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Adaptation to oscillopsia
A psychophysical and questionnaire investigation

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Summary
In this study we explore the reasons why patients with bilateral vestibular failure report disparate degrees of oscillopsia. Twelve bilateral labyrinthine-defective (LD) subjects and twelve normal healthy controls were tested using a self- versus visual-motion psychophysical experiment. The LD subjects also completed a questionnaire designed to quantify the severity of handicap caused by oscillopsia. Additional standardized questionnaires were completed to identify the role of personality, personal beliefs and affective factors in adaptation to oscillopsia. During the psychophysical experiment subjects sat on a motorized Barany chair whilst viewing a large-field projected video image displayed on a screen in front of them. The chair and video image oscillated sinusoidally at 1 Hz in counter-phase at variable amplitudes which were controlled by the subject but constrained, so that the net relative motion of the chair and video image always resulted in a sinusoid with a peak velocity of 50°/s. The subject's task was to find the ratio of chair versus video image motion that subjectively produced the 'most comfortable visual image'. Eye movements were recorded during the experiment in order that the net retinal image slip at the point of maximum visual comfort could be measured. The main findings in the LD subjects were that, as a group, they selected lower chair motion amplitude settings to obtain visual comfort than did the normal control subjects. Responses to the questionnaires highlighted considerable variation in reported handicap due to oscillopsia. Greater oscillopsia handicap scores were significantly correlated with a greater external locus of control (i.e. the perception of having little control over one's health). Retinal slip speed was negatively correlated with oscillopsia handicap score so that patients who suffered the greatest retinal slip were those least handicapped by oscillopsia. The results suggest that adaptation to oscillopsia is partly related to the patient's personal attitude to the recovery process and partly associated with the development of tolerance to the movement of images on the retina during self-motion. The latter is likely to be related to previously described changes in visual motion sensitivity in these patients.

Keywords: vestibular; handicap; retinal slip; motion perception

Abbreviations: COR = cervico-ocular reflex; LD = bilateral labyrinthine defective; VOR = vestibular ocular reflex

Introduction
Lesions in the oculomotor, vestibular and cerebellar systems may result in a symptom known as oscillopsia (an illusionary movement of the visual world), first reported by Brickner (Brickner, 1936). This symptom is common among bilateral labyrinthine-defective (LD) patients during head movements and is caused by the absence of the vestibular ocular reflex (VOR). Although patients' descriptions of the illusory visual movement differ, the symptom is due to poor image stabilization on the retina during head movements. In the acute stage oscillopsia is pronounced, often resulting in great interference with the patient's daily activities. With time the severity of oscillopsia decreases (Bronstein and Hood, 1987) and there are cases where the symptom disappears altogether so that the patient denies experiencing oscillopsia (Hess *et al*., 1978). Except for a single case report (Bronstein *et al*., 1995), recovery of VOR function is not reported by these patients and consequently they continue to experience slip of visual images on the retina. It is likely, therefore, that the reported improvement in oscillopsia results from some form of adaptation. Clinical observations suggest, however, that some patients continue to experience oscillopsia severe enough to interfere with their daily activities and mobility

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(Bronstein and Hood, 1987). The extent of adaptation to oscillopsia appears, therefore, to differ considerably between LD patients.

Several mechanisms could underlie the adaptation process. The cervico-ocular reflex (COR) is enhanced in LD subjects during head movement (Kasai and Zee, 1978; Bronstein and Hood, 1986). However, due to the low-pass characteristics of the COR, the compensation provided will not be effective at the higher frequencies of natural head movement (Wilson and Melvill-Jones, 1979; Huygen *et al*., 1991). Furthermore, no correlation has been found between COR gain and self-reports of oscillopsia (Bronstein and Hood, 1987). Enhanced gain of optokinetic and pursuit eye movements in LD subjects has been demonstrated (Gresty *et al*., 1977; Huygen *et al*., 1989), and this may contribute to the stabilization of images on the retina during head movement, leading to a reduction in oscillopsia.

More recently, Morland and colleagues examined the visual responses of LD subjects to determine whether adaptation to oscillopsia is mediated by changes in visual function (Morland *et al*., 1998). They observed that both self-motion and visual stimulus motion resulted in a degradation of spatial vision in LD subjects and concluded that deterioration in the visual responses was caused solely by retinal slip. The authors did, however, observe that some LD subjects experienced a deterioration in velocity discrimination under conditions of self-motion, a finding also reported by Shallo-Hoffmann and Bronstein (Shallo-Hoffmann and Bronstein, 1998). It was concluded that this reduction of visual motion sensitivity represented a central form of adaptation to oscillopsia, thereby increasing tolerance to retinal slip (Morland *et al*., 1998). A similar proposal has been put forward previously by Dieterich and Brandt to account for the rarity of reports of oscillopsia in patients with oculomotor disorders (Dieterich and Brandt, 1987).

Adaptation to oscillopsia may also be influenced by individual differences in health-related coping behaviour. Previous research has demonstrated that psychological factors including hardiness—the ability to adjust to or cope with illness (Folkman, 1984; Pollock *et al*., 1990), information-seeking behaviour (Felton and Revenson, 1984) and perceived control over an illness (Wallston, 1997) may be of importance in the adaptation and recovery process. Furthermore, reported handicap among patients with vestibular disorders has been found to be influenced by autonomic symptoms, a fear of losing control and depressed mood (Yardley *et al*., 1992; Yardley, 1994). Negative perceptions of symptoms may lead to increased anxiety, a restriction of activity and ultimately an unbreakable cycle of vertigo (Yardley, 1994). There is, however, little research relating to coping behaviour and handicap experienced by patients with oscillopsia resulting from bilateral vestibular failure.

Currently there is no method available to quantify objectively the degree of oscillopsia experienced by individuals or the impact of oscillopsia on the patient's life. A test has previously been reported to distinguish between healthy subjects and patients with infranuclear oculomotor disorders (if oscillopsia is reported at 1 Hz then this is interpreted as a sign of pathology) and to quantify the amplitude of any target oscillation during head movement (Wist *et al*., 1983). The test, however, is artificial and does not reflect the difficulties which a patient may experience during everyday activities. For example, during normal walking conditions head movements of 1–4 Hz are produced (Gresty *et al*., 1977) and yet normal subjects do not report oscillopsia. However, the normal subjects in the study by Wist and colleagues experienced oscillopsia at frequencies of 2 Hz due to the large amplitude head movements required by the test protocol (Wist *et al*., 1983). Attempts have been made to evaluate oscillopsia in LD subjects using a physician reported rating scale (Bronstein and Hood, 1987). Again, this method may not reflect the everyday experience of oscillopsia.

In the present study we have designed a questionnaire to determine the impact of oscillopsia on everyday life and have applied additional questionnaires to evaluate personality (extroversion, neuroticism), personal beliefs/resources (self-esteem, perceived control over illness, optimism) and affective factors (anxiety, depression). We also aimed to determine whether the experience of oscillopsia influenced patients' performance on a psychophysical test. We wanted to test the hypothesis that increased adaptation to oscillopsia would lead to a greater tolerance of self-motion while viewing an image. The final goal was to identify any relationship between reported handicap, other psychological factors and psychophysical responses which may be consistent with adaptation to oscillopsia.

Methods

Rationale

In order to measure LD patients' tolerance to self-motion our stimulus design needed to meet specific criteria. First, it was necessary to produce a motion stimulus condition under which retinal slip occurred. Secondly, we required that slip be maintained during all values of self-motion for the LD subjects. In order to fulfil these criteria an experiment was designed in which the relative motion between the subject's head and a coloured video image (on a screen in front of the subject) was always sinusoidal at 1 Hz $\pm$ 50°/s. This constant oscillation was the result of a combination of whole-body and visual stimulus motion, the ratio of which could be controlled by the subject. The chosen peak velocity of 50°/s is within the normal range for pursuit eye movements to ramped stimuli (Meyer *et al*., 1985); however, the oscillation frequency of 1 Hz prevents pursuit eye movements from achieving unity gain in normal subjects (Barnes *et al*., 1978). Thus, the chosen oscillation of 1 Hz $\pm$ 50°/s will lead to retinal slip in the LD subjects for all values of self-motion (Morland *et al*., 1998). A normal subject will be able to compensate during self-motion (due to the utilization of VOR) but will suffer retinal slip during movement of the

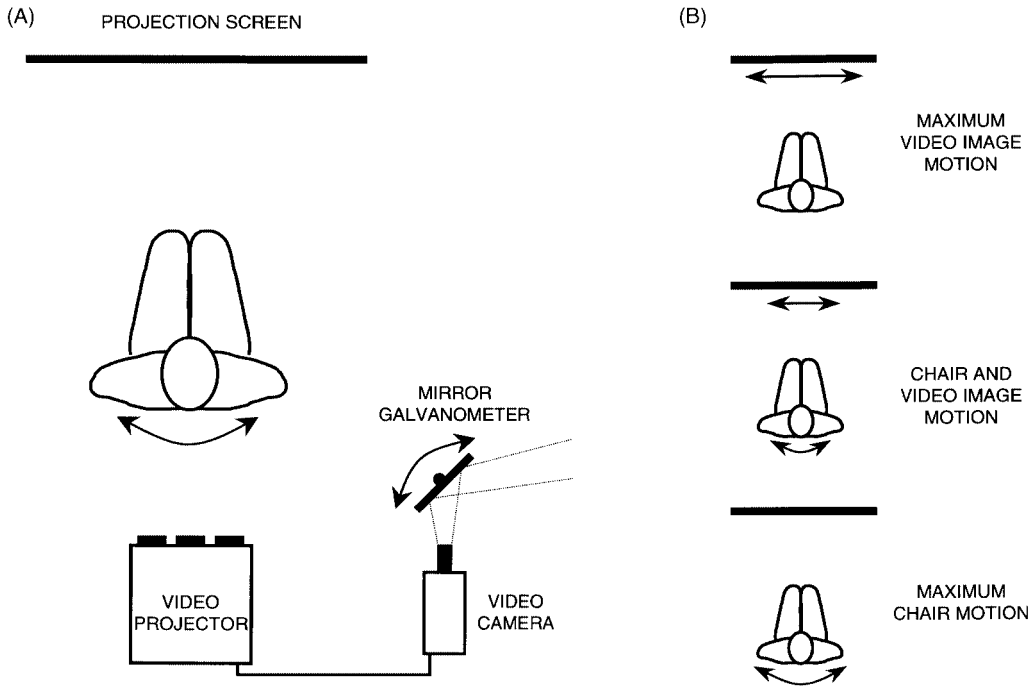

Fig. 1 (**A**) A schematic of the experimental set-up as viewed from above. A colour image of the laboratory was acquired by a video camera viewing through a mirror galvanometer. This was projected on to a screen in front of the subject seated in a motorized Barany chair. (**B**) Three conditions of motion: top, motion of the video image alone; middle, motion of the chair and video image; bottom, motion of the chair alone. In each condition the oscillation between the subject's head and the video image was at constant frequency (1 Hz) and amplitude (±50°/s, ±8°). The subject controlled the proportion of chair motion contributing to the net oscillation.

visual stimulus (pursuit alone). The technique should allow us to determine whether LD subjects demonstrate greater tolerance to the image motion during self-motion or visual stimulus motion.

In summary, the technique can measure individual preferences for self versus image motion. At the chosen settings, the magnitude of retinal slippage can be determined (see Eye movement analysis below). Finally, the measurements of self versus image motion preference and retinal slip will be correlated with an oscillopsia handicap score and with psychological factors (i.e. personality, personal beliefs and affective factors).

Experimental set-up

The subject sat upright in a motorized Barany chair in front of a screen on to which was projected a colour video image of the laboratory. The camera which acquired the video image was fixed, but the light it gathered was reflected off a mirror galvanometer so that sinusiodal image motion could be produced (Fig. 1). The video image was projected on to the screen by means of a video projector (BARCO, Kuurne, Belgium). Constant amplitude sinusoidal oscillation between the subject's head and the viewed image was presented. This was achieved by generating complementary sinusoidal oscillations of the chair and the video image, such that the sum of the two terms always resulted in 1 Hz (amplitude: ±8°, ±50°/s) sinusoidal oscillation of the image with respect to the subject's head. The ratio of video image motion and chair motion was controlled by the subject using a three-turn potentiometer. The video image motion, although translational, was tangent-corrected such that its angular motion with respect to the subject's head was identical to motion generated by the chair alone. The subject adjusted the potentiometer (the end-points could be altered to correspond to either maximum chair or maximum video image motion) to control the relative amount of chair and video image motion. Earth-fixed cues were removed by restricting the field of view with modified spectacles worn by the subject (subjects with refractive defects were also able to wear their prescription spectacles during testing). The field of view defined by the modified spectacles was 25° and therefore extended over a larger region of the visual field than the motion displacement of ±8°. Modified earmuffs were used as clamps to fix the subject's head to the head-rest and the legs were also clamped to minimize physical discomfort during self-motion.

Chair velocity was transduced via the motor tachometer. The video image velocity was determined from the output of the galvanometer. Electro-oculograph (EOG) recordings were made using bi-temporal DC coupled electrodes and the signal was filtered at 70 Hz. Eye movement recordings were acquired at 250 Hz by a personal computer and analysed off-line. The chair and visual stimulus velocities (as chosen

by the subject to achieve the most comfortable viewing conditions) were recorded separately using a Schlumberger (SI 1220) FFT (Fast Fourier Transform) spectrum analyser. This provided immediate on-line velocity measurements (used in subsequent analyses) and allowed the experimenter to monitor the ratio of chair and image motion in order to determine the consistency of the subject's responses. In addition, the spectrum analyser allowed the phase relationship between the visual stimulus and chair oscillations to be continually monitored and any distortions of chair motion to be assessed. These parameters were always checked and found to be unaffected for all subjects tested. Head velocity was recorded with a helmet-mounted angular rate sensor (Watson Industries, Romsey, UK) to ensure that the head clamps were effective in securing the subject's head. In all cases the recorded head motion was identical to the chair motion.

Procedure

Each trial began with either total chair or total video image motion. The subject's task was to find the potentiometer setting (the ratio of self-motion versus video image motion) that produced a visual image that was comfortable to view. When the subject had obtained this setting he/she indicated verbally to the experimenter who pressed a button connected to the computer to record this point in the trial. The task was repeated for 12 trials.

Eye movement analysis

The reported measurements correspond to the moment when the subject indicated the most comfortable visual image. Slow phase eye movement speeds were calculated using an in-house analysis programme (previously unreported). The EOG was smoothed using a five-point moving average technique and then differentiated by a two-point central difference algorithm (see Bahill *et al*., 1982). Next the data were desaccaded and the whole wave rectified. The desaccading technique calculates values for the average and peak noise present in the trace and then assigns a value of peak noise multiplied by 1.8 as the threshold. The program then uses an 11-point moving average technique and identifies whether the new average is above or below the old average plus threshold. If so, this portion of the trace is removed and replaced by a random value close to the old averaged value.

An average of the eye speed trace over a 2 s period (centred on the point indicated as the best perceived visual image) was calculated. This RMS (root mean square) value was then multiplied by the square root of 2 (to convert it to peak speed) and this measurement used for subsequent analysis. Retinal slip was calculated by subtracting the eye speed from the summated motion of the chair and video image (50°/s). Our measure of retinal image slip is the mean difference in speed between the slow phase eye movement and the speed of the visual stimulus with respect to the head over a 2 s period. This was considered a more appropriate measure of retinal slip than measuring peak eye velocity over a short duration, because the latter would involve subjective judgements and only two values would be obtained for the stimulus cycle of 1 Hz.

Questionnaires

A questionnaire was designed for this study to enable the quantification of symptoms (including oscillopsia) and handicap (a disadvantage that limits or prevents the fulfilment of a role that is normal for that individual). In the present study handicap was defined as the degree of disruption to the daily life and social activities of that individual. A patient's reported handicap is thought to give a clearer indication of the impact of an illness on everyday functioning than would be obtained from a description of impairment or disability alone (World Health Organization, 1980).

Scale development

A set of questions was developed with the aim of categorizing the handicap experienced by LD subjects with oscillopsia. The items were generated through a focus group of relevant specialists (researchers, neurologists, audiologists and ophthalmologists) and from a previous pilot questionnaire administered to a small sample of LD subjects ($n = 6$). The symptom subsection relates to symptoms experienced (i.e. feelings of unsteadiness, rotation, nausea) and to the history of the patient's disorder. It is included for a comprehensive account of the disorder and to enable identification of other symptoms (resulting from the vestibular disorder) which might influence the oscillopsia handicap score. The handicap subsection consists of 12 items relating to difficulties experienced with everyday or regular tasks, for example, 'driving along a bumpy road' or 'recognizing faces while moving'. Each handicap item is scored from 1 (no difficulty) to 4 (cannot do) and the scores are summed to give an oscillopsia handicap score. Potential oscillopsia handicap scores range from 12 to 48, with a higher score indicating greater handicap. The complete questionnaire can be found in the Appendix.

The reliability of the questionnaire has been tested previously on a sample of 23 LD subjects and 50 patients with vestibular disorders not classified as LD and with no reported oscillopsia (Grunfeld, 1998). LD subjects are relatively rare in neuro-otology clinics and as such it is difficult to obtain large samples. Cronbach's alpha (Cronbach, 1951) was used to obtain a measure of the internal consistency of the scale; for the LD group the coefficient was 0.75 and for the vestibular group it was 0.80. The items on the scale should all measure the same element and therefore they should be correlated with one another. If the items on the scale were all perfectly correlated (identical) then the result would be $\alpha = 1$; conversely, if all the items were independent then $\alpha = 0$. α values of 0.7–0.8 are thought to be satisfactory

Table 1 *Questionnaires used in the study*

No.	Questionnaire	Authors	Purpose
1	Vertigo Symptom Scale	Yardley *et al*., 1992	Classification of symptoms observed in patients with vertigo
2	Recovery Locus of Control Scale	Partridge and Johnston, 1989	Extent of perceived control over illness
3	Hospital Anxiety and Depression Scale	Zigmond and Snaith, 1983	Quantify anxiety/depression, taking account of physical illness
4	Rosenberg Self Esteem Scale	Rosenberg, 1989	Self-esteem
5	Life Orientation Test	Scheier and Carver, 1987	Optimism—habitual style of anticipating favourable outcomes
6	Eysenck Personality Questionnaire	Eysenck and Eysenck, 1975	Extroversion/introversion and neuroticism

for comparison of groups (Bland and Altman, 1997). The item total statistics revealed that removal of any of the items would make little difference to the α coefficient and thus all 12 items were retained. The LD group (mean score 31.5, SD 7.15) and the vestibular group (mean score 28.0, SD 6.64) were found to be significantly different in their total oscillopsia handicap score ($Z = -2.66$, $P < 0.01$). A non-parametric Kruskal–Wallis ANOVA revealed that the most useful items for distinguishing between the two groups were 'walking in a straight line', 'reading/counting objects while moving', 'going up and down stairs' and 'recognizing faces while moving' with LD subjects reporting significantly greater handicap on all these items ($P < 0.01$).

Six additional standardized questionnaires (see Table 1) were also administered to identify the role of personality (extroversion and neuroticism), personal beliefs/resources (self-esteem, optimism, perceived control over illness) and affective factors (anxiety, depression) in adaptation to oscillopsia. One of the questionnaires also examined vestibular and autonomic symptoms (Yardley *et al*., 1992).

Subjects

The patient sample consisted of 12 LD subjects as determined by absent nystagmic responses on rotational (velocity step stimuli in darkness at ±60–80°/s) and bi-thermal caloric tests (30 and 44°C, with and without visual fixation). There were five female and seven male subjects with a mean age of 52.2 years (range 33–68 years). All subjects reported oscillopsia and the duration with this symptom ranged from 9 months to 16 years. No other visual abnormalities, other than minor refractive errors, were present. The aetiology of the vestibular lesion was idiopathic ($n = 8$), bacterial meningitis ($n = 2$), neurofibromatosis II with bilateral removal of acoustic neuroma ($n = 1$) and idiopathic cerebellar-vestibular degeneration ($n = 1$). The large proportion of subjects in this study with labyrinthine failure of idiopathic origin is in agreement with previous studies and this may be due to the nature of the patients seen in our tertiary referral neuro-otological clinic (Rinne *et al*., 1998). All but two of the subjects showed normal pursuit gain for sinusoidal laser targets (0.2 Hz ± 16°), and the two patients with a mild deficit were aged 60 and 68 years, so age related effects could have caused the reduction in pursuit gain. Twelve normal subjects with no history of labyrinthine, neurological or visual abnormalities (with the exception of refraction defects) were used as the control group. These subjects were age and sex matched to the LD subjects and thus they consisted of five female and seven male subjects with a mean age of 51.3 years (range 32–69 years). They all gave informed consent to participate in the study, which was approved by the Ethical Committee of the Institute of Neurology and the National Hospital for Neurology and Neurosurgery, London.

Results

Psychophysical responses

Patients and normal controls were able to follow the instructions and complete the task. In Fig. 2, traces of chair velocity, video image displacement, head velocity and eye displacement are shown for a sample trial for an LD patient and normal control. It is clear that during the trials, the chair and video image oscillations are complementary. Furthermore, the head motion accurately reflects the corresponding chair motion. The marker channel indicates the point of maximum visual comfort and it can be seen that, at this point, the two subjects differed in their preferred degree of chair motion with the normal control selecting greater self-motion.

The distributions of the chair amplitude settings were examined using histograms (Fig. 3). The distributions show some overlap, but the clear trend is that the distribution of the normal subjects is skewed to high, whereas the patient distribution is skewed to low values of chair speed. LD subjects preferred less chair motion (mean 19.62°/s, SD 10.34) than age-matched normals (33.5°/s, SD 8.04). The data were not normally distributed, so the differences between the groups were examined using the Mann–Whitney test. The chair settings for the two groups were significantly different ($Z = -2.89$, $P < 0.01$). As outlined in Methods, the oscillations of the chair and the visual stimulus were measured independently. The mean peak speed of the video image was 30.13°/s (SD 10.52) for the LD subjects and 16.85°/s (SD 7.79) for the normals, which clearly demonstrates that the chair and visual stimulus motions summated to the required constant oscillation (±50°/s).

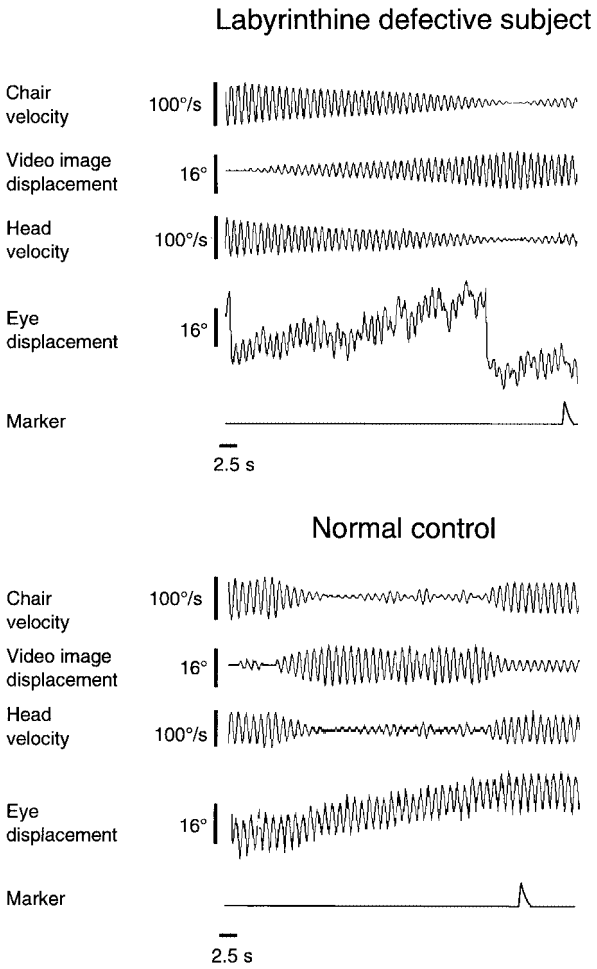

Fig. 2 Traces of chair velocity, video image displacement, head velocity and eye displacement, plotted as a function of time. Data are given for an LD patient (top) and a normal control (bottom). The marker channel indicates the point at which the subject indicated 'maximum visual comfort'. The traces are screen dumps to a printer and do not reflect the resolution of the data used for subsequent analysis.

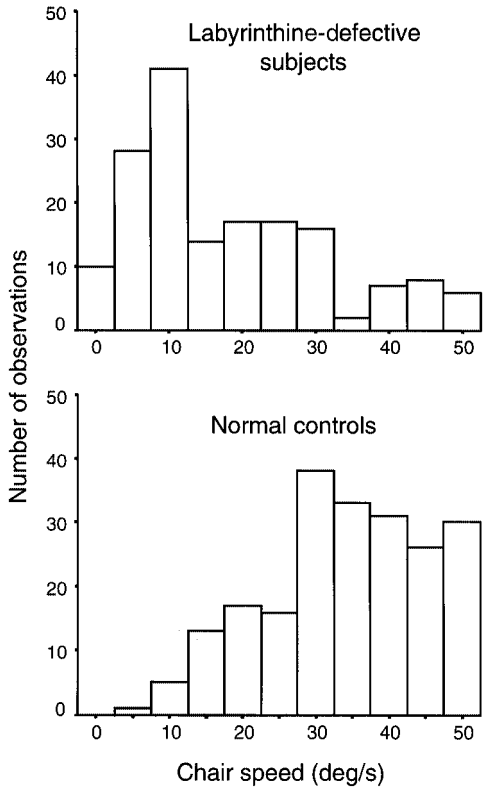

Fig. 3 Frequency histograms of the chair settings chosen by the LD subjects (top) and normal controls (bottom).

Eye movements

Eye movement and retinal slip speed were calculated at the point of greatest visual comfort. LD subjects exhibited significantly greater retinal slip ($Z = -3.35$, $P < 0.01$, Mann–Whitney) (15.06°/s, SD 8.65) than age-matched controls (5.22°/s, SD 2.87).

Correlation between psychophysical responses and psychological factors

Eleven of the 12 LD subjects completed a booklet of questionnaires to enable the quantification of psychological factors. Correlations were calculated using Spearman's r correlation coefficient for ranked data (Table 2). Greater oscillopsia handicap scores were significantly correlated with a strong external locus of control ($r = -0.663$, $P < 0.05$). A low score on the locus of control questionnaire indicates a strong external locus of control and vice versa (which is why the above correlation coefficient is negative). Individuals with a strong internal locus of control were found to be more optimistic ($r = 0.817$, $P < 0.01$) and have greater self-esteem ($r = 0.691$, $P < 0.05$). Individuals who had high optimism scores also tended to report less anxiety ($r = -0.687$, $P < 0.05$), neuroticism ($r = -0.874$, $P < 0.05$) and autonomic symptoms ($r = -0.690$, $P < 0.05$).

One aim of the study was to determine if increased adaptation to oscillopsia is associated with greater tolerance of self-motion while viewing an image. In Fig. 4A, oscillopsia handicap score is plotted as a function of chair amplitude setting. The correlation between chair amplitude settings and reported handicap was, however, non-significant ($r = 0.176$, $P = 0.606$) leading to an acceptance of the null hypothesis that handicap is not related to tolerance for self-motion while viewing a moving object. In contrast, oscillopsia handicap scores were negatively correlated with retinal slip ($r = -0.674$, $P < 0.05$) as shown in Fig. 4B. Thus, subjects with poorer compensatory eye movements reported less handicap than subjects with more effective compensatory eye movements. The influence of age and duration of oscillopsia on reported handicap were non-significant ($r = -0.241$, $P = 0.476$ and $r = -0.204$, $P = 0.547$, respectively). In Fig. 4C, retinal slip is plotted as a function of chair amplitude setting and, as expected, they were not significantly correlated ($r = -0.182$, $P = 0.593$). This demonstrates that those LD patients with less retinal slip (better image stabilization) were not

Table 2 *Spearman's correlation matrix of the questionnaire and behavioural data*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Chair velocity	.	0.182	0.005	–0.219	0.128	–0.147	0.176	0.470	0.194	–0.055	0.445	–0.282	–0.023	–0.301
2 Retinal image motion	–0.182	.	–0.200	0.247	0.014	0.530	–0.674*	–0.129	–0.129	0.006	–0.360	0.236	0.000	0.260
3 Age	0.005	–0.200	.	–0.011	–0.565	–0.062	–0.241	–0.083	0.058	–0.261	–0.410	0.314	–0.032	0.238
4 Time	–0.219	0.247	–0.011	.	0.041	–0.116	–0.204	0.148	–0.100	0.146	–0.083	0.114	–0.373	0.333
5 Global autonomic	0.128	0.014	–0.565	0.041	.	0.215	–0.213	0.366	0.347	–0.134	0.730*	–0.690*	0.620*	–0.507
6 Global vertigo	–0.147	0.530	–0.062	–0.116	0.215	.	0.100	0.189	0.586	0.271	0.192	–0.180	0.434	–0.132
7 Handicap	–0.176	–0.674*	–0.241	–0.204	–0.213	0.100	.	–0.133	–0.180	0.266	0.093	0.166	–0.440	–0.663*
8 Anxiety	0.470	–0.129	–0.083	0.148	0.366	0.189	–0.133	.	0.498	–0.228	0.652*	–0.687*	0.115	–0.338
9 Depression	0.194	–0.129	0.058	–0.100	0.347	0.586	–0.180	0.498	.	0.148	0.678*	–0.438	0.386	–0.146
10 Extroversion	–0.055	0.006	–0.261	0.146	–0.134	0.271	0.266	0.228	0.148	.	–0.134	0.515	–0.450	0.450
11 Neuroticism	0.445	–0.360	–0.410	–0.083	0.730*	0.192	0.093	0.652*	0.678*	–0.134	.	–0.874*	0.416	–0.508
12 Optimism	–0.282	0.236	0.314	0.114	–0.690*	–0.180	0.166	–0.687*	–0.438	0.515	–0.874*	.	–0.592	0.817**
13 Self–esteem	–0.023	0.000	–0.032	–0.373	0.620*	0.434	–0.440	0.115	0.386	–0.450	0.416	–0.592	.	–0.691*
14 Locus of control	–0.301	0.260	0.238	0.333	–0.507	–0.132	–0.663*	–0.338	–0.146	0.450	–0.508	0.817**	–0.691*	.

*Correlation is significant at the 0.05 level; **correlation is significant at the 0.01 level.

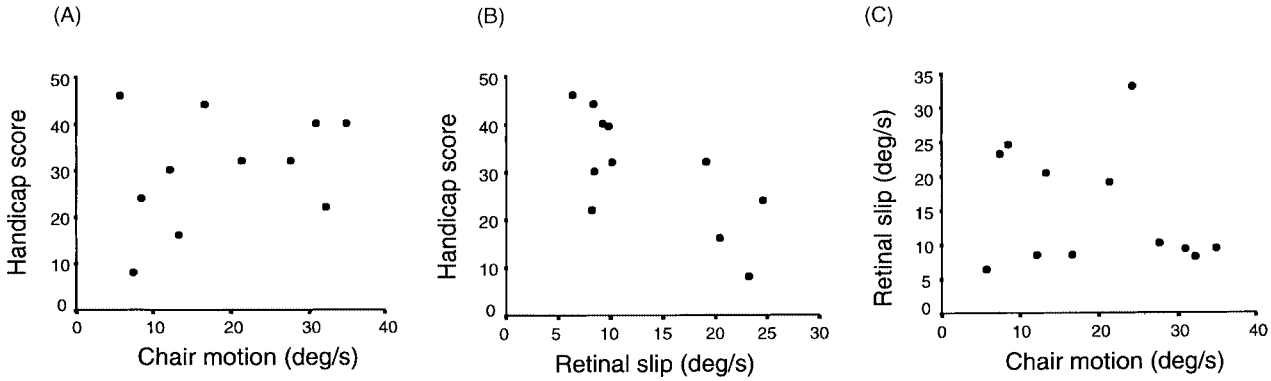

Fig. 4 Scatter-plots of data from the LD subjects showing the relationship between (**A**) oscillopsia handicap scores and chair amplitude settings ($r = -0.176$, $P = 0.606$), (**B**) handicap scores and retinal slip ($r = -0.674$, $P < 0.05$) and (**C**) retinal slip and chair amplitude settings ($r = -0.182$, $P = 0.593$).

able to tolerate greater self-motion than subjects with poorer image stabilization.

Discussion

The results of the psychophysical experiment highlighted a difference between the chair amplitude settings chosen by LD patients and controls when attempting to establish their most comfortable view of the video image. Under these experimental conditions patients preferred significantly less chair motion than the controls. The patients did, however, choose a wide range of chair amplitude settings, but these were not correlated with the amount of retinal slip experienced during the test. In addition, there was no correlation between handicap due to oscillopsia and the chosen chair speed. However, lower oscillopsia handicap scores were associated with a greater degree of retinal slip during the tests. In our questionnaire, patients were required to indicate the degree of difficulty experienced with activities (handicap) that are potentially disrupted by oscillopsia. It is assumed that the degree of difficulty reported corresponds with the severity of oscillopsia experienced by the patient. For this study, therefore, reported handicap was taken as a measure of the severity of oscillopsia in our patient group.

Self-motion and oscillopsia

A feature of our psychophysical study was the difference between chair amplitude settings made by the LD subjects and controls. We can conclude that mechanisms which may compensate for oscillopsia are incapable of allowing patients to feel entirely comfortable viewing images under conditions of self-motion. LD subjects' preferences for less self-motion may have been expected if patients employed a strategy of minimizing self-motion to reduce oscillopsia. However, if the patients had employed this strategy we would have expected a correlation between chair amplitude setting and oscillopsia handicap score. The absence of such a relationship indicates that patients did not minimize self-motion in order to reduce the impact of oscillopsia.

Chair amplitude settings were also not found to be correlated with retinal slip suggesting that chair settings were not influenced by the accuracy of compensatory eye movements achieved during the task. Although enhanced compensatory eye movements would lead to a reduction in retinal slip during self-motion, our patients who suffered least retinal slip were not necessarily those who selected greater chair motion. This appears to rule out the hypothesis that enhanced pursuit and optokinetic eye mechanisms, which may allow LD subjects to stabilize images on the retina during self-motion (Gresty *et al*., 1977; Huygen *et al*., 1989), lead to reduction of oscillopsia.

Retinal slip and oscillopsia

Normal subjects in this study experienced a degree of retinal slip (~5°/s) even under the best viewing conditions of the experiment. It is known that a small degree of retinal slip (up to ~100′arc/s) is crucial to maintain a clear visual image as it provides important cues about the visual environment and prevents perceptual fading (Kelly, 1979; Skavenski *et al*., 1979; Tulunay-Keesey and VerHoeve, 1987). In addition, Steinman and Collewijn asked subjects to fixate on a stationary distant target (5000–35 000 m) and to actively oscillate their head about the vertical axis (the rotations were between 0.25 and 5 Hz). They found mean retinal slip of around 4°/s (SD 3.9) and, even with this degree of slip, vision was subjectively reported to be stable, clear and fused (Steinman and Collewijn, 1980). However, movement of sinusoidal gratings (at 1°/s) increases contrast detection thresholds (compared with a static condition), particularly at high spatial frequencies (Burr and Ross, 1982). The retinal slip that our normal subjects suffered at the point where they perceived the most comfortable visual image, however, is more consistent with the findings of Steinman and Collewijn (Steinman and Collewijn, 1980) than those of Burr and Ross (Burr and Ross, 1982). In the present study and that of Steinman and Collewijn, complex images with broad band spatial frequency information were presented and may

indicate that perceptual image stability is established on the basis of coarse, rather than fine, image features.

For the LD subjects in this study, greater retinal slip correlated with lower oscillopsia handicap scores. Wist and colleagues found a dissociation between retinal slip and self-reports of oscillopsia in patients with oculomotor dysfunction (Wist *et al*., 1983); furthermore, normal subjects achieve perceptual image stability during retinal image motion (Steinman and Collewijn, 1980). In contrast, the results of our study are intriguing as they indicate a strong relationship between retinal slip suffered during our task and handicap reported by patients. A similar finding in LD patients has been reported previously in that optokinetic gain during whole-body oscillation was found to be inversely related to the degree of oscillopsia (Bronstein and Hood, 1987). We propose, therefore, that a tolerance to retinal slip may underlie adaptation to oscillopsia.

An explanation of how retinal slip may be tolerated by LD subjects is through the reduction of visual motion sensitivity. Evidence for such a loss of sensitivity to motion was first described in patients with oculomotor disorders and was proposed to account for the rarity of reports of oscillopsia among these patients (Dietrich and Brandt, 1987). Subsequent studies have shown similar results for LD patients (Morland *et al*., 1995, 1998; Grunbauer *et al*., 1998; Shallo-Hoffmann and Bronstein, 1998). Morland and colleagues measured the velocity discrimination of four LD subjects under static and self-motion conditions; they found that two subjects had normal and two had reduced velocity discrimination (Morland *et al*., 1998). Similar results were found among a sample of 11 LD subjects for the detection of both vertical and horizontal moving gratings (Shallo-Hoffmann and Bronstein, 1998). Grunbauer and colleagues found that elevations in displacement thresholds for small, slow moving targets were evident even when patients' heads were stationary (Grunbauer *et al*., 1998). In contrast, one of the patients studied by Morland and colleagues only displayed an elevation in motion discrimination thresholds during whole-body motion (Morland *et al*., 1998). Although the stimuli used in the studies described differed significantly, the raised visual motion detection thresholds in LD patients have emerged from all the studies and have been interpreted as an adaptive compensatory mechanism that could reduce oscillopsia.

It should be stressed that all the measures of motion discrimination described above do not assess genuine object motion perception. Object motion perception (as opposed to retinal image motion) has been shown to vary with whole-body motion in normal subjects (Probst *et al*., 1984). However, Mesland and colleagues evaluated object motion perception during whole-body motion in a group of LD patients and found that the judgement of object motion was made only with respect to the body (even during body motion) (Mesland *et al*., 1996). It would appear, therefore, that object motion perception during whole body motion is non-veridical in LD patients, but that judgements of object motion are made with respect to the head/body independent of its motion. The experiments reported here were designed to maintain a constant sinusoidal motion between the body and visual image, and given the results of the study by Mesland and colleagues (Mesland *et al*., 1996), we believe that object motion perception of the visual stimulus is unlikely to have varied for different whole-body oscillations.

Relationship between handicap and other psychological factors

Greater reports of handicap were found to relate to a strong external locus of control. The concept of locus of control is frequently used in health research (Partridge and Johnston, 1989) and refers to a person's tendency to view their illness as something that they have control over (internal locus of control) as opposed to being outside their control (external locus of control). Thus, LD subjects, for whom higher oscillopsia handicap scores were observed, perceived themselves to have little personal control over their disorder. This is of relevance because it is widely held that adaptation to vertigo (Cooksey, 1946) and adaptation to prisms in VI nerve palsy patients (Shallo-Hoffmann *et al*., 1996) requires repeated exposure to perceptually incongruent situations. Therefore, patients who question the benefit of rehabilitation programmes and who subsequently adopt avoidance strategies could potentially hinder the development of compensatory mechanisms. This in turn could increase, or at least prevent reduction of handicap.

The present study did not establish any significant relationship between age, length of time since the onset of the disorder and the degree of reported handicap due to oscillopsia. However, in a previous study of LD patients (aged 17–73 years, with oscillopsia for 6 months to 35 years) it was observed that older subjects with more recent vestibular loss were classified with a greater severity of oscillopsia (Bronstein and Hood, 1987). The discrepancy between those findings and the present results may relate to the different age ranges of the two patient samples.

In conclusion, the results of this study suggest that, among LD subjects, there may be a change in visual processing that reduces oscillopsia and thus limits the handicap experienced by the patient in their everyday activities. However, the questionnaire results demonstrate that psychological factors, such as locus of control, have an important role in patient perception of illness and their potential adaptation to that illness.

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Appendix

BALANCE DISORDER CHECKLIST

Balance problems can produce a range of symptoms as well as having various effects on a person's life. This questionnaire is aimed at addressing YOUR balance difficulties. Please read the questions carefully and remember that there are no right or wrong answers—we are interested in your personal experiences.

SECTION A: SYMPTOMS

Please think of your symptoms since the start of your illness and state (by circling the appropriate letter) whether you have experienced any of the following:

A	B	C	D	E
Never	At the beginning but not anymore	I occasionally have this symptom	I frequently experience this symptom	I continuously experience this symptom

1. A feeling that your surroundings are spinning or moving around	A	B	C	D	E
2. An appearance of the world wobbling, jumping or blurring in some way	A	B	C	D	E
3. Pains in lower part of back	A	B	C	D	E
4. Nausea	A	B	C	D	E
5. Vomiting	A	B	C	D	E
6. A feeling that you are spinning around	A	B	C	D	E
7. Pains in heart or chest region	A	B	C	D	E
8. Unsteadiness that may cause you to fall	A	B	C	D	E
9. Heavy feeling in arms or legs	A	B	C	D	E
10. Light-headedness	A	B	C	D	E
11. Tension or soreness in muscles	A	B	C	D	E
12a. The appearance of the world:					
moving up and down	A	B	C	D	E
moving side to side	A	B	C	D	E
swaying or tilting	A	B	C	D	E
moving in and out	A	B	C	D	E

12b. If you do experience this movement does it occur when looking:

straight ahead	YES	NO
left	YES	NO
right	YES	NO
up	YES	NO
down	YES	NO

If you do not experience this movement pass to question 13

13. ONLY ANSWER THIS QUESTION IF YOU HAVE EVER HAD A SENSATION OF SPINNING. IF NOT PASS TO QUESTION 14

If you have ever had spinning attacks then please think back to when you first had these attacks and state whether you became aware of having a spinning sensation gradually, over a period of time, or was it a sudden occurrence (i.e. you can remember the occasion when it first happened)?

GRADUAL SUDDEN

Please answer either section (a) or section (b) below:

(a) If the spinning attacks were of gradual onset please could you give an indication of the period of time over which you became aware of it:

_____

(b) If the spinning attacks were of sudden onset please could you give the approximate date of when you first noticed it:

_____

Now please think of whether there have been any changes in the spinning sensation since you first noticed it:

Do you think that these attacks occur less often, more often or about the same?

LESS MORE SAME

When the attacks occur are they less severe, more severe or about the same?

LESS MORE SAME

14. ONLY ANSWER THIS QUESTION IF YOU HAVE EVER HAD A WOBBLING, JUMPING OR BLURRING OF VISION. IF NOT PASS TO QUESTION 15

If you have ever noticed a wobbling, jumping or blurring then please indicate if you became aware of this gradually, over a period of time, or was it a sudden occurrence?

GRADUAL SUDDEN

Please answer either section (a) or section (b) below:

(a) If the wobbling, jumping or blurring was of gradual onset please could you give an indication of the period of time over which you became aware of it:

_____

(b) If the wobbling, jumping or blurring was of sudden onset please could you give the approximate date of when you first noticed it:

_____

Now please think of whether there have been any changes in the wobbling, jumping or blurring since you first noticed it:

Do you think that the movement occurs less often, more often or about the same?

LESS MORE SAME

Do you think that the intensity of the movement (i.e. the speed or size of the movement) has increased, decreased or is it about the same?

INCREASED DECREASED SAME

15. If you experience a spinning sensation does anything
    (a) provoke it YES NO
    (b) stop it YES NO

If yes, please give details below.

_____

_____

_____

If no, please move to question 16.

16. If you ever experience a wobbling, jumping or blurring movement does anything:
    (a) provoke it YES NO
    (b) stop it YES NO

If yes, please give details below.

_____

_____

_____

If no, please move to question 17

SECTION B: THE EFFECTS OF YOUR BALANCE PROBLEM

Please think of the activities that you have been unable to participate in since the start of your illness and also think about how you are able to function now. For each of the following questions you will have four options:

A	B	C	D
No difficulty	Sometimes difficult	Difficult but can cope	Cannot do it

17. Driving along a bumpy road A B C D
18. Walking in a straight line A B C D
19. Reading/counting objects while moving A B C D
20. Cycling A B C D
21. Swimming A B C D

22. Watching sporting activities from the sideline	A	B	C	D
23. Participating in sporting activities	A	B	C	D
24. Going up and down stairs	A	B	C	D
25. Dancing	A	B	C	D
26. Using public transport	A	B	C	D
27. Recognising faces while you are moving	A	B	C	D
28. Walking down supermarket aisles	A	B	C	D

29. Other activities (please state):

30. Do you sometimes avoid any of the above activities because it is upsetting for you to try them?

YES NO

If yes, please write the number of the activities (which can be found on the previous page) below:

31. Do you have difficulty with any of the above activities because of physical limitations (i.e. it is uncomfortable or difficult for you to carry out)?

YES NO

If yes, please write the number of the activities (which can be found on the previous page) below:

32. Are any of these activities more difficult:
    (a) in darkness YES NO
    (b) after drinking alcohol YES NO

If yes, please state the situation and the particular activity.

33. Please indicate below any other symptoms or difficulties that you have experienced. You can also use this space for any comments that you might have.

Thank you for your co-operation