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The influence of accommodation and fixation on the visual evoked response and visual acuity of normal and amblyiopic subjects

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Abstract

Twelve normal and twelve amblyopic subjects were examined to investigate the differences in visual evoked response (VER) as well as the state and influence of the accommodative posture and accommodative response on the VER and visual acuity. The VER amplitudes were shown to be lower in the amblyopic eye a significant proportion of the time, while the implicit times were not significantly different. The accommodative system of the amblyope was shown to differ in both eyes from that of the normal subject, with the amblyopic eye also hypoposturing in comparison to the normal eye of the amblyope. This did not affect the VER or visual acuity significantly. The degree of eccentric fixation had no statistically significant relationship to the VER, accommodative, or visual acuity data. The VER, Haidinger brushes and Maxwell spot were in close agreement for differentiating organic from functional amblyopia.

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THE INFLUENCE OF ACCOMMODATION AND FIXATION ON THE VISUAL EVOKED RESPONSE AND VISUAL ACUITY OF NORMAL AND AMBLYOPIC SUBJECTS

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ABSTRACT

Twelve normal and twelve amblyopic subjects were examined to investigate the differences in visual evoked response (VER) as well as the state and influence of the accommodative posture and accommodative response on the VER and visual acuity. The VER amplitudes were shown to be lower in the amblyopic eye a significant proportion of the time, while the implicit times were not significantly different. The accommodative system of the amblyope was shown to differ in both eyes from that of the normal subject, with the amblyopic eye also hypoposturing in comparison to the normal eye of the amblyope. This did not affect the VER or visual acuity significantly. The degree of eccentric fixation had no statistically significant relationship to the VER, accommodative, or visual acuity data. The VER, Haidinger brushes and Maxwell spot were in close agreement for differentiating organic from functional amblyopia.

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TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Amblyopia is a visual defect that affects 3.2 percent of the population (Schapero 1971) and is thus a substantial problem. Perceptual anomalies often accompany this defect. Due to the relatively high incidence and importance of amblyopia it has been studied by many ophthalmic scientists in great depth. While attempting to explain the etiology of the reduction in visual acuity other characteristics have become evident. This paper studies the problem of amblyopia further.

This study is concerned with accommodation and fixation of the amblyope and methods of investigating these systems. Normal individuals were examined, and the results were compared with similar results from amblyopic observers. Specifically the influence of amblyopia, accommodative posture, accommodative response, and degree of eccentric fixation on the visual evoked response (VER) and visual acuity were measured. A comparison was made between the Haidinger brush, Maxwell spot, and VER in an attempt to decide their validity as diagnostic tools. These instruments have been used by many clinicians for this purpose.

DEFINITION OF TERMS

Accommodative Posture - The position of the accommodative focus mechanism relative to the plane of regard. Posturing in front of the plane is positive and behind it, negative. The accommodative posture is measured by dynamic cross-cylinders, dynamic retinoscopy, or with the use of an optometer.

Accommodative Response - The amount of accommodative effort exerted. Measured from the endpoint of the system. The accommodative response is equal to the accommodative stimulus - accommodative posture. The same sign convention holds.

Amblyopia - Reduced visual acuity not correctable by refractive means and not attributable to obvious structural or pathological ocular anomalies.

Dynamic Retinoscopy - The determination of the conjugate focus of the retina while the subject views a near object.

Eccentric Fixation - Fixation not employing the central foveal area.

Fixation - The act of directing the eye toward an object of regard such that the image of the object is placed on the fovea.

Functional Amblyopia - Amblyopia attributable to functional disorders. The retinal receptors and visual pathways are considered being free from pathology. The prognosis for an improvement in acuity is generally considered good.

Organic Amblyopia - Amblyopia attributable to anatomical or pathological anomalies in the retinal receptors or visual pathways. Prognosis is considered poor.

P Factor (Pacific Factor) - A determination of the distance refractive error utilizing methods outlined by Dr. C. B. Pratt of Pacific University. The method of calculation can be seen in Appendix I, and is similar to that calculated by Bybee (1970), and described by Haynes (1976).

BACKGROUND AND SIGNIFICANCE

A. VER (Background; variables; method of comparison; present investigation; significance.)

Background - The VER is an electrophysiological measure of cortical activity as a result of visual stimulation. Electrodes, attached to the scalp, record electrical responses to visual stimulation. The stimulus is usually a change in light form or intensity. Electrical activity, which appears to be representative of the amount of neural activity, and dominated by the central visual response, can be measured on the scalp above the area of the cortex (De Voe, et al 1968; Freeman and Thibos 1975).

Variables - The amplitude and latency of the VER signals have been shown to vary as a function of many variables. These variables include visual acuity (Sokol and Dobson 1976), clear imagery (Ludlam and Meyers 1972, Harter and White 1968), type of target (Spehlmann 1965; Armington, et al 1967; Rietveld, et al 1967; Dawson, et al 1968; Ciganek 1969), luminance (Shipley 1969), wavelength (Shipley, et al 1968), frequency (Dawson, et al 1972), distance, stimulus size (Sokol and Bloom 1973), visual pathway integrity (Copenhaver and Perry 1964, Halliday and Michael 1970), area of retina stimulated (Jeffreys 1971; Arden, et al 1974), color vision defects (van Balen and Henkes 1962, Harter and White 1968), adaptation level (Perry and Childers 1969), electrode placement (Perry, et al 1968; Halliday and Michael 1970), and state of attention (van Balen and Henkes 1962, Lazarus 1974).

Method of Comparison - The usual method of VER evaluation is a comparison of VER wave form, amplitude and implicit time between the two eyes.

Present Investigation - The above variables influencing the VER amplitude and implicit time have been examined. However, the influence of accommodative posture and accommodative response on the VER signal has not been measured. This study determined the relationship between the VER amplitude and implicit time, and the accommodative posture and accommodative response. The accommodative posture, which is a measure of conjugate focus of the eye relative to the plane of regard, has an effect on optical imagery (Haynes 1976). The accommodative response may be thought of as a measure of accommodative activity.

Significance - It was thought that the influence of accommodative posture and accommodative response on the VER should be of interest to clinicians and researchers in the field, and that the study may help to explain or clarify the VER wave form, amplitude and implicit time in normal and amblyopic subjects.

B. VER in Amblyopia (Background; flash and pattern VER; shortcomings; accommodation of amblyope; present investigation; significance.)

Background - Much attention has been focused on the VER of amblyopes. However, there seems to be conflicting views as to the typical response of the functional amblyope (Sokol 1976).

Flash VER - Early studies utilized diffuse, flashing lights as the stimulus to produce a VER. The amblyopic eye produced a typical response. Some investigators showed implicit time and amplitude irregularities in the amblyopic eye compared to the normal eye. Generally, the amplitude of the response was reduced (van Balen and Henkes 1962; Nawratzki, et al 1966; Potts and Nagaya 1969; Shipley 1969). Other investigators found no significant difference in the signal (Fishman and Copenhaver 1967, Levi 1975).

Pattern VER - Most current studies use a checkerboard pattern of varying sizes as the stimulus. This may be continually alternating checks, known as "steady state VER", or a flashed target. The amplitude response of the amblyopic eye to checkerboard-pattern is most often reduced (Lomboroso, et al 1969; Sokol and Bloom 1973). Some reports show reduced amplitude and latency changes (Yinon, et al 1974), while others only reduced amplitude (Levi 1975).

Shortcomings - Many studies on the subject are equivocal. The state of accommodation during measurement has been almost totally ignored. Few investigators have presented sufficient information about the visual system of the subject. This is important in the strabismic and non-strabismic amblyope.

Accommodation of Amblyope - Clinically amblyopes often present a hypoposturing, anomalous accommodative posture (Abraham 1961). This is especially true of eccentric fixators where the foveal area is not used for fixation. When the central 30' of arc is not being stimulated by the object of regard, the accommodation cannot be precise (Crane 1966). The amblyopic eye also presents larger than normal oscillatory movements, or instability of fixation (Adler 1959; Flom, et al 1963; von Noorden and Helveston 1970). This will affect the accommodative system which is reliant upon oscillatory movements of about 10' of angle (Fincham 1951). However, it has been stated that at lower stimulus levels the accommodative response of the amblyopic eye is equal to or increased with relation to the plane of regard. The response is decreased at higher stimulus levels (Wood and Tomlinson 1975). The increased activity reported at lower levels may be a function of the blurred image which has been shown to cause such a response (Heath 1956).

Many VER studies of amblyopes have been performed at near. The accommodative posture, which affects imagery and interpretation, has not been taken into account. The present investigator proposed that a defocused image, due to an accommodative posture off the plane of regard, could reduce the VER amplitude without any additional neurological mechanism associated with the amblyopia. A difference of accommodative posture between the amblyopic and normal eyes under comparison could have an effect on the VER and its evaluation. A stimulus to accommodation requiring discrimination has not always been employed. This is important, in order to help stabilize and assess the level of accommodation.

Present Investigation - This study utilized a definite stimulus to accommodation. The influence of the accommodative posture and accommodative response was considered at different stimulus levels. The status of the visual system was noted.

Significance - It was intended that the study may discriminate between the VER measured on amblyopic and normals while considering the influence of accommodative posture and accommodative response. This may help other researchers and clinicians demonstrate the etiology or mechanism for the reduction of visual discrimination in amblyopia.

C. Eccentric Fixation (Background; normal and amblyope; visual acuity measurement factors; accommodation of eccentric fixator; discussion; present investigation; significance.)

Background - Many workers have postulated the etiology of the reduced visual acuity in amblyopia. It has been suggested that the use of an area of the retina other than the fovea may be the cause of amblyopia in eccentric fixating amblyopes (Flom and Weymouth 1961).

Normal - For normal untrained subjects the resolution decreases linearly at 1.77' per degree of eccentricity (Weymouth 1958). Shapero (1971) summarizes the work of Wertheim, Aubert and Forster, Feinberg and Weymouth on the subject (Fig. 1 & 2). As shown in these figures, there appears to be a discrepancy in the measurement of visual acuity as a function of eccentricity, although this does not appear great. Millidot (1966) and Low (1951) also demonstrate this fact.

Amblyopes - Responses from eccentric fixators have shown a relationship between the reduction in acuity and the acuity of a similar eccentric point in a normal individual. Thus, it has been concluded that some amblyopias are primarily a function of eccentricity (Flom and Weymouth 1961, Koppenberg 1972). Other investigators have shown that the amblyopia is not primarily due to eccentric fixation and propose other models (Burian and Cortimiglia 1962; Alpern, et al 1967). The reduction in acuity also depends upon the direction of eccentricity. Visual acuity falls more rapidly temporally and superiorly to the fovea (Burian and Cortimiglia 1962).

Visual acuity measurement factors - Visual acuity measurements are dependent upon the type of target used. Additional contours in the visual field can reduce the resolution depending upon their spatial orientation. This

WERTHEIM		AUBERT AND FÖRSTER		FEINBERG		WEYMOUTH	
Eccentricity	*Visual Acuity*	*Eccentricity*	*Visual Acuity*	*Eccentricity*	*Visual Acuity*	*Eccentricity*	*Visual Acuity*
1°	20/33	1°	20/40	1°	20/31	1°	20/30
2°	20/40	2°	20/80	2°	20/42	2°	20/50
		2°52′	20/100				
		3°13′	20/120	3°	20/48		
		3°51′	20/140	4°	20/58		
5°	20/67	4°17′	20/160	5°	20/70	5°	20/95
		7°14′	20/240				
		8°32′	20/320				
10°	20/100	10°13′	20/380			10°	20/160
		14°37′	20/480				
20°	20/180	16°17′	20/900			20°	20/300
		30°20′	20/2000				

Figure 1. (Schapero 1971). Variation of visual acuity with eccentricity of retinal stimulation, a comparison of four studies.

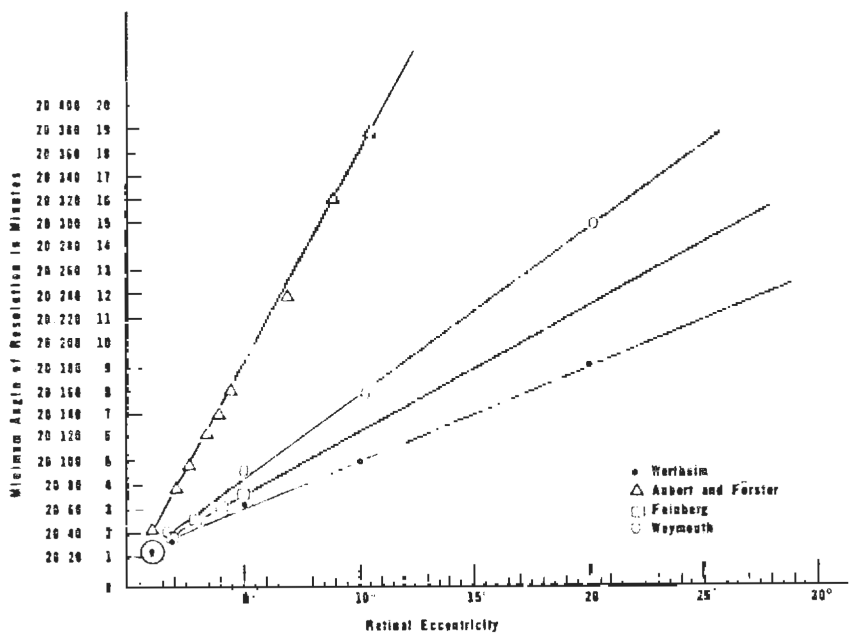

Figure 2. (Schapero 1971). A graphic representation of visual acuities listed in Figure 1.

is especially true of the amblyope where this contour interaction seems to have more effect (Flom, et al 1963; Stuart and Burian 1962). The improvement in visual acuity with single letters has been termed "crowding phenomenon" or "separation difficulty". A reduction in lateral inhibition has been described as the mechanism for the increased contour interaction and reduced visual acuity of the amblyope (Miller 1954). A spread of retinal excitation reduces the visual acuity. The lateral inhibition of the normal eye was shown to be of the magnitude of 10' of arc centrally, whereas in the amblyope with eccentric fixation it was about 17' of arc (Lawwill, et al 1974). The contrast enhancement appears to be reduced due to decreased inhibitory function (Sawyer, 1972). The spatial summation is greater in the amblyopic eye than in normal eyes (Flynn 1967). Abnormal retinal lateral interactions are demonstrated by a shift in contrast function in the amblyope (Levi and Harwerth 1974).

Accommodation of Eccentric Fixator - As explained above, the accommodative system of the eccentric fixating amblyope presents anomalies in accommodative posture and accommodative response.

Discussion - Most of the previous studies have measured the degree of eccentric fixation at near utilizing a single method. In some cases the visual acuity was then measured at distance. This assumes a constant degree of eccentric fixation, steadiness of fixation, illumination, and pupil size at near and distance. When the visual acuity has been measured at near the accommodative posture has not been considered. The importance of this has been explained above, and the loss in visual acuity may be partly due to poor optical correction as a result of a hypoposturing accommodative system at the plane of regard.

Present Investigation - The investigator measured the degree of eccentric fixation by more than one method. Visual acuity was measured with three different targets at distance and near, with the appropriate lens correction to compensate for any accommodative posture abnormalities. Line, single letter, and Flom's "S" chart were employed to take into consideration the effects of contour interaction during interpretation of data. The "S" chart introduces additional contour interaction. This psychophysical acuity chart is described by Flom, et al (1963).

Significance - The effect of eccentric fixation, without the influence of accommodative posture or accommodative response, on the visual acuity of the amblyope was determined.

D. Haidinger Brushes, Maxwell Spot and VER (Background; theoretical basis; use; discussion; present investigation; significance.)

Background- Haidinger brushes and Maxwell spot are entoptic phenomenon that have been used for evaluation of ocular fixation and macula integrity.

Haidinger Brushes - W. K. von Haidinger in 1844 first reported the entoptic phenomenon which bears his name. In plane polarized, evenly illuminated light most normal eyes can see two tufts or brushes radiating out from a fixation point. The illusion is accentuated by the use of a blue filter and rotating polaroid. A dark blue propellor can be seen and its motion may be reversed with a quarter wave plate or cellophane. Both the Haidinger brushes and Maxwell spot present reverse size perception, i.e., the further they are from the observer the larger they appear, and vice versa.

Theoretical Basis - The etiology of the brushes is thought by some to be due to the fovea and its anatomy, especially the yellow macula pigment (Shute 1974, Coren 1971, Naylor and Stanworth 1954). The general opinion is that the phenomenon is caused by a polarizing effect of the doubly refracting, slightly yellowish, radial fibres of Henle's layer (Schmidt 1954, Borish 1970, Goldschmidt 1950). Helmholtz explained the Haidinger brushes to be as a result of the radially oriented macula fibres being dichroic and therefore absorbing blue light, especially when it is vibrating perpendicular to the fibre. The yellow macula pigment also plays a role (Sloan and Naquin 1955). Gording (1950) suggests that the Haidinger brushes are a result of the residue of the yellow spot after polarization. The Haidinger brushes occupy a four to five degree central field corresponding closely to the pigmented area.

Use - It is generally agreed that the Haidinger brushes can only be seen in the macula area of an intact eye with intact foveal and macula pathways (Kavner and Suchoff 1969). In the event of macular pathology the Haidinger brushes are often absent. Some authors have related this to macula lesions (Sloan and Naquin 1955, Goldschmidt 1950, Forster 1954, Vodnoy 1962), and other foveal lesions (Smith 1971, Carter 1970). Pathology of the visual pathway may also influence the ability to see the brushes. From the ability to detect pathological lesions from this test, it has been used to differentiate organic from functional amblyopia and in prognosis (Gording 1950, Watts 1972, Sherman 1972). Haidinger brushes are not seen by a small percentage of the apparently normal population (Sloan and Naquin 1955, Coren 1971). There does not appear to be a close dependence on color vision (Schmidt 1954, Forster 1954).

Maxwell Spot - J. C. Maxwell (1856) first reported a dark red spot in the blue region of the prismatic spectrum. Most normal people see a circular reddish pattern upon looking at a light filtered by a purple dichromic filter which transmits only red and blue light.

Theoretical Basis - Spencer (1971) describes some of the theories put forward to explain the cause of Maxwell spot. It is most widely accepted that the phenomenon is due to the yellow macula pigment, lying in front of the retinal receptors, absorbing the blue light and allowing longer visible wave lengths to pass. The structure of Maxwell spot varies from observer to observer. The size and form may also vary with time in the same individual.

Use - The visibility of the Maxwell spot is a positive sign of foveal integrity. The Maxwell spot disappears with lesions of the macula area or visual pathways, especially those involved with color vision processes (Schmidt 1954, Carter 1970). The Maxwell spot appears to be linked to color vision. A relationship between the red-green aspect of color vision and the phenomenon has been noted (Schmidt 1954). Deuteranopic or deuteranomalous individuals do not perceive the spot (Carter 1970). The Maxwell spot, like Haidinger brushes, has been used to evaluate the visual system and determine the prognosis before visual training of the amblyope.

VER - Background and Use - Of late, the VER has been used for the objective determination of macula and visual pathway integrity. Since the VER is a function of the central vision, it has been inferred that a diminished or atypical response represents organic amblyopia, which rarely improves with visual training (Sherman 1970; Arden, et al 1974; Fishman 1967). Depression of the VER is an indication of macula field defects (Halliday and Michael 1970; Potts 1969; De Voe, et al 1968).

Discussion - It can be seen that the above three techniques have been, and are presently being clinically used, to determine the integrity of the macula area. This is extremely important before the commencement of visual training for the amblyope, and gives an indication of the results that may be expected. It should be pointed out that the Haidinger brushes and Maxwell spot investigate a macula area subtending the central 5, whereas the VER is dominated by a response from a more central area (Dobson 1976).

Present Investigation and Significance - The study investigated the correlation between the Haidinger brushes, Maxwell spot and VER in their use as diagnostic tools for determining organic amblyopia. This has not previously been studied, and should be of interest to many clinicians due to the widespread use of the instruments under question and the large economic and instrument cost factors involved.

EXPERIMENTAL QUESTIONS

The following questions were addressed by the research project:

I. Are the accommodative posture and accommodative response related to the amplitude and implicit times of the VER in the normal eye?

II. Is the VER in functional amblyopes altered from normals, and what is the influence of the accommodative posture and accommodative response on this result? Does the state of binocularity, or type of visual condition or adaptation, have any influence on the VER, accommodative posture or accommodative response?

III. What is the relationship between eccentric fixation and the visual acuity, accommodative posture, accommodative response and VER? Does the magnitude and direction of the eccentric fixation have any significant relationship to the above variables?

IV. What is the relationship between the Haidinger brush, Maxwell spot and VER and their use in determination of the integrity of the visual system?

METHOD

Subjects - Twelve clinically normal subjects and eighteen amblyopes were investigated. Amblyopia was defined as less than 6/9 best corrected visual acuity in the worse eye, and more than one line difference between the two eyes.

Clinical Evaluation - Comprehensive visual and orthoptic examinations were performed in order to evaluate the monocular and binocular status of each participant. Distance retinoscopy, subjective examination, pathological and color evaluation were performed on all patients. The strabismic was evaluated by subjective and objective angles of deviation in the synoptophore. A cover test was also performed at distance and near. Anomalous retinal correspondence was evaluated with the Bagolini striated lenses and Bielschowsky after-image test. All other evaluations, e.g., visual acuity, Haidinger brushes, Maxwell spot, VER, and dynamic retinoscopy were performed during experimentation. An example of the recording forms used can be seen in Appendix II.

EXPERIMENTAL APPARATUS

VER - The OEU-4 produced by Electronics Circuit Systems of South Orange, New Jersey, was used for VER measurement. Basically, the electrical impulses were fed into a band-limited, low-noise preamplifier and then into a signal averager (Princeton Applied Research Wave Form Educator Model TDH-9). The sequencing of the optical stimuli, time delay and processing was accomplished with the use of electronics. A programmable sequencer and trigger generator, timed and processed the above information. The amplified signal from the high-gain preamplifier was fed into a switched inverter, which is a unity-gain amplifier controlled by the sequencer. The on-line monitoring, allowing the operator to view the build-up of the VER, was accomplished by the feeding of selected signals from the analog signal averager to an oscilloscope. Permanent records were made on a strip recorder. The active electrode was placed 2.5 cm. above the inion, and the reference and ground electrodes to the earlobes. The summation of ten flashes represents the VER. A subtraction technique of pattern-plus light was used. The first projector flashed a 12' of arc checkerboard and the second a plain flash. A 12^{o} field size was used and external noise held constant. At 6m the VER luminance was 6.9 millilamberts and at 40 cm. it was 9.0 millilamberts. Ambient illumination was 0.16 millilamberts at distance and 1.6 millilamberts at near, which was bright enough to allow accommodative localization. This also reduced the occipital alpha level. The 40 cm. distance utilized rear projection. A small series of white-on-black letters were projected by a third projector as an accommodative stimulus.

Visual Acuity Charts - Snellen line, single letter and Flom's "S" chart were used (Fig. 3).

Dynamic Retinoscopy Apparatus - Beam splitters in front of the subject's eyes reflected the light so that it could be seen by the retinoscopist from the side (Fig. 4). Neutralizing lenses were interposed so as not to be in the line of sight of the subject. Thus, the stimulus to accommodation was left unaltered while the retinoscopic reflex was neutralized. This method of retinoscopy was reported by Pheiffer (1955).

Haidinger brushes, Maxwell spot and after-image transfer were done on conventional clinic instruments, at the 40 cm. distance. Visuoscopy was performed with the Neitz instrument. The degree of eccentric fixation was determined by these findings.

Color vision was examined with a Farmsworth D15.

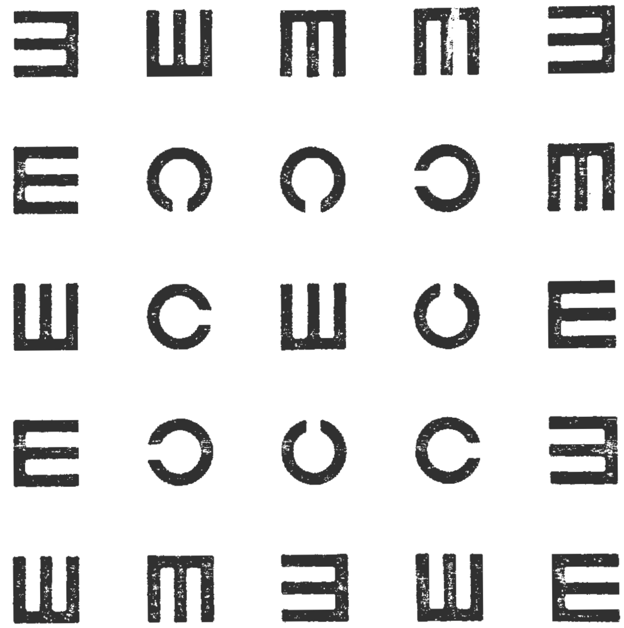

Figure 3. Flom's "S" Visual Acuity Chart

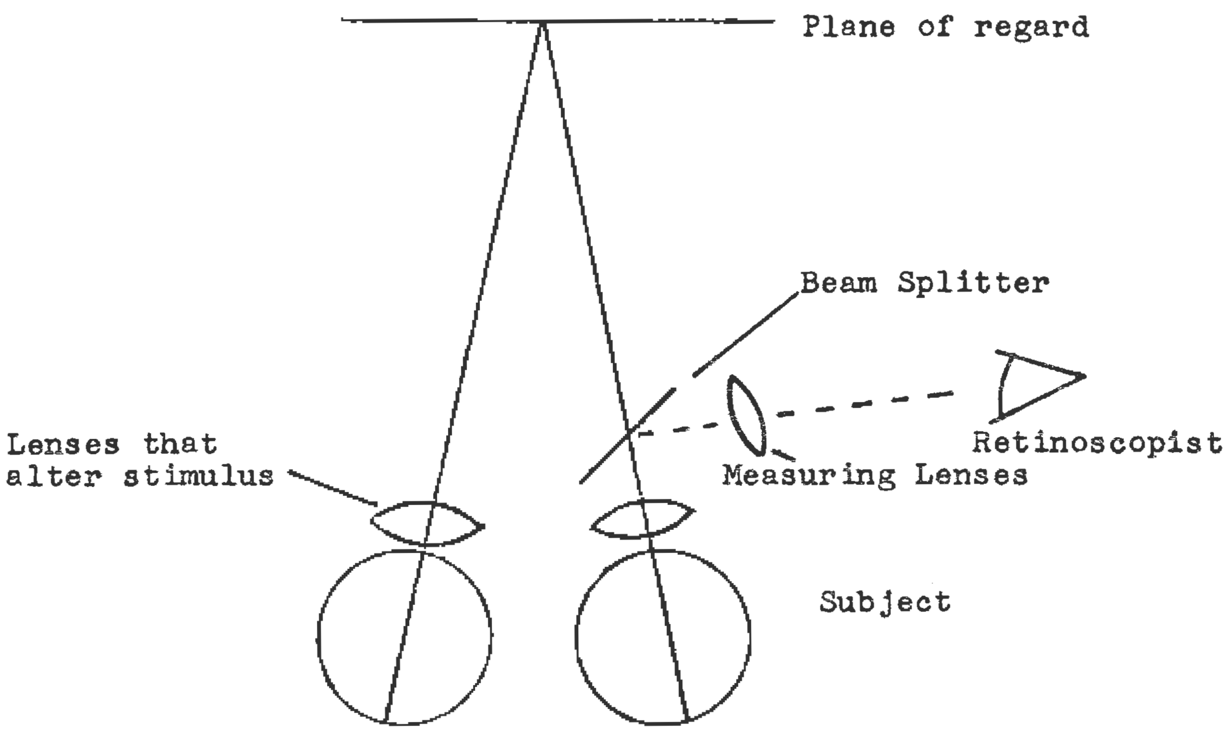

Figure 4. Method of Dynamic Retinoscopy

ORDER OF EXPERIMENTAL PROCEDURE

1. Clinical evaluation
2. Haidinger brushes
3. Maxwell spot
4. After-image transfer
5. VER at distance with distance prescription in place
6. Visual acuity at distance with distance prescription in place
7. VER at near with distance prescription in place
8. VER at near with low neutral in place
9. VER at near with low neutral +1.00 DS in place
10. VER at near with low neutral -1.00 DS in place
11. Visual acuity at near with distance prescription in place
12. Visual acuity at near with low neutral in place
13. Visual acuity at near with low neutral +1.00 DS in place
14. Visual acuity at near with low neutral -1.00 DS in place

The VER routine was first performed at distance and then near. Two sequences were done at near, starting at #7 above going to #10, and then back to #7. The results were averaged. The eyes were exposed in a counterbalancing ABBA fashion.

EXPERIMENTS

The following are four experiments addressed to the above four experimental issues.

Experiment I - VER Normal Eyes

Purpose - This experiment investigated relationship between VER amplitude, implicit time, accommodative posture and accommodative response on normal subjects and normal eyes of amblyopic subjects.

Methods and Procedures - The VER was performed at distance and near. The accommodative posture was measured using retinoscopy and a beam splitting device. Fixation targets at the appropriate visual acuity of the individual maintained stimulus levels. Accommodative posture and accommodative response were manipulated with the use of lenses. VER amplitude was measured from the trough of the a-wave to the peak of the b-wave. Implicit time was measured from the flash to the trough of the a-wave, and to the peak of the b-wave (Fig. 5).

Experiment II - VER and Accommodation of Amblyopes

Purpose - This experiment isolated the influence of amblyopia on the VER and accommodation, as well as evaluated the influence of the amblyopic accommodative system on the

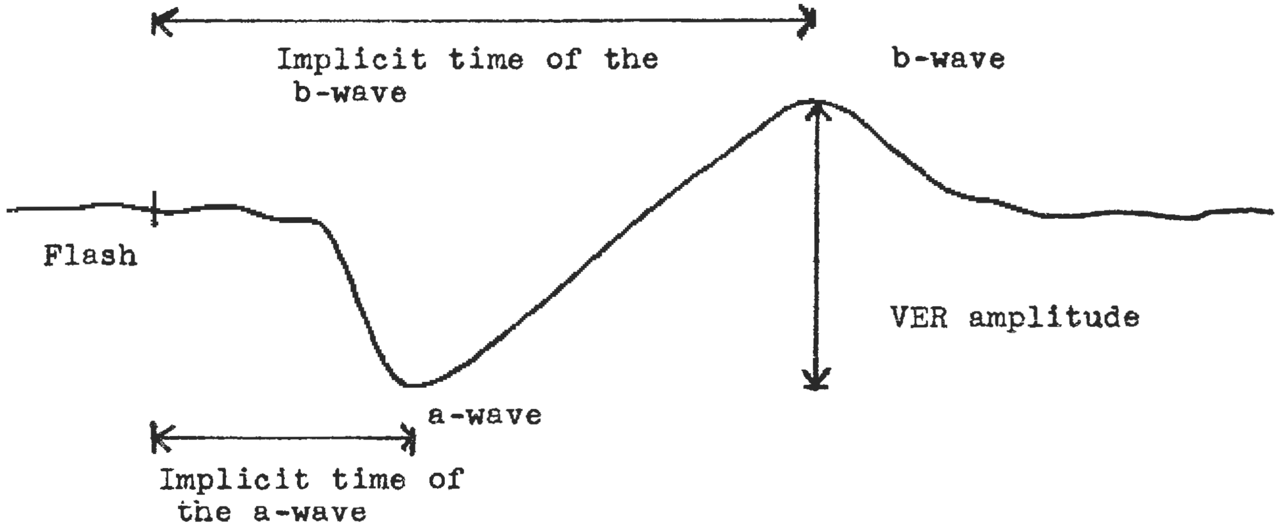

Figure 5. The VER Wave

VER. The effect of the state of binocularity on the VER, accommodative posture and accommodative response was also investigated.

Methods and Procedures - An experiment similar to Experiment I was performed. The electrode placement was not altered when observation was changed from the normal to the amblyopic eye. The same measurement and analysis of the VER wave form, amplitude and implicit time, accommodative posture and accommodative response as in Experiment I was made.

Experiment III - Eccentric Fixation

Purpose - This experiment investigated the visual acuity, accommodative posture, accommodative response and VER amplitude and implicit time as a function of eccentric fixation.

Methods and Procedures - The degree and direction of eccentric fixation was measured by means of the Haidinger brushes, Maxwell spot and visuscope. Visual acuities were measured at distance and near with the appropriate lens in place. Line acuity, single letter acuity, and Flom "S" acuity were recorded.

Experiment IV - Haidinger Brushes, Maxwell Spot and VER

Purpose- This experiment examined the relationship between the Haidinger brushes, Maxwell spot and VER in their diagnostic capacity of pathologic lesions and organic amblyopia.

Methods and Procedures - The usual clinical procedure for the use of these instruments was performed. An attempt was made to elicit a positive response in all cases. The responses to the Haidinger brush and Maxwell spot were either recorded as positive or negative, depending upon whether the phenomenon was seen or not. A grossly reduced or lack of VER wave form was recorded as negative.

RESULTS AND ANALYSIS

Twelve normal subjects were examined. The subjects' ages ranged from 23 years to 31 years with a mean age of 25.6 years. Nine of the subjects were male and three female. Eighteen amblyopes were examined. After refraction, two of the previously diagnosed amblyopes no longer met the criteria based on visual acuity. One of the subjects presented a constant alpha pattern with either eye preventing the analysis of a VER wave form. Three other amblyopes either prescribed no VER from one eye at all, suggesting organic amblyopia, or did not give a response under one or more of the conditions thus preventing statistical analysis. The ages of the remaining twelve amblyopes ranged from 8 years to 48 years with a mean age of 21.75 years. There were six male and six female subjects.

The "t" test used to analyze the data was:

$$\frac{\bar{X}_1 - \bar{X}_2}{S_p\sqrt{1/n_1 + 1/n_2}} \qquad df = n_1 + n_2 - 2$$

where

$$S_p^2 = \frac{\sum_{i=1}^{n_1} (\bar{X}_c - \bar{X}_1)^2 + \sum_{i=1}^{n_2} (\bar{X}_c - \bar{X}_2)^2}{n_1 + n_2 - 2}$$

The alpha level was set at 0.05.

$\bar{X}_1$ represents a mean value on the dependent variable for the normal observers

$\bar{X}_2$ represents a mean value on the dependent variable for the experimental group of observers

n_1 and n_2 represent the number of observers in each group respectively

This "t" test is used to test the difference between the means of two separate groups.

Experiment I - Normal Subjects

This experiment deals with the twelve normal subjects, where n = 24 eyes.

A. Raw Scores

The data are shown in Table 1. The mean (m), standard deviation (s), variance (v) and sum of squares (ss) were calculated for each variable (Freund 1967) and are indicated at the bottom of Table 1.

a. Ver Amplitude

The VER amplitude was found to be variable from subject to subject. As can be seen on Table 1, the standard deviation was larger than the mean amplitude of the twelve subjects under each one of the five conditions, i.e., distance with P, 40 cm. with P, 40 cm. with low neutral, 40 cm. with low neutral +ID and 40 cm. with low neutral -ID. When comparing the mean amplitudes from each of the above five conditions to one another using a "t" test, none appeared to differ significantly.

A Pearson moment correlation coefficient was calculated in order to determine the extent of covariance between the VER amplitude and the implicit time of the a-wave, implicit time of the b-wave, accommodative posture and accommodative response under each of the five conditions stated above. The VER amplitude did correlate with the accommodative posture and accommodative response at 40 cm. with P ($r = 0.43$; $p < 0.02$; Fig. 6) and at 40 cm. with the low neutral -ID ($r = 0.615$; $p < 0.001$ Fig. 7). A significant correlation was found between the difference in implicit times of the a and b waves and the VER amplitude ($r = 0.438$; $p < 0.02$ Fig. 8).

b. Implicit Time of the A-Wave

The implicit time of the a-wave seemed consistent at about 93 milliseconds after the flash with a standard deviation of smaller than 16 msec. This is shown in Table 1. There was a significant difference between the implicit time of the a-wave at 40 cm. with low neutral -ID, and distance with P ($t = 2.162$; $p < 0.02$). The implicit time of the a-wave was correlated with that of the b-wave at distance with P ($r = 0.8$; $p < 0.001$ Fig. 9), 40 cm. with P ($r = 0.64$; $p < 0.001$ Fig 10), 40 cm. with low neutral

TABLE I

NORMAL SUBJECTS. RAW SCORES.

Subjects	Distance with P					40cm with P					40cm with low Neutral					40cm with low Neutral +1D					40cm with low Neutral - 1D				
	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar
BM	0.73	108	152.8	0	0	1.29	80	143.4	0	+2.50	1.29	80	143.4	0	+2.50	0.86	109	171	+0.25	+1.75	0.78	108	151.4	0	+3.50
	0.87	97.4	160.8	0	0	0.78	78.8	148.4	0	+2.50	0.78	78.8	148.4	0	+2.50	0.65	90	138	+0.25	+1.75	1.14	101	155	0	+3.50
JNcV	1.03	97.4	142.8	0	0	1.75	75	134	0	+2.50	1.75	75	134	0	+2.50	1.83	68.8	128	+0.25	+1.75	2.0	66	130	0	+3.50
	1.3	77.4	125.4	0	0	1.36	72	126	0	+2.50	1.36	72	126	0	+2.50	1.73	75.4	131.4	+0.25	+1.75	2.25	75	127	0	+3.50
CL	1.0	108.8	164	0	0	0.84	112	167.2	0	+2.50	0.84	112	167.2	0	+2.50	1.12	90	154	0	+1.50	0.92	110	152	0	+3.50
	0.8	122.6	163.4	0	0	1.01	94	159.4	0	+2.50	1.01	94	159.4	0	+2.50	0.5	116	152	0	+1.50	0.92	104	160	0	+3.50
JF	4.45	101	154	0	0	4.44	99.6	153.6	0	+2.50	4.44	99.6	153.6	0	+2.50	4.6	96.6	152	+0.25	+1.75	4.7	96	150	-0.50	+3.00
	4.13	106.8	162	0	0	4.57	94.6	155.4	0	+2.50	4.57	94.6	155.4	0	+2.50	4.5	100	154	+0.75	+2.25	4.45	97	153	-0.25	+3.25
MMS	2.65	97	161	0	0	3.1	96	156.8	0	+2.50	3.1	96	156.8	0	+2.50	2.63	100	164.8	+0.50	+2.00	2.42	94	152	0	+3.50
	1.65	102.6	149.6	0	0	2.63	99.4	177.4	0	+2.50	2.63	99.4	177.4	0	+2.50	3.4	88	172	+0.25	+1.75	2.75	95	138	0	+3.50
LPP	2.25	115	161	0	0	2.5	110	150	-0.25	+2.25	2.9	96	141	0	+2.25	4.3	92	147	+0.50	+2.00	6.0	80	136	-0.50	+3.00
	1.7	134	166	0	0	2.7	120	156	-0.25	+2.25	2.6	108	155	0	+2.25	4.8	91	144	+0.50	+2.00	6.1	94	155	-0.50	+3.00
KK	2.3	118	171	0	0	4	109.4	151.4	-0.50	+2.00	5.15	102	150	0	+1.75	5.2	96.0	151	+0.50	+2.00	5.45	97	149	-0.50	+3.00
	2.45	117	168	0	0	4.4	102	149	-0.50	+2.00	5.15	104	152	0	+1.50	5.25	93	149	+0.75	+2.25	5.55	96	148	-0.50	+3.00
IH	11.32	88	152.8	0	0	17.5	92	149	-0.50	+2.00	17.1	82	139	0	+2.00	17.6	81	138	+0.50	+2.00	17.4	79	130	-0.25	+3.25
	10.7	90	154	0	0	16.7	87	144	0	+2.50	16.7	87	144.	0	+2.50	15.3	76	127	+0.50	+2.00	16.2	76	126	-0.50	+3.00
GS	0.52	90.8	144	0	0	0.58	89	140.8	0	+2.50	0.58	89	140.8	0	+2.50	0.78	88	143.4	+0.50	+2.00	0.4	99	130	0	+3.50
	0.62	84	118	0	0	0.44	116	158.4	0	+2.50	0.44	116	158.4	0	+2.50	0.49	96	132.8	+0.50	+2.00	0.38	108	149	0	+3.50
TS	0.65	65	117.6	0	0	0.56	102.4	144	0	+2.50	0.56	102.4	144	0	+2.50	1.05	113	170	+0.50	+2.00	2.05	60	96	-0.25	+3.25
	0.57	98.8	138	0	0	0.95	88	148	0	+2.50	0.95	88	148	0	+2.50	1.15	99	155	+0.50	+2.00	1.7	60	100	-0.25	+3.25
PL	1.13	84	134	0	0	1.26	87.6	146.8	0	+2.50	1.26	87.6	146.8	0	+2.50	1.2	81	140	+0.25	+1.75	1.35	92	154	0	+3.50
	1.23	77.4	141.4	0	0	1.15	89	14 5	0	+2.50	1.15	89	145	0	+2.50	1.35	82	152	+0.25	+1.75	1.4	78	138	0	+3.50
RZ	0.37	93	137	0	0	0.98	80.8	147.6	0	+2.50	0.98	80.8	147.6	0	+2.50	1.07	82.6	158	0	+1.50	1.05	92	161	0	+3.50
	0.63	90.6	159.4	0	0	1.08	82	144.4	0	+2.50	1.08	82	144.4	0	+2.50	0.9	90	141	+0.25	+1.75	1.2	77	142	0	+3.50
n =	24	24	24	0	0	24	24	24	24	24	24	24	24	0	24	24	24	24	24	24	24	24	24	24	24
m =	2.294	98.52	149.92	0	0	3.19	94.03	149.83	-0.083	2.42	3.27	92.3	149.07	0	2.39	3.43	91.68	148.59	0.365	1.864	3.69	88.92	140.93	-0.167	3.333
s =	2.893	16.01	15.39	0	0	4.48	13.1	10.31	0.175	0.175	4.45	11.699	10.66	0	0.266	4.35	11.817	12.923	0.208	0.2084	4.442	14.72	16.95	0.2170	0.2170
v =	8.375	256.38	236.75	0	0	20.11	171.61	106.288	0.031	0.031	19.844	136.89	113.71	0	0.0705	18.93	139.65	167.03	0.0433	0.0433	19.73	216.69	287.31	0.0471	0.0471
ss =	192.617	5896.69	5445.25	0	0	462.57	3946.94	2444.62	0.7083	0.7083	456.42	3148.44	2615.37	0	1.622	435.42	3212	3841.62	0.9974	0.999	453.83	4983.8	6608.12	1.0833	1.0833

A = VER Amplitude
Ia = Implicit time of the a-wave (Msecs)
Ib = Implicit time of the b-wave (Msecs)
Ap = Accommodative posture (Diopters)
Ar = Accommodative response (Diopters)

($r = 0.69$; $p < 0.001$ Fig. 11), 40 cm. with low neutral +ID ($r = 0.66$; $p < 0.02$ Fig. 12), and 40 cm. with low neutral - ID ($r = 0.85$; $p < 0.001$ Fig. 13).

c. Implicit Time of the B-Wave

The implicit time of the b-wave also showed close agreement at most levels with b-wave implicit time of about 147 msec. and the largest standard deviation being 16.95 msec. The implicit time of the b-wave under the conditions of 40 cm. with low neutral -ID was significantly different from that at distance with P ($t = 1.924$, $p < 0.05$), 40 cm. with P ($t = 2.198$, $p = < 0.02$), 40 cm. with low neutral ($t = 1.99$, $p < 0.02$), and 40 cm. with low neutral +ID ($t = 1.76$, $p < 0.02$).

d. Accommodative Posture

Inspection of the data shows the accommodative system to be active and accurate with low standard deviations and no significant correlation to the above variables. The accommodative response is tightly linked to the accommodative posture due to the method of calculation and therefore shows similar results.

B. Difference Between Scores

This appeared to be the best way to compare the scores because subject, condition, electrode and instrument variability from individual to individual is minimized. The scores for amplitude and implicit times are calculated from $1 - \frac{OD}{OS}$.[1] The results are presented as an index which represents a relative difference between eyes. The accommodative findings were calculated by arithmetic differences. The data is presented in Table II.

A matched-pairs signed-rank or Wilcoxon test, and a sign test were also used to investigate this data (Friedman 1972). This would demonstrate whether the five variables being investigated, i.e., VER amplitude, implicit time of the a-wave, implicit time of the b-wave, accommodative posture and accommodative response, presented a larger or smaller value in one eye as compared to the other a significant proportion of the time. This test was employed under each of the five experimental conditions, and no variable showed a significant preference to one eye in this normal population.

a. VER Amplitude

The mean difference in peak to peak a-b wave amplitude between the eyes of each subject under the five conditions, varied from an index of -0.17 to 0.03 (Table 11) with an average of 0.063 for all the conditions.

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[1] In the amblyope the difference is calculated by $1 - \frac{\text{amblyopic response}}{\text{normal eye response}}$ and allows direct comparison to the normal population.

TABLE II

NORMAL SUBJECTS. DIFFERENCE BETWEEN EYES $(1 - \frac{OD}{OS})$

Subjects	Distance with P					40cm with P					40cm with low Neutral				
	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar
BM	0.16	-0.11	0.05	0	0	-0.65	-0.02	0.03	0	0	-0.65	-0.02	0.03	0	0
JMcV	0.21	-0.26	-0.14	0	0	-0.29	-0.04	-0.06	0	0	-0.29	-0.04	-0.06	0	0
CL	-0.25	0.11	0	0	0	0.17	-0.19	-0.05	0	0	0.17	-0.19	-0.05	0	0
JF	-0.08	0.05	0.05	0	0	0.03	-0.05	0.01	0	0	0.03	-0.05	0.01	0	0
MMS	-0.61	0.05	-0.07	0	0	-0.18	0.03	0.12	0	0	-0.18	0.03	0.12	0	0
LPP	-0.32	0.14	0.03	0	0	0.07	0.08	0.04	0	0	-0.12	0.11	0.09	0	0
KK	0.06	-0.01	-0.02	0	0	0.09	-0.07	-0.02	0	0	0	0.02	0.01	0	0.25
IH	-0.06	0.02	0.01	0	0	-0.05	-0.06	-0.03	0.50	0.50	-0.02	0.06	0.03	0	0.50
GS	0.16	-0.08	-0.22	0	0	-0.32	0.23	0.11	0	0	-0.32	0.23	0.11	0	0
TS	-0.14	0.34	0.15	0	0	0.41	-0.16	0.03	0	0	0.41	-0.16	0.03	0	0
PL	0.08	-0.09	0.05	0	0	-0.10	0.02	-0.01	0	0	-0.10	0.02	-0.01	0	0
RZ	0.41	-0.03	0.14	0	0	0.09	0.01	-0.02	0	0	0.09	0.01	-0.02	0	0
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
M	-0.0317	0.01	0	0	0	-0.0608	-0.02	0.012	0.042	0.042	-0.0817	0.002	0.024	0	0.063
S	0.2743	0.15	0.106	0	0	0.274	0.109	0.057	0.144	0.144	0.2684	0.111	0.058	0	0.155
V	0.0752	0.022	0.017	0	0	0.0753	0.012	0.003	0.021	0.021	0.0720	0.012	0.003	0	0.024
SS	0.8279	0.246	0.124	0	0	0.8285	0.131	0.036	0.229	0.229	0.7921	0.137	0.037	0	0.265

Subjects	40cm with low Neutral +ID					40cm with low Neutral -ID				
	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar
BM	-0.32	-0.21	-0.24	0	0	0.32	-0.07	0.02	0	0
JMcV	-0.08	0.09	0.03	0	0	0.11	0.12	-0.02	0	0
CL	-1.24	0.22	-0.01	0	0	0	-0.06	0.05	0	0
JF	-0.02	0.03	0.01	0.50	0.50	-0.06	0.01	0.02	0.25	0.25
MMS	0.23	-0.2	0.04	0.25	0.25	0.12	0.01	-0.1	0	0
LPP	0.10	-0.01	-0.02	0	0	0.02	0.15	0.12	0	0
KK	0.01	-0.03	-0.01	0.25	0.25	0.02	-0.01	-0.01	0	0
IH	-0.15	-0.07	-0.09	0	0	-0.07	-0.04	-0.03	0.25	0
GS	-0.59	0.08	-0.08	0	0	-0.05	0.08	0.13	0	0
TS	0.09	-0.14	-0.1	0	0	-0.21	0	0.04	0	0
PL	0.11	0.01	0.08	0	0	0.04	-0.18	-0.12	0	0
RZ	-0.19	0.08	-0.12	0.25	0.25	0.13	-0.19	-0.13	0	0
N	12	12	12	12	12	12	12	12	12	12
M	-0.1708	-0.013	-0.043	0.014	0.014	0.0308	-0.015	0	0.04	0.04
S	0.4029	0.127	0.088	0.167	0.167	0.1320	0.104	0.885	0.098	0.098
V	0.1624	0.016	0.008	0.028	0.028	0.0174	0.01	0.007	0.009	0.009
SS	1.7865	0.178	0.084	0.307	0.307	0.1919	0.12	0.079	0.104	0.104

A = VER Am;itude
Ia = Implicit Time of the a-wave
Ib = Implicit Time of the b-wave
Ap = Accommodative posture
Ar = Accommodative response

Standard deviations varied from 0.13 to 0.4 between conditions with a standard error of the mean being 0.12.

b. Implicit Time of the A-Wave

This variable was more consistent between the eyes of an individual. The range of mean differences between the eyes under each condition varied from an index of -0.02 to 0.013 (Table 11) with a 0.053 standard error of the mean.

c. Implicit Time of the B-Wave

This was more variable than the a-wave showing differences in means under all conditions, from an index score of -0.043 to 0.024 (Table 11), but with a smaller standard error of the mean of 0.035. A "t" test showed a significant difference between the implicit time of the b-wave at 40 cm. with the low neutral, and at 40 cm. with the low neutral +ID ($t = 2.22$, $p < 0.02$).

d. Accommodative Posture

The differences in accommodative posture between eyes were from 0.0D to 0.1D with a mean of 0.01D and standard error of the mean of 0.04D.

e. Accommodative Response

These results are like those of the accommodative posture due to the method of calculation.

Experiment II - VER and Accommodation of Amblyope

This experiment deals with the amblyopic subjects.

A. Raw Scores

The data are displayed in Table III where the results of the normal eye of the amblyope and the amblyopic eye have been separated into two groups. The mean (m), standard deviation (s), variance (v), and sum of squares (ss) are presented for each group.

1. Amblyopic Eyes

a. VER Amplitude

The amplitude, as in Experiment I with the normal population, varied between subjects. When comparing the mean amplitudes from each of the five conditions, i.e., distance with P, 40 cm. with P, 40 cm. with low neutral, 40 cm. with low neutral +ID and 40 cm. with low neutral -ID, to one another using a "t" test, none appeared to differ significantly. The amplitude correlated significantly with the implicit time of the a-wave at distance with P ($r = -0.68$; $p < 0.01$ Fig. 14), 40 cm. with P ($r = -0.71$; $p < 0.01$ Fig. 15), 40 cm. with low neutral +ID ($r = -0.63$; $p < 0.02$ Fig. 16), and with the b-wave at 40 cm. with P ($r = -0.57$; $p < 0.02$ Fig 17).

b. Implicit Time of the A-Wave

The mean implicit time of the a-wave was 98 msec. with a standard error of the mean of 9.08 msec.

There was no significant difference between the mean implicit times of the a-wave at any stimulus level. The implicit time of the a-wave varied linearly with that of the b-wave at distance with P ($r = 0.76$; $p < 0.001$ Fig. 18), 40 cm. with P ($r = 0.94$; $p > 0.001$ Fig. 19), 40 cm. with low neutral ($r = 0.92$; $p > 0.001$ Fig. 20), 40 cm. with low neutral +ID ($r = 0.95$; $p > 0.001$ Fig. 21), and 40 cm. with low neutral -ID ($r = 0.89$; $p > 0.001$ Fig. 22).

c. Implicit Time of the B-Wave

The mean implicit time of the b-wave under all conditions was 150.4 msec. with a standard error of the mean of 9.43 msec. Using a "t" test it was shown that there was no significant difference between the mean implicit time of the b-wave under each one of the five stimulus conditions, and the mean implicit time of the b-wave at any one other of the five levels.

d. Accommodative Posture and Response

Inspection of the accommodative posture and accommodative response data in Table III makes it evident that the amblyopes under-accommodate in both eyes, with the amblyopic system usually more off the plane of regard than the normal eye. Large inter-subject variability was noted.

2. Normal Eyes of Amblyopes

a. VER Amplitude

The amplitude, as in the normal population and the amblyopic population, varied between subjects. When comparing the mean amplitude of any one of the five stimulus conditions to that at another one of the five conditions, utilizing a "t" test, it was shown that there was no significant difference between means at any stimulus level. The amplitude was negatively correlated to the implicit time of the a-wave at distance with P ($r = -0.61$; $p < 0.02$ Fig 23), 40 cm. with P ($r = -0.62$; $p < 0.01$ Fig. 24), 40 cm. with low neutral ($r = -0.73$; $p < 0.001$ Fig. 25), and 40 cm. with low neutral +ID ($r = -0.87$; $p > 0.001$ Fig 26), and to the b-wave at 40 cm. with P ($r = -0.60$; $p < 0.02$ Fig. 27) and 40 cm. with low neutral -ID ($r = -0.57$; $p < 0.02$ Fig. 28).

b. Implicit Time of the A-Wave

The mean implicit time of the a-wave under all conditions was 91.6 msec. with a standard error of the mean of 8.4 msec. The a-wave correlated with the b-wave at distance with P ($r = 0.72$; $p < 0.001$ Fig. 29), 40 cm. with P ($r = 0.92$; $p > 0.001$ Fig. 30), 40 cm. with low neutral ($r = 0.72$; $p < 0.01$ Fig. 31), and 40 cm. with low neutral -ID ($r = 0.77$; $p < 0.001$ Fig. 32). There was no significant difference

TABLE III

AMBLYOPIC SUBJECTS. RAW SCORES.

Subjects		Distance with P					40cm with P					40cm with low Neutral					40cm with low Neutral +ID					40cm with low Neutral -ID				
Normal Eye		A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar
LB	OS	0.73	100.6	145.4	0	0	0.63	98	154	-1.00	+1.50	0.9	96	139	0	+1.25	0.45	94	128	+0.25	+1.75	0.6	98	149	-0.75	+2.
GE	OD	1.12	90	153	0	0	0.89	103	160.6	0	+2.50	0.89	103	160.6	0	+2.50	0.72	96	162	+0.25	+1.75	1.12	100.6	170.6	0	+3.
PP	OD	1.43	101.4	149.4	0	0	1.53	118	173.4	-2.25	+0.25	1.75	109	178	0	+1.00	1.0	122	176	+0.25	+1.75	1.25	107	161	-1.00	+2.
KR	OD	1.5	98	191.4	0	0	1.75	107	170	-1.50	+1.00	1.1	115	179	0	+1.50	0.9	112	157	+0.75	+2.25	1.0	104	184	-1.00	+2.
JD	OD	1.0	97.2	155.2	0	0	0.87	105.4	166	0	+2.50	0.87	105.4	166	0	+2.50	0.93	114	158.6	0	+1.50	0.85	116	162	0	+3.
SS	OD	4.23	93.4	171.4	0	0	3.5	90	140	-0.50	+2.00	3.65	93	147	0	+2.00	3.9	92	152	+0.25	+1.75	2.7	88	162	-0.25	+3.2
RH	OD	3.2	78	122	0	0	8.4	8.4	131.4	-0.50	+2.00	8.0	79	129	0	+2.00	7.2	8.2	130	+0.25	+1.75	6.2	69	116	-0.25	+3.2
KB	OD	2.96	75.4	126.4	0	0	3.0	119	178	-1.25	+1.25	3.9	66	154	0	+1.25	4.9	68	151	+0.50	+2.00	3.0	62	134	-0.50	+3.
JK	OS	8.12	74	128.6	0	0	8.0	68	120	0	+2.50	25.2	51	140	0	+2.50	24.4	16	152	0.25	+1.75	11.8	92	138	-0.50	+3.
HM	OD	1.7	83.4	125.4	0	0	0.8	104	146	-0.25	+2.25	1.5	124	170	0	+2.50	1.27	75.4	121.4	0	+1.50	0.7	96	156	-0.50	+3.0
GC	OD	2.7	72.6	137.4	0	0	2.15	101	176	0	+2.50	2.15	101	176	0	+2.50	2.1	113.4	180.6	0	+1.50	1.97	98.8	156	-0.50	+3.0
AG	OS	4.35	60.4	116.4	0	0	1.85	76	128	0	+2.50	1.85	76	128	0	+2.50	3.0	82	142	0	+1.50	2.4	82	140	0	+3.5
M		2.753	85.367	143.5	0	0	2.781	97.78	153.62	-0.6041	1.896	4.343	93.2	155.55	0	2.0	4.231	88.9	150.88	0.229	1.729	2.799	92.783	152.38	-0.438	3.06
S		2.089	13.307	22.1801	0	0	2.6807	15.64	20.18	0.7421	0.7421	6.874	21.33	18.757	0	0.5935	6.67	28.56	18.203	0.223	0.225	3.233	15.54	18.217	0.3555	0.35
V		4.367	177.07	692.22	0	0	7.1862	244.57	407.36	0.55066	0.55066	43.26	455.03	351.89	0	0.3523	44.55	815.84	331.36	0.0507	0.0507	10.45	241.34	331.86	0.1264	0.12
SS		48.062	1947.81	5414.47	0	0	79.048	2690.22	4481	6.0573	6.0573	519.84	5005.31	3870.75	0	3.875	490.04	8974.2	364.5	0.557	0.557	114.98	2654.84	3650.25	1.39062	1.39
Amblyopic Eye																										
LB	OD	0.95	104.4	169	0	0	0.4	134	168	-2.00	+0.50	1.1	110	149	0	+0.75	1.0	140	188	+0.25	+1.75	0.3	94	128	-0.75	+2.7
GE	OS	1.04	92.8	145.4	0	0	0.99	112.6	166.6	-1.50	+1.00	0.84	113	163	0	+1.50	0.54	122	182	+0.50	+2.00	0.64	152	210	-0.75	+2.7
PP	OS	1.2	90	135	0	0	0.6	140	188	-2.25	+0.25	1.3	122	183	0	+0.50	1.2	129	182	+0.25	+1.75	0.45	108	138	-1.00	+2.5
KR	OS	0.85	96	146	0	0	1.05	112	158	-2.00	+0.50	1.23	120	182.4	0	+0.25	0.6	78	134	+1.00	+2.50	1.2	106	162	-1.25	+2.2
JD	OS	1.0	90	146	0	0	0.63	114	160	-2.00	+0.50	0.43	94	146	0	+0.25	0.8	110	150	+0.75	+2.25	0.6	112	161	-1.00	+2.5
SS	OS	3.45	79	156	0	0	3.65	88	138	0	+2.50	3.6	92	144	0	+2.50	3.45	98	164	+0.50	+200	3.2	91	150	-1.00	+2.5
RH	OS	2.68	64	107.4	0	0	8.52	80.6	134	-2.50	0	7.6	85	134	0	0	6.8	73	118	+0.75	+225	6.6	75	124	-1.00	+2.5
KB	OS	1.5	90	139	0	0	2.3	81	132	-2.00	+0.50	2.74	110	166.6	0	+0.25	3.2	80	134	+0.50	+2.00	3.6	80	134	-0.75	+2.7
JK	OD	7.5	62	127	0	0	10.6	7 6	132	0	+2.50	22.0	82	144	0	+2.50	13.6	62	133	+0.25	+1.75	15.2	85	134	-0.75	+2.75
HM	OS	0.6	116	140	0	0	0.5	96	132	-2.00	+0.50	0.9	80	130	0	+1.00	1.0	84	142	+0.75	+2.25	0.65	78	120	-1.00	+2.5
GC	OS	1.6	126.4	192.8	0	0	1.32	101.2	154	0	+2.50	1.32	101.2	154	0	+2.50	2.0	124	180	+0.50	+2.00	1.35	90	146	+0.50	+3.00
AG	OD	3.4	85	147	0	0	2.3	100.4	167.4	-2.00	+0.50	2.5	74	134	0	+0.50	3.2	98	154	+0.75	+225	1.8	101	140	-0.50	+300
M		2.148	91.3	145.88	0	0	2.708	102.98	152.5	-1.521	0.979	3.797	98.6	152.5	0	1.04	3.11	99.83	155.58	0.563	2.063	2.966	97.67	145.58	-0.854	2.64
S		1.951	18.68	21.057	0	0	3.356	20.5	18.663	0.9442	0.9442	6.055	16.39	17.902	0	0.965	3.77	25.08	23.65	0.241	0.241	4.267	20.96	24.24	0.225	0.22
V		3.8064	348.9	443.41	0	0	11.26	420.27	347.58	0.892	0.892	36.67	268.72	320.49	0	0.931	14.21	629.24	559.54	0.0583	0.0582	18.20	439.52	587.54	0.050	0.05
SS		41.87	3837.89	4877.53	0	0	123.86	4622.94	3823.37	9.807	9.807	403.36	2955.9	3525.37	0	10.25	156.33	6921.67	6154.96	0.6407	0.6407	200.23	4834.07	6462.94	0.557	0.55

A = VER amplitude
Ia = Implicit time of the a-wave (Msec)
Ib = Implicit time of the b-wave (Msec)
Ap = Accommodative posture (Diopters)
Ar = Accommodative response (Diopters)

between the mean implicit times of the a-wave at various stimulus levels when using a "t" test.

c. Implicit Time of the B-Wave

The mean implicit time of the b-wave under all conditions was 151.2 msec. with a standard error of the mean of 8.72 msec. The implicit time of the b-wave correlated with the VER amplitude at 40 cm. with P ($r = -0.60$; $p < 0.02$ Fig. 27) and 40 cm. with low neutral -ID ($r = -0.57$; $p < 0.02$ Fig. 28).

d. Accommodative Posture and Accommodative Response

Inspection of the accommodative posture and accommodative response data on Table III shows a hypoposturing accommodative system in the normal eye of the amblyope in many cases.

3. Comparison of Amblyopic and Normal Eyes of Amblyopes

This analysis utilizes the "t" test to compare the mean of each variable of the amblyopic eye with its corresponding value in the normal eye of the amblyope, under a particular condition. A similar "t" test to that previously stated was employed.

a. VER Amplitude, Implicit Time and the A and B-Wave.

There was no significant difference of these values between the two eyes of the amblyopic subject.

b. Accommodative Posture and Response

Accommodative posture and accommodative response are artificially controlled at distance with P and 40 cm. with low neutral, which prevents comparison of these variables between the two eyes of the amblyope. There was a significant difference in accommodative posture and accommodative response between the two eyes of the amblyope at 40 cm. with P ($t = 3.01$; $p < 0.001$), 40 cm. with low neutral +ID ($t = 3.506$; $p < 0.001$), 40 cm. with low neutral -ID ($t = 3.425$; $p < 0.001$), and in accommodative response between eyes at 40 cm. with low neutral ($t = 2.934$; $p < 0.001$).

4. Comparison of Amblyopic Eyes to Normal Eyes

This analysis utilizes the "t" test to compare the accommodative findings of the amblyopic eye to the normal subject. The VER data was not compared because of the inter-subject variability normally presented by different subjects under different conditions, especially with different electrode placements. The accommodative posture at distance with P and at 40 cm. with the low neutral were artificially rendered zero as was the accommodative response at distance. There was a significant difference between amblyopic eyes and normal subjects in accommodative posture and accommodative response at 40 cm. with P ($t = 7.32$; $p > 0.001$), 40 cm. with low neutral +ID ($t = 2.56$; $p < 0.01$), low neutral -ID

($t = 8.84$; $p > 0.001$), and accommodative response at 40 cm. with low neutral ($t = 6.46$; $p > 0.001$).

5. Comparison of Normal Eyes of Amblyopes to Normal Eyes

A "t" test was utilized for this comparison of accommodative results only. There were significant differences in accommodative posture and accommodative response between these two populations at 40 cm. with P ($t = 3.304$; $p < 0.001$), 40 cm. with low neutral +ID ($t = 5.033$, $p > 0.001$), 40 cm. with low neutral -ID ($t = 4.916$; $p > 0.001$), and accommodative response at 40 cm. with low neutral ($t = 2.41$; $p < 0.02$).

B. Difference Between Scores

As in Experiment I, this appeared to be a good method of analysis because many of the adverse factors introducing variability into the results are reduced. Further analysis of the data is made with the Wilcoxon and sign tests.

1. Amblyopes

The data are presented in Table IV. The values shown are calculated by $1 - \frac{\text{amblyopic response}}{\text{normal response}}$, which is an index that represents a relative difference between the amblyopic and normal responses. The accommodative posture and response data are arithmetic differences between the normal and amblyopic eyes.

a. VER Amplitude

The difference between the normal and amblyopic VER mean amplitudes varied from an index of 0.038 to 0.212

TABLE IV

AMBLYOPIC SUBJECTS. DIFFERENCE BETWEEN EYES $(1 - \frac{\text{Amblyopic}}{\text{Normal}})$

Subjects	Distance with P					40cm with P					40cm with low Neutral					40cm with low Neutral +ID					40cm with low Neutral -ID				
	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar
LB	-0.3	-0.04	-0.16	0	0	0.37	-0.37	-0.09	+1.00	1.00	-0.22	-0.15	-0.07	0	0.50	-1.22	-0.49	-0.47	0	0	0.5	0.04	0.14	0	0
GE	0.07	-0.03	0.05	0	0	-0.11	-0.09	-0.04	+1.50	1.50	0.06	-0.1	-0.01	0	1.00	0.25	-0.27	-012	0.25	0.25	0.43	-0.51	-0.23	0.75	0.75
PP	0.16	0.11	0.10	0	0	0.61	-0.19	-0.08	0	0	0.26	-0.12	-0.03	0	0.50	-0.2	-0.06	-0.03	0	0	0.64	-0.01	+0.14	0	0
KR	0.43	0.02	0.24	0	0	0.4	-0.05	0.07	+0.50	0.50	-0 12	-0.04	-0.02	0	1.25	0.33	0.30	0.15	0.25	0.25	-0.2	-0.02	0.12	0.25	0.25
JD	0	0.07	0.06	0	0	0.28	-0.08	0.04	+2.00	2.00	0.51	0.11	0.12	0	2.25	0.14	0.04	0.02	0.75	0.75	0.29	0.03	0.01	1.00	1.00
SS	0.18	0.15	0.09	0	0	-0.04	0.02	0.02	+0.50	0.50	0.01	0.01	0.02	0	0.50	-.12	-0.07	-0.08	0.25	0.25	-0.19	-0.03	0.07	0.75	0.75
RH	0 16	0.18	0.12	0	0	-0.01	0.04	-0.02	+2.00	2.00	0.05	-0.08	-0.04	0	2.00	0.06	0.11	0.09	0.50	.05	-0.06	-0.09	-0.07	.75	.75
KB	0.49	-0.19	-0.1	0	0	0.23	0.32	0.26	0.75	0.75	0.3	-0.67	-0.08	0	1.00	0.35	-0.18	0.11	0	0	-0.2	-0.29	0	0.25	0.25
JK	0.08	0.16	0.01	0	0	-0.33	-0.12	-0.1	0	0	0.13	-0.61	-0.03	0	0	0.44	-2.88	0.13	0	0	-0.29	0.08	0.03	0.25	0.25
HM	0.65	-0.39	-0.12	0	0	0.38	0.08	0.1	1.75	1.75	0.4	0.35	0.24	0	1.50	0.21	-0.11	-0.17	0.75	0.75	0.07	0.19	0.23	0.50	0.50
GC	+0.4	-0.74	-0.4	0	0	0.39	0	0.13	0	0	0.39	0	0.13	0	0	0.05	-0.09	0	0.50	0.50	0.31	0.09	0.09	0	0
AG	0.22	-0.41	-0.26	0	0	-0.24	-0.32	-0.31	2.00	2.00	-0.35	0.03	-0.05	0	2.00	-0.07	-0.2	-0.08	0.75	0.75	0.25	-0.23	000	0.50	0.50
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
M	02117	-0.093	-0.903	0	0	0.1608	-0.063	0.002	1.0	1.0	0.118	-0.11	0.02	0	1.04	0.038	-0.325	-0.04	0.33	0.33	0.129	-0.06	0.044	0.417	0.417
S	0.253	0.287	0.182	0	0	0.296	0.183	0.142	0.819	0.819	0.265	0.282	0.097	0	0.775	0.435	0.828	0.17	0.308	0.308	0.316	0.194	0.119	0.343	0.343
V	0.064	0.082	0.033	0	0	0.0879	0.0336	0.02	0.6705	0.6705	0.07	0.08	0.009	0	0.6	0.189	0.686	0.029	0.09	0.09	0.1	0.038	0.014	0.117	0.117
SS	0.703	0.9016	0.3625	0	0	0.0967	0.369	0.224	7.375	7.375	0.77	0.877	0.104	0	6.604	2.087	7.544	0.32	1.042	1.042	1.096	0.413	0.155	1.291	1.291

A = VER Amlitude
Ia = Implicit time of the a-wave
Ib = Implicit time of the b-wave
Ap = Accommodative posture
Ar = Accommodative response

with a mean of 0.132. The standard error of the mean was 0.139. It was shown by the Wilcoxon and sign tests that the VER amplitude of the amblyopic eye was significantly often (10 to 1) reduced in comparison to the normal eye of the amblyope at distance.

b. Implicit Time of the A-Wave

Under the five test conditions the mean difference in implicit time of the a-wave varied from an index score of 0.06 to 0.325, with a mean of 0.13. The standard error of the mean was 0.159.

c. Implicit Time of the B-Wave

The means of the difference in implicit times of the b-wave between eyes varied from an index of 0.004 to 0.049 and was less variable with a mean of 0. The standard error of the mean was 0.064.

d. Accommodative Posture

The results showed differences in accommodative posture between the eyes from 0.33D to 1.04D with a mean of 0.58D and standard error of the mean of 0.22D. There was a significant deviation between the difference in accommodative posture of the eyes at 40 cm. with P and difference in accommodative posture at 40 cm. with low neutral +ID ($t = 2.653$; $p < 0.01$). A statistically significant difference ($t = 2.27$; $p < 0.02$) in mean difference in accomodative posture at 40 cm. with P and difference in accommodative posture at 40 cm. with low neutral -ID also existed. The Wilcoxon and sign test substantiated the fact that the amblyopic eye most often under accommodates compared to the normal eye.

e. Accommodative Response

The results of the accommodative response are tightly linked to that of accommodative posture, except that a result is obtained at the 40 cm. with low neutral condition which was also significantly different from that at 40 cm. with low neutral +ID ($t = 2.95$; $p < 0.01$), and that at 40 cm. with low neutral -ID ($t = 2.55$; $p < 0.02$).

2. Comparison of Differences Between Amblyopic Subjects' Eyes and Normal Subjects

a. VER Amplitude

There were significant differences between amblyopes and normal differences in amplitude at distance with P ($t = 2.26$; $p < 0.02$) and 40 cm. with P ($t = 2.64$; $p < 0.01$).

b. Implicit Time of the A-Wave

There was no significant difference between populations under any conditions.

c. Implicit Time of the B-Wave

There was no significant difference between populations under any conditions.

d. Accommodative Posture

There were significant differences in populations at 40 cm. with P ($t = 3.99$; $p > 0.001$), 40 cm. with low neutral +ID ($t = 2.23$; $p < 0.01$), and 40 cm. with low neutral -ID ($t = 3.67$; $p < 0.001$).

e. Accommodative Response

Significant differences in populations were presented at 40 cm. with P ($t = 3.99$; $p > 0.001$), 40 cm. with low neutral ($t = 4.28$; $p > 0.001$), 40 cm. with low neutral +ID ($t = 2.23$; $p < 0.01$), and 40 cm. with low neutral -ID ($t = 3.67$; $p < 0.001$).

3. Comparison Between Strabismic Amblyopes and Normal Subjects

The data is presented in Table V. Due to the small sample of amblyopes, and the relatively large percentage (75%) of amblyopes with strabismus, it was decided not to compare the difference between eyes of the strabismic amblyope with the non-strabismic amblyope but rather with the normal population.

a. VER Amplitude

In comparing the results of the difference between eyes of the amblyopic and normal populations, significant differences existed between VER amplitudes at distance with P ($t = 2.29$; $p < 0.02$) and at 40 cm. with low neutral +ID ($t = 2.39$; $p < 0.02$).

b. Implicit Time of the A and B-Waves

There was no significant difference in implicit times between populations under any conditions.

TABLE V

STRABISMIC AMBLYOPES. DIFFERENCE BETWEEN EYES.

Subjects	Distance with P					40cm with P					40cm with low Neutral					40cm with low Neutral +ID					40cm with low Neutral -ID				
	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar	A	Ia	Ib	Ap	Ar
GE	-0.07	-0.03	0.05	0	0	-0.11	-0.09	-0.04	+1.50	1.50	0.06	-0.1	-0.01	0	1.00	0.25	-0.27	-0.12	0.25	0.25	0.43	-0.51	-0.23	0.75	0.75
KR	0.43	0.02	0.24	0	0	0.4	-0.05	0.07	+0.50	0.50	-0.12	-0.04	-0.02	0	1.25	0.33	0.30	0.15	0.25	0.25	-0.2	-0.02	0.12	0.25	0.25
JD	0	0.07	0.06	0	0	0.28	-0.08	0.04	+2.00	2.00	0.51	0.11	0.12	0	2.25	0.14	0.04	0.02	0.75	0.75	0.29	0.03	0.01	1.00	1.00
SS	0.18	0.15	0.09	0	0	-0.04	0.02	0.02	+0.50	0.50	0.01	0.01	0.02	0	0.50	0.12	-0.07	-0.08	0.25	0.25	-0.19	-0.03	0.07	0.75	0.75
RH	0.16	0.18	0.12	0	0	-0.01	0.04	-0.02	+2.00	2.00	0.05	-0.03	-0.04	0	2.00	0.06	0.11	0.09	0.50	0.50	-0.06	-0.09	-0.07	0.75	0.75
JK	0.08	0.16	0.01	0	0	-0.33	-0.12	-0.1	0	0	0.13	-0.61	-0.03	0	0	0.44	-2.88	0.13	0	0	-0.29	0.08	0.03	0.25	0.25
HM	0.65	-0.39	-0.02	0	0	0.38	0.08	0.1	+1.75	1.75	0.4	0.35	0.24	0	1.50	0.21	-0.11	-0.17	0.75	0.75	0.07	0.19	0.23	0.50	0.50
GC	+0.4	-0.76	-0.4	0	0	0.39	0	0.13	0	0	0.39	0	0.13	0	0	0.05	-0.01	0	0.50	0.50	0.31	0.09	0.09	0	0
AG	0.22	-41	-0.26	0	0	-0.24	-0.32	-0.31	+2,00	2,00	-0.35	0.03	-0.05	0	2.00	-0.07	-0.2	-0.08	0.75	0.75	0.25	-0.23	0	0.50	0.50
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
M	0.2278	-0.11	-0.012	0	0	0.08	-0.058	-0.002	1.139	1.139	0.1200	-0.031	0.04	0	0.944	0.17	-0.343	-0.006	0.446	0.444	0.067	-0.054	0.027	0.528	0.528
S	0.2286	0.3251	0.1978	0	0	0.2867	0.118	0.128	0.876	0.876	0.274	0.253	0.100	0	0.798	0.158	0.9661	0.114	0.273	0.273	0.2633	0.208	0.129	0.317	0.317
V	0.0523	0.1057	0.0391	0	0	0.0822	0.014	0.0165	0.767	0.767	0.075	0.064	0.010	0	0.637	0.024	0.9333	0.013	0.075	0.075	0.069	0.043	0.016	0.101	0.101
SS	0.4182	0.8456	0.313	0	0	0.6576	0.112	0.132	6.139	6.139	0.602	0.511	0.080	0	5.097	0.194	7.467	0.1036	0.597	0.597	0.555	0.347	0.132	0.806	0.806

A' = VER Amptitude
Ia = Implicit time of the a-wave
Ib = Implicit time of the b-wave
Ap = Accommodative posture
Ar = Accommodative response

c. Accommodative Posture

There were significant differences in populations at 40 cm. with P ($t = 4.29$; $p > 0.001$), 40 cm. with low neutral +ID ($t = 5.13$; $p > 0.001$) and low neutral -ID ($t = 5.05$; $p > 0.001$).

d. Accommodative Response

Significant differences in the normal and strabismic amblyope populations were present at 40 cm. with P ($t = 4.29$; $p > 0.001$), 40 cm. with low neutral ($t = 3.97$; $p > 0.001$), 40 cm. with low neutral +ID ($t = 5.13$; $p > 0.001$), and low neutral -ID ($t = 5.05$; $p > 0.001$).

<u>Experiment III - Eccentric Fixation</u>

The data from this experiment are presented in Table VI.

The influence of the eccentric fixation on the VER amplitude, implicit times, accommodative posture, accommodative response, and visual acuities was investigated. A correlation coefficient was calculated between the degree of eccentric fixation in prism diopters and the above variables. The data was subdivided into those amblyopes with eccentric fixation, and those with central fixation. A further subdivision was made into those who had previously done visual training and those who had not.

Twelve amblyopes are presented for the VER data, four of whom had central fixation. Fifteen amblyopes are

TABLE VI

DATA OF ECCENTRIC FIXATORS. IN MINUTE OF ARC.

Subjects	Degree of E.F.	Direc-tion	V/A dist. with dist. Rx. Ln	Sl	"S"	V/A 40cm with dist. Rx. Ln	Sl	"S"	V/A 40cm with low neutral Ln	Sl	"S"	V/A 40cm with low neutral +1.00 Ln	Sl	"S'	V/A 40cm with low neutral -1.00 Ln	Sl	"S'
GC	3.5$^{\Delta}$	I/N	7.5	7.5	20	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
DB	1.5$^{\Delta}$	I/N	50	15	20	30	15	20	15	15	20	20	15	20	15	15	20
RC	7.5$^{\Delta}$	S/N	25	15	30	30	15	30	20	15	30	20	15	30	20	15	30
HM	0		10	10	15	20	10	30	20	10	30	20	15	30	20	10	30
JK	11.5$^{\Delta}$	N	12	5	10	15	7.5	1 0	15	7.5	1 0	15	7.5	10	15	7.5	10
KB	1$^{\Delta}$	N	10	6.5	20	15	30	20	15	15	20	15	20	20	15	15	20
RH	0.75$^{\Delta}$	S/T	17.5	17.5	25	30	30	30	30	30	30	30	30	30	30	30	30
SS	0.75$^{\Delta}$	I	10	10	10	15	15	15	15	15	15	15	15	15	15	15	15
KR	3$^{\Delta}$	N	10	7.5	10	20	10	15	15	7.5	15	15	10	15	.5	10	15
PP	0		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
GE	0		7.5	7.5	15	10	7.5	15	10	7.5	15	10	10	15	10	7.5	15
LB	0		15	15	30	20	20	30	20	20	30	20	20	30	20	20	30
JD	4$^{\Delta}$	S/T	20	15	50	30	15	50	30	15	50	30	15	50	30	15	50
TD	0		50	50	50	50	50	50	30	50	50	50	50	50	30	50	50
AG	-$^{\Delta}$	S/T	15	7.5	30	15	7.5	20	15	10	20	15	10	30	15	7.5	20
N	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
M	1.6333$^{\Delta}$		20.633	15.933	25.67	23.83	19.33	26.17	20.5	18.33	26.17	22.17	19.33	26.83	20.5	18.33	26.17
S	2.089		15.9278	14.369	14.38	12.92	14.44	14.29	10.7	14.16	14.29	12.85	13.708	14.22	10.7	14.163	14.29
V	4.3649		253.69	206.46	206.67	166.85	208.45	204.35	114.46	200.6	204.35	165.06	187.92	202.20	114.46	200 6	204.35
SS	61.1083		3551.73	2890.43	2893.3	2335.8	2918.33	2860.83	1602.5	2808.3	2860.83	2310.8	2630.83	2830.8	1602.5	2808.3	2860.83

Ln = Line acuity
Sl = Single letter acuity
"S" = Flom's "S" acuity

I = Inferior
N = Nasal
S = Superior
T = Temperal

presented for the visual acuity data, five of whom had central fixation and four of whom had been involved in a visual training program in the past.

No correlation was found between the degree of eccentric fixation and the VER, accommodative or visual acuity data in any of the above populations, under any of the five experimental conditions.

A "t" test was employed to compare the mean line, single letter and Flom's "S" acuity of each condition with the corresponding acuity under the other conditions. No significant difference in resolution between the same type of acuity demand (line acuity, single letter, Flom "S" chart) was found under any of the five conditions. Using a "t" test there was also no significant difference in the mean angle of resolution between the different types of acuity demands. However, when a sign test was used it was seen that a significant proportion of the subjects improved their acuity from the line and Flom "S" acuity to the single letter, and a significant proportion presented a decrease in resolution from line and single letter to Flom "S" chart acuity.

Experiment IV - Haidinger Brushes, Maxwell Spot and VER

The data are presented in Table VII.

Inspection of the data shows close agreement between positive responses of the Haidinger brushes, Maxwell spot and VER especially in the normal subjects where only one subject was unable to appreciate the Maxwell spot in one eye. One amblyope presented a similar result.

TABLE VII

RESULTS OF EXPERIMENT IV

	Amblyopic eyes				Normal eye of Amblyopes					Normals OD				Normals OS			
	HB	MS	VER	D15	HB	MS	VER	D15		HB	MS	VER	D15	HB	MS	VER	D15
GC	✓	✓	✓	✓	✓	✓	✓	✓	RZ	✓	✓	✓	✓	✓	✓	✓	✓
DB	✓	✓	✓	✓	✓	✓	✓	✓	PL	✓	✓	✓	✗	✓	✓	✓	✗
RC	✓	✓	✓	✓	✓	✓	✓	✓	TS	✓	✓	✓	✓	✓	✓	✓	✓
HM	✓	✓	✓	✓	✓	✓	✓	✓	GS	✓	✓	✓	✓	✓	✓	✓	✓
JK	✓	✗	✓	✓	✓	✓	✓	✓	IH	✓	✓	✓	✓	✓	✓	✓	✓
KB	✓	✓	✓	✓	✓	✓	✓	✓	KK	✓	✓	✓	✓	✓	✓	✓	✓
RH	✓	✓	✓	✓	✓	✓	✓	✓	PP	✓	✓	✓	✓	✓	✓	✓	✓
SS	✓	✓	✓	✓	✓	✓	✓	✓	MS	✓	✗	✓	✓	✓	✓	✓	✓
KR	✓	✓	✓	✓	✓	✓	✓	✓	JF	✓	✓	✓	✓	✓	✓	✓	✓
PP	✓	✓	✓	✓	✓	✓	✓	✓	CL	✓	✓	✓	✓	✓	✓	✓	✓
GE	✓	✓	✓	✓	✓	✓	✓	✓	JMcV	✓	✓	✓	✓	✓	✓	✓	✓
LB	✓	✓	✓	✓	✓	✓	✓	✓	RM	✓	✓	✓	✓	✓	✓	✓	✓
JD	✓	✗	✓	✗	✓	✗	✓	✗	BM	✓	✓	✓	✓	✓	✓	✓	✓
TD	✗	✗	✗	✓	✗	✗	✓	✓									
AG	✓	✓	✓	✓	✓	✓	✓	✓									

HB = Haidinger Brushes
MS = Maxwell Spot
VER = Visual evoked response
D15 = Farnsworth D15 Color Test

The single organic amblyope in the study was unable to see the Haidinger brushes or Maxwell spot in either eye, but the VER was evident in the normal eye and not the amblyopic. One amblyopic subject who was color anomalous was not able to perceive the Maxwell spot with either eye. A deuternomal from the normal group did perceive the phenomenon.

DISCUSSION AND CONCLUSIONS

Experiment I - Normal Subjects

Examination of the data shows inter-subject variability in the VER amplitude and less variability in the implicit times. Similar results have been presented by other investigators (Cappin and Nissim 1975; Sokol 1976; Wooten 1972; Asselman, et al 1975). However, intra-subject VER amplitudes are less variable, as can be seen by the similarity in the results from each eye of the normal subject. As stated above, many variables do influence the amplitude. It was for this reason that averaged values of a forward-reverse sequence and an ABBA routine was used. Other constant differences, such as electrode placement, could not be accounted for by this method and therefore an analysis of the difference between the two eyes was made. This reduces the influence of the constantly present variables on the VER amplitude and allows a more complete analysis. The VER and accommodative data showed minimal diffences between the eyes of the normal subject both with parametric and non-parametric statistical methods, which substantiates the fact that a truly "normal population" had been investigated.

The first hypothesis that the accommodative posture and VER amplitude varied systematically with each other was substantiated by a correlation between these variables under two of the five experimental conditions.

The implicit time of the a and b-waves were less variable than the VER amplitude. A strong correlation existed between the two implicit times. This indicates a consistency in the duration of that part of the VER wave form considered to be the informative, which is from the trough of the a-wave to the peak of the b-wave. The mean implicit time of the a-wave was similar to that generally presented by most investigators; however, the implicit time of the b-wave was slightly lower, i.e., 147 msec. versus 175 msecs. Thus, for a normal population the implicit time is fairly constant while the amplitude is more variable.

The normal accommodative system was shown to be efficient with accommodation maintained close to the plane under the conditions presented. These results are similar to those of Wood and Tomlinson (1975) in their normal population.

Experiment II - Amblyopes

Initially the data from this population was separated into normal eyes and amblyopic eyes. Comparison of the mean VER amplitude, implicit time, accommodative posture and accommodative response data from one of the five experimental conditions, i.e., distance with P, 40 cm. with P, 40 cm. with low neutral, 40 cm. with low neutral +ID and 40 cm. with low neutral -ID, to a mean under another one of the conditions using a "t" test showed that the amblyopic eye and the normal eye of the amblyope behaved in a similar manner within their specific population. A linear analysis showed that the VER amplitude, implicit time, accommodative posture and accommodative response were correlated in the amblyopic and normal eye of the amblyope. As in the normal population, greater variability was seen in the VER amplitudes of each group and less in the implicit times.

A "t" test showed no significant difference in mean VER amplitude under any of the five conditions within the amblyopic population and the amplitude did not correlate significantly with accommodative posture or accommodative response. Thus, part of the second question is answered. Since the VER amplitude did not increase significantly under the low neutral condition when the eye was artificially rendered conjugate with the stimulus, and there was no correlation of VER amplitude or implicit time to accommodative posture, it cannot be assumed that the hypoposturing accommodative system was a major factor in affecting the VER amplitude or implicit times.

As in the normal population the implicit times of the amblyope correlated with each other, and with the VER amplitude under some conditions. This may indicate some type of artifact in the system of measuring and evaluating VER amplitudes and implicit times whereby one of these variables may be influencing another, or some neurological process.

When the normal eye of the amblyope is compared to the amblyopic eye, the VER amplitude was reduced in the latter in a significant number of subjects. This confirms the work of Sokol and Bloom (1973); Lomboroso, et al (1969); Yinon, et al (1974).

There was no significant difference between the implicit times of either eye, as has been found by Levi (1975).

A significant difference in accommodative posture and accommodative response was evident with the amblyopic eye comparatively hypoposturing. Wood and Tomlinson (1975) also presented reduced accommodative response in amblyopes at the 40 cm. distance. The normal eye of the amblyope presented significantly different accommodative postures from that of the normal population. This is of interest to the clinician indicating that the non-amblyopic eye is part of an anomalous visual system and also requires visual training to become efficient.

In comparing the differences between the two eyes of the amblyopic and normal subjects, a statistically significant difference in VER amplitude is noted at both distance and near. This substantiates the above results which showed the amplitude reduced in the amblyopic eye.

The data was also separated differentiating the strabismic from the non-strabismic amblyope, and the patients who had previously participated in visual training from those who had not. Although the sample sizes were small, the results were in line with those found in the above experiments.

Thus, the amblyope showed a reduced VER amplitude a significant percentage of the time (ten out of eleven eyes) and no significant difference in implicit time compared to the normal eye and the normal subject.

The accommodative posture, which was hypopostured in both eyes of the amblyope but more so in the amblyopic eye, did not influence the VER results significantly.

The type or degree of binocular visual adaptation, state of binocularity or visual condition did not differentiate the different types of amblyopes based on the VER and accommodative data.

Experiment III - Eccentric Fixation

The degree of eccentric fixation did not appear to influence the VER results in a systematic manner. This result is what was expected since the checkerboard field subtended a 12° field, and the largest amount of eccentric fixation present was about 4°. The macula area, which dominates the VER, was being stimulated in every case even though eccentric fixation was present. Similarly the visual acuity and accommodative posture did not correlate significantly with the eccentric fixation.

The addition of lenses to compensate for the accommodative posture of the amblyope did not improve the visual acuity significantly. A subjective report of improvement was often noted but this was not great enough to improve the minimum angle of resolution. The results of the different acuity demands are in keeping with the literature with the best acuity evident on single letters, then line, and lastly Flom "S" chart. As well as the influence of contour interaction, the investigator believes that the typically erratic fixation of the amblyope had a large influence on this result. The unsteady fixation made the exact determination of the degree of eccentric fixation difficult.

Differentiating the groups into those who had participated in visual training and those who had not, as well as those amblyopes with central fixation and those with eccentric fixation, did not alter the above results or conclusions significantly.

Thus, the eccentric fixation did not correlate with the VER, visual acuity, or accommodative posture.

Experiment IV - Haidinger Brushes, Maxwell Spot and VER

Unfortunately only one organic amblyope was examined and the subject was unable to appreciate the Haidinger brushes or Maxwell spot with either eye. The VER did, however, differentiate the two eyes. Only two color defective individuals were examined. The deuternomal was able to see the Maxwell spot; but the anomalous trichromat could not perceive the phenomenon. The investigator is unable to explain the response of the two subjects who were unable to perceive the phenomenon in one eye only.

SUMMARY

Twelve normal and twelve amblyopic subjects were examined to investigate the differences in visual evoked response as well as the state and influence of the accommodative posture and accommodative response on the VER and visual acuity. The VER amplitude was reduced in the amblyopic eye compared to the normal eye a significant proportion of the time. However, the implicit times were not significantly different. It was shown that the amblyopic subject presents a hypoposturing accommodative system in both the affected and normal eyes, compared to normal subjects. The amblyopic eye also significantly under-accommodated compared to the normal eye of the amblyope. The results did not demonstrate that this anomaly of accommodation had any significant relationship to the VER amplitude, implicit times, or visual acuity of the amblyope.

An investigation of the eccentric fixating amblyopes showed that the degree of eccentric fixation did not vary in a statistically significant manner with the VER, accommodative, or visual acuity data.

A final experiment showed a close correlation between positive results on the Haidinger brushes, Maxwell spot and

VER. These tests have been used for differentiating functional from organic amblyopia in the past.

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APPENDIX I

List of Figures

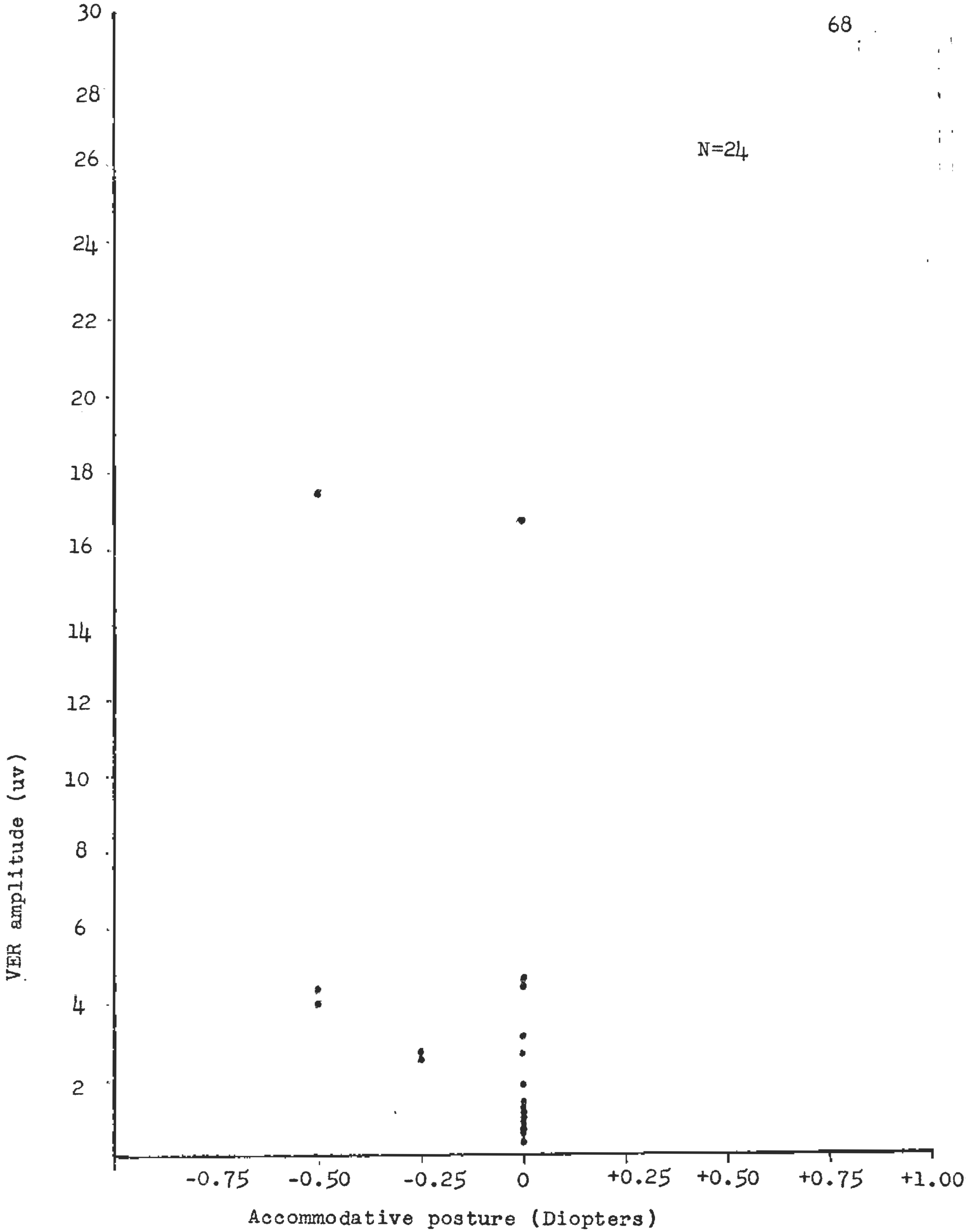

Fig. 6 Normal subjects. Accommodative posture vs. VER amplitude. 40 cm. with P.

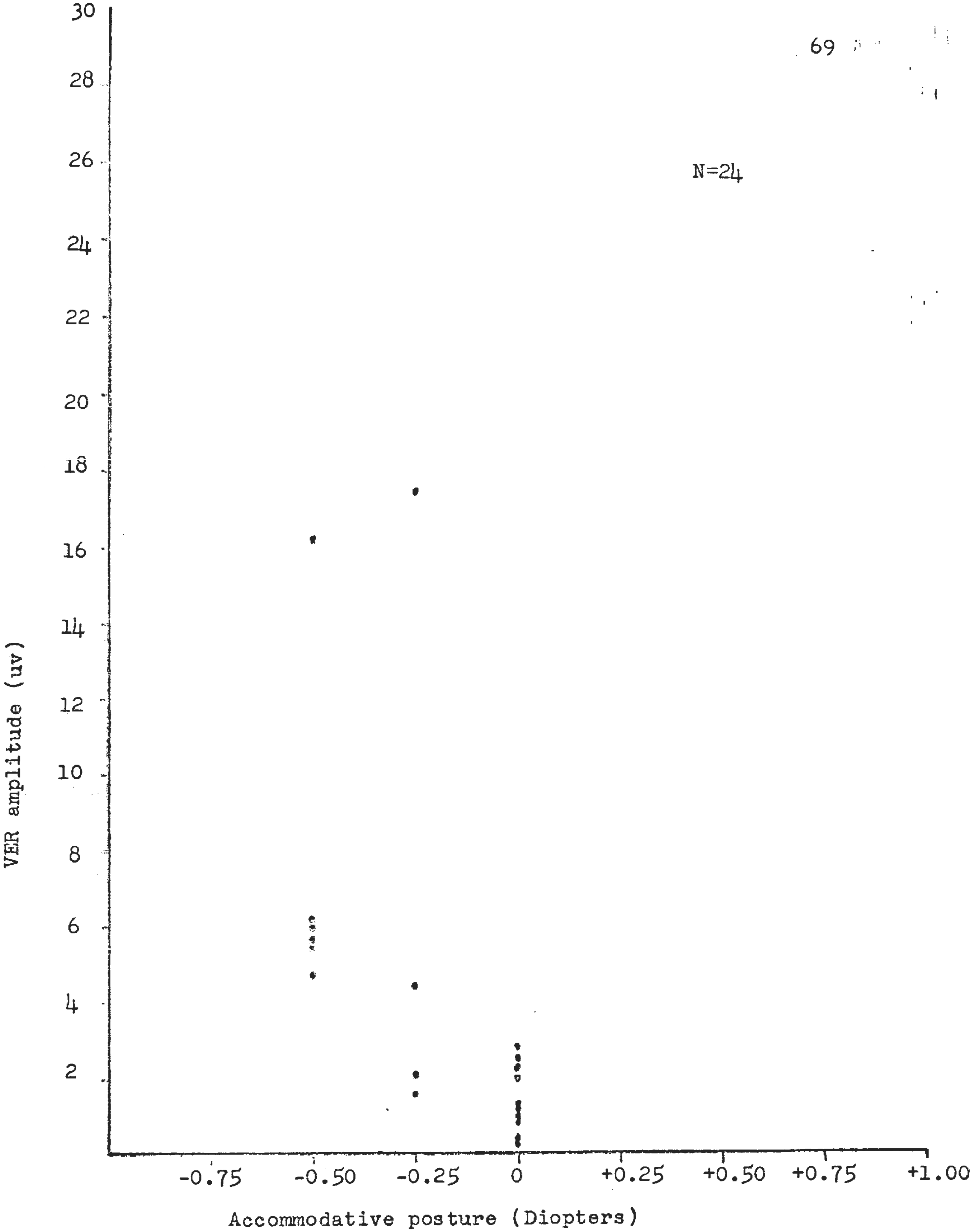

Fig. 7 Normal subjects. Accommodative posture vs. VER amplitude. 40 cm. with low neutral -ID.

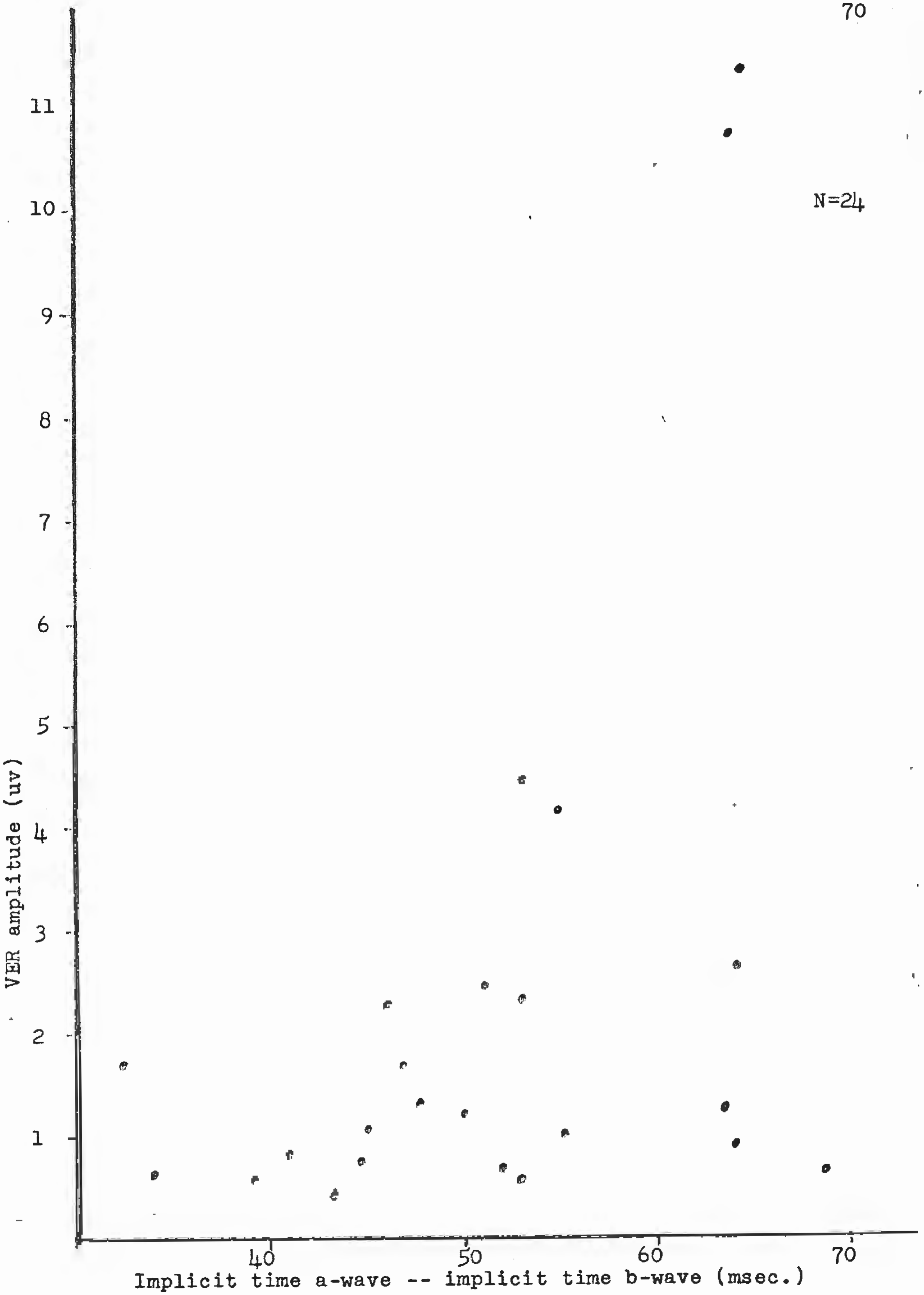

Fig. 8 Normal subjects. Difference in a-wave and b-wave implicit time vs. VER amplitude. Distance with P.

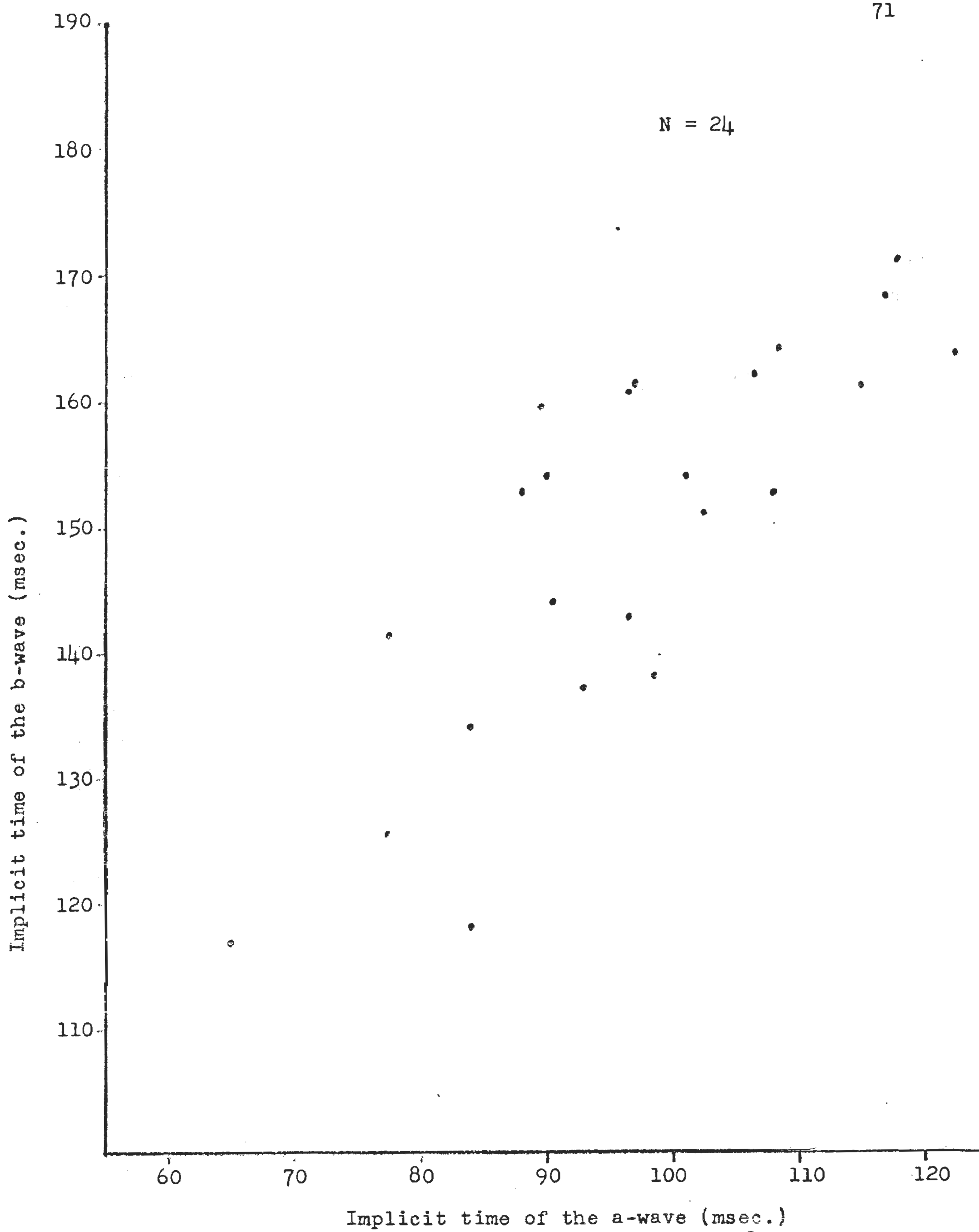

Fig. 9 Normal subjects. Implicit time of the a-wave vs. implicit time of the b-wave. Distance with P.

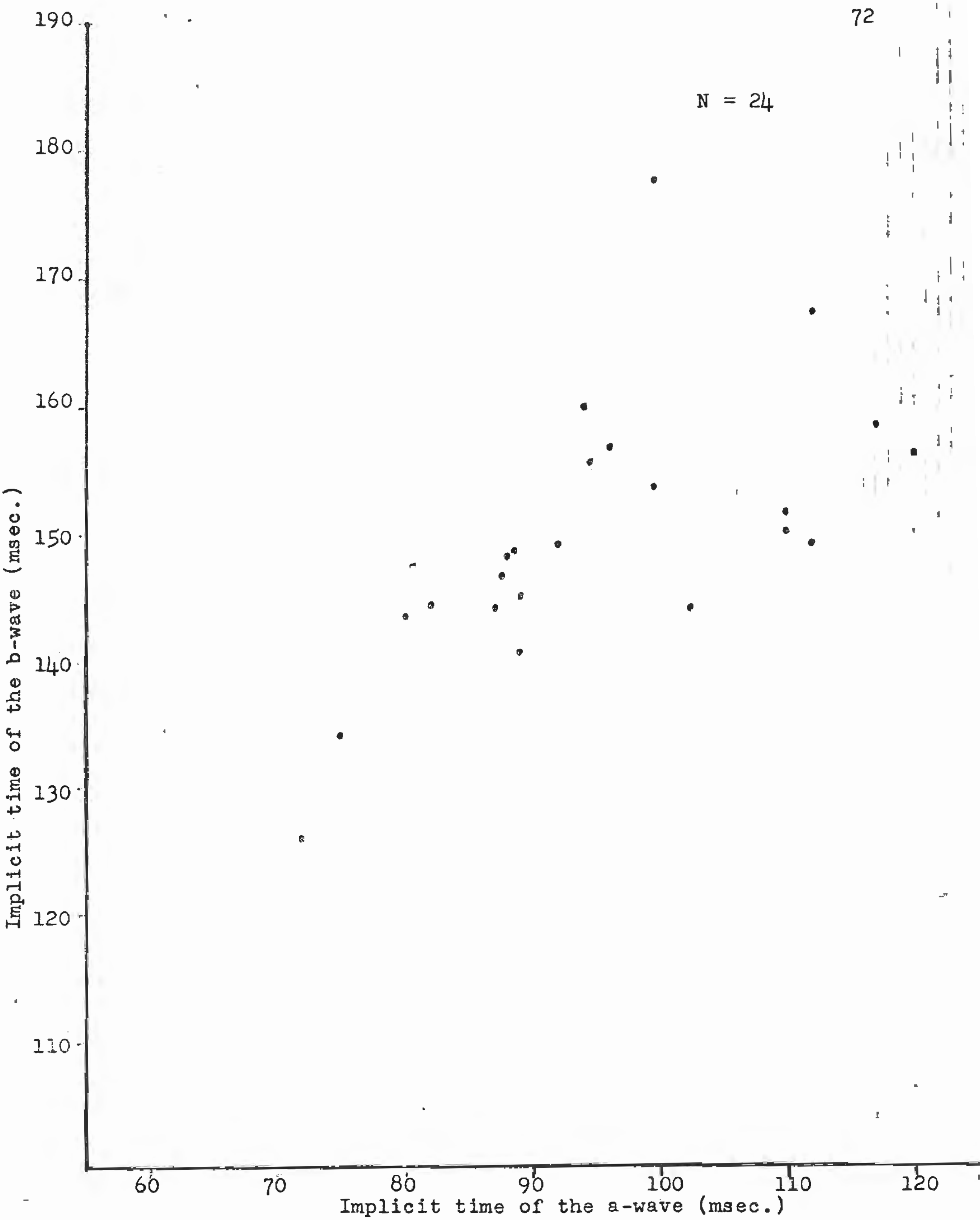

Fig. 10 Normal subjects. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with P.

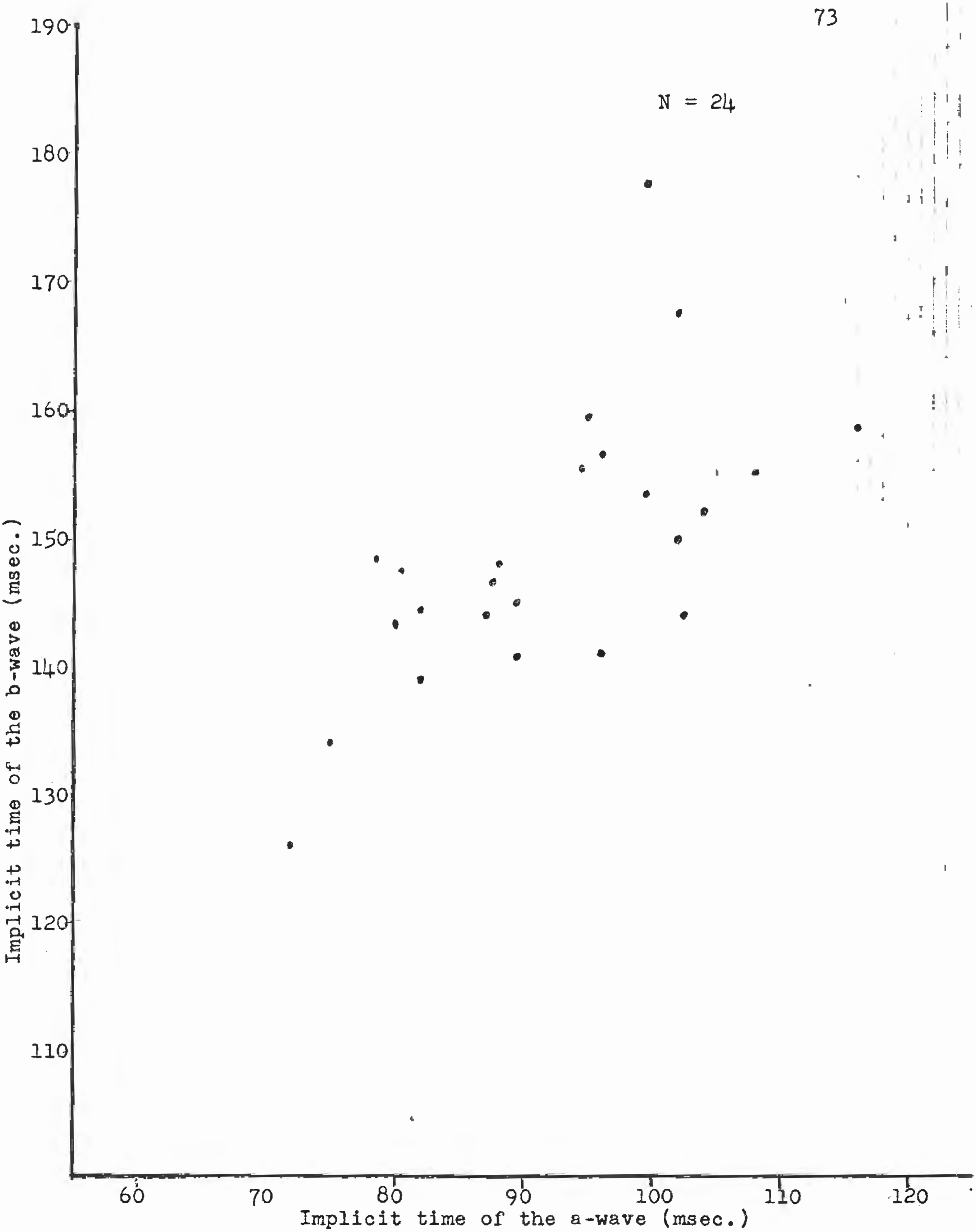

Fig. 11 Normal subjects. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral.

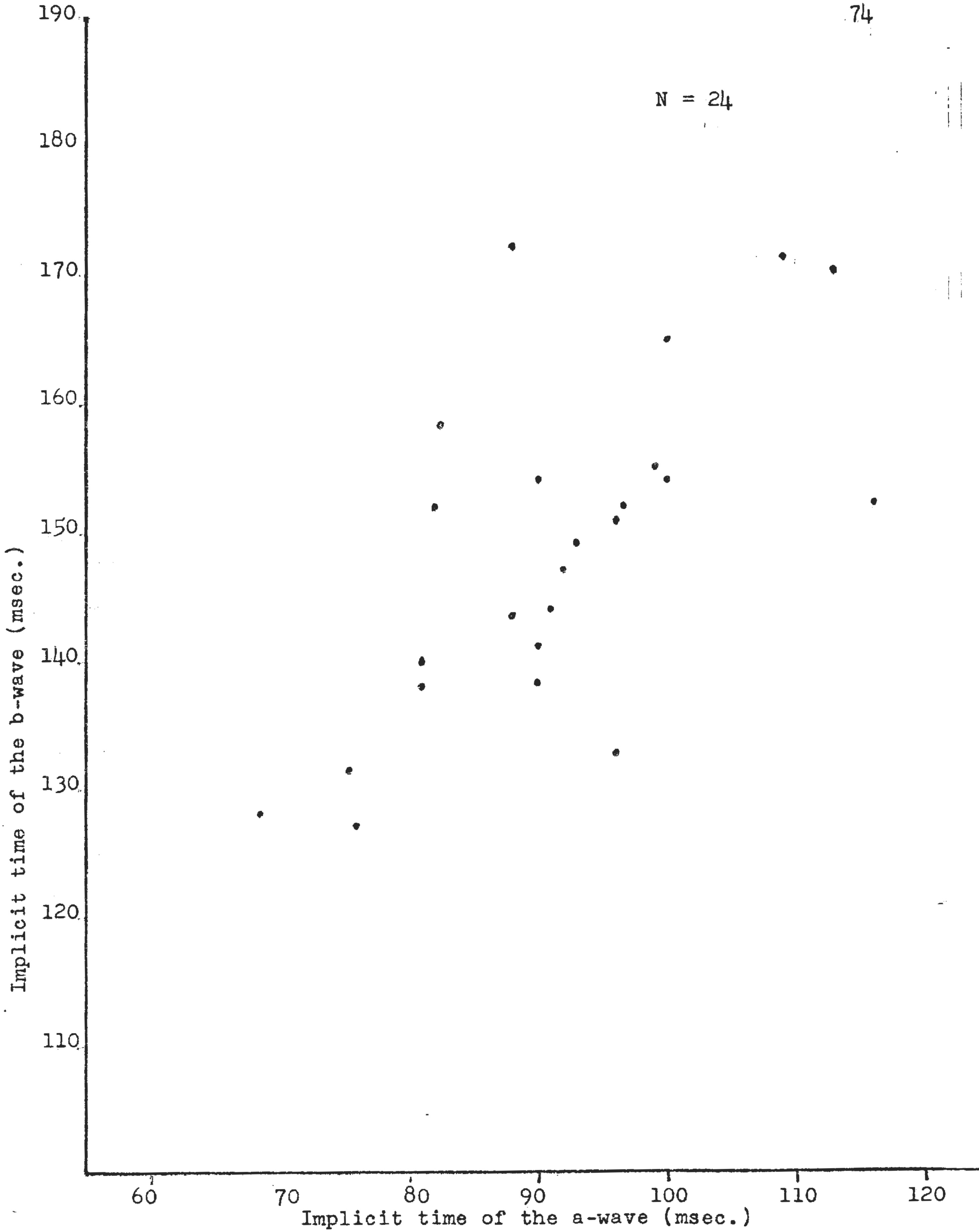

Fig. 12 Normal subjects. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral +ID.

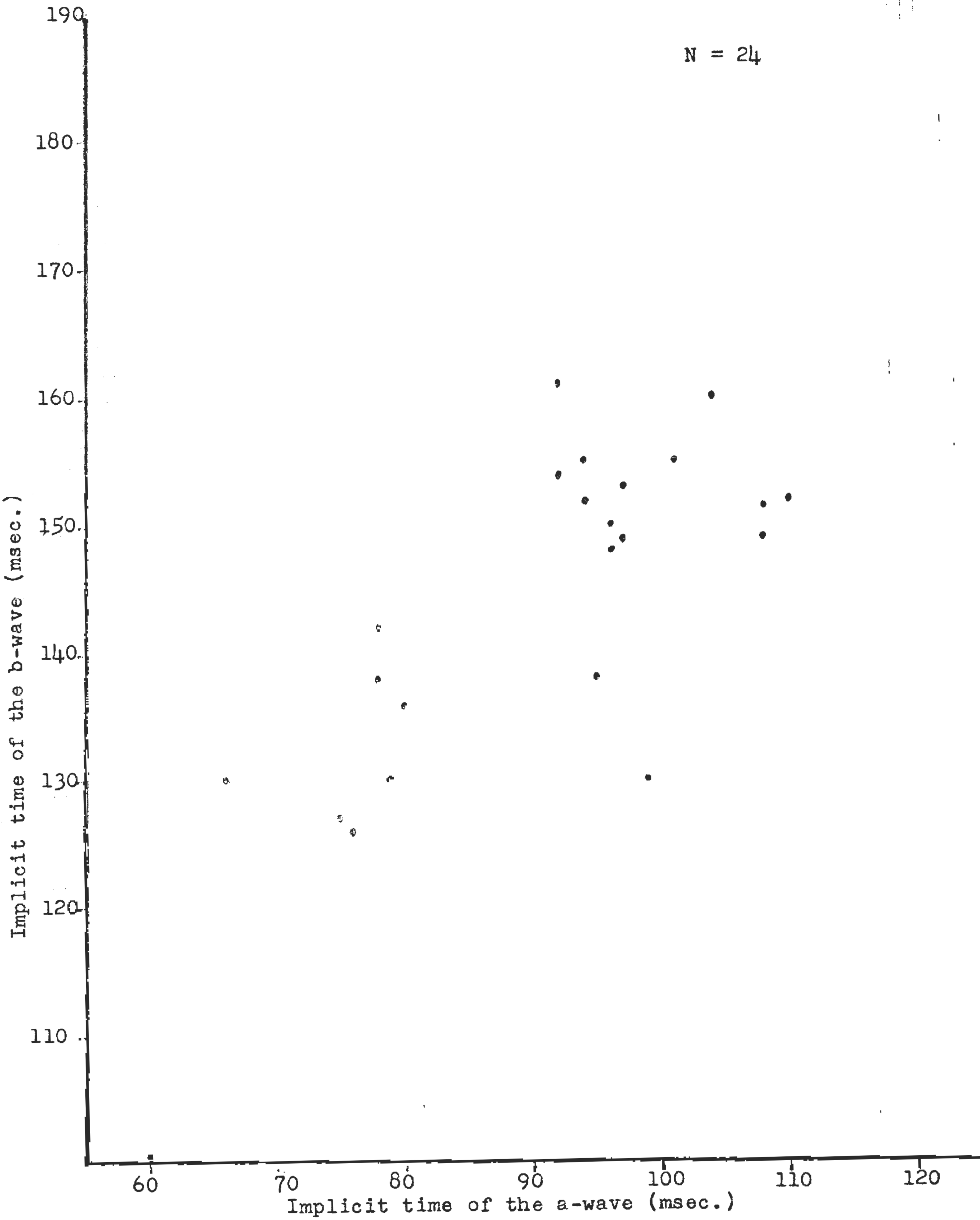

Fig. 13 Normal subjects. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral -ID.

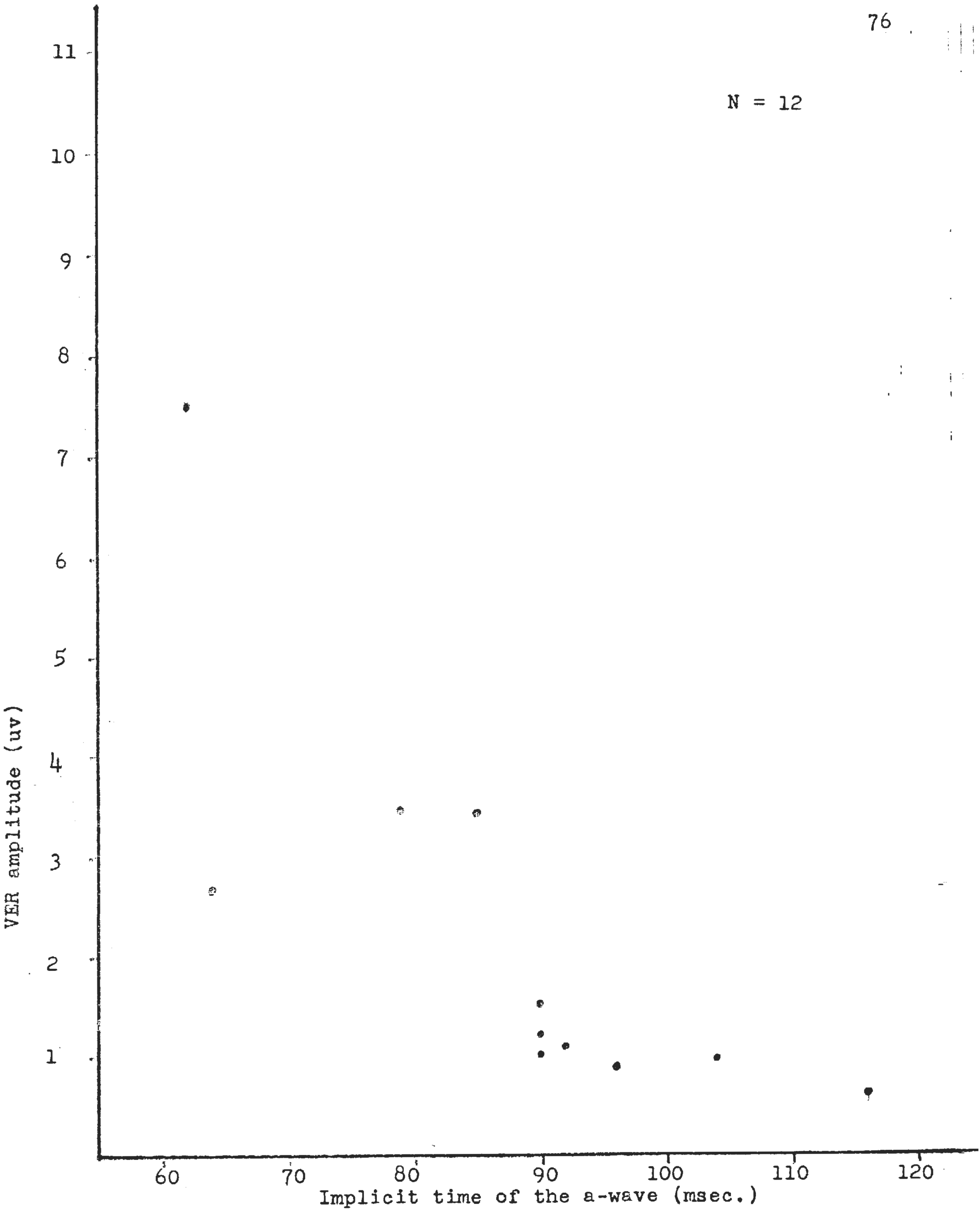

Fig. 14 Amblyopic eyes. Implicit time of the a-wave vs. VER amplitude. Distance with P.

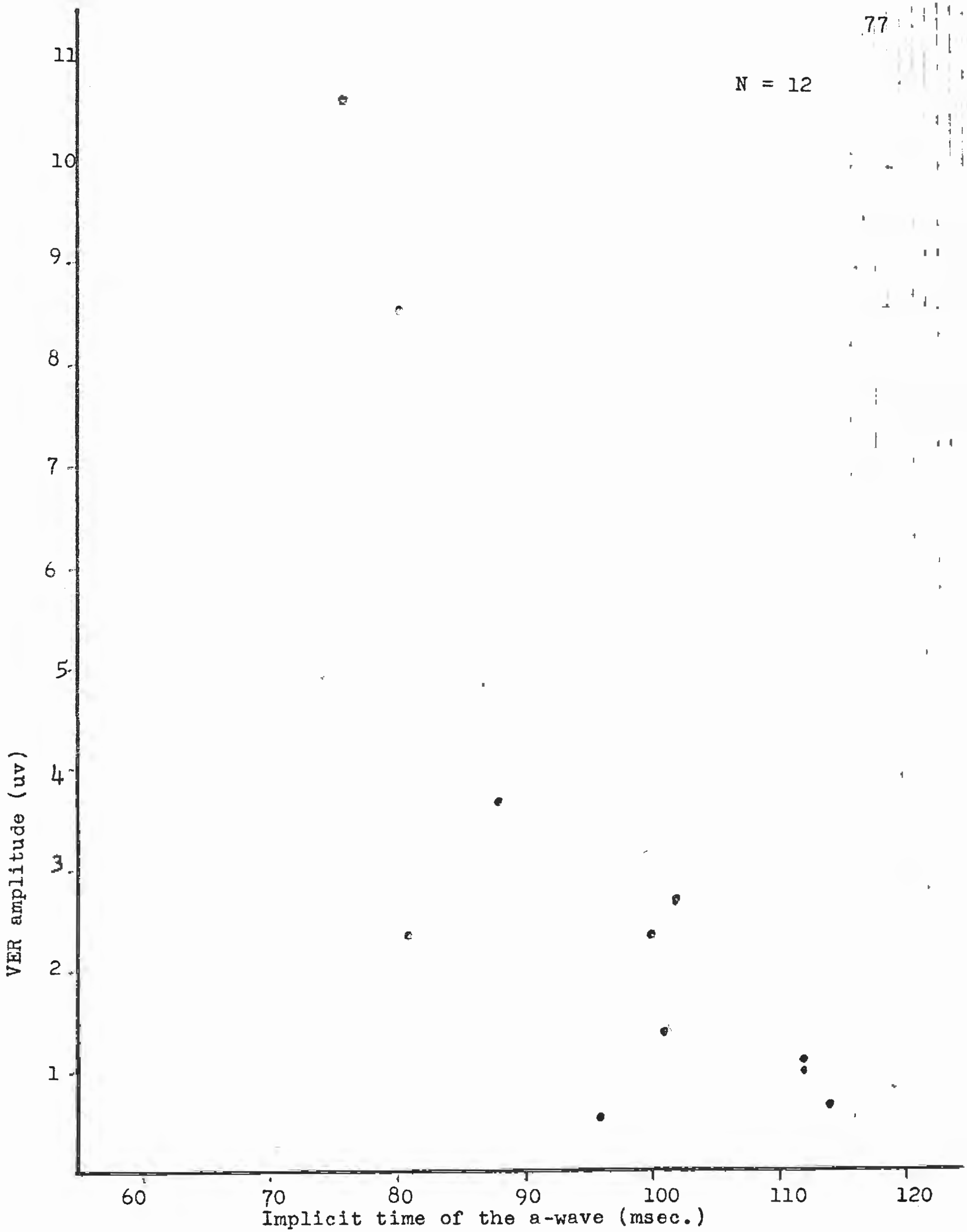

Fig. 15 Amblyopic eyes. Implicit time of the a-wave vs. VER amplitude. 40 cm. with P.

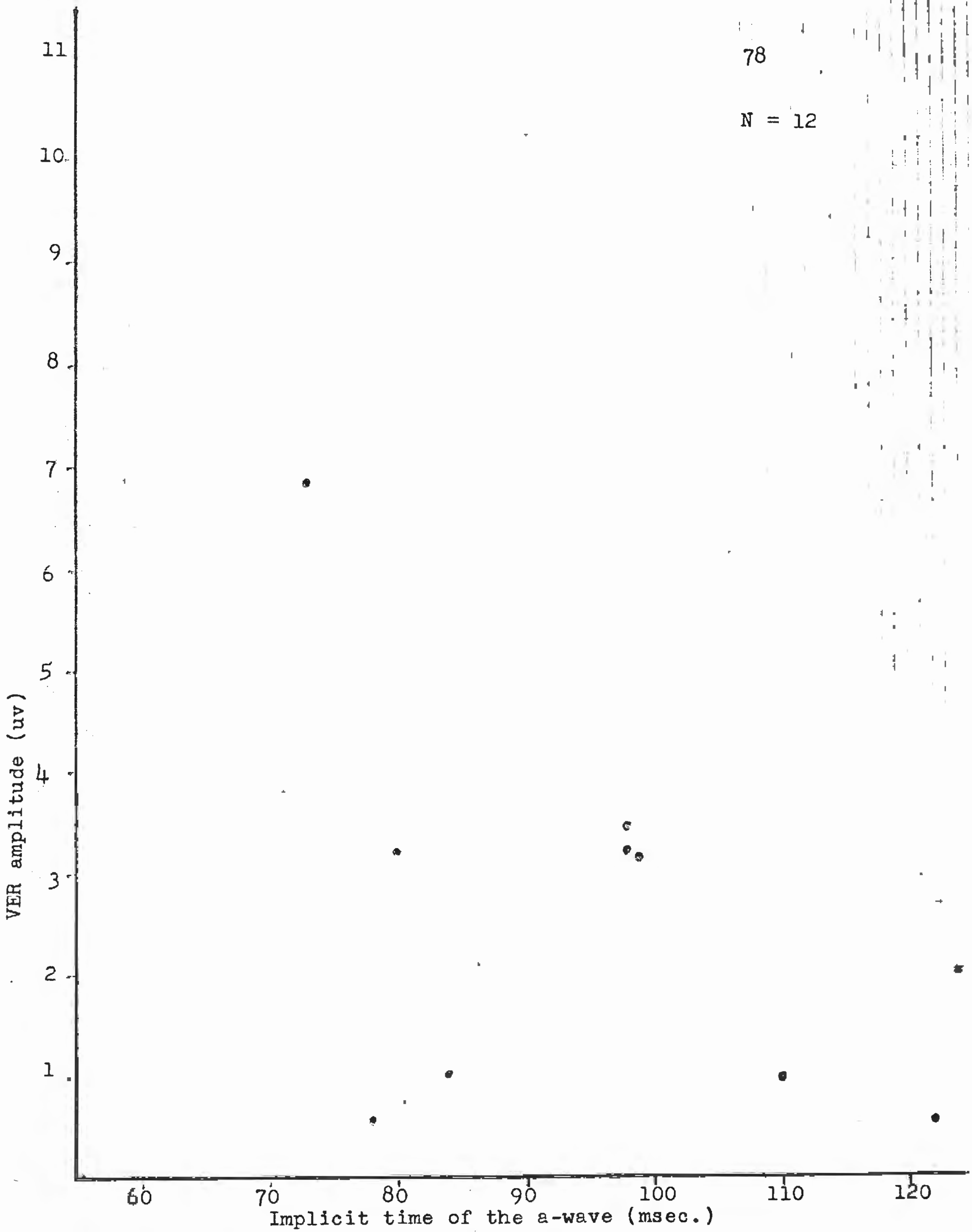

Fig. 16 Amblyopic eyes. Implicit time of the a-wave vs. VER amplitude. 40 cm. with low neutral +ID.

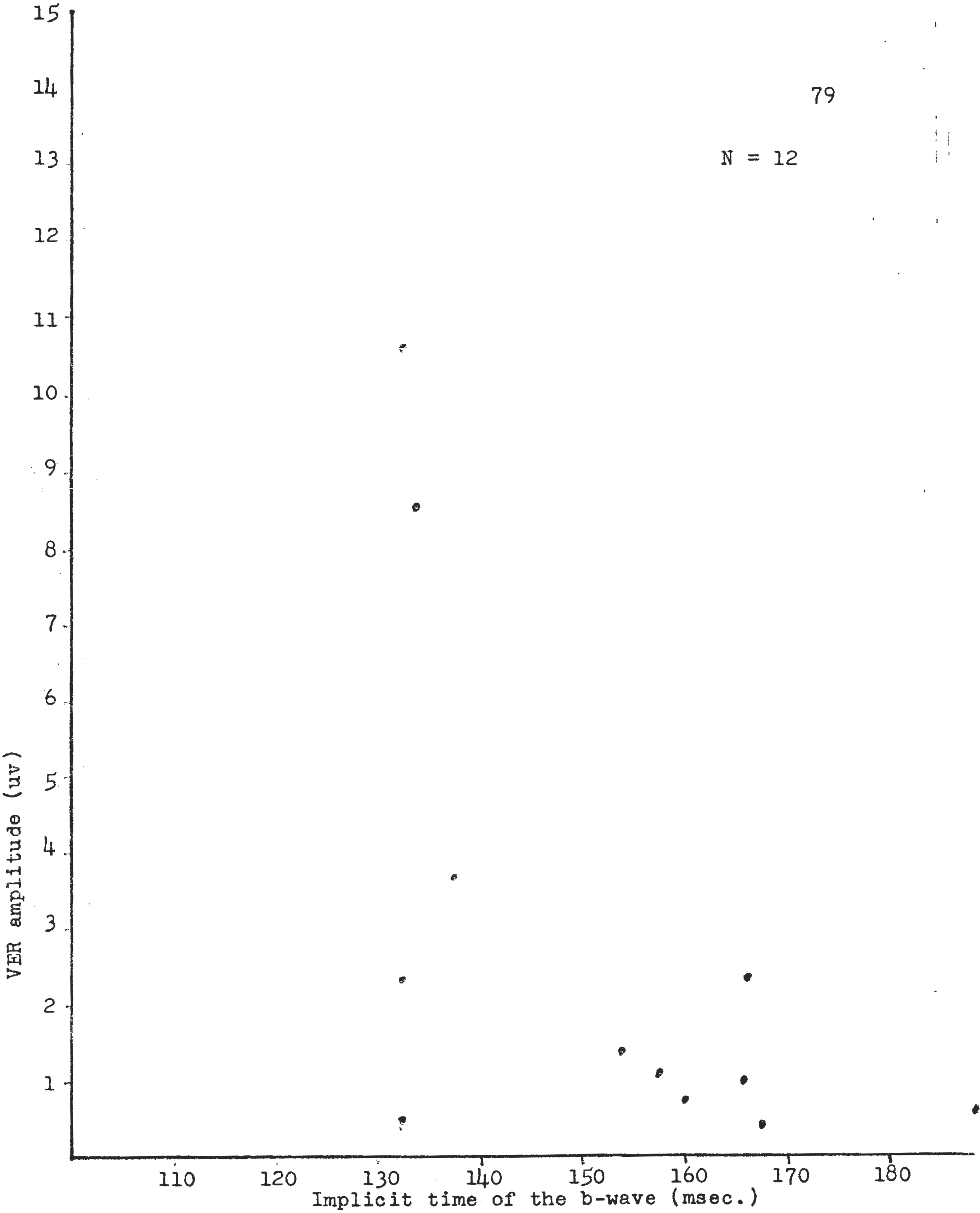

Fig.17 Amblyopic eyes. Implicit time of the b-wave vs. VER amplitude. 40 cm. with P.

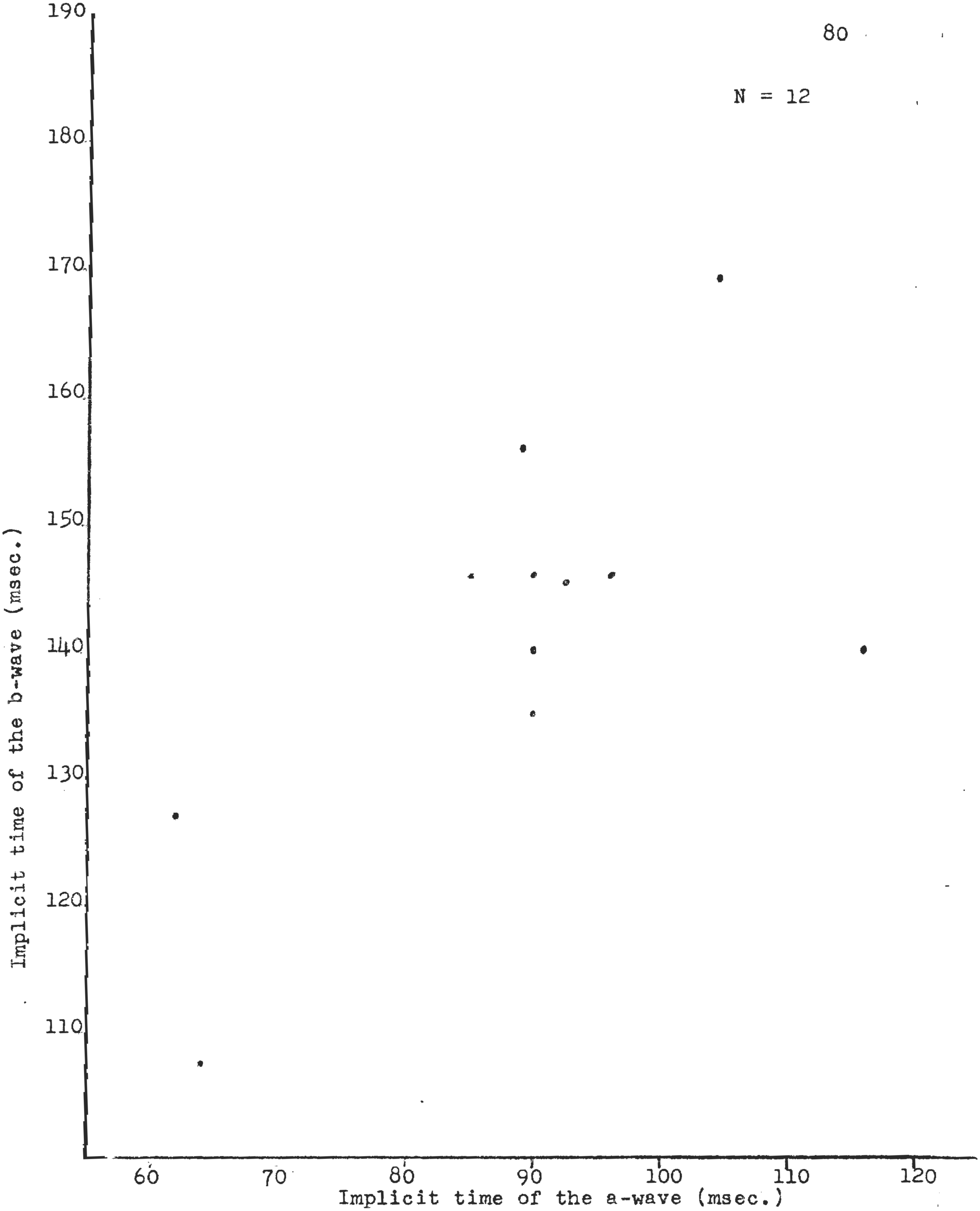

Fig. 18 Amblyopic eyes. Implicit time of the a-wave vs. implicit time of the b-wave. Distance with P.

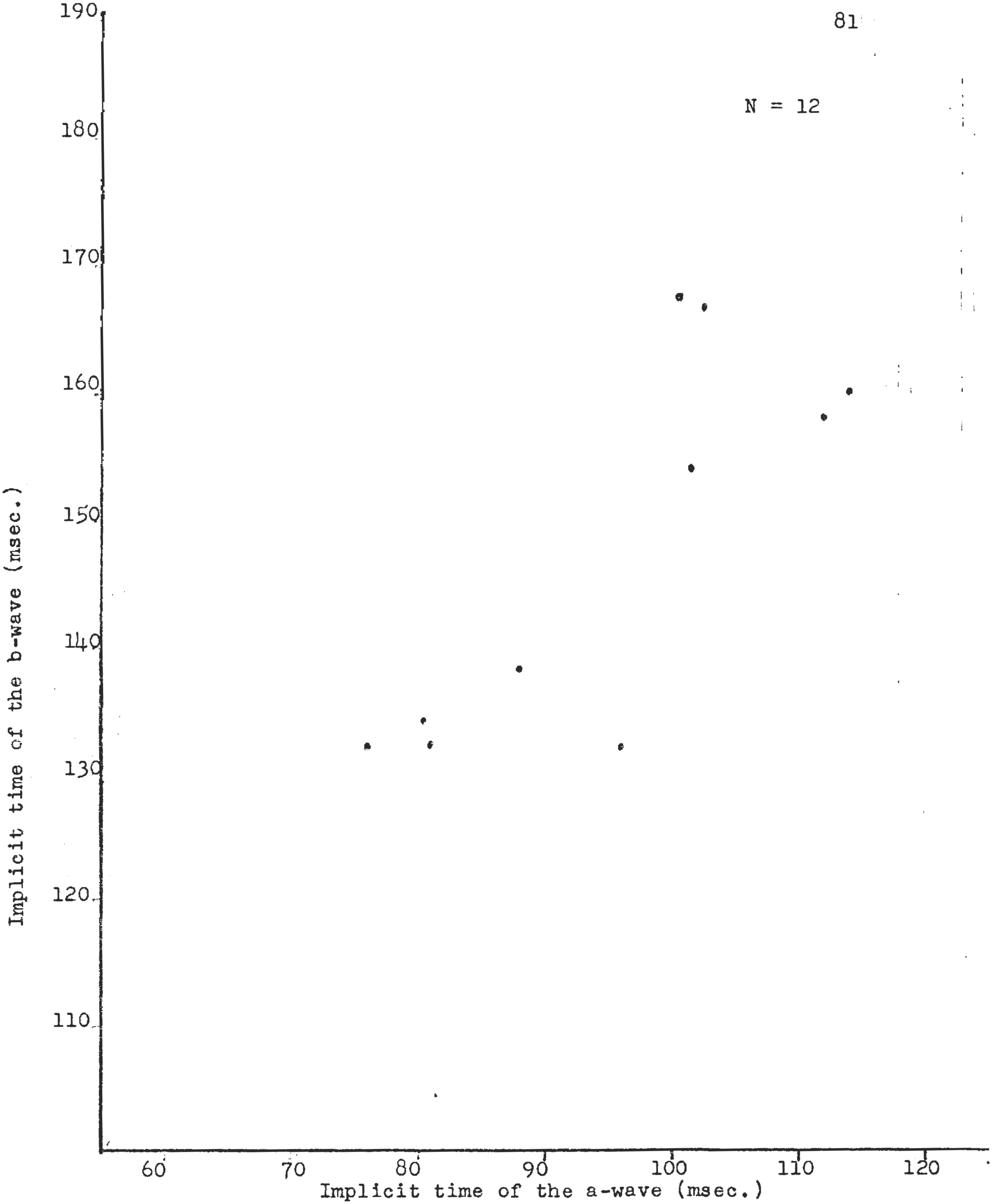

Fig. 19 Amblyopic eyes. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with P.

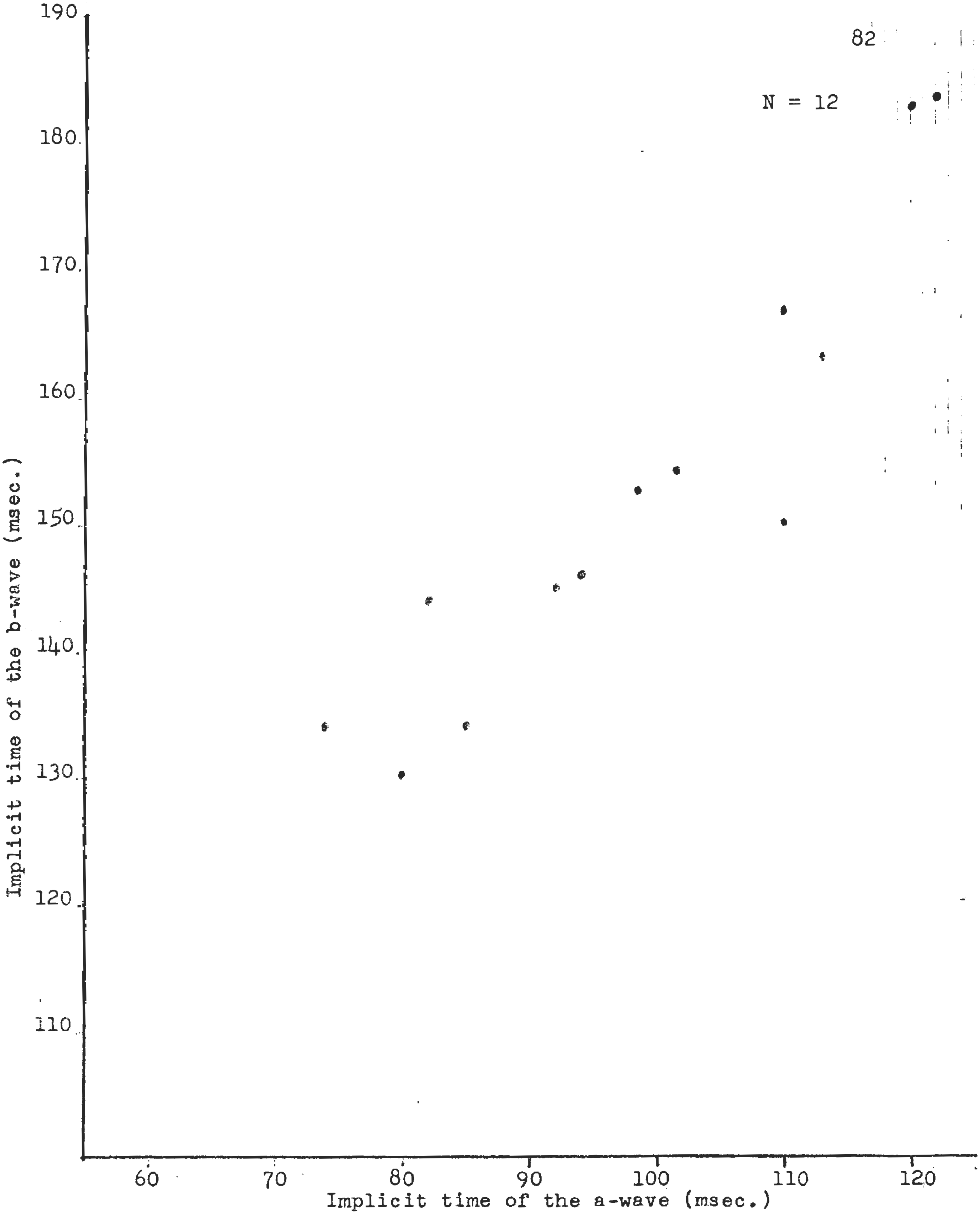

Fig. 20 Amblyopic eyes. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral.

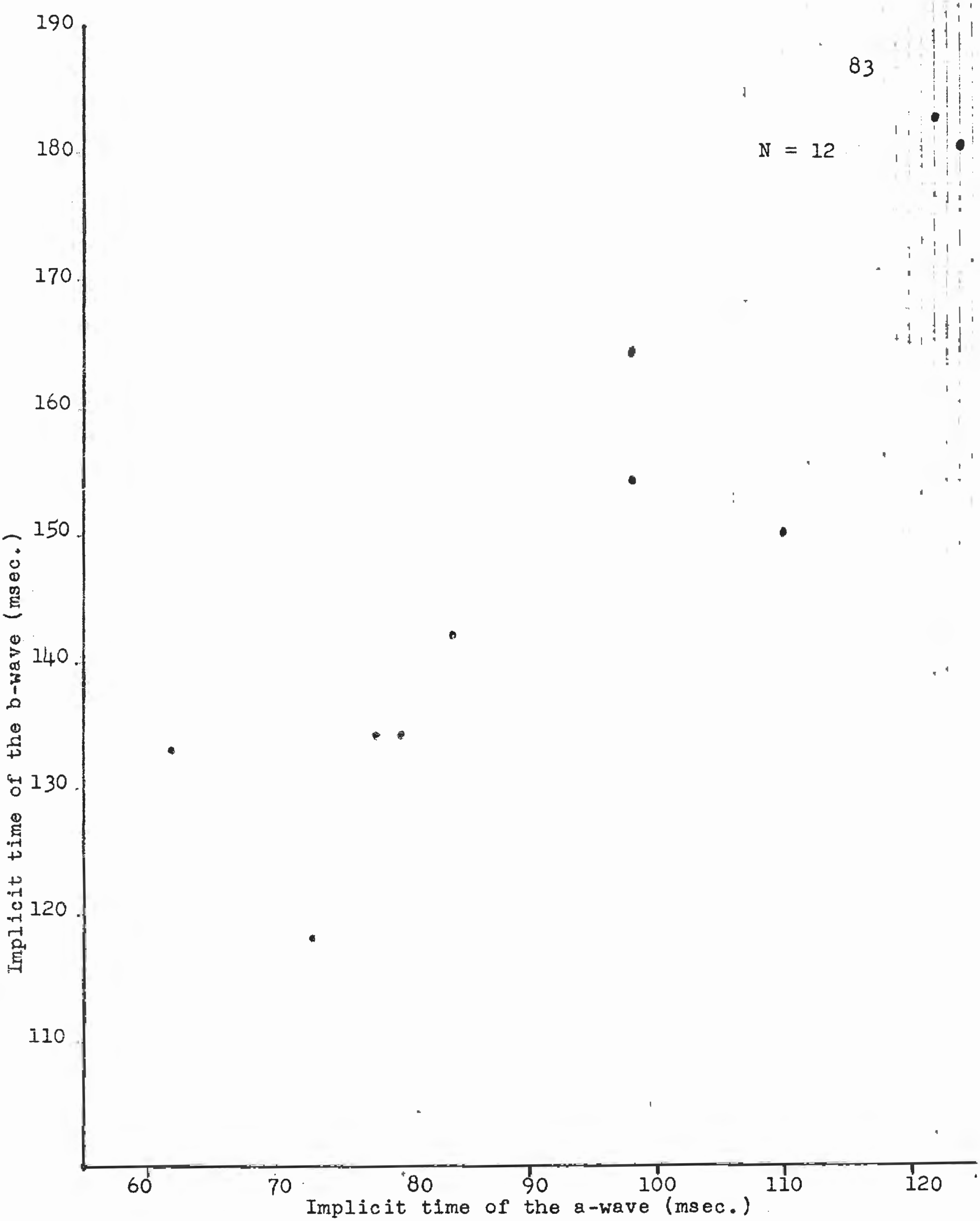

Fig. 21 Amblyopic eyes. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral ID.

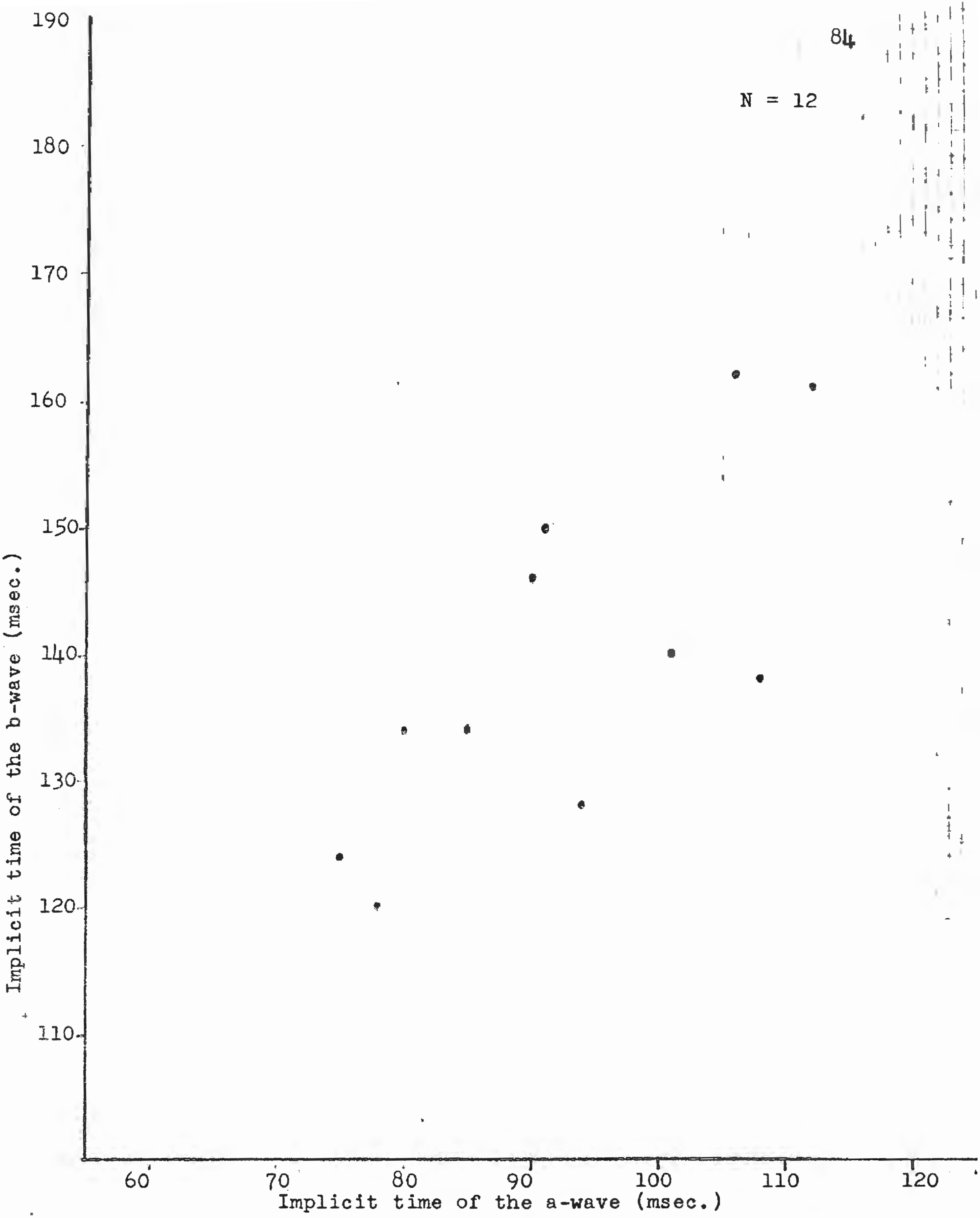

Fig. 22 Amblyopic eyes. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral -ID.

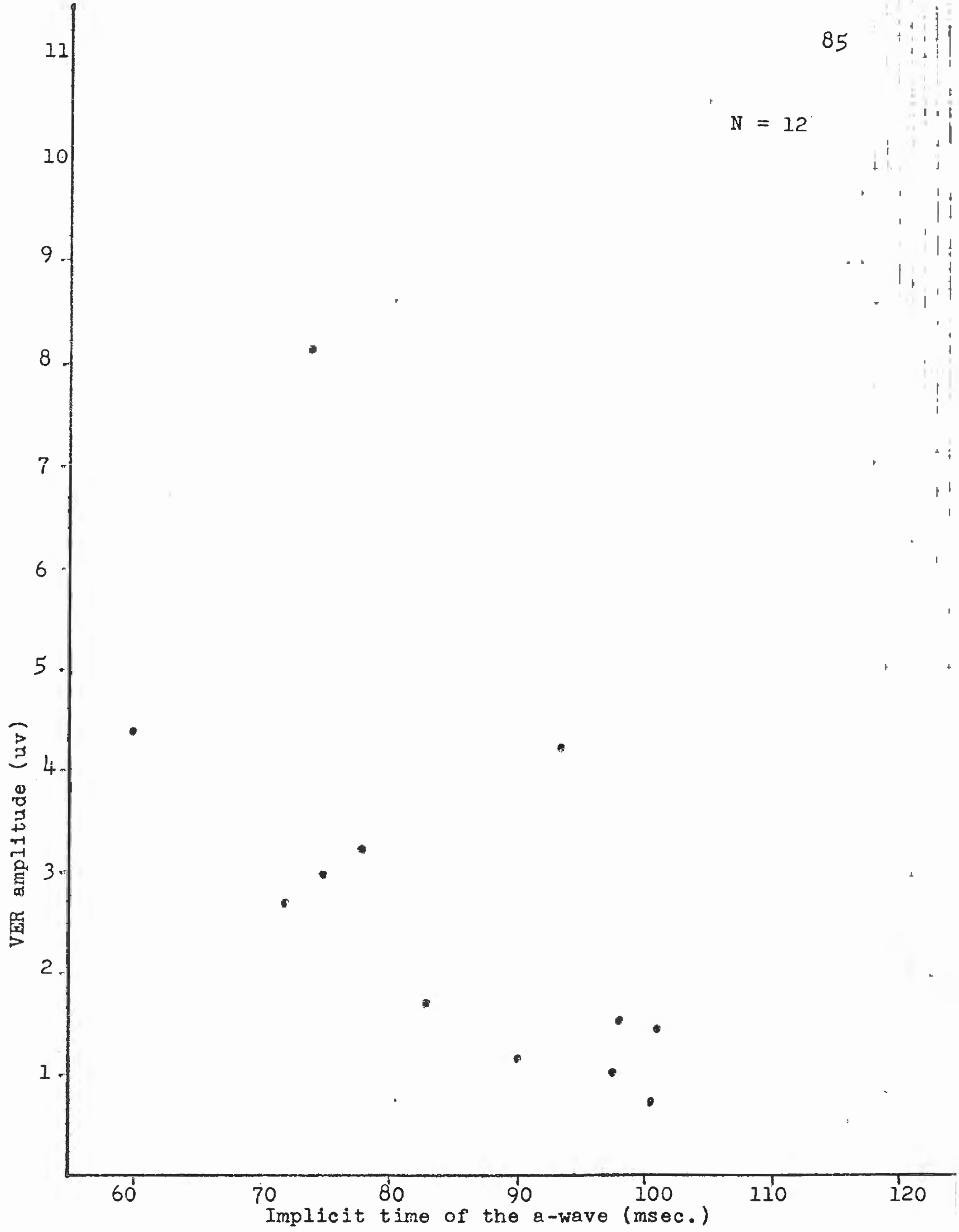

Fig. 23 Normal eye of amblyope. Implicit time of the a-wave vs. VER amplitude. Distance with P.

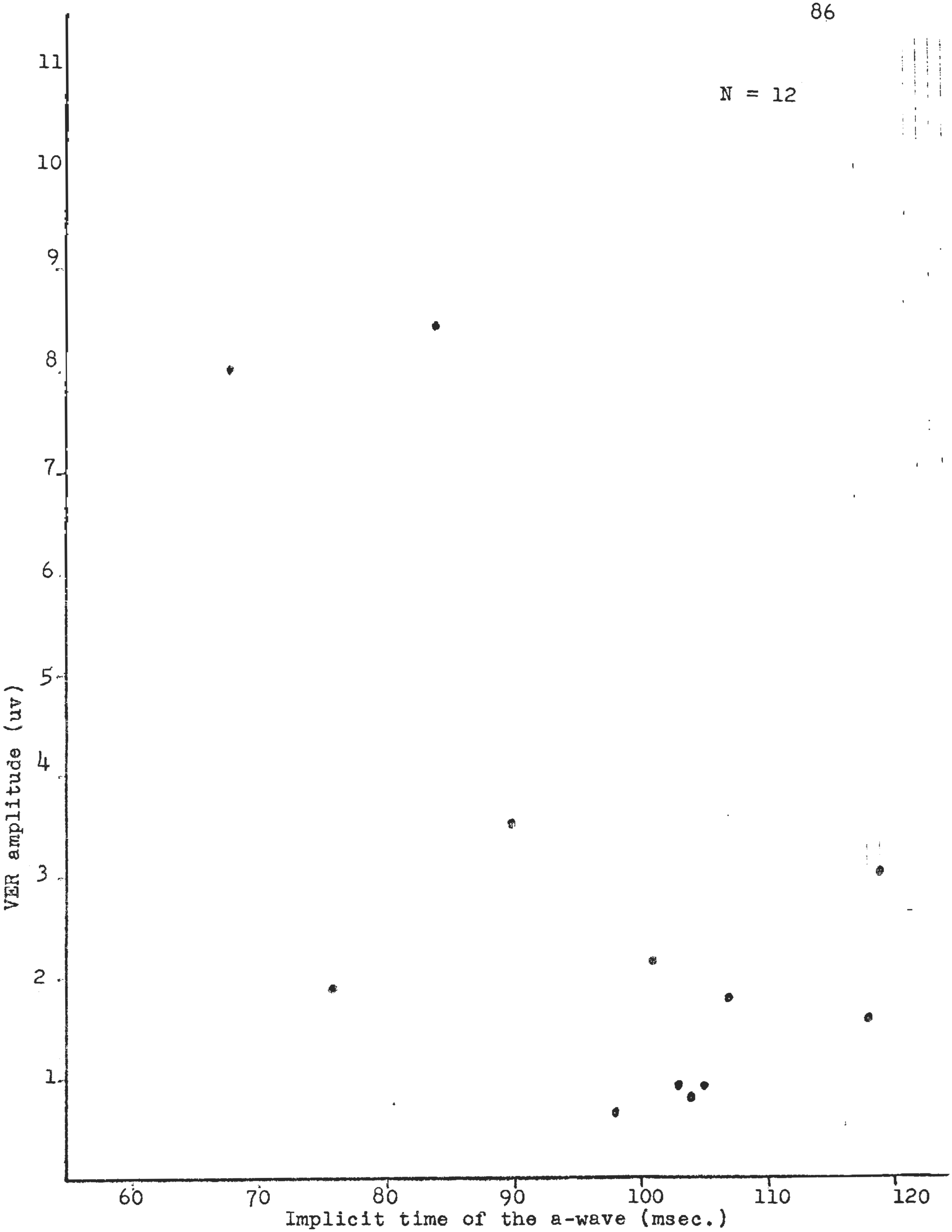

Fig. 24 Normal eye of amblyope. Implicit time of the a-wave vs. VER amplitude. 40 cm. with P.

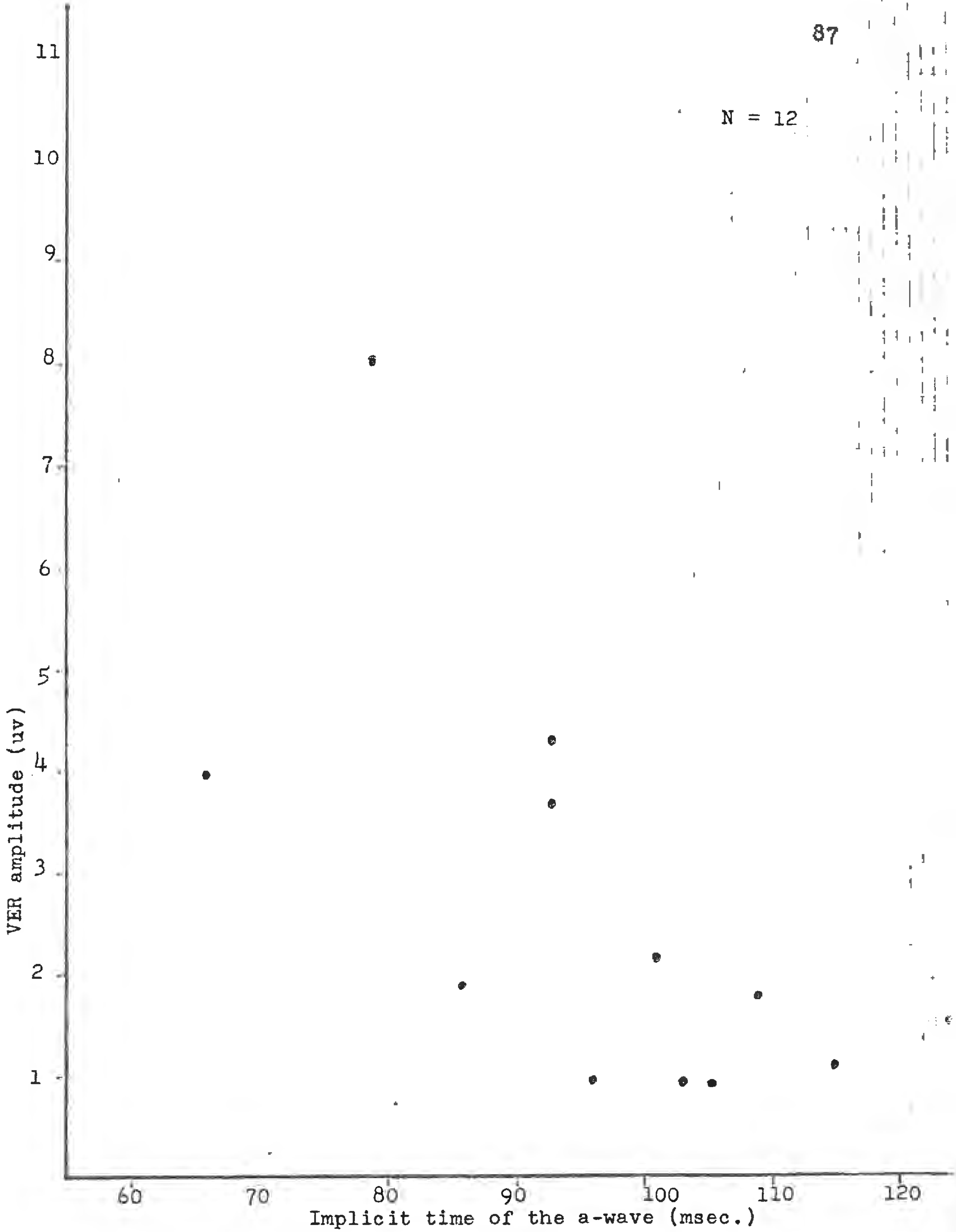

Fig. 25 Normal eye of amblyope. Implicit time of the a-wave vs. VER amplitude. 40 cm. with low neutral.

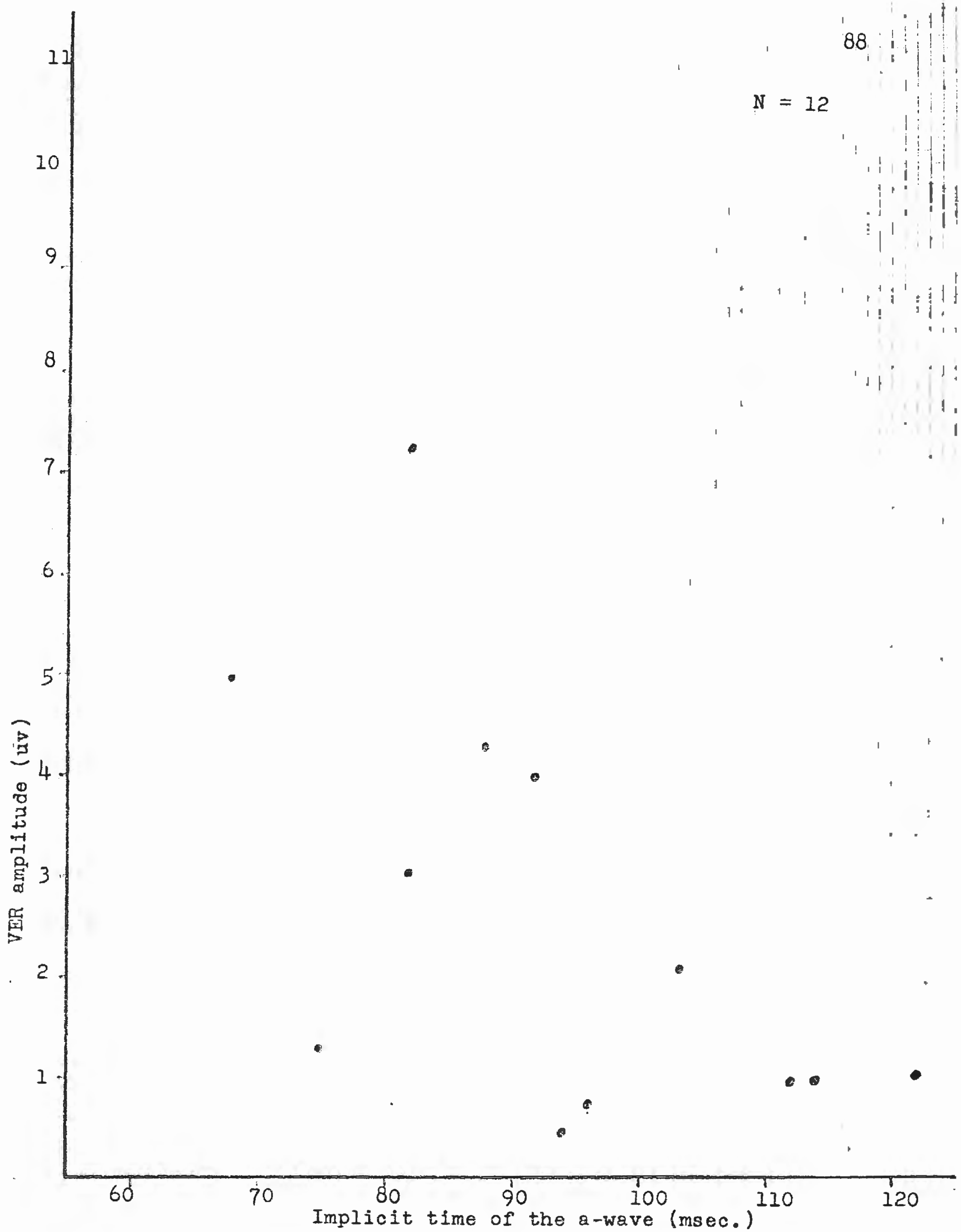

Fig. 26 Normal eye of amblyope. Implicit time of the a-wave vs. VER amplitude. 40 cm. with low neutral +ID.

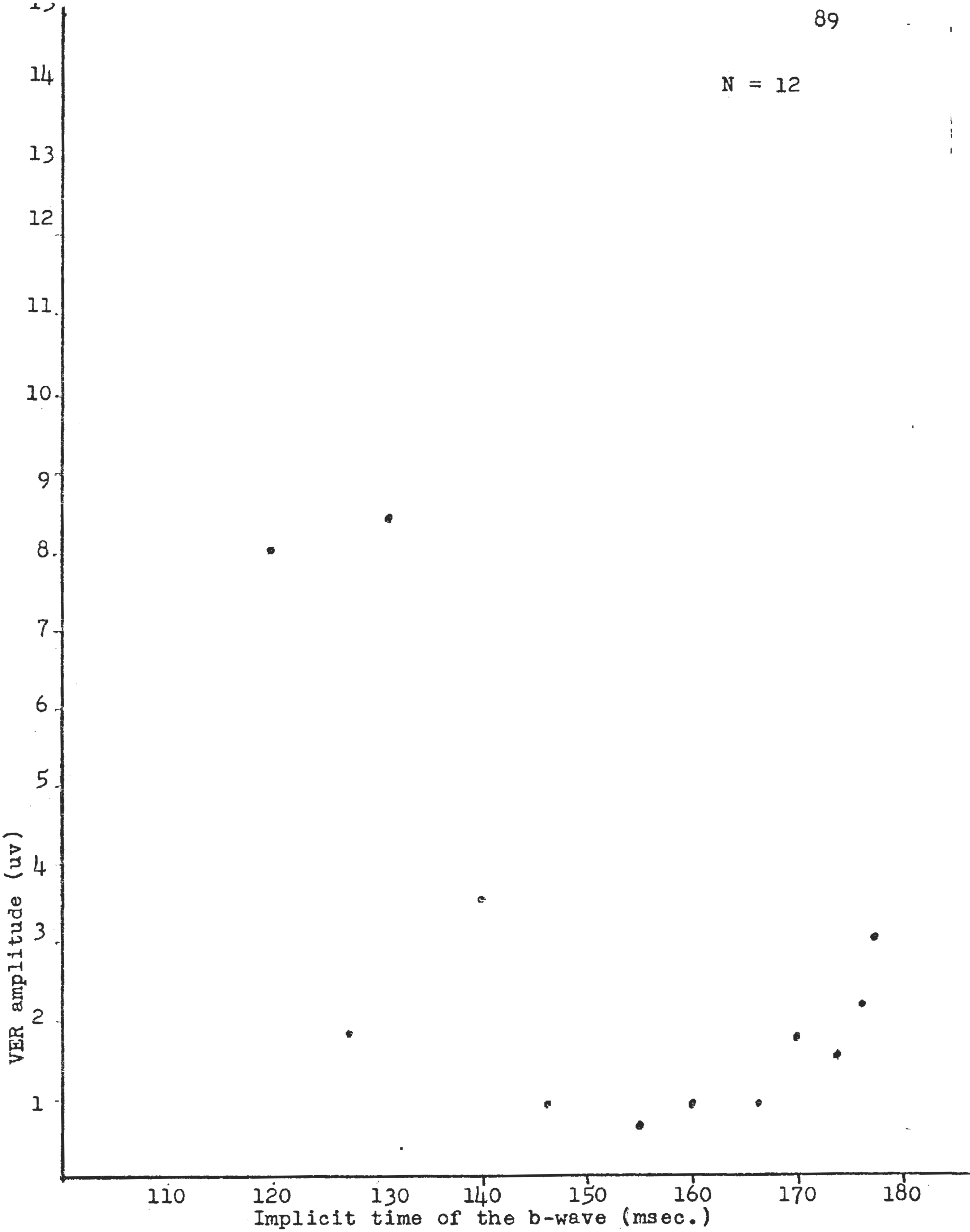

Fig. 27 Normal eye of emblyope. Implicit time of the b-wave vs. VER amplitude. 40 cm. with P.

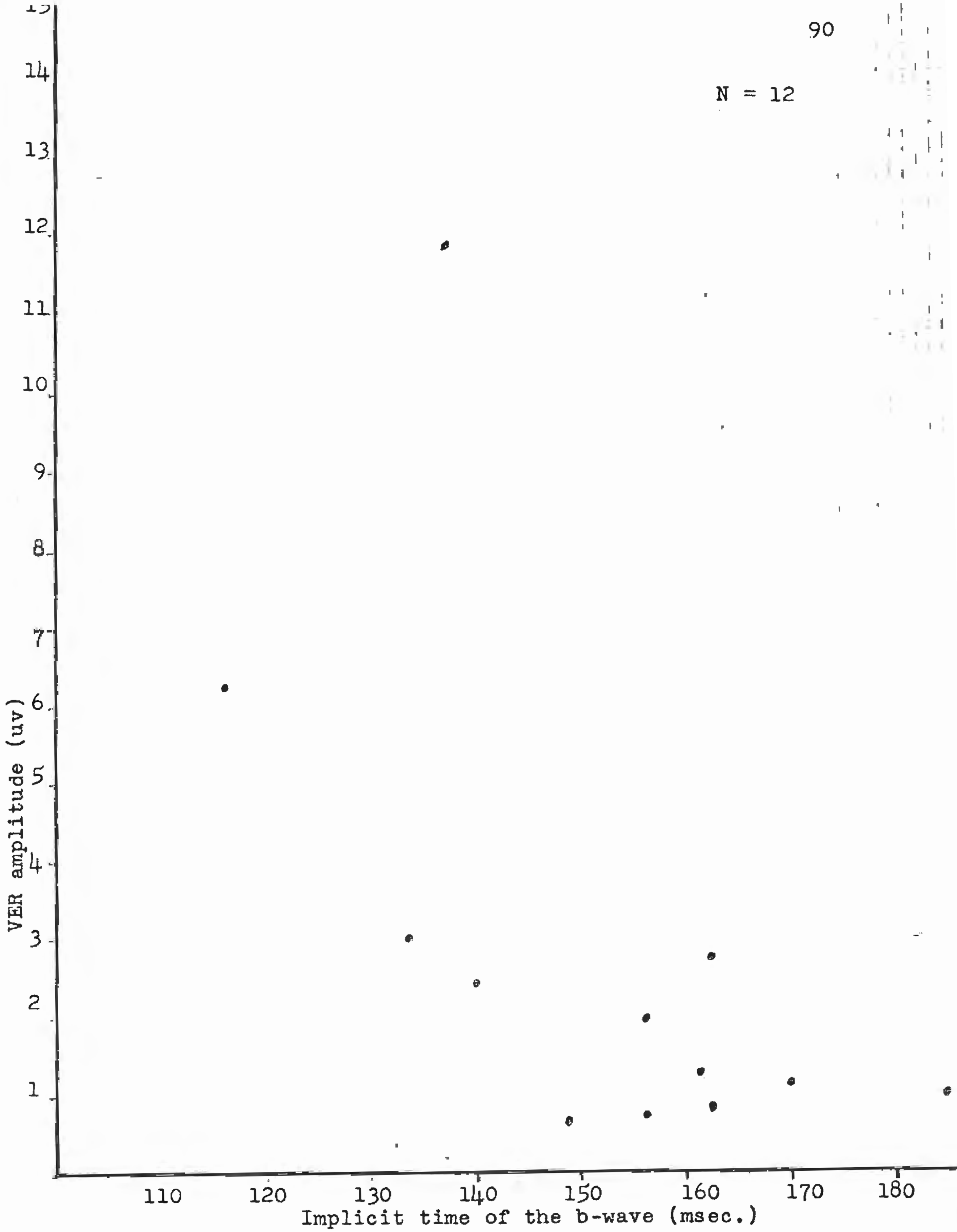

Fig. 28 Normal eye of emblyope. Implicit time of the b-wave vs. VER amplitude. 40 cm. with low neutral -ID.

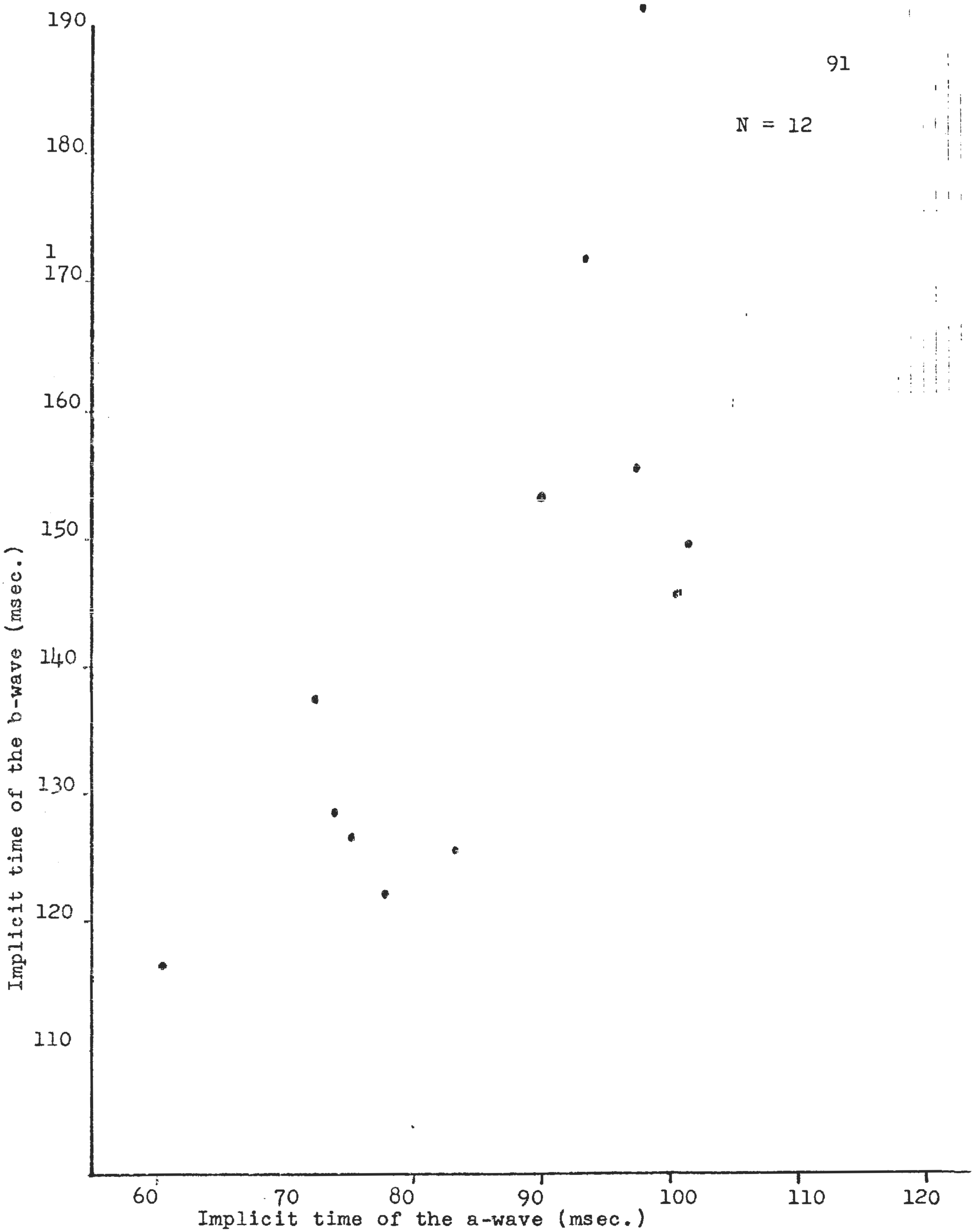

Fig. 29 Normal eye of the amblyope. Implicit time of the a-wave vs. implicit time of the b-wave. Distance with P.

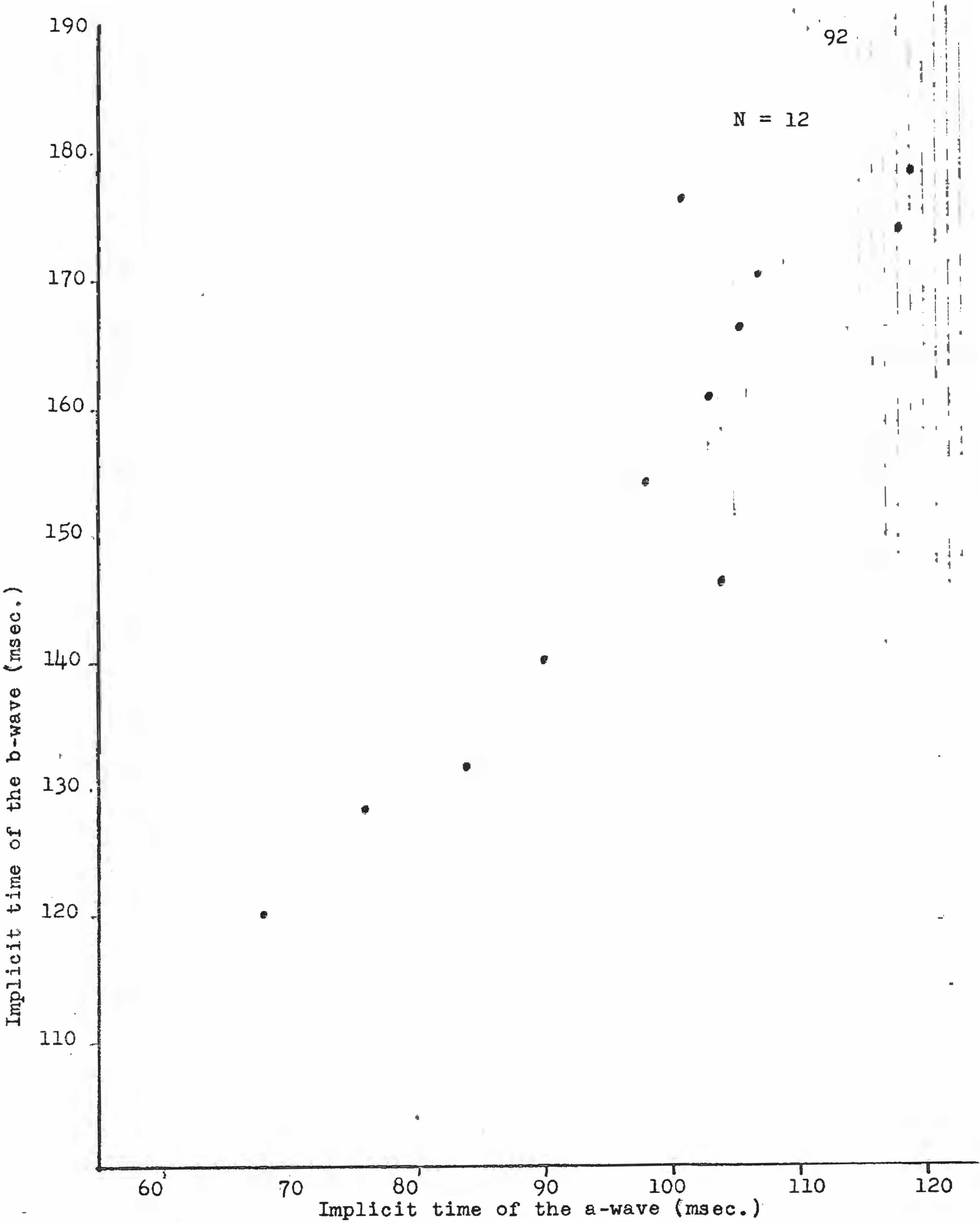

Fig. 30 Normal eye of amblyope. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with P.

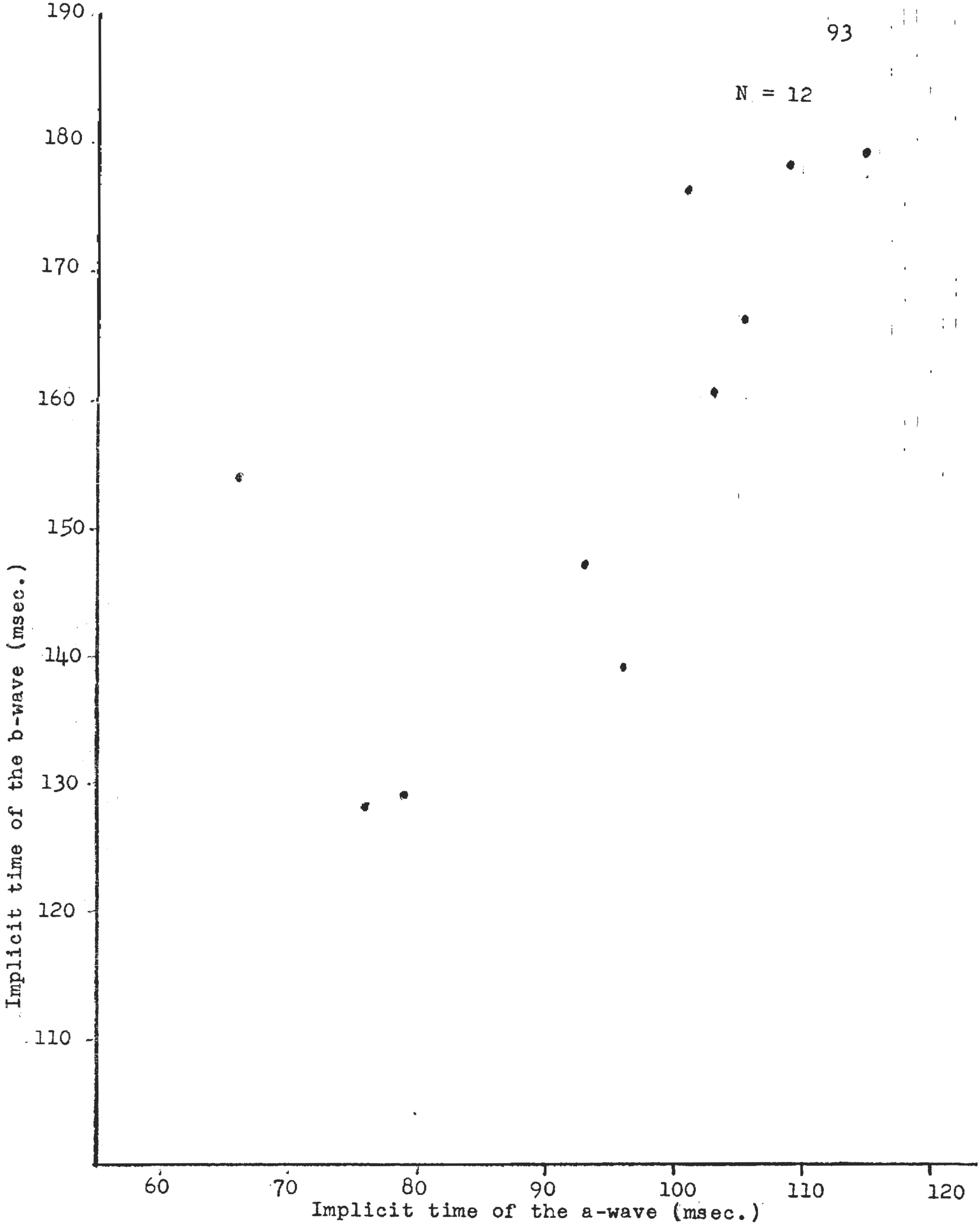

Fig. 31 Normal eye of amblyope. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral.

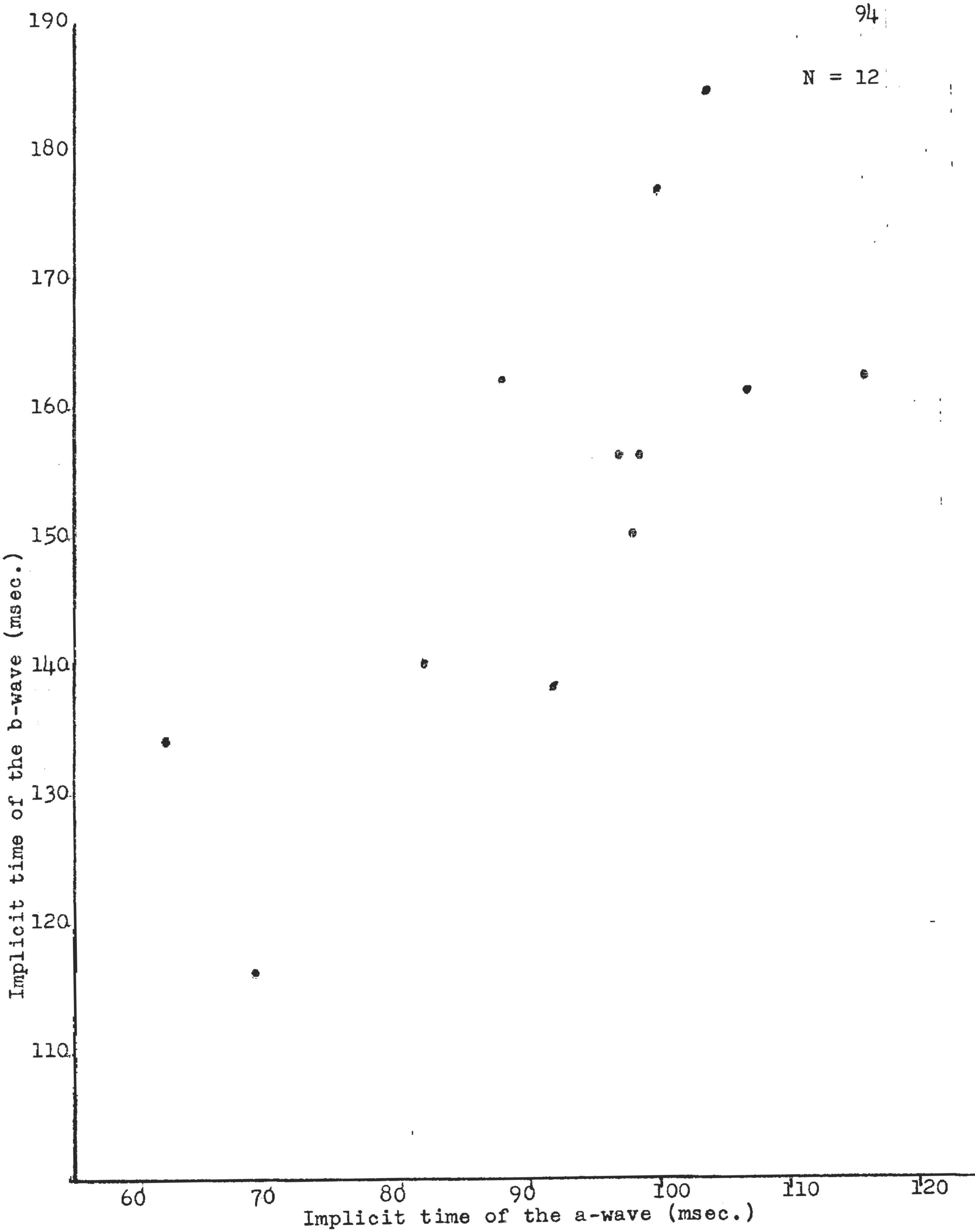

Fig. 32 Normal eye of amblyope. Implicit time of the a-wave vs. implicit time of the b-wave. 40 cm. with low neutral -ID.

APPENDIX II

SAMPLE HUMAN RELEASE FORM

1. Institution
   A. Title of Project. The influence of Accommodation and Fixation on the Visual Evoked Response and Visual Acuity of Normal and Amblyopic Subjects.
   B. Principle Investigator: Kevin Katz.
   C. Advisor: William M. Ludlam.
   D. Location: Drs. Furie, Jessen, and Ludlam, 233 E. Baseline, Hillboro, Oregon.
   E. Date: 1977.

2. Description of Project

This project is designed to investigate the influence of anomalies of accommodation on the visually evoked response and visual acuity. Normal and amblyopic subjects will be compared. The integrity of the visual pathways will be assessed.

3. Description of Risks

There appear to be no risks involved in the techniques which are all used clinically.

4. Description of Benefits

The study should help to clarify the results of the visual evoked response and thereby help explain the etiology and mechanism of amblyopia. The clinical assessment and prognosis of the amblyopia may also be clarified.

5. Offer to Answer any Questions

The experimentors will be happy to answer any questions that you may have at any time during the course of this study.

6. Freedom to Withdraw

You are free to withdraw your consent and to discontinue participation in this project or activity at any time without prejudice to you.

7. The evaluation being performed is being used for research purposes. However, a similar procedure is used clinically and the usual fee at the Pacific University Clinic is in excess of $75.00.

I have read and understand the above,

Signed .... Date ....
(Parent or guardian if under 18 years of age.)

THE RESEARCHERS THANK YOU FOR YOUR PARTICIPATION.

Name: Address: Date

Date of Birth

History:

Habitual Rx OD
OS
Pd

Examination -

Persuits OD
OS
OU

NPC

Cover c̄ habitual Rx Dist

Near -

Pd -

#4 OD
OS

#7 OD
OS

#7a OD
OS

RG OD
OS

CC OD
OS

#8

#13b

#14A OD
OS

#15A

#14B

#20 OD
OS
OU

#21 OD
OS
OU

External -

	OD	OS
"P" #4		
#7 -0.50		
#7a		
RG		
CC+0.25		
÷5		
"P"		

	Present/Absent	Dev(cm)	Direct
Haidinger Brushes OD			
OS			
Maxwell Spot OD			
OS			

AI transfer c̄ Haidinger Br & fixation p

Brelchowsky AT

Visuscope

Bagolini

Hirschberg

RG

Keystone

Synoptophore :- Obj - Subj -

	Line	Single letter	"S"
V/A Dist OD			
OS			

Near	Monoc	Binoc
Ap c̄ "P" OD		
OS		
LN OD		
OS		
Ap LN+1.00 OD		
OS		
Ap LN-1.00 OD		
OS		

LN from 40cm ahead
Monoc
OD
OS

Ophthalmoscopy -

D15.

VER

Dist	OD	OS	OS	OD
40cm c̄ "P"	OD	OD	OS	OS
40cm c̄ LN	OS	OD	OD	OS
40cm c̄ LN+100	OD	OS	OS	OD
40cm c̄ LN-100	OS	OD	OD	OS

V/A

		Line	Single [illegible]	"S"
Dist c̄ "P"	OD			
	OS			
40cm c̄ P	OD			
	OS			
40cm c̄ LN	OD			
	OS			
40cm c̄ LN+100	OD			
	OS			
40cm c̄ LN-100	OD			
	OS			