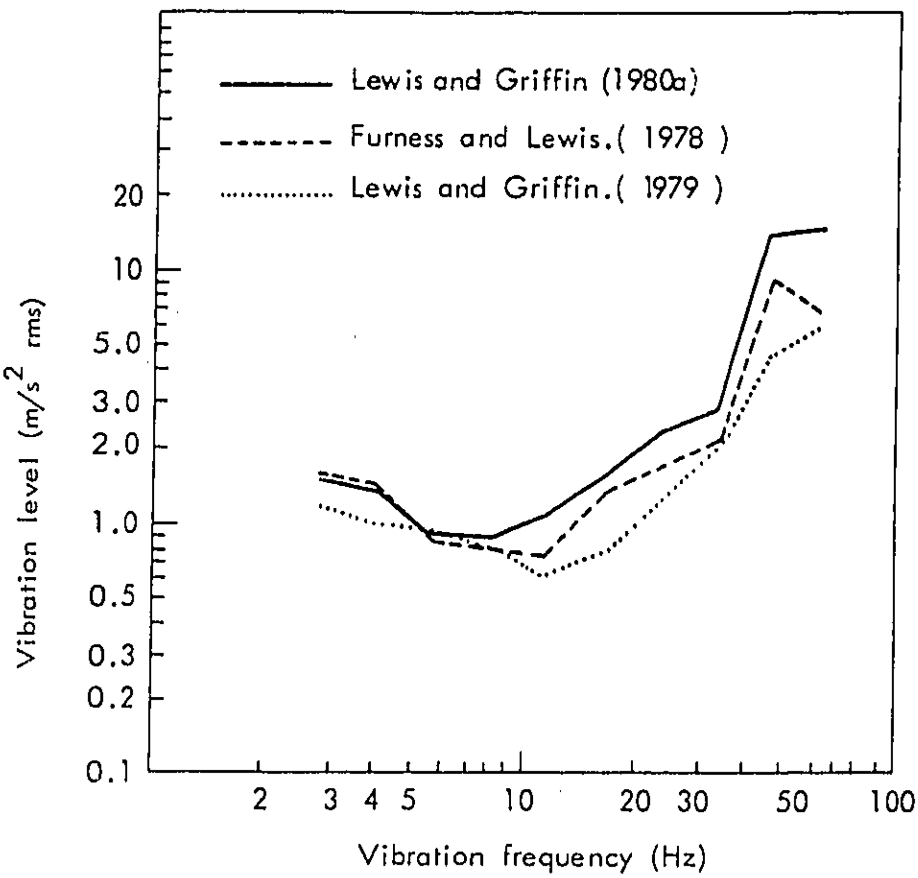

Figure 1: 20% mean reading error contours illustrating an effect of vibration frequency on visual performance during vertical (z-axis) vibration. (After Lewis and Griffin, 1980a).

3.1.2 The fore-and-aft (x-) axis

The equal performance contours shown in Figure 2 illustrate the effect of vibration frequency for whole-body fore-and-aft (x-) axis motion. These data were obtained using a simulated helicopter seat with a backrest and similar viewing conditions to those described in Section 3.1.1. The frequency range extends from 2.8 to 31.5 Hz. Maximum sensitivity to vibration acceleration occurred at 5.6 Hz. (Contact with a backrest has a large influence on the effect of fore-and-aft vibration on vision (see Section 3.4)).

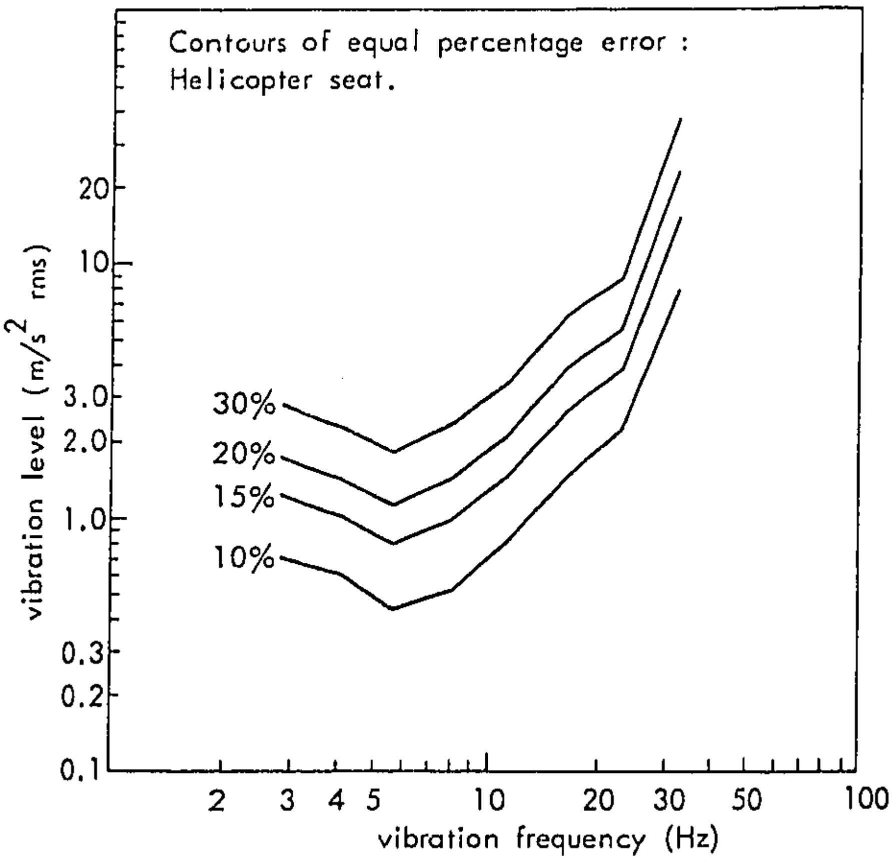

Figure 2: Equal performance contours illustrating the effect of vibration frequency on visual performance during fore-and-aft (x-axis) vibration. (After Lewis and Griffin, 1980a).

3.1.3 The lateral (y-) axis

The largest reported error during a numeral reading task has been 15%

(Johnston and Wharf, 1979). Subjects viewed characters subtending 20 min arc whilst contact with the headrest was maintained. In the absence of headrest contact, reading errors decreased to less than 5%. The frequency range investigated extended from 3 to 25 Hz.

Lateral whole-body vibration is likely to result in less severe performance decrements than motion in any other translational axis.

3.1.4 Multiple-axis vibration

Although multiple-axis vibration will be present in many environments, its effects have not been fully investigated. During simultaneous observer and display vibration a circular motion consisting of combined vertical and lateral sinusoidal vibration can produce a greater reduction in acuity than vibration in either single axis alone (Banbury et al, 1983). Similar results have been demonstrated when stationary observers have viewed vibrating displays (Meddick and Griffin, 1976). Thus vibration environments containing multiple-axis vibration may cause a greater loss of performance than if vibration occurred in a single axis alone.

When viewing a target vibrating in a single axis, sinusoidal motion may result in the formation of nodal images (where velocity is zero and displacement maximal). These will not necessarily occur with multiple axis vibration and hence the difficulty in identifying the visual target may increase.

3.2 Vibration Waveform

Whilst sinusoidal vibration stimuli have been used in most laboratory studies, random vibration stimuli are more representative of those found in operational environments.

Experimental comparisons of sinusoidal and random whole-body vibration have generally found random vibration causes less severe decrements in visual performance than sinusoidal vibration. Data shown in Figure 3 illustrate this finding as demonstrated by Moseley et al (1982). These authors postulated that the observed differences in performance are due to the higher probability of low image velocity with random vibration (a model subsequently shown to predict visual performance with simulated aircraft vibration (Moseley, 1984)).

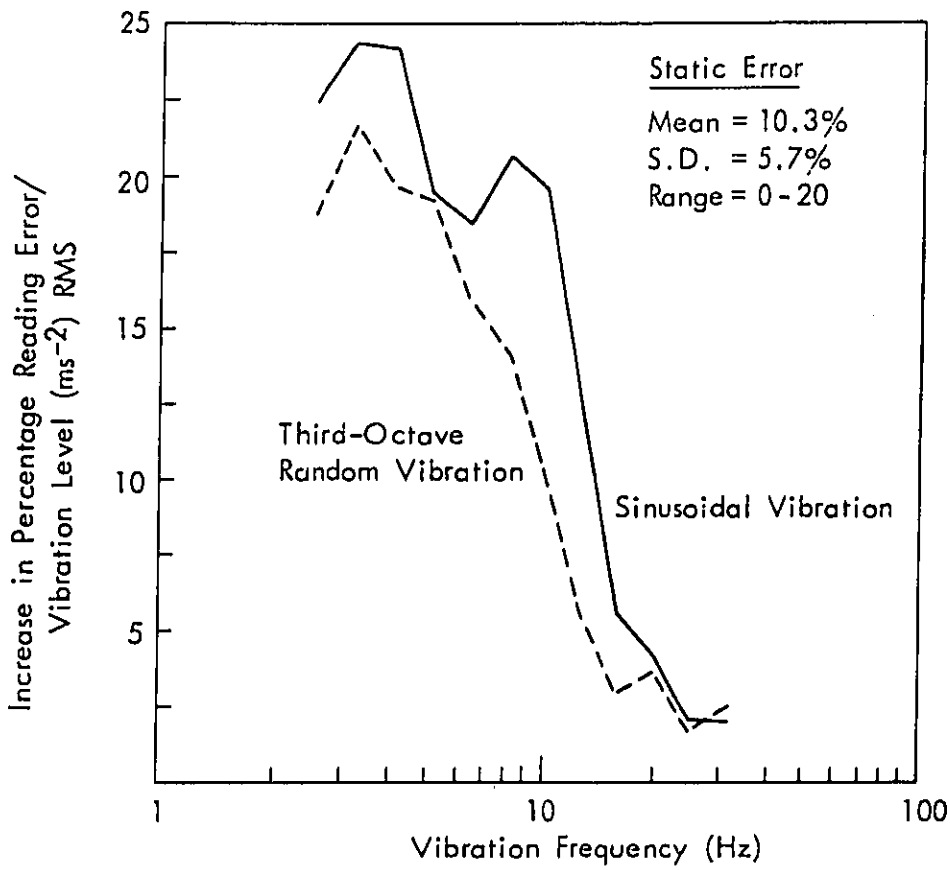

Figure 3: A comparison of the effects of one-third octave-band and sinusoidal vibration on reading performance. Mean values for 12 subjects. (After Moseley et al, 1982).

The effect of combining different frequencies of whole-body sinusoidal vibration on visual performance has been examined by Lewis and Griffin (1980b). Using a numeral reading task, these authors generally found that fewer errors occurred during multiple frequency vibration than with the spectral component of greatest frequency-weighted magnitude.

<u>The experimental evidence suggests that sinusoidal vibration will, in most cases, represent a 'worst case'. It may be appropriate for the designer to consider this when extrapolating the results of laboratory studies using</u>

sinusoidal vibration to vibration environments characterised by more complex vibration.

3.3 Whole-body, Display and Simultaneous Whole-body and Display Vibration

Visual performance may be affected by vibration of the observer, vibration of the display or simultaneous vibration of both display and observer. Vibration of the observer has received most attention although simultaneous vibration of observer and display may be considered more representative of most environments.

Data illustrated in Figure 4 compare the effects of vibration in each of the three viewing conditions. Sinusoidal vibration at each of eleven frequencies in the range 0.5 to 5.0 Hz were presented at five vibration magnitudes: 1.0, 1.25, 1.6, 2.0 and 2.5 ms^{-2} r.m.s. Target numerals subtended 5 min arc.

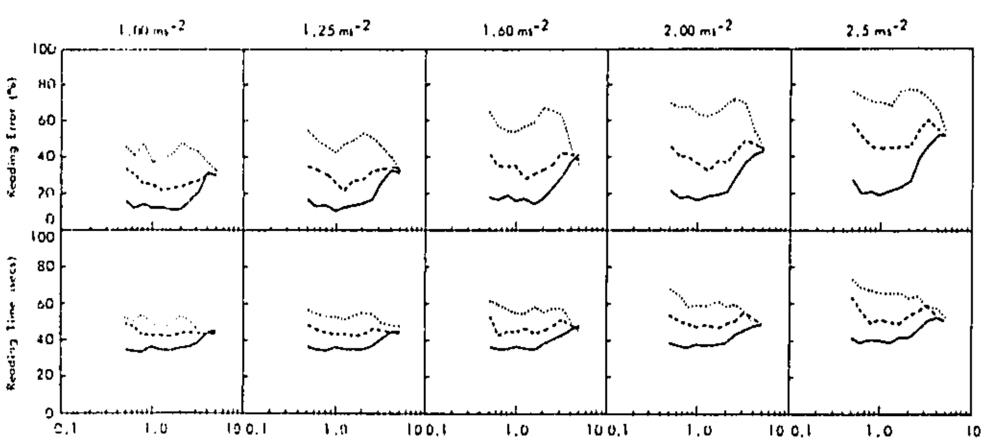

Figure 4: A comparison of the effects of whole-body (---) display (···) and whole-body-and-display vibration (——) on visual performance. Mean values of 15 subjects. Static performance = 6.2%, 27.8 seconds. (After Moseley and Griffin, 1986a).

The effect of the different viewing conditions depends on viewing distance and other variables. For typical uncollimated aircraft displays it may be assumed that for frequencies of approximately 3 Hz and below, simultaneous vibration of the display and observer will result in the least performance decrement and vibration of the display with a stationary observer will result in the greatest decrement.

3.4 Seating, Posture and Restraint

The type of seat, its harness and posture influence performance by modifying the vibration transmitted to the head. Data shown in Figure 5 compare reading performance for two seating conditions. In the first condition subjects sat restrained with full backrest contact ('back-on'). In the second condition, subjects were unrestrained and sat forward on the seat eliminating all contact with the backrest ('back-off'). In both conditions subjects performed a reading task with characters subtending 5 min arc. The seat consisted of a rigid seat pan, backrest and footrest geometrically identical to that found in a Sea King helicopter.

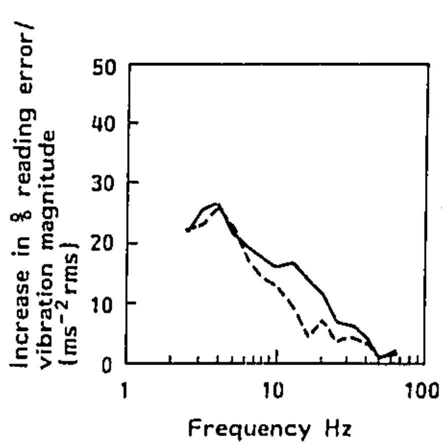

Figure 5: A comparison of reading performance with and without backrest contact (—— 'back-on', --- 'back-off'). (After Moseley et al, 1981).

In the frequency range 6.3 to 40 Hz significantly fewer reading errors occurred in the 'back-off' condition. The biodynamic origin of this finding was subsequently confirmed by measurements of rotational and translational head motion; significant increases in head motion occurred as a result of backrest contact.

Other examples of the influence of biodynamic variables may be obtained from the references supplied in Section 5. Biodynamic effects are so great that the designer must consider the seating configuration when attempting to assess whether visual performance will be influenced by vibration. This may involve the measurement of head vibration.

3.5 Duration

The vibration exposures employed in most laboratory experiments have been of short duration (<1 hour) and intermittent. The possibility that visual performance may decline as a result of prolonged vibration exposure other than through changes in arousal and motivation has received little attention. Recent experiments suggest that a significant loss of visual acuity (Grzesik et al, 1984) and contrast sensitivity (Moseley and Griffin, 1986b) may occur in some subjects after vibration exposure of 1 to 2 hours. These findings suggest that some disruption of the physiological and/or optical mechanisms of the eye may be induced by prolonged vibration exposure. Alternatively, these findings may be due to myopia resulting from repeated performance of a near visual task.

Some of the reported changes in visual performance with vibration duration are due to changes in transmissibility that occur during prolonged vibration exposures. Biodynamic variables (see Section 3.4) are likely to exert a significantly greater influence on visual performance than any effect directly attributable to vibration exposure duration.

4.0 DISPLAY PARAMETERS AND LEGIBILITY

4.1 Character Size

For displays viewed under normal viewing conditions, current recommendations for minimum character size range from 10 min to 20 min arc (see Helander and Rupp, 1984).

The effect of vertical whole-body vibration on the legibility of characters subtending less than 10 min arc has been investigated by Lewis and Griffin (1979). Vibration magnitude ranged from 0 to 2.0 ms^{-2} rms for 4 Hz vibration and 0 to 2.8 ms^{-2} rms for 11 Hz vibration. The display was not vibrated. Subjects were seated on a rigid flat seat without a backrest. Mean reading error data are shown in Figure 6 illustrating the disruptive effect of whole-body vibration on the legibility of small characters. The lower recommended limit (10 min arc) for a stationary viewing environment appears inappropriate for displays situated in vibration environments. The use of large characters has been shown to be one of the simplest methods of overcoming vibration-induced display degradation. Displays should use the largest characters with which the task can be presented up to a maximum of 37 min arc (excessively large characters have been shown to impair legibility). (see Kraft and Howell, 1959)

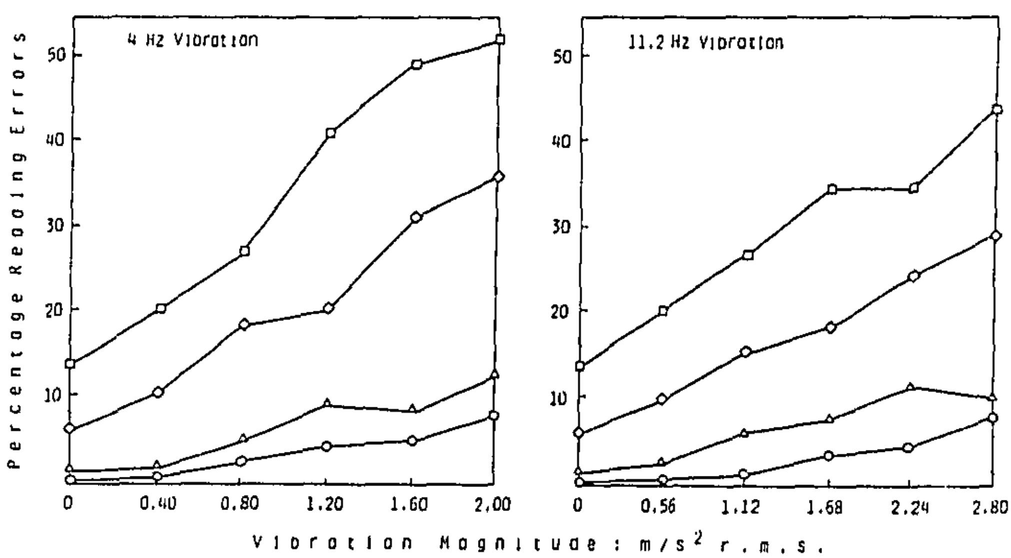

Figure 6: The effect of vertical (z-axis) whole-body vibration on the legibility of characters subtending 4.58 min arc □, 5.73 min arc , 7.56 min arc Δ, 9.17 min arc O. Mean data for 10 subjects. (After Lewis and Griffin, 1979).

4.2 Horizontal Character Separation

Under normal viewing conditions closely spaced characters have been shown to impair legibility (Treuniet, 1979). However, if character separation is too great then less information can be processed within a given period of time. The choice of an optimum horizontal separation will be a trade-off between these two factors. Typical recommendations for horizontal spacing under static conditions range from 10% to 50% of vertical character height (see Helander and Rupp, 1984).

The effect of horizontal character separation on display legibility during whole-body vibration has been investigated by Moseley (1986). Separation between 5 x 7 dot-matrix characters was either 3 (43%), 11 (157%) or 19 (271%) pixels. Reading error and reading time data for a numeric display were obtained during vertical whole-body vibration at frequencies of 3.15, 4, and 5 Hz at magnitudes of 1.6 ms^{-2} and 2.8 ms^{-2} rms. The display was not vibrated. For characters subtending 12 min arc, variations in horizontal separation did not influence legibility. However, with characters subtending 5 min arc significantly fewer errors occurred with 11 (157%) pixel separation than with either 3 (43%) or 19 (271%) pixel separation. <u>These results suggest that in a predominantly vertical vibration environment, with realistically sized characters (>12 min arc), horizontal separation is not a critical display parameter</u>. If, however, a fine resolution task is contemplated, an optimum range of separation will exist as identified above.

4.3 Vertical Character Separation

Data illustrated in Figure 7 indicate the effect of vertical character separation on display legibility. Separations between 5 x 7 dot-matrix characters are 4 (57% of vertical character height), 15 (214%), 26 (371%) or 48 (685%) pixels. Performance measures were obtained from a numeral reading task during sinusoidal whole-body vibration at frequencies of 3.15, 4, and 5 Hz. The display was not vibrated. In general, significantly greater reading times and reading errors occurred with a 4 pixel separation than with each of the larger separations. Most relevant to display design are the data obtained from characters subtending 12 min arc. Whilst, irrespective of separation, negligible errors occurred during static conditions, during some vibration conditions a difference of more than 20% in reading errors occurred between separations of four and fifteen pixels.

__A 4 pixel (57%) separation of 5 x 7 dot-matrix characters will not normally provide adequate legibility. A significant improvement in legibility may be achieved if vertical separation is increased to 15 (214%) pixels.__

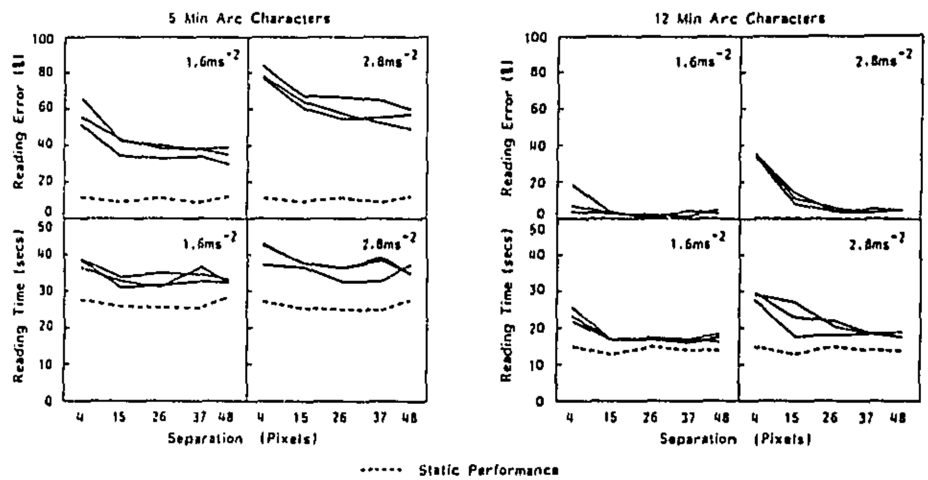

Figure 7: The effects of vertical character separation on display legibility during three conditions of sinusoidal vertical whole-body vibration (3.15 to 5.0 Hz). Mean data for 10 subjects. (After Moseley, 1986).

4.4 Viewing Distance and Display Collimation

Vertical whole-body vibration may cause both translational and rotational eye motion. The magnitudes of image movement arising from rotational eye motion are independent of viewing distance. Image motions arising from translational eye motion are inversely proportional to viewing distance so reductions in viewing distance will increase both the angular size of chraracters and their angular movement. If the character height is reduced so as to maintain the same angular size with shorter viewing distances, there may be decreased performance.

To determine the viewing distances at which the effects of either rotational or translational eye motion predominate, Lewis and Griffin

(1980b) measured reading performance at 0.75, 1.5, and 3.0 metres. Characters subtended a constant 4.5 min arc and the magnitude of vertical whole-body vibration ranged from 0.40 to 2.5 ms^{-2} rms at frequencies of 3.15 and 16 Hz. Whilst similar levels of performance were obtained at 1.5 and 3.0 metres, significantly greater errors occurred at the shortest (0.75m) viewing distance. This result was particularly marked at the lower frequency where the greatest relative translational motion between eye and display would have occurred. <u>For the vibration conditions investigated, the effects of translational eye motion will predominate at viewing distances less than about 1.5 metres. Most head-down displays are likely to be viewed at distances less than 1.5 metres and hence the designer should consider the benefits that may arise from display collimation</u>. If the display is positioned in the focal plane of a converging lens (the collimator) the effects of image movement due to translational eye motion will be eliminated.

The use of display collimation has been examined by Banbury et al (1983) (see Figure 8) and found to provide significant improvements in visual resolution during whole-body vibration.

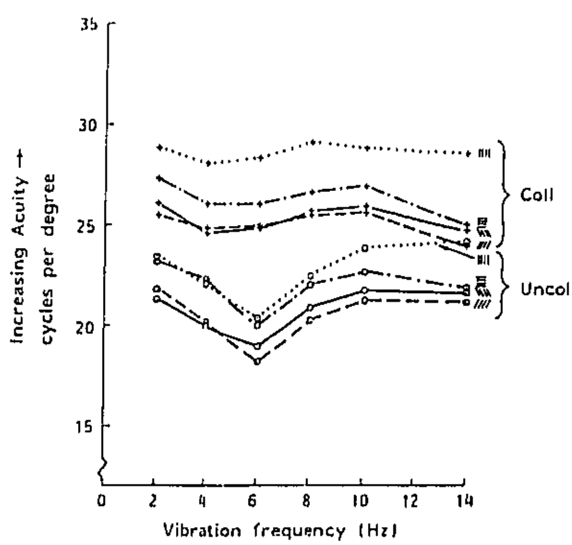

Figure 8: The effect of display collimation on square-wave grating acuity during whole-body vibration (4 orientations). Mean data for 10 subjects averaged over vertical, lateral and combined vertical and lateral vibration. Viewing distance = 0.9 m. (After Banbury et al, 1983).

4.5 Display Contrast

The relationship between legibility, display contrast and vibration has not been thoroughly investigated. The major consideration of the display designer has been to ensure that aircraft cockpit displays are of sufficient brightness to prevent 'wash out' caused by high ambient illumination.

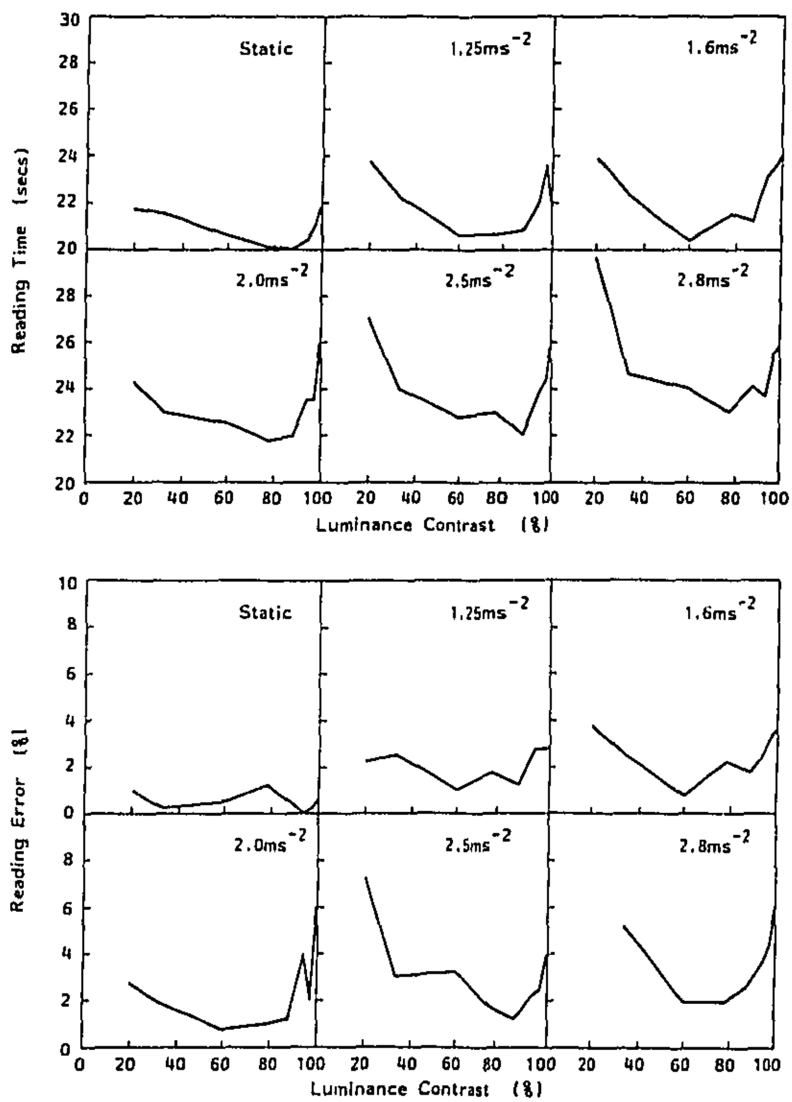

Figure 9: The effect of luminance contrast on display legibility during vertical whole-body vibration. Mean data for 8 subjects. (After Moseley, 1986).

Data shown in Figure 9 were derived from an experiment in which subjects performed a reading task during static and whole-body vibration conditions (1.25 to 2.8 ms^{-2} r.m.s) (Moseley, 1986). Display contrast was varied between 20% and 99% (Michelson) by projecting a light source of varying intensity on to the surface of the screen containing the characters.
As expected, poor contrast (<60%) impaired legibility. There is also a decline in reading performance at high contrast (>80%). The U-shaped relationship occurred in all conditions with the exception of reading errors under static conditions where errors were very low (<2%). Optimum legibility will be obtained with contrast in the range 60% to 80%. The observation that high contrast may impair acuity has also been demonstrated during static viewing conditions (Banbury et al, 1983).

4.6 Symbol Definition

The 'definition' on raster-driven displays refers to the number of picture elements ('pixels') that make up a symbol or character. For example, a character specified as '3 x 5' is formed from three vertical columns and five horizontal rows of pixels. The smallest definition which has been shown to provide good legibility under adequate viewing conditions is 5 x 7. During degraded viewing conditions an increase in matrix size beyond 5 x 7 may significantly improve legibility.

Figure 10 compares the legibility of 5 x 7 and 7 x 9 dot matrix characters during normal viewing conditions and during vertical whole-body vibration (4 Hz, 2.8 ms^{-2} rms). During vibration, significantly greater reading times and reading errors occurred with 5 x 7 characters than with 7 x 9 characters. Greater reading times also occurred during static conditions with 5 x 7 characters. The designer should adopt a 7 x 9 or larger symbol matrix size for displays situated in vibration environments. If reading speed is considered to be important then 7 x 9 dot matrix characters should also be preferred in the absence of display or observer vibration.

4.7 Character Font

The term character font refers to the particular typographical design of alphanumeric characters. Two particular designs, the Huddleston (Huddleston, 1970, 1974) and the Lincoln Mitre (see Shurtleff, 1969) have been shown to achieve a high standard of legibility (see Shurtleff, 1980).

A comparison of the legibility of Huddleston and Lincoln Mitre fonts (see

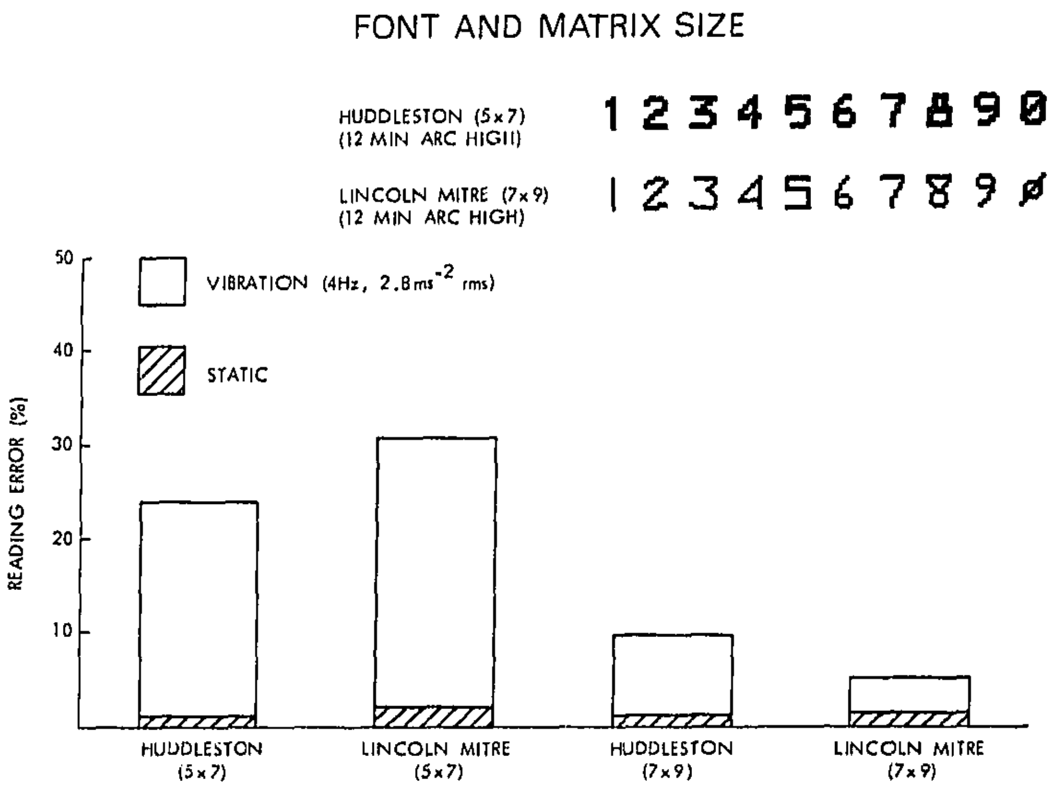

Figure 10: The effect of vertical whole-body vibration on the legibility of 5 x 7 and 7 x 9 dot-matrix characters. Mean data for 8 subjects, Huddleston and Lincoln Mitre fonts. (Adapted from Moseley, 1982).

Figure 11) during static and vibration-degraded (whole-body) viewing conditions has been reported by Moseley (1982). Subjects read arrays of dot matrix alphanumeric characters with symbol definitions of 5 x 7 and 7 x 9 pixels. Characters subtended 12 min arc at a 0.63 metre viewing distance. Vibration magnitude was maintained at 2.8 ms^{-2} rms at a frequency of 4 Hz. In this experiment subjects were able to read characters in the 5 x 7 Huddleston font significantly faster than those in the 5 x 7 Lincoln Mitre. During static conditions both 5 x 7 fonts were of similar legibility. <u>Huddleston and Lincoln Mitre fonts are both suitable for use with 7 x 9 characters. If the use of 5 x 7 characters is enforced, preference should be given to the Huddleston font</u>.

A B C D E F G H I J K L M N O P Q R
S T U V W X Y Z 1 2 3 4 5 6 7 8 9 0

THE HUDDLESTON 5 x 7 FONT

A B C D E F G H I J K L M N O P Q R
S T U V W X Y Z Ø 1 2 3 4 5 6 7 8 9

THE LINCOLN MITRE 5 x 7 FONT

A B C D E F G H I J K L M N O P Q R
S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9

THE HUDDLESTON 7 x 9 FONT

A B C D E F G H I J K L M N O P Q R
S T U V W X Y Z 1 2 3 4 5 6 7 8 9 Ø

THE LINCOLN MITRE HAZLETINE 7 x 9 FONT

Figure 11: The Huddleston and Lincoln Mitre fonts.

5.0 FURTHER READING AND BIBLIOGRAPHY

This section provides a source of reference for the designer seeking further information. Topics covered include those discussed in this document together with the measurement of vibration and relevant standards.

TOPIC	SECTION NUMBER	REFERENCES
Vibration and Visual Performance		
Visual performance during vertical (z-axis) whole-body vibration	3.1.1	Banbury et al (1983) Griffin (1975) Griffin and Lewis (1978) Johnston and Wharf (1979) Lewis and Griffin (1980a) Lewis and Griffin (1980b) Moseley (1986)
Visual performance during fore-and-aft (x-axis) whole-body vibration	3.1.2	Griffin and Lewis (1978) Lewis and Griffin (1980a)
Visual performance during multiple axis vibration	3.1.3	Banbury et al (1983) Griffin and Lewis (1978) Meddick and Griffin (1976)
The effect of vibration waveform on visual performance	3.2	Alexander (1972) Griffin and Lewis (1978) Lewis and Griffin (1980b) May (1982) Moseley et al (1982)
Comparisons of display, whole-body and simultaneous whole-body-and-display vibration	3.3	Johnston and Wharf (1979) Lewis and Griffin (1980a) Moseley and Griffin (1986)
Seating, posture and restraint	3.4	Lewis and Criffin (1980a) Moseley et al (1981)

TOPIC	SECTION NUMBER	REFERENCES
Duration	3.5	Grzesik et al (1984) Moseley and Griffin (1986b)
Display Parameters, Legibility and Standards		
Character size	4.1	Lewis and Griffin (1979)
Horizontal character separation	4.2	Moseley (1986)
Vertical character separation	4.3	Moseley (1986)
Viewing distance and collimation	4.4	Banbury et al (1983) Griffin (1976)
Contrast	4.5	Banbury et al (1983) Furness (1981) Moseley (1983) Moseley (1986)
Symbol definition	4.6	Moseley (1982) Moseley (1986)
Character font	4.7	Moseley (1982) Moseley (1986)
Standards and guidelines	-	Cakir (1979) Cakir et al (1980) DIN 66234 (1981) Gould (1968) Health and Safety Executive (1983) Helander and Rupp (1984) Kolers et al (1981) NATO STANAG 3329A1 Edition 6 Rupp (1981)

TOPIC	SECTION NUMBER	REFERENCES
		Shurtleff (1980) Treuniet (1979) USA Department of Defence (1981)
Vibration Measurement, Transmission and Standards		
The measurement of vibration	-	Defence Standard 00-970 (1985)
The transmission of vibration from seat-to-head	2.1	Griffin et al (1978) Lewis and Griffin (1980a) Moseley et al (1981) Paddan (1984)
The transmission of vibration from head-to-eye	2.2	Benson and Barnes (1978) Stott (1984) Wells (1983) Wells and Griffin (1983)
Standards	-	ISO (1974, 1978, 1985) BSI (1986) Defence Standard 00 970 (1985)

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APPENDIX

A PROCEDURE FOR USE OF THE GUIDE

The legibility attainable for a given display is a complex function of many interacting variables. Quantitative information indicating the level of performance likely to be attained for a given display and vibration environment cannot therefore be given here.

This appendix describes a procedure by which the information contained within the guide may be applied. The approach outlined in Table A may enable the designer to improve performance and display legibility by measurement and optimisation.

STAGE	SECTION	DETAILS
1 Define vibration environment(s)	3.0	Determine the nature of the vibration environment with respect to magnitude, frequency, axis, waveform and seating conditions. Details of vibration measurement techniques may be obtained from the bibliography in Section 5.0.
2 Modification of vibration environment	3.0	Investigate the effects of modification to the vibration environment eg changes in seating and posture, use of anti-vibration mounts.
3 Modification of the display	4.0	Optimise display legibility by adopting the recommendations described in Section 4.0. In some cases this may interact with stage 2 above - for example changing the viewing distance may involve a change in the seating configuration.

Table A: Procedure for evaluating the effects of vibration on visual tasks.