

THE AMPLITUDE OF ACCOMMODATION IN PRESBYOPIA\*

Duco Hamasaki†

School of Optometry, University of California  
Berkeley, California

Jin Ong‡

Oakland, California

Elwin Marg§

School of Optometry, University of California  
Berkeley, California

It is well known that the amplitude of accommodation decreases with increasing age. Extensive investigations on this problem have been made by Donders,<sup>1</sup> Kaufmann,<sup>2</sup> and Duane.<sup>3, 4</sup>

Donders measured the farpoint and nearpoint of clear vision for subjects between the ages of 10 and 80 years. He recognized three types of accommodation: absolute, binocular, and relative. For absolute accommodation, the farthest and nearest point of clear vision was measured for each eye. For binocular accommodation, the same points were measured but with binocular fixation. Relative accommodation was measured by the addition of convex and concave lenses binocularly while maintaining a given convergence. When the nearpoint of the absolute and binocular accommodation was farther than 22 cm. (8 Parisian inches), added convex lenses were used to image it closer. Black wires were used as the target and measurements were made with respect to the nodal point of the eye.

Kaufmann investigated the change in the amplitude of accommodation of 200 subjects between the ages of 5 and 68 years. Although his procedure was not described in detail it is assumed to be similar to Donders' investigation since Kaufmann intended to duplicate Donders' work on a larger number of subjects. Only subjects with "normal" visual acuity, low refractive error, and no pathological conditions affecting accommodation were included in his study. His results, in general, were similar to the results of both Donders and Duane.

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†Optometrist. M.Opt. Graduate Student in Physiological Optics.

‡Optometrist. B.S.

§Optometrist. Ph.D., Member of faculty. Fellow, American Academy of Optometry.

Duane included in his study more than 1,000 subjects between the ages of 8 and 70 years. A careful determination of the refractive error was made of all subjects, using a cycloplegic on those below the age of 48 years. A single black line on a white card was used as the target to measure monocularly the nearest point of clear vision, using "first blur" as the endpoint. Convex lenses were used when the near-point of clear vision was farther than 40 cm.

The results of these investigations were very similar to one another, although there were some differences which have been pointed out by Hofstetter.<sup>5</sup> In general, the mean amplitude of accommodation decreased rapidly up to the age of 50 to 52 and then decreased only slightly during subsequent years. Even at the age of 60 years, there still remained approximately 1.50 D. of accommodation measurable.

It is widely known that a fixation object can be moved a finite distance toward or away from the eye before it is noticed to blur even when accommodation is held constant. This is due to the depth of focus of the eye. When the amplitude of accommodation is measured by the "push-up" method this factor becomes important in the determination of the endpoint. With maximum accommodation the target will be seen clearly if it is conjugate to the retina. However, the target can be moved closer to the observer before "blurring" is noted. This distance is the depth of focus of the eye and it is, nevertheless, customarily included as part of the measured amplitude of accommodation. Therefore, the "push-up" method should give measured values of the amplitude of accommodation which are artificially high.

A more accurate measurement of the dioptric change of the eye can be made by stigmatoscopy. Descriptions of stigmatoscopy have been presented by Ames and Gliddon,<sup>6</sup> Fry,<sup>7</sup> and Bannon et al.<sup>8</sup> In this technique a stigma (point source of light) can be optically placed so that it is conjugate to the retina. The dioptric distance of the stigma will then represent the refractive state of the eye. If now the accommodative state of the eye is changed, the stigma must be moved a dioptric distance equal to the change in accommodation. By using a series of increasing accommodative stimuli and measuring the accommodative response by stigmatoscopy, the amplitude of accommodation can be determined.

Thus, the influence of the depth of focus is minimized by stigmatoscopy and a more accurate measure of the true amplitude of accommodation can be made. It is the purpose of this investigation to compare the measurements of the "push-up" and stigmatoscopic amplitudes of accommodation in presbyopes.

## PROCEDURE

A total of 106 subjects (212 eyes) were examined with a minimum of five subjects in each age group. The subjects were patients in the clinic at the School of Optometry and were selected on the following bases: (1) a complete visual examination within the last three months, (2) no known pathology, (3) visual acuity of 20/25 or better in each eye, and (4) ages 42 through 60 years. Several older subjects were tested but since their results were similar to the results of the 60-year-old subjects, the upper age limit for the statistical treatment of the data was set at 60 years. The birth date of each subject was recorded and the age calculated to the closest year.

With the subjective correction giving maximum visual acuity and a +2.00 D. lens in a trial frame, the amplitude of accommodation was measured monocularly for each eye by the "push-up" method. A nearpoint card with six point type was used as the target. Measurements were made with respect to the spectacle plane and "first blur" was used as the endpoint.

With the same lenses in the lens cells of the haploscope and one eye occluded, the subject was shown the change in the appearance of the stigma as the stigmatoscope knob was turned. When this operation was understood, he was instructed to focus the stigma using the same criteria for focus for all of the measurements. The same nearpoint card was used as the target and its luminance was kept at 5 ft.-L.

Five measurements of the accommodative response were made at each of the following distances: 60 cm., 50 cm., 33.3 cm., 28.6 cm., 25 cm., 22.2 cm., 20 cm., and 18.2 cm. With the +2.00 D. lens and the subjective correction, these distances correspond to stimulus levels of -0.33 D. and 0 to +3.50 D. in 0.50 D. steps.\* This range of stimulus levels was sufficient to elicit the maximum amount of accommodation in all of the subjects, but if there was any doubt, additional measurements were made at higher stimulus levels. For the first six subjects, the measurements were made using optical distances as well as actual target distances, e.g., at 6 M. and at 50 cm. with a +2.00 D. add, or at 100 cm. and at 33.3 cm. with a +2.00 D. add. Since there were no significant differences in the results, optical distances were used thereafter for convenience. To help insure optimum accommodative response, the subject was instructed and constantly reminded to keep the print clear while focusing the stigma.

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\*a minus sign indicates an inhibitory stimulus to accommodation while a plus sign indicates an excitatory stimulus.

Approximately twenty to twenty-five minutes were required to complete all of the measurements for both eyes of each subject.

## RESULTS

The results of the measurements are presented in Table 1. The "push-up" amplitudes of accommodation represent the mean of the right and left eye. The stigmatoscopic amplitude of accommodation was determined for each subject by plotting a curve of accommodative stimulus versus accommodative response. The amplitude of accommodation is then represented by the distance from the bottom to the highest point on the curve as shown in a typical curve in Figure 1. It is believed

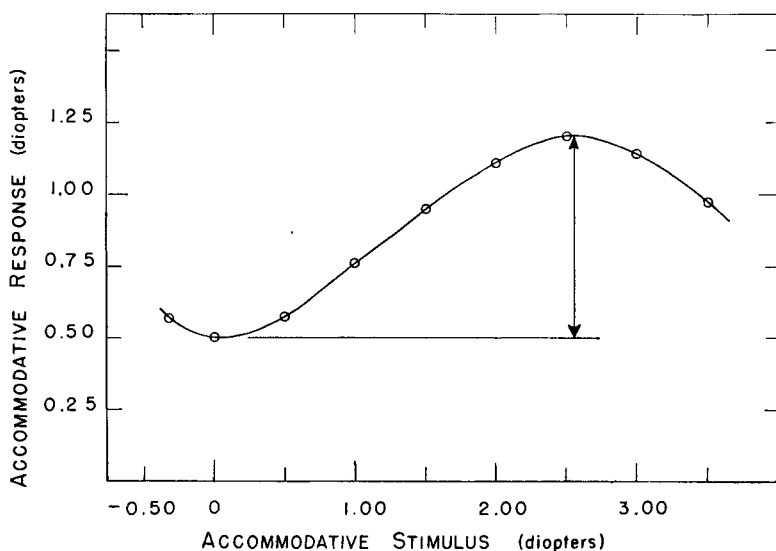


Fig. 1. Accommodative stimulus versus accommodative response curve. Accommodative response measured by stigmatoscopy. Accommodative amplitude is represented by the difference between the highest and lowest point on the curve on the response coordinate.

that the circle of least confusion of the conoid of spherical aberration, which is 0.50 D. to 0.75 D. in front of the retina, is used in stigmatoscopy. However, this concept does not effect our results since differences and not absolute values are used in the calculation of the amplitude of accommodation.

The mean amplitudes of accommodation, measured by the "push-up" method, are shown in Figure 2. In this and the following graphs, the abscissa represents the age in years while the ordinate represents the amplitude of accommodation in dipters. For comparison, the results of Donders and Duane are also shown. The values of the ampli-

TABLE 1  
MEAN AMPLITUDE OF ACCOMODATION IN DIOPTERS

Age	Number of Subjects	Push-up	stigmatoscopy		
			right	left	mean
42	6	4.26	1.20	1.32	1.26
43	5	2.95	1.14	1.15	1.14
44	5	2.61	0.66	0.86	0.76
45	5	2.35	0.74	0.60	0.67
46	6	2.70	0.77	0.92	0.85
47	6	2.71	0.57	0.51	0.54
48	6	2.15	0.43	0.33	0.38
49	7	2.06	0.34	0.31	0.32
50	5	2.13	0.28	0.24	0.26
51	5	1.37	0.38	0.44	0.41
52	7	1.89	0.32	0.35	0.34
53	6	1.45	0.16	0.18	0.17
54	6	1.48	0.11	0.11	0.11
55	6	1.93	0.10	0.12	0.11
56	5	1.96	0.10	0.11	0.10
57	5	1.91	0.09	0.03	0.06
58	5	1.43	0.07	0.06	0.06
59	5	1.73	0.07	0.08	0.08
60	5	1.51	0.09	0.06	0.07

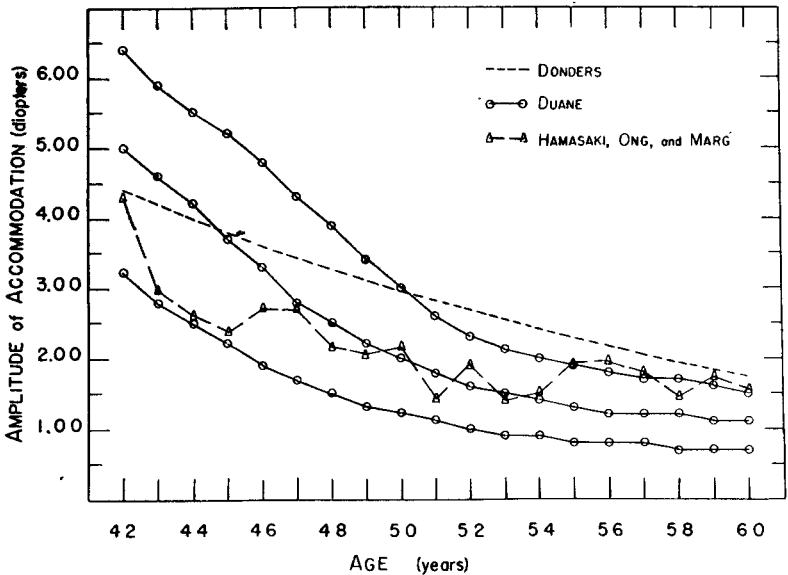


Fig. 2. Mean "push-up" amplitudes of accommodation. The upper and lower limits of normal variation of the amplitude of accommodation reported by Duane are also shown.

tude of accommodation used to plot Donders' curve were extracted from his curve and corrected for spectacle plane refraction. Besides the mean amplitudes of accommodation, the upper and lower limits of normal variation of the accommodative amplitude reported by Duane are shown. These limits were not statistically calculated but were drawn so that most of the data points were included within these limits.

A scatter diagram of the stigmatoscopic amplitudes of accommodation of the right and left eye of each subject is shown in Figure 3. The minus amplitudes of accommodation are due to experimental error of measurement. The mean amplitudes of accommodation are connected

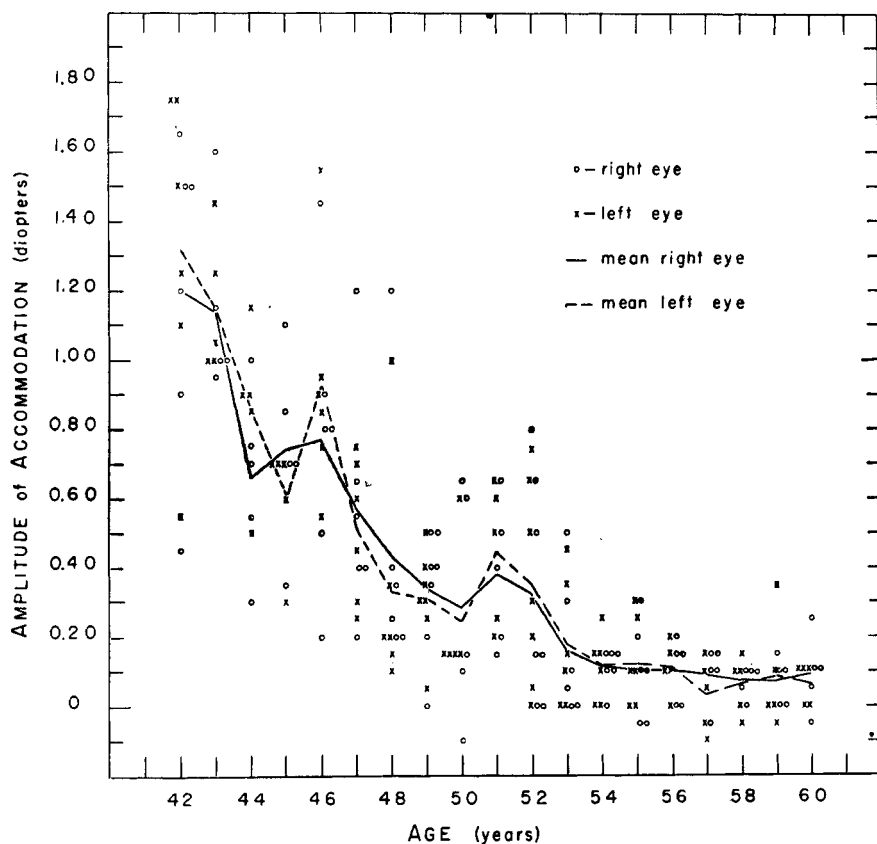


Fig. 3. Stigmatoscopic amplitudes of accommodation. The amplitudes of accommodation of the right and left eye of each subject are shown. The mean amplitudes of accommodation are connected by straight line segments. The amplitudes of accommodation of the right eye are displaced to the right while those of the left eye to the left of the age when there were more than one with the same amplitude of accommodation.

by straight line segments. Since there did not seem to be any significant differences in the amplitudes of accommodation of the right and left eye, the mean of the right and left eye was used in the statistical analysis.

In Figure 4 the mean log amplitudes of accommodation are plotted on a log scale together with the regression line on the mean log amplitude of accommodation on age. Also shown are the 95.0 per cent and the 50.0 per cent confidence limits.

The best fitting quadratic was also calculated. A comparison of the sums of the squares of the mean log amplitudes of accommodation from the best fitting straight line and the quadratic indicated that there was no significant difference, i.e., the decrease in the mean log amplitude of accommodation with increasing age could be described equally well by either equation. For simplicity, the best fitting straight line or the linear regression curve has been used.

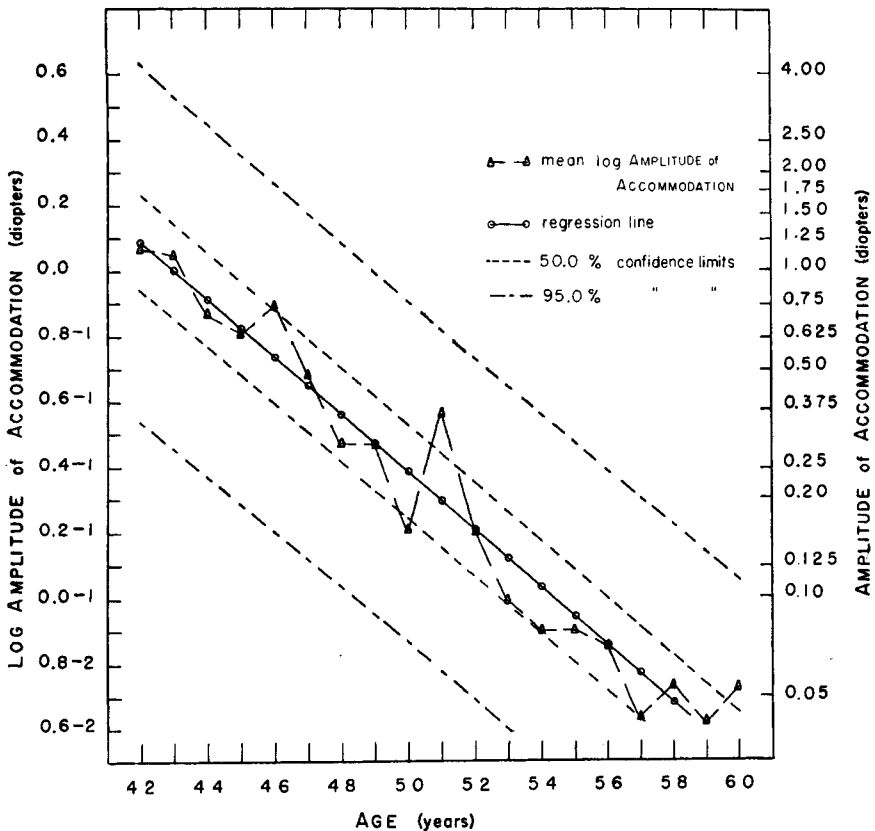


Fig. 4. Regression line and confidence limits for the mean log stigmatoscopic amplitude of accommodation.

For a comparison of the amplitudes of accommodation measured by the two methods, the mean "push-up" amplitudes of accommodation and the regression line with the 95.0 per cent confidence limits are shown in Figure 5. Also shown are the mean amplitudes of accommodation reported by Donders and by Duane.

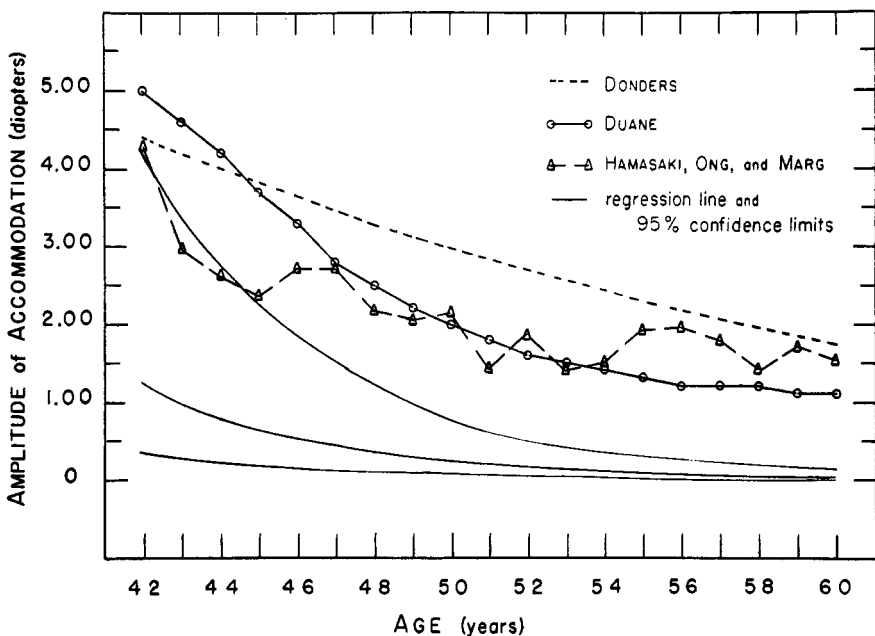


Fig. 5. A comparison of the amplitude of accommodation measured by "push-up" and stigmatoscopic methods. Donders, Duane, and Hamasaki et al. represent "push-up" amplitudes of accommodation. The regression line and the 95 per cent confidence limits were calculated from the stigmatoscopic amplitudes of accommodation.

#### DISCUSSION

The values of the mean amplitudes of accommodation measured by the "push-up" method in this study are similar to the amplitudes of accommodation reported by Donders and by Duane. Between the ages of 43 and 46 years the mean amplitudes of accommodation are lower than those reported by both Donders and Duane, while between the ages of 55 and 60 years they lie between the values reported by the two previous investigators.

Several factors can account for the differences in the three investigations, namely, size of sample, differences in the technique used in the measurement of the amplitude of accommodation, and differences in the method of determining the refractive error. An increase in the size of

the sample in this study would probably "smooth out" the curve and may also displace the curve up or down. Some of the differences in technique which may affect the results are illumination, targets, and the criteria used for the endpoint. The criterion used for the correction of the refractive error will definitely affect the value of the measured "push-up" amplitude of accommodation. This point was emphasized by Duane and he believed that a cycloplegic must be used to insure a maximum correction of the refractive error. However, it has been reported that a cycloplegic refraction may "overcorrect" the refractive error "in plus."<sup>9</sup> In these cases the value of the measured amplitude of accommodation will be higher.

Considering these three factors, the differences of the amplitudes of accommodation reported in this study and those reported by Donders and by Duane do not appear to be significant. Thus, it can be said that the mean amplitude of accommodation, measured by the "push-up" method, decreases rapidly up to the age of 50 to 52 and then remains essentially the same up to the age of 60 years.

Examination of Figures 3 and 5 shows that the amplitude of accommodation measured by stigmatoscopy is lower than that measured by the "push-up" method. The mean difference between the two is 1.75 D. This difference is essentially due to the depth of focus of the eye. After the age of 54 years the mean amplitude of accommodation is insignificant and can be considered to be zero.

From Figure 4 it can be seen that the decrease of the mean log amplitude of accommodation with increasing age may be described as linear. The coefficient of correlation between the amplitude of accommodation and age is  $-0.76$ . The equation of the regression line of the mean log amplitude of accommodation (A) in diopters on age in years is:

$$\text{Log } A = 3.767 - (0.088) (\text{age})$$

The equation of the best fitting quadratic is:

$$\text{Log } A = 6.977 - (0.215) (\text{age}) + (0.00125) (\text{age})^2$$

If the regression line is used to predict the mean amplitude of accommodation at a given age, the 95 per cent confidence limits include the range within which one may predict and be correct 95 per cent of the time. The same is true for the 50 per cent confidence limits.\*

\*The validity of these limits and the regression line is based on several assumptions. First, the regression of the mean log amplitude of accommodation is linear. Second, the log amplitudes of accommodation are normally distributed around the population mean. Third, the standard deviation of the log amplitudes of accommodation is constant for all ages.

This equation will not be valid for ages other than those studied in this investigation. A similar type of investigation must be done to determine the rate of change of the amplitude of accommodation for other ages.

A common technique used by clinicians to determine the spherical add for near work is the prescribing of an add which will leave a certain percentage of the amplitude of accommodation in reserve. This is based on the clinical impression that part of the amplitude of accommodation must be kept in reserve if the patient is to do extended periods of close work without discomfort. If the mean depth of focus is assumed to be 1.50 D. then a minimum spherical add of 1.00 D. should allow the patient to read at 40 cm. without using any accommodation. This would imply that the adds usually prescribed leave not part, but all of the amplitude of accommodation in reserve.

This investigation emphasizes the importance of the depth of focus in presbyopes. The importance of the depth of focus has been previously pointed out by Miles.<sup>10</sup> A decrease in the size of the pupil with increasing age would tend to increase the depth of focus, however, other factors such as the reduced clarity of the media and degenerative changes of the retina would tend to decrease the depth of focus of the eye.

Although this is not a longitudinal study, some evidence of the variation of the depth of focus with increasing age can be derived from an examination of the "push-up" and stigmatoscopic amplitudes of accommodation.

The mean amplitudes of accommodation reported by Duane show that there is a decrease of approximately 0.50 D. between the ages of 54 and 60 years. The amplitudes of accommodation measured by stigmatoscopy show a decrease of only 0.08 D. between these ages. This difference may possibly be due to a decrease of 0.42 D. in the depth of focus between these ages. If this is true then this may explain why adds are commonly increased after the age of 54 years.

On the other hand, if a constant value of 1.50 D. is added to the mean stigmatoscopic amplitudes of accommodation the resulting curve fits the "push-up" curve very well between the ages of 51 and 60 years. This would indicate that the depth of focus does not change between these ages. This then brings up the interesting point of why adds are commonly increased after the age of 51 years when both the amplitude of accommodation and the depth of focus do not show any significant decrease. One important factor that should be considered is the increased magnification provided by higher powered adds.

Thus no definite conclusions can be made at this time concerning the change of the depth of focus with increasing age. Direct measurements of the depth of focus should be made to solve this problem.

#### SUMMARY AND CONCLUSIONS

The amplitude of accommodation was measured on both eyes on 106 subjects, ages 42 through 60 years, by the "push-up" and stigmatoscopic methods.

A comparison was made between the mean "push-up" amplitudes of accommodation measured in this study and those reported by Donders and by Duane. In general, the mean amplitude of accommodation, measured by the "push-up" method, decreased rapidly up to the age of 50 to 52 years and then remained essentially the same until age 60.

The values of the stigmatoscopic amplitudes of accommodation were found to be significantly lower than the "push-up" amplitudes of accommodation. The difference is due to the depth of focus of the eye. After the age of 52 years the amplitude of accommodation is essentially zero (absolute presbyopia).

Statistical analysis of the data showed that the decrease of the amplitude of accommodation with increasing age could be described equally well by a linear or quadratic equation. The equation of the regression line of the mean log amplitude of accommodation on age is presented together with the 95 per cent and 50 per cent confidence limits.

Evidence for a change of the depth of focus of the eye with increasing age was contradictory and no conclusions could be made at this time.

The significance of the marked difference of the "push-up" and stigmatoscopic amplitudes of accommodation was discussed in relation to the prescription of spherical adds in presbyopes.

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