The amplitude of accommodation of the eye is essentially assessed subjectively, although it can also be determined objectively by retinoscopy and refractometry, but the results usually differ from those obtained subjectively. An alternative objective method which is accurate would represent a useful tool to the clinician as well as the experimentalist using laboratory animals.

Refraction measured by visually evoked potentials (VEP) has proved to be very feasible. Using a similar technique to that adopted for refraction, we report measurements of the amplitude of accommodation which are in very good accord with the results obtained subjectively.

Materials and methods

APPARATUS
The pattern reversal stimulus consisted of a checkerboard made up of high-contrast black and white squares which was produced by a television pattern generator (Grass model, VPGM) fitted with a standard (P4) phosphor screen. The individual squares subtended 20 min of arc within a 5° square field. The mean luminance of the field was 70 cd/m². The stimuli were presented at a rate of 12 reversals per second and at a viewing distance of 66 cm.

Bipolar electrode configuration was used with the active electrode placed 2 cm above the inion on the midline and the reference electrode 7 cm above the inion on the midline. The ground electrode was attached to the right ear lobe. The active and reference electrodes were gold plated and applied to the head with electrode paste after the area had been thoroughly cleaned with acetone. The ground electrode was a silver disc similarly applied.

The scalp potentials were amplified by a Grass preamplifier (P511) and through a bandpass filter 3–100 Hz. The potentials were summed with a Princeton Applied Research Corporation Waveform Eductor model TDH–9, which was synchronised to the stimulus. 60 responses were averaged, each response lasting for 500 ms; thus a run lasted some 30 seconds. Simultaneously the potentials averaged by the computer were fed into a waveform integrator and the results were displayed on line digitally on a voltmeter. The integrator calculates the total area under the sine wave building up over the analysis period of 500 ms. In addition the VEPs were also written out on a strip chart recorder.

PROCEDURE
Each subject wore his distance correction, if any. The left eye was covered with a dark patch. The subject’s right eye adapted to the field luminance for some 5 minutes prior to starting the experiment. Fixation was on a point in the centre of the field, but no other instruction was given to the subject. We placed ophthalmic lenses in front of the right eye, starting with a +2.5 D lens, then in 0.5 D step towards plano continuing in 0.5 or 1 D step with minus lenses until the VEP was more or less constant. Between runs the subject was given a short rest. Frequent repetitions were carried out to test reliability throughout the experiment, and the whole procedure was repeated on 4 subjects several weeks.
later. The subject's judgment of sharpness or blurredness of the stimulus was also recorded. Finally a control run was made, that is, with the subject looking at the illuminated field but without the pattern.

Measurements of the subjective amplitude of accommodation were also made with the near-point rule (the push-up method), on which the subject is asked to fixate a word of the smallest paragraph on the card, which is brought towards the eye until it is blurred and retrieved until just clear. That last distance was taken to calculate the near point, and the amplitude of accommodation was determined by taking into consideration the distance refraction, if uncorrected. The measurement was repeated 3 times, monocularly.

In a preliminary investigation with the checkerboard pattern situated 2 m away from the subject's eye (with the squares also subtending 20 min of arc and the field 5° square) we found a low correlation between the amplitude of accommodation assessed subjectively (using the push-up method) and that assessed by VEP. Thus in the later study all measurements were carried out with the checkerboard relocated 66 cm from the subject's eye, thereby eliciting proximal accommodation.

Subjects
Forty-four people (22 females, 22 males) participated in this experiment. They ranged in age from 13 to 65 years and all had acuity of 6/6 or better.

Results
Amplitude of Accommodation
The effect of diminishing the power of the positive lenses was the same in all subjects. It consisted of a greater amplitude VEP up to a maximum which corresponds to the equivalent spherical ametropia of the subject (Fig. 1). Then, as minus lenses of increasing power were placed in front of the eye, accommodation was stimulated but to a different extent, and that is in addition to the well-known reduction with age. In fact the 44 subjects could be separated into 3 main groups. Group A (Fig. 1) represents people who maintain approximately the same VEP (that is, they accommodate progressively more and more as minus lenses are increased in order to maintain a retinal image focused approximately to the same degree) and then fall abruptly. Fifteen people (34%) were found to belong to this group. Group B (Fig. 1) represents people whose VEP falls rapidly just after the peak and then stays either constant or increases, to fall eventually quite steeply. Fifteen people (34%) belonged to this group.

Group C (Fig. 1) stands for people whose VEP diminishes progressively from the peak. This group contained 14 people (32%). Obviously little accommodative effort was made by these people, who accepted a rather blurred image. Typical results are shown in Fig. 2.

Then in almost all cases the VEP reached a nearly constant value as minus lenses were increased. That point (E in Fig. 1) is the highest negative lens which just produces a blurred image. This was confirmed by correlating the negative power for which each of the 41 subjects saw the pattern as blurred with that point on the individual curve. The correlation coefficient was found to be r=0.99, which is very high. In 3 cases belonging to group C it was not possible to assess a point at which the VEP became nearly constant, as the VEP progressively decreased until it reached noise level. In these 3 cases the upper limit of the amplitude was determined on the basis of the subject's verbal judgment of target sharpness.

In all other cases the upper limit of the amplitude of accommodation has been taken as that value of the negative lens at E, minus 0.5 D. The peak representing the higher VEP amplitude for the least accommodative effort represents the lower limit of the amplitude of accommodation and also by definition the subject's refraction. The validity of this VEP measurement of the amplitude of accommodation was determined by comparing it with that found by the clinical method by the near-point rule. These results are illustrated in Fig. 3. The correlation coefficient between the two sets of data was r=0.91.
In addition it was thought worthwhile to determine the difference in relative VEP amplitude between the point corresponding to maximum accommodation (X in Fig. 1) and the control level (N in Fig. 1). For each subject, (X−N) was calculated and the mean for the 44 subjects was found to be 19.4% (SD=11.8). Thus in cases where X may be difficult to determine, as in some subjects belonging to group C, it can be obtained by drawing a horizontal line 19.4% above the control value. It may be noted that this

![Graph showing typical results of VEP amplitude and the ophthalmic lens placed in front of the eye for one subject of each of the 3 types.](image)

**Fig. 2** Typical results of VEP amplitude and the ophthalmic lens placed in front of the eye for 1 subject of each of the 3 types. The arrows at the top of the curves indicate when the subject says that he sees the test pattern clearest, while those at the bottom indicate when he says that the test pattern is blurred. The fact that the age of each subject increases from group A to C is coincidental. CN=control.

![Graph showing comparison between subjective (push-up technique) and the VEP results of the amplitude of accommodation.](image)

**Fig. 3** Comparison between subjective (push-up technique) and the VEP results of the amplitude of accommodation. Each data point represents 1 subject. The bisecting line is represented on the graph.
horizontal line intersects the curve at two points, X and F in Fig. 1. X represents the upper limit of the amplitude of accommodation, and F was found to represent a mean positive lens of value 1.95 D (SD=0.7).

Therefore in difficult cases the upper limit of accommodation (X) may also be determined after first calculating point F, which lies on a more reliable part of the curve.

RELIABILITY
Reliability of the VEP measurements was determined by repeating the whole experiment (19 data points) on another day on 4 subjects. It was found to be very good, since correlation coefficients between the two sets of results were r = 0.91 (p < 0.001), 0.84 (p < 0.01), 0.90 (p < 0.001), and 0.71 (p < 0.05) for each subject, respectively.

REFRACTION
The mean spherical refraction for all 44 subjects obtained by VEP was found to be -0.43 D (SD=0.75), while the mean spherical refraction determined by the subject's subjective judgment of the target sharpness was -0.52 D (SD=0.73). The difference between the two is not significant (p > 0.1) and therefore one has to accept that the VEP spherical refraction provides as good a result as that obtained subjectively, a fact already established.5-8

EFFECT OF AGE
The amplitude of accommodation obtained by VEP as described above for each subject is plotted as a function of age in Fig. 4. It illustrates the well-known relationship between accommodation and age. The present data are compared to those of Donders' and Duane's.9-10 Our data tend to yield higher results of the amplitude of accommodation than either of these studies.

Discussion
The technique of determining the amplitude of accommodation by VEP is a feasible one. It provides a new objective means which is valid as evinced by the good correlation found with the subjective measurement (Fig. 3). It is also reliable. Like other studies of accommodation10 the results yield larger variations in the amplitude among younger than older subjects, and we also note the rapid decline up to the age of about 50 years and thereafter only a slight decrease (Fig. 4).

This objective method of measuring the amplitude of accommodation is of course more cumbrous and time-consuming than the subjective determination, but these technical constraints are common to all VEP measurements.4 However, the electrical responses, as in VEP refraction,5-8 are more valid than the other objective methods such as retinoscopy and refractometry, since they depend on the same initial receptive processes as vision itself. The other methods depend on light reflected from a different layer from that of the receptors.3

The present technique affords additional information on the accommodative behaviour of each subject, as accommodation is stimulated reflexly by negative lenses. We found that people can be divided into 3 categories depending on the stance which their accommodative system takes irrespective of age. Some people accept an increasingly more blurred image without accommodating to compensate this blurredness as negative lenses are placed in front of their eye (there were 32% of these people; group C). Other people maintained high accommodative responses under the same conditions (there were 68% of these people; groups A and B). This phenomenon has been observed clinically in patients' response to blur with negative and positive lenses, but not quantified. In addition the VEP method is more informative, as it yields information on the accommodative effort over a 30 second period as compared to the instantaneous glimpse afforded when measuring the amplitude of
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accommodation subjectively (by the push-up method), and it is therefore somewhat more realistic. The discrepancy found between the objective (VEP) and subjective (push-up) findings shown in Fig. 3 and in Fig. 4 (with Donders’s data) can be accounted for in various ways. VEPs were measured with a much larger test pattern than with the near point rule. Thus on that basis alone the VEPs’ amplitude should be much larger than the subjective amplitude. The present results are consistent with this view. However, the difference is mitigated by the fact that the push-up method tends to provide higher values of the amplitude of accommodation due to (1) the depth of focus of the eye,11 (2) the increasingly larger size of the pattern as it is approached towards the eye, and (3) the shorter viewing time of the target. As to the difference with Donders’s data, it could also be explicable by the fact that either our sample is much smaller or that perhaps, nowadays, people have more accommodation than in Donders’s time.

Nevertheless, the results of this investigation suggest that the present technique is of value in assessing the amplitude of accommodation in uncooperative people, malingerers, infants, and animals, where established subjective methods are of no avail.

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