Pulfrich's phenomenon in unilateral cataract

Stephen M Scotcher, D Alistair H Laidlaw, Christopher R Canning, Mark J Weal and
Richard A Harrad

Updated information and services can be found at:
http://bjo.bmj.com/cgi/content/full/81/12/1050

These include:

References
This article cites 18 articles, 4 of which can be accessed free at:
http://bjo.bmj.com/cgi/content/full/81/12/1050#BIBL

1 online articles that cite this article can be accessed at:
http://bjo.bmj.com/cgi/content/full/81/12/1050#otherarticles

Rapid responses
You can respond to this article at:
http://bjo.bmj.com/cgi/eletter-submit/81/12/1050

Email alerting service
Receive free email alerts when new articles cite this article - sign up in the box at the
top right corner of the article

Notes

To order reprints of this article go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to *British Journal of Ophthalmology* go to:
http://journals.bmj.com/subscriptions/

Pulfrich's phenomenon in unilateral cataract

Stephen M Scotcher, D Alistair H Laidlaw, Christopher R Canning, Mark J Weal, Richard A Harrad

Abstract

Aims—To determine whether unilateral cataract causes a pathological Pulfrich's phenomenon.

Methods—29 subjects with unilateral cataract and contralateral pseudophakia were assessed on their ability to perceive the Pulfrich phenomenon. Using a computer generated pendulum image, and graded neutral density filters, a series of forced choice trials were performed in which the subject was required to describe the direction of any apparent pendulum rotation. A pathological Pulfrich effect was said to occur when apparent rotation was perceived in the presence of a zero strength neutral density filter. The size of any pathological Pulfrich effect which was present was quantified by neutralising the perceived pendulum rotation with neutral density filters of varying strength placed before the better seeing eye.

Results—20 out of 29 subjects were able to perceive apparent pendulum rotation when uniocular filtering was performed. In the group (n=12) which was tested both before and after cataract extraction with intraocular lens implantation, a statistically significant pathological Pulfrich effect was demonstrated preoperatively, compared with a group of normal control subjects. This effect was abolished after cataract extraction (p=0.009). The median size of the effect was equivalent to a 0.25 log unit neutral density filter over the non-cataractous eye. The subjects who were unable to perceive the Pulfrich phenomenon at all had a significantly greater difference in the visual acuity of each eye (p=0.045) and significantly worse stereoacuity than those who were able to perceive the effect (p=0.002).

Conclusions—Unilateral cataract can cause a pathological Pulfrich phenomenon. This finding may explain why some patients with unilateral cataract complain of visual symptoms that are not easily accounted for in terms of visual acuity, contrast sensitivity, or stereoacuity.

(*Br J Ophthalmol* 1997;**81**:1050–1055)

Pulfrich's phenomenon[1] (or effect) is a binocular visual illusion in which a pendulum swinging in the fronto-parallel plane appears to follow an elliptical path when one eye is covered with a light attenuating filter. The illusory rotation is clockwise from above when the left eye is filtered, and anticlockwise when the
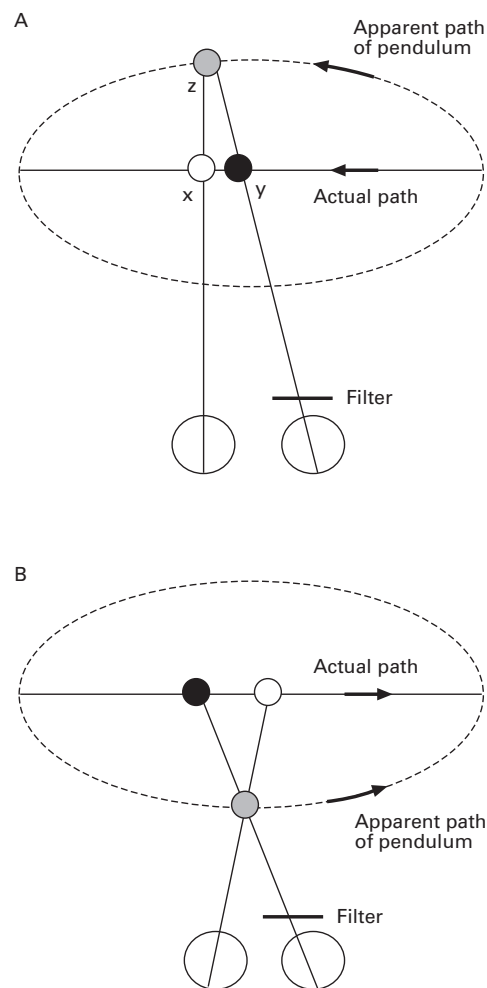
filter is over the right eye. The depth of apparent rotation increases with the density of the filter.

The phenomenon is thought to be due to a uniocular delay in retinocortical transmission. The attenuating filter induces a delay by reducing retinal illumination, thereby increasing photoreceptor latencies.[2] At a cortical level this delay leads to a disparity between the inputs of the two eyes, which is interpreted as a change in the apparent distance between the target and the observer (Fig 1).

Pulfrich's phenomenon is recognised to occur pathologically (that is, in the absence of a uniocular filter) in patients with unilateral or asymmetrical optic nerve disease, such as might be induced by demyelination.[3] The 'size', or depth, of a pathological Pulfrich effect may be quantified by placing neutral density filters of increasing strength over the better seeing eye until the apparent rotation is abolished.

Distortions of apparent velocity, attributed to the Pulfrich effect, have been described when driving while wearing a uniocular filter.[4] Patients with optic nerve disease who experience a pathological Pulfrich effect may also be aware of symptoms relating to depth perception and judging distances—for example, when driving.[5]

Patients with unilateral cataract are handicapped in ways that are not explained by their binocular visual acuity or contrast sensitivity; they frequently complain that their cataractous eye interferes with their vision.[6-8] A cataract may reduce retinal illumination, or may blur the retinal image. Decreased retinal illumination[9] and blur[10] both cause a prolongation of the visual evoked response. Might a unilateral cataract induce a pathological Pulfrich effect?

We designed a computer graphics program to present a perpetually swinging pendulum on a monitor. We used this to investigate for the presence of a pathological Pulfrich's phenomenon in patients before and after second eye cataract surgery.

Subjects and methods

SUBJECTS

Three groups of subjects were tested. The *preoperative* group contained 29 patients with unilateral cataract and contralateral pseudophakia but no other eye disease. These subjects were patients listed at Southampton Eye Unit for second eye cataract surgery, who fulfilled the entry criteria and consented to participate in the study. The mean age was 69.4 years (range 45–86). All had corrected visual acuities

Southampton Eye Unit
S M Scotcher
C R Canning

Department of Ophthalmology, University of Bristol
D A H Laidlaw

Department of Electronics and Computer Science, University of Southampton
M J Weal

Bristol Eye Hospital
R A Harrad

Correspondence to:
Mr S M Scotcher, Birmingham and Midlands Eye Centre, City Hospital NHS Trust, Dudley Road, Birmingham B18 7QU.

Figure 1 *Pulfrich's phenomenon. In this example the right eye is covered by a light attenuating filter. As the pendulum swings from right to left (A), the left eye sees the pendulum at point x. At the same moment, the right eye sees the pendulum at point y. At a cortical level this disparity between the inputs from the two eyes is interpreted as a change in the apparent distance between the target and observer, and the pendulum is consequently perceived as being at point z, behind the actual plane of the swinging pendulum. When the pendulum changes direction (B), the pendulum is perceived to swing anterior to its true path.*

of at least 6/9 in the pseudophakic eye (median acuity 6/6, range 6/5 to 6/9). The visual acuity of the cataractous eyes varied between 6/9 and counting fingers (median acuity 6/12). The median Titmus stereoacuity of this group was 100 seconds of arc (range 40–3000 seconds of arc).

The *postoperative* group contained 12 patients from the preoperative group, all of whom had been able to perceive Pulfrich's phenomenon, who were retested when visually rehabilitated following second eye cataract surgery. All had undergone a successful phacoemulsification (n=10) or extracapsular procedure with posterior chamber lens implantation. The mean age of this group was 69.0 years (range 45–83). The median acuity of each eye in this group was 6/6 for the recently operated eye (range 6/4–6/6), and 6/6 for the first operated eye (range 6/4–6/6). Their median stereoacuity was 60 seconds of arc (range 40–80 seconds of arc).

The *control* group contained 11 healthy volunteers, who underwent the same testing procedure. The mean age was 29.8 years (range 25–46 years). The corrected visual acuity was at least 6/6 in each eye. The median stereoacuity of this group was 40 seconds of arc (range 40–60 seconds of arc).

All subjects were refracted and wore an appropriate distance (6 metres) correction throughout the experiment. The best corrected visual acuity of each eye was measured using a Snellen chart. Where statistical analysis was required, the visual acuity results were converted to a logMAR format by taking the base 10 logarithm of the reciprocal of the decimalised Snellen fraction. Stereoacuity was measured using the Titmus test, read at 33 cm with the appropriate near correction, employing a forced choice technique (subjects being required to make a specific choice until an incorrect response was given). Pulfrich's phenomenon was then demonstrated to each patient. Those who could not perceive pendulum rotation with any strength of uniocular filter did not undergo further testing.

APPARATUS

A personal computer with a 486DX66 processor and a S-VGA graphics card was used to generate the 'pendulum' stimulus. Smooth harmonic motion was achieved using a programming technique which computed dynamically each new position of the bob, simultaneously erasing the old bob and redrawing the new bob for each frame. The stimulus, a black target on a white background, was presented on a 14 inch monitor viewed from 2.5 metres. The screen luminance was 80 lux, with a target contrast of approximately 80%. The target, or bob, was 0.75 cm in diameter. The radius, angular extent and frequency of the swing of the pendulum were 80 cm, 6 degrees, and 0.72 Hz respectively. The room lighting was standardised at 5.0 lux. These settings were chosen following trials in normal subjects, which had established the optimum conditions for visualising the Pulfrich effect using this apparatus.

TESTING PARADIGM

Those subjects who were able to perceive pendulum rotation underwent a series of single blind forced choice trials. During these trials they binocularly viewed the swinging pendulum with a neutral density filter (NDF) over one eye and a clear ('zero strength') filter over the fellow eye. During each trial the subject was required to describe the apparent rotation of the pendulum as clockwise from above, anticlockwise, or absent (neutralised). The neutral density filters ranged in 0.1 log unit steps from 0 up to 1.0 log units. For each strength of filter used, a total of five trials per eye were performed, but the strength and laterality of the NDF for each individual trial was known only to the examiner. When consistent responses for all five trials with a particular filter were recorded for two successive filter strengths (that is, scores of +5 or −5, as described below), then no filters of a higher strength were presented to that eye.
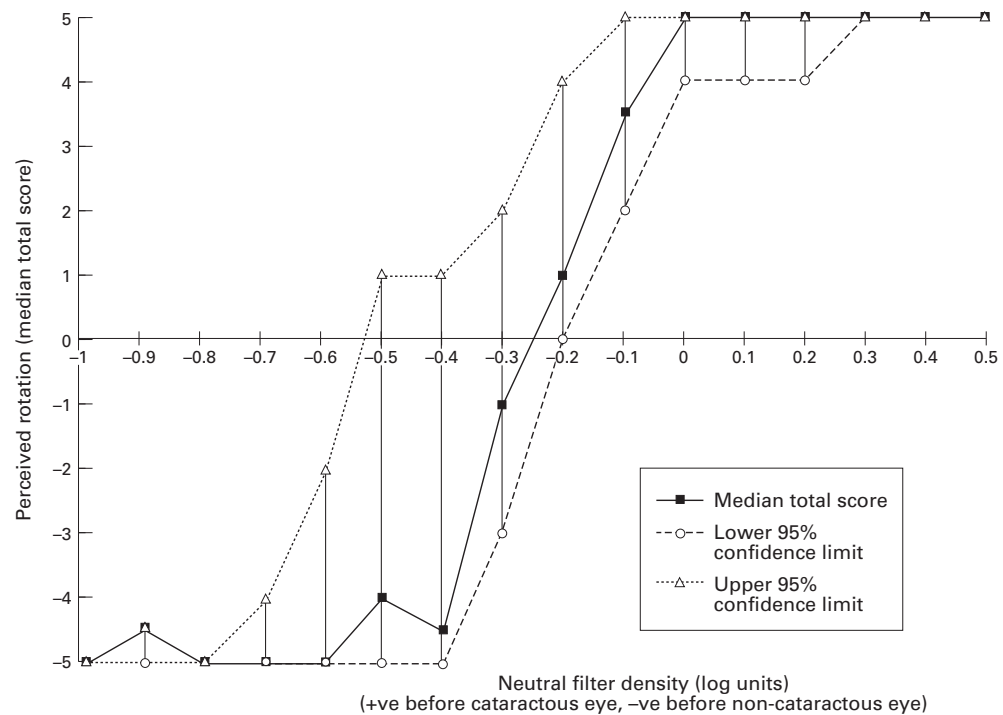
Figure 2 Preoperative subjects (n=12). Perceived rotation (median total score) with 95% confidence intervals plotted against neutral filter density (log units); +ve filter value = filter over cataractous eye; −ve filter value = filter over pseudophakic eye.

The test time per subject ranged from 30 to 45 minutes.

SCORING

An objective of the testing procedure was to measure, and graphically represent, the Pulfrich effect in terms of the magnitude of 'perceived rotation' at different filter densities. Filters placed before the cataractous eye would be expected to enhance any pathological Pulfrich effect caused by the cataract (that is, rotation made more apparent), while filters placed before the better seeing eye would be expected to reduce, neutralise, or reverse the effect. The density of filter required to neutralise rotation was taken as a measure of any pathological Pulfrich effect induced by the cataractous eye.

During each trial the cataractous eye (or the right eye in the case of the control subjects) was deemed to be the reference eye. A filter before the reference eye was regarded as a positive filter; the same filter placed before the fellow eye was regarded as a negative filter. For each individual trial, perceived rotation in the direction that would be expected if the reference eye was filtered scored +1. Rotation which was in the opposite direction to that which would be expected scored −1, and neutralised or absent rotation scored zero. For example, in a subject with a left cataract, clockwise rotation scored +1; anticlockwise rotation in the same subject scored −1.

From these trials a series of total scores between −5 and +5 were calculated for each subject; these represented the sum of the individual scores for the five trials of each filter strength in front of each eye. A high plus or minus score implied a consistently perceived direction of rotation and by inference a strong Pulfrich effect. A total score of zero for any strength and laterality of filter was considered to reflect the *neutralisation point* for that patient, this being a measure of any pathological Pulfrich effect that was present.

Results

Nine of the 29 preoperative patients (31%) were unable to perceive pendulum rotation, irrespective of the strength of uniocular neutral density filter which was used. One of the 29 patients (3%) perceived a Pulfrich's phenomenon which could not be reversed with any strength of available filter over her pseudophakic eye.

The other 19 subjects (66%) with unilateral cataract were able to perceive Pulfrich's phenomenon which could be reversed if a sufficiently strong filter was placed over the pseudophakic eye. Twelve of these 19 subjects were tested both before and after second eye cataract extraction (Figs 2 and 3); data regarding these 12, who acted as their own controls, were analysed in detail. The other seven subjects did not make themselves available for retesting.

For the 12 subjects tested pre- and postoperatively, in trials using a zero strength neutral density filter (clear filters over both eyes) the median net *preoperative* score was +5 (non-parametric 95% confidence interval[11] +4 to +5). The results are presented graphically in Figure 2. The estimated median size of the Pulfrich effect was 0.25 log units. This was the density of filter over the pseudophakic eye required to neutralise the effect, resulting in a total score of zero, as represented by the
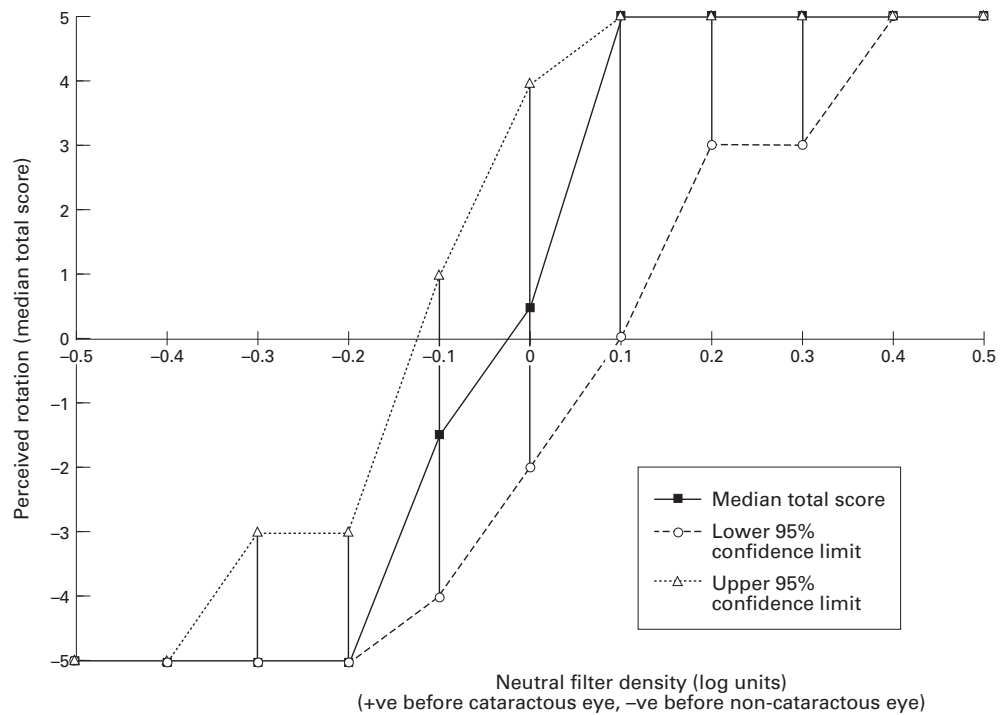
Figure 3   Postoperative subjects (n=12). Perceived rotation (median total score) with 95% confidence intervals plotted against neutral filter density (log units). +ve filter value = filter over second operated eye, −ve filter value = filter over first operated eye.
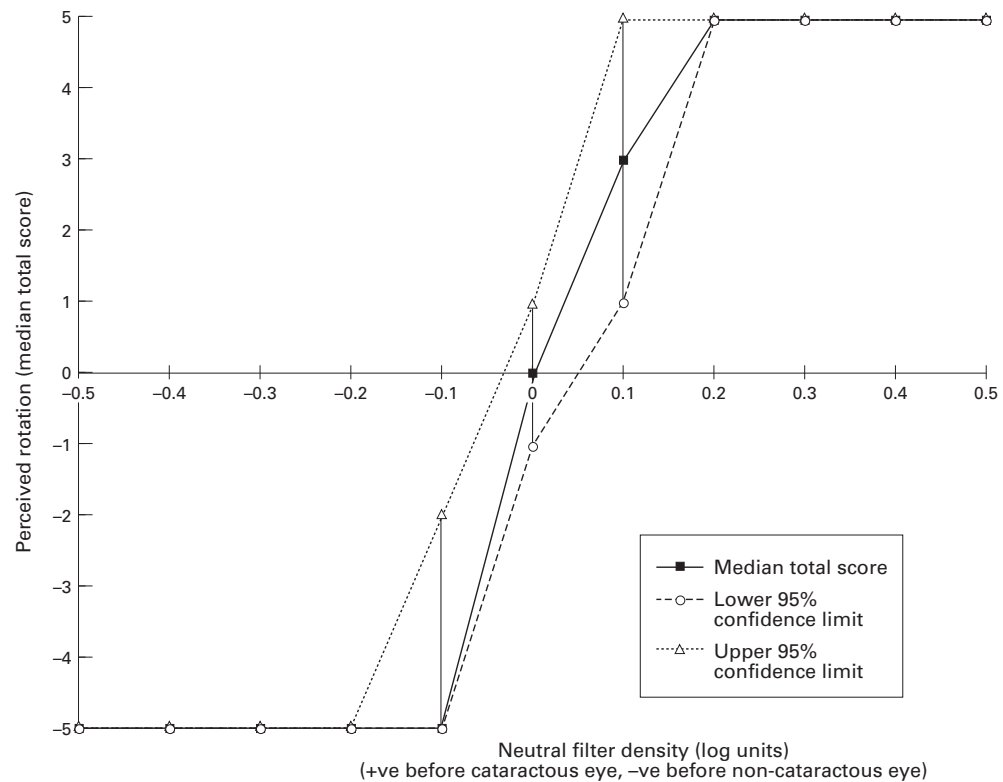

Figure 4   Control subjects (n=11). Perceived rotation (median total score) with 95% confidence intervals plotted against neutral filter density (log units). +ve filter value = filter over right eye, -ve filter value = filter over left eye.

intersect of the frequency of seeing curve with the abscissa.

In trials using a zero strength neutral density filter the median total *postoperative* score for these 12 subjects was +0.5 (95% confidence interval −2 to +4). The results are presented graphically in Figure 3. Postoperative total scores using a zero strength filter were significantly lower than preoperative scores, following second eye surgery (Wilcoxon matched pairs signed rank sum test p=0.009).

Similar results were observed in the normal controls to those in the postoperative group (Fig 4; median total score 0, 95% confidence

interval −3 to +1, for trials using zero strength NDF). Preoperative total scores in trials using a zero strength filter were significantly higher than those of normal controls (p=0.0002, Mann–Whitney U test for unpaired data). Postoperative total scores using a zero strength filter were not significantly different from those of normal controls (p=0.37, Mann–Whitney U test).

The median difference in the visual acuity of each eye of the nine patients who could not perceive Pulfrich's phenomenon was 0.48 (log-MAR format) with a range 0.12 to 0.86. This was significantly worse than that of the 19 patients who could perceive a reversible Pulfrich's phenomenon (median difference 0.30, range 0–0.68; Mann–Whitney U test p=0.045). The median stereoacuity in the group who could not perceive Pulfrich's phenomenon was 3000 seconds of arc (range 80–3000). This was also significantly worse than that of the 19 patients who could perceive Pulfrich's phenomenon (median stereoacuity 100 seconds of arc, range 40–3000, Mann–Whitney U test p=0.002).

Discussion

This is the first full report of a pathologically occurring Pulfrich's phenomenon in patients with cataract.[12] We believe that this is also the first use of this type of testing paradigm and scoring system in the investigation of Pulfrich's phenomenon. By combining this paradigm with very fine gradations of neutral density filter strength we have been able to detect subtle defects of binocular function. The validity of this scoring system was supported by the fact that those patients who were able to perceive a reversible Pulfrich's phenomenon demonstrated the full range of net scores between +5 and −5; furthermore, the scores appeared to follow the sigmoid shaped progression which is typical of a 'frequency of seeing curve'.

We have obtained statistically significant evidence of a pathological Pulfrich's phenomenon in a subgroup of patients with unilateral cataract and contralateral pseudophakia. This pathological Pulfrich's phenomenon disappeared following second eye cataract extraction. No evidence of a significant pathological Pulfrich's phenomenon was found in a group of young normal controls. From this we conclude that unilateral cataract may induce a pathological Pulfrich's phenomenon.

Retinocortical transmission is delayed by reduced retinal illumination[9]; this is believed to be the mechanism by which Pulfrich's phenomenon is induced by a uniocular neutral density filter. It may also be delayed by retinal defocusing (blur),[10] this effect being most marked with small targets. Sokol and Moskowitz[13] showed that a 3 dioptre refractive error will result in a 12 ms increase in the latency of the pattern reversal VEP when a 12 second check is used, but only a 4.8 ms increase in latency when a 48 second check is used.

A cataract can both blur the retinal image and may also reduce retinal illumination via backward light scattering and absorption in a pigmented nucleus. The transmission of light through an 'optically significant' cataract is said to be reduced to 10% of normal; this is equivalent to the effect of a 1 log unit filter.[14 15] However, we only found an average effect of approximately 0.25 log units. The absence of a relative afferent pupillary defect as a result of this reduction in light transmission has been attributed to retinal compensatory mechanisms.[16] Wolpert *et al*[17] measured the size of the Pulfrich effect over a 9 day period of continuous uniocular filtering in normal subjects and demonstrated a 60% adaptation during this time (in other words the measured Pulfrich effect became smaller). They postulated that the most likely site of adaptation is the retina, responding to the change in mean luminance. Landrigan[18] also showed that adaptation occurs and is complete after 22 days of wearing an uniocular X chrom lens. It seems likely therefore that significant, if not complete, retinal adaptation to reduced illumination would have occurred in our patients with cataract. Mechanisms such as defocusing may consequently be more important than reduced retinal illumination in causing a pathological Pulfrich effect in unilateral cataract. Our target size was small, and this may have enhanced any effect of defocusing on the VEP. On the basis of this study we do not feel it is possible to state with certainty which mechanism plays the more important role. It seems possible, however, that certain cataract types will be more likely to cause a pathological Pulfrich effect than others, although this study did not specifically address this issue.

The 9/29 patients who did not perceive pendulum rotation had a significantly greater difference in the acuity of each eye and significantly worse stereoacuity than those who were able to perceive the effect. Their inability to perceive Pulfrich's phenomenon may be because the stereo system is unable to function when the image in the cataractous eye is very degraded, as has been shown with respect to binocular inhibition summation and suppression.[19]

IS THE PULFRICH EFFECT RESPONSIBLE FOR VISUAL SYMPTOMS IN UNILATERAL CATARACT?

A number of the subjects in this study who were found to have a pathological Pulfrich effect also described difficulties while driving, in particular judging the position of the nearside kerb, and the position and trajectory of passing cars. The possibility that the Pulfrich phenomenon might be responsible for some of the symptoms experienced by patients with cataract was raised as early as 1925.[20] Enright[4] was the first to describe illusions when driving caused by the Pulfrich phenomenon. He noted that when viewing a landscape from the side window of a moving car with the leading eye filtered, the velocity of the vehicle appears to be increased with an apparent increase in the size of objects and an increase in their apparent distance. When the trailing eye is filtered there is an apparent reduction in the speed of the vehicle, accompanied by dwarfing of objects and a reduction in their apparent

distance. Other authors have described the difficulties experienced by subjects with a pathological Pulfrich effect. These include playing ball games,[21] judging the direction of movement of pedestrians in a crowded street, and car travel,[22] when oncoming cars are perceived to cross the central reservation. There was a similarity between these difficulties and those noted by our subjects.

Recent studies have demonstrated that many patients with second eye cataract are aware that their cataractous eye interferes with their vision, and it has been shown that such patients perceive their vision to be improved following second cataract surgery.[6–8] While many of their symptoms may be explained by reduced visual acuity and contrast sensitivity leading to binocular inhibition, binocular rivalry, and poor stereoacuity,[6 8 19] we suggest that the Pulfrich phenomenon may also contribute to this problem, particularly in a moving environment. In summary, we have shown that a unilateral cataract can induce Pulfrich's phenomenon. Pulfrich's phenomenon may be a previously unrecognised cause of visual disability in patients with unilateral cataract.

1 Pulfrich C. Die Stereoskopie im Dienste der Isochromen und Heterochromen Photomtrie. *Naturwissenschaften* 1922;**10**:533–64.
2 Mansfield RJW, Daugman JD. Retinal mechanisms of visual latency. *Vision Res* 1978;**18**:1247–60.
3 Rushton D. Use of the Pulfrich pendulum for detecting abnormal delay in the visual pathway in multiple sclerosis. *Brain* 1975;**98**:283–96.
4 Enright JT. Distortions of apparent velocity: a new optical illusion. *Science* 1970;**168**:464–7.
5 Heron G, Dutton GN. The Pulfrich phenomenon and its alleviation with a neutral density filter. *Br J Ophthalmol* 1989;**73**:1004–8.
6 Laidlaw A, Harrad R. Can second eye cataract extraction be justified? *Eye* 1993;**7**:680–6.
7 Javitt JC, Steinberg EP, Sharkey P, Schein OD, Tielsch JM, West MD, *et al*. Cataract surgery in one eye or both. *Ophthalmology* 1995;**102**:1583–93.
8 Harrad RA, Whitaker A, Laidlaw DAH. Binocular rivalry in patients with unilateral cataract: A previously unrecognised cause of visual disability. *Invest Ophthalmol Vis Sci* 1994;**35**:1964.
9 Carroll WM, Halliday AM, Kriss A. Improvements in the accuracy of pattern visual evoked potentials in the diagnosis of visual pathway disease. *Neuro-ophthalmology* 1982;**2**:237–53.
10 Collins DWK, Carroll WM, Black JL, Walsh M. Effect of refractive error on the visual evoked response. *BMJ* 1979;**1**:231–2.
11 Altman DG. In: *Practical statistics for medical research*. London: Chapman and Hall, 1991:535.
12 Scotcher SM, Canning CR, Weal MJ, Hutchings GA, Laidlaw DAH, Harrad RA. Pulfrich's phenomenon in patients with unilateral cataract: A previously unrecognised cause of visual disability. *Invest Ophthalmol Vis Sci* 1995;**36**:S794.
13 Sokol S, Moskowitz A. Effect of retinal blur on the peak latency of the pattern evoked potential. *Vis Res* 1981;**21**:1279–86.
14 Sadun AA, Libondi T. Transmission of light through cataracts. *Am J Ophthalmol* 1990;**110**:710–2.
15 Zigman S, Groff J, Yulo T, Griess G. Light extinction and protein in the lens. *Exp Eye Res* 1976;**23**:555–67.
16 Sadun AA, Bassi CJ, Lessell S. Why cataracts do not produce afferent pupillary defects. *Am J Ophthalmol* 1990;**110**:712–4.
17 Wolpert DM, Miall RC, Cummings B, Boniface SJ. Retinal adaptation of visual processing time delays. *Vision Res* 1994;**33**:1421–30.
18 Landrigan DT. Measurements of the Pulfrich effect over days of exposure. *J Psychol* 1984;**117**:125–33.
19 Pardhan S, Gilchrist J. The importance of measuring binocular contrast sensitivity in unilateral cataracts. *Eye* 1991;**5**:31–5.
20 Grimsdale H. A note on the Pulfrich phenomenon with a suggestion on the possible clinical importance. *Br J Ophthalmol* 1925;**9**:63–5.
21 Frisen L, Hoyt WF, Bird AC, Weale RA. Diagnostic uses of the Pulfrich phenomenon. *Lancet* 1973;**ii**:385–6.
22 Larkin EB, Dutton GN, Heron G. Impaired perception of moving objects after minor injuries to the eye and midface: the Pulfrich phenomenon. *Br J Oral Maxillofacial Surg* 1994;**32**:360–2.