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Measurement of Interocular Delays with Dynamic Random-Dot Stereograms

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Summary. A psychophysical method of measuring interocular delay based on dynamic random-dot stereograms is presented. The measurement requires only about 2 min. The sensitivity of this method to detect differences in the transmission times of the two optic nerves is demonstrated in patients with multiple sclerosis and in healthy subjects in whom interocular delays were produced by using different luminance levels for each eye. This new method may be a useful and economic method for monitoring the time course of optic neuritis.

Key words: Random-dot stereograms – Interocular delay – Multiple sclerosis – Visual evoked potentials

Introduction

By the time multiple sclerosis (MS) is diagnosed there is usually an increased transmission time in at least one optic nerve due to demyelination. The monocular visual evoked potential (VEP) of the affected eye has an increased latency. If both optic nerves are affected, the effect on transmission is usually not equal for both pathways. Demyelination of one or both optic nerves may therefore yield an interocular delay (IOD). Since the early 1970s (Halliday et al. 1972) increased latencies and IODs of pattern-reversal VEPs have formed an important part of the diagnosis of MS.

IODs may also have an influence in the perceptual domain. One well-known effect is the Pulfrich phenomenon. An object moving on the fixation plane seems to move in front or behind this plane as a function of IOD, velocity and direction of movement. Wist et al. (1978) used a psychophysical method based on the Pulfrich phenomenon (Pulfrich spatial-frequency method) for the diagnosis of MS. In this way, the authors were able to diagnose 93% of their MS sample correctly, compared with 97% correct diagnoses by the VEP method. In combination, both methods resulted in 100% correct diagnoses. In spite of the effectiveness of this combined psychophysical/VEP method, psychophysical approaches have not been used routinely in the diagnosis of MS. Although the Pulfrich spatial-frequency method cited above requires only a further 15 min in addition to the 30 min for the standard VEP method, this additional time has probably been a factor preventing its routine use.

This paper describes a psychophysical method for the measurement of IODs, which requires only 1–2 min. It is based on dynamic random-dot stereograms (DRDSs) which were introduced by Julesz (1971) for the investigation of global stereopsis. This procedure, called "Intocdelmeter," can be carried out with a simple microcomputer.[1]

Materials and Methods

Definitions

Random-Dot Stereograms. RDSs consist of two random-dot pictures which are identical except for some sections of the pictures (e.g. squares) that are different only with respect to their horizontal displacements. By means of a stereoscope, both pictures can be binocularly fused: the horizontally displayed sections are perceived as shifted in depth. When horizontal disparity is crossed or uncrossed, these sections seem to be in front or behind the background, respectively.

Dynamic Random-Dot Stereograms. A DRDS consists of many RDSs which are uncorrelated with regard to the random-dot pattern but all have the same stereoscopic displacement in common. By means of a microcomputer, the RDSs can be shown with high frame rates on a screen. With monocular viewing one only sees dynamic noise; with binocular viewing, features shifted in depth are recognizable as in the case of single RDSs.

Delayed Dynamic Random-Dot Stereogram (DDRDS). Corresponding random dots of horizontally displaced sections within a

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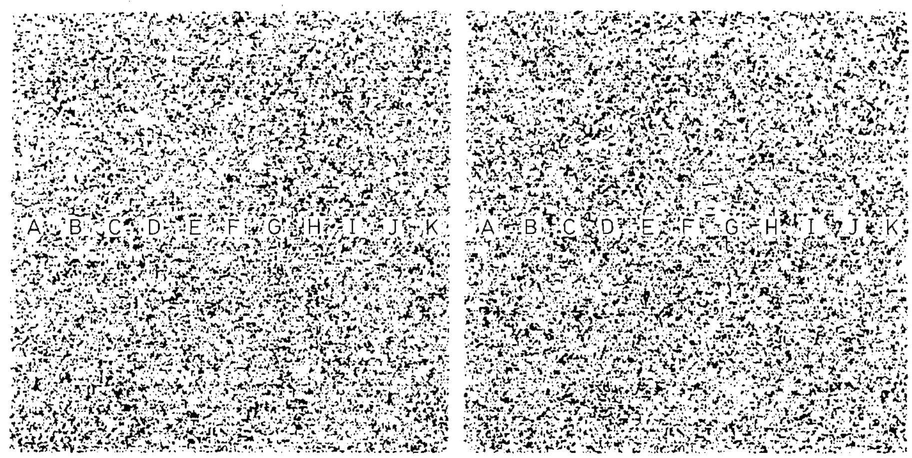
[1] Requests for copies of the procedure "Intocdelmeter" should be sent to the author. Please enclose an empty 3.5 inch diskette



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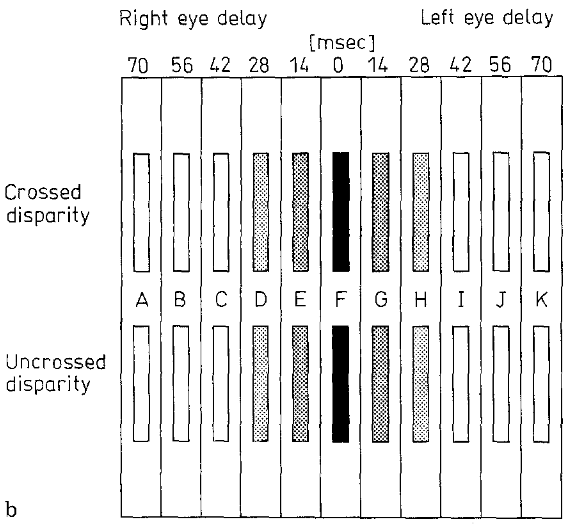

b

Fig. 1. **a** One of the 22 random-dot stereograms which are shown with a frame rate of 71.4 pictures/s. Without binocular fusion, only the letters can be recognized as figures on the random-dot background. **b** The internal structure of the random-dot stereograms. The 11 rectangles and their corresponding stripes which are characterized by crossed or uncrossed disparity differ with respect to interocular delay. For a healthy subject only the stripes from D to H are perceivable. The darkness of the stripes represents the degree of visual clearness. See text for further details

DRDS do not have to be presented simultaneously to each eye but can also be shown with an IOD. If this delay is not too large, stereoscopic vision is still possible.

Intocdelmeter

The method of DDRDS was used for the diagnostic procedure Intocdelmeter. It is programmed for an Atari ST microcomputer with a SM124 monitor adapted with a stereoscope fixed in front of the monitor. Intocdelmeter consists of 22 RDSs (see Fig. 1a) which are presented with a frame rate of 71.4 Hz, i.e. a new RDS appears every 14 ms on the screen. Each RDS has 11 rectangles labelled from left to right with A, B and so on up to K on the horizontal middle axis (see Fig. 1b). Above each letter are smaller stripes with crossed horizontal disparity and below such with uncrossed horizontal disparity. The larger rectangles and the smaller stripes vary from A to K in IOD. The delays change between A and E in steps of 14 ms from 70 ms to 14 ms for the right eye and between G and K from 14 ms to 70 ms for the left eye. There is no delay at position F.

In general, people experience stereoscopic vision in this procedure with delays of up to 28 ms. Thus, a normal subject without any IOD perceives the stripes most clearly at F (which have no delay), sees stripes at E and G (where the delays are 14 ms for the right and left eye, respectively) less clearly and perhaps sees blurred stripes at D and H (28 ms delays). Patients with a neuritis and delay of 40 ms on the left optic nerve will see the stripes most clearly at position C, because physically there is an IOD of 42 ms for the right eye, which compensates IOD due to increased transmission times of the left eye pathway. This patient should also see (less clearly) stripes in the neighbourhood of C (A, B and D, E). The effect of optic neuritis on IOD can easily be simulated with normal subjects by using neutral density filters which are known to increase transmission times (Wist et al. 1978). A 1 log unit filter held over the right eye would produce an IOD of about 15 ms for the right eye and would result in stereoscopic vision being most clear, seen at position G.

Diagnostic Procedure

The patients view the DDRDS through the stereoscope. They are asked whether they recognize structures displaced in depth above or below the letters. Most subjects report seeing stripes within 30 s. If after 1 min the patients do not see any stripes, they may be stereo-blind and the test cannot be carried out. If the patients do see stripes, they should be asked at which positions they see them. The patients will typically name 3–5 letters, e.g. E, F, G, H. They should then be asked for the sequence in which the stripes are most clearly seen. They may report seeing stripes most clearly at G, those at F and H equally clearly but less clearly than those at G, and only very blurred stripes at position E. The result should be noted in the form of a relation:

$G > F = H > E$

Fitting of IOD

Weighting factors are attached to each letter determined by its rank position. A weighting of 1 is given to the letter standing furthest to the right in the relation, a weighting of 2 to the letter to the left of this and so on. If ties are present, as in the example (F = H), average weightings are calculated:

G	F	H	E
4	2.5	2.5	1

The weighting of each letter is multiplied by the delay according to the letter position, and the products of all letters are then added. Delays of letters indicating left eye IODs (A, B, C, D, E) have a negative sign. This sum is divided by the sum of ranks. The result is a fit for the IOD.

$$\text{IOD} = \frac{4 \cdot (14\,\text{ms}) + 2.5 \cdot (0\,\text{ms}) + 2.5 \cdot (28\,\text{ms}) + 1 \cdot (-14\,\text{ms})}{4 + 2.5 + 2.5 + 1} = 11.2\,\text{ms}$$

Positive signs indicate a right eye IOD, while negative signs indicate a left eye IOD. The validity of the IOD fit is considered in the discussion.

Results

In nine healthy male subjects Intocdelmeter IODs were determined for 21 different neutral filter conditions ranging from 0 to 2.0 log units. Filters were held over the right eye only. Figure 2 shows mean values and standard deviations for the nine subjects. The relation between filter density and IOD is log-linear, as is known from previous studies. The regression slope from the mean values is 12.9 ms, i.e 1 log unit filter density increases IOD by 12.9 ms. The standard deviations increase between 0 and 2.0 log units from 2 to 6 ms because individual regression slopes vary between 9.8 and 19.3 ms per log unit.

Intocdelmeter IODs for seven MS patients were measured and related to IODs of VEP latencies. VEPs were evoked by a checkerboard pattern-reversal stimulus on a black and white monitor with a field size of 15° × 15° and a check size of 1° × 1°. The pattern-reversal frequency was 1 reversal/s. VEPs were recorded from position Oz (3 cm above the inion) against the linked ear lobes as reference. Two records were made, one with monocular right stimulation and one with monocular left stimulation. The peak latency of the major positive deflection (P100-Wave) was measured, which in normal people has a latency of 100 ms. The VEP IOD was determined by subtracting the left eye latency from the right eye latency.

The VEP IODs of the seven patients are shown together with the Intocdelmeter IODs in Table 1. Spearman's rank correlation between both sets of data was 0.96, but on the average the VEP IODs (mean value: 19.7 ms) were twice as large as the Intocdelmeter IODs (mean value: 10.3 ms).

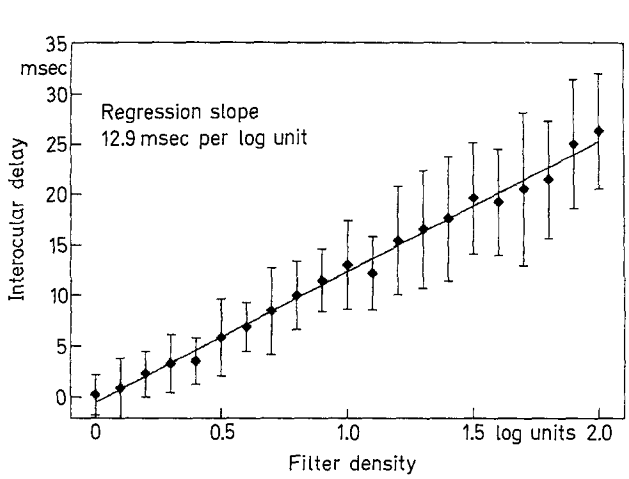

Fig. 2. Filter induced IODs measured by Intocdelmeter. Mean values and standard deviations from nine subjects for 21 different luminance conditions. While the luminance was kept constant (60 cd/m^2) for the left eye, the luminance of the right eye was decreased with filter densities between 0 and 2.0 log units. The slope of the mean values is 12.9 ms/log unit

Table 1. Visual evoked potential (VEP) interocular delays (IODs) and Intocdelmeter IODs from seven patients with multiple sclerosis (in ms)

Patient	VEP IOD	Intocdelmeter IOD
1	+26	+14
2	+13	+2
3	−12	−10
4	+29	+10
5	−4	0
6	−23	−13
7	+31	+23
$\frac{\sum\lvert\text{IOD}\rvert}{7}$	19.7	10.3

Discussion

The data points in Figure 2 show clearly that Intocdelmeter can detect even small changes in IOD. In spite of the fact that RDSs change only every 14 ms on the screen, it is possible to measure IOD to within a few milliseconds by scaling the perceived stripes with their relative clearness. The only preconditions for Intocdelmeter are sufficient visual acuity and stereopsis at least for a crossed or an uncrossed disparity. The task for the patient – ranking labelled stripes according to their perceived clearness – is thought to be less difficult than the demands of other psychophysical procedures, e.g. the Pulfrich method, where the perceived depth of a moving object has to be matched with the depth of a static object, or a procedure used by Regan et al. (1977), where the perception of "simultaneous" versus "successive" is the dependent variable. One further advantage of Intocdelmeter is that it does not require a time-consuming forced choice procedure. Only "one trial" for IOD determination is necessary. This makes Intocdelmeter useful in the daily monitoring of an optic neuritis. There remains the question of the validity of Intocdelmeter with regard to the "real" IOD. But what is the "real" IOD?

The correlation between the perceptual IOD and the VEP IOD in the data shown above is close, but the absolute values are not identical. VEP IODs are in all cases larger (up to 19 ms) than IODs from Intocdelmeter. Many other studies comparing VEP IODs and psychophysical IODs also show large differences between these methods in MS patients (Rushton 1975; Cook and Arden 1977; Wist et al. 1978; Bodis-Wollner et al. 1979). Furthermore, Regan et al. (1977) showed that VEP IODs can vary depending on temporal parameters of the visual stimulus. These results suggest that the extension of increased transmission time due to demyelination may depend on characteristics of the visual stimulation. It is probably not appropriate to speak of an absolute or "real" delay, independent of stimulus characteristics.

The important question for clinical use of Intocdelmeter is whether Intocdelmeter IOD is indicative of optic nerve demyelination. The first results with MS patients presented above seem to show this. The measurement of Intocdelmeter IODs from a larger sample of MS patients is in progress as a part of a larger study of stereoscopic VEPs.

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