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Abstract

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A LONGITUDINAL STUDY OF
CONVERGENCE CHANGES WITH AGE

by

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ABSTRACT

Longitudinal changes in convergence behavior measured by phoria and duction tests were studied in twenty-one subjects between the ages of 35 and 60 years. The far lateral phoria and base-out duction recovery at near did not change significantly. In agreement with other studies, the near lateral phoria was found to shift in an exophoric direction, but only by approximately two prism diopters. A composite measure of the convergence-divergence system (convergence index scores) showed a decline, indicating a loss in ability compared to young adult standards. Wide variations were found both between and within subjects among individual test components of the convergence-divergence system.

INTRODUCTION

An intriguing question that eventually develops among most, if not all, of the researchers in vision is what happens to the convergence system with the onset of presbyopia. A review of the literature shows many approaches to this question, with little consensus of opinion as to what is actually occurring or what clinical applications can be drawn from the data.

Since convergence is linked to accommodation, it may be helpful to review two theories of the loss of accommodation. Morgan[1] lists the three aspects of one model: "(1) There occurs with age a decrease in the limit to which the lens can be made to change its form; (2) in so far as the lens can be made to change its form, the same amount of ciliary contraction is required at all ages to produce a unit change in the form of the lens; and (3) as age increases it is to be expected that there will be an ever-increasing excess amount of ciliary contraction beyond the ability of the lens to respond to it."

Other researchers[2] postulated that a greater amount of ciliary muscle contraction is required to produce changes in lens shape with increasing age of the subject. Therefore, a decrease in effectiveness of ciliary contraction occurs with increasing age. However, studies do not support the idea of loss of responsivity of the ciliary muscle with increasing age.[3]

Contradictory theories have also been proposed for the accommodation-convergence association and are further discussed by Ogle[4] as either labile and flexible, innate and invariable, or stable.

All three theories have found experimental support but a common point is that accommodation and convergence are intimately linked and modification within this association requires some modification of both members.

This point is supported by considering the Hess theory for accommodation which states that innervation levels are considered constant for the production of a given amount of accommodation regardless of age.[5] This corollary would appear to indicate that as age increases, the proportion of ciliary muscle contraction, that fails to result in lenticular change, increases.

Intuitively, if an increase in innervation to the ciliary muscle is required for a given amount of accommodation, an associated convergence increase would be expected. Investigations of the accommodative-convergence linkage would be expected to show some transition with the onset of presbyopia if the system was "hard-wired". As the presbyope works to attain the appropriate level of accommodation, overconvergence would be expected. This excessive convergence has not been found experimentally. Although he did not differentiate types of convergence, Provine[6] found a decrease in convergence amplitude of 0.29^{o}/year. (see Graph 1). Analysis of Tait's[7] data of accommodative convergence in successive age groups showed a slight decrease from age 10 to 60. (see Table 1 and Graph 2). It appears that presbyopes are able to properly utilize accommodative convergence even though little if any accommodative ability remains.

Eames[8] actually found an increase in exophoria at both far and near as age increases and the amplitude of accommodation decreases. This finding was disputed by Sheedy and Saladin[9] as an artifact of the testing conditions. Since phoria measurements for presbyopes are taken with accessory lenses and under dissociated conditions, the stimulus to accommodative convergence is eliminated, resulting in a large exophoria finding. Wick[10] supports their contention that fixation disparity testing would be more appropriate to determine the convergence posture for the presbyope.

The convergence changes in presbyopia would also be exemplified in the AC/A ratio. Many researchers[2,3,11] have found an increase in accommodative convergence parallels the drop in accommodative amplitude, leading to an increased AC/A. Fry[5] cites his own and other researchers' data supporting this finding and its corollary that an increase in ciliary muscle force was needed to produce a given amount of accommodation with increasing age. Other researchers,[1,12] however, report little change in the AC/A with age.

In pointing out the problem of differentiating between the stimulus AC/A measurements and the response AC/A measurements, Morgan[13] partially explains the contradictory experimental data. Chin's[12] studies verify the constancy of the stimulus AC/A but show an increase in response AC/A with age. This increase in response AC/A would be expected to cause over-convergence among the presbyopic population.

It thus appears that the presbyope is in danger of both a convergence insufficiency due to his/her increased near exophoria and a convergence excess due to the increased response AC/A. Whatever the expectations, the fact remains that asthenopia due to vergence dysfunction is rare in presbyopes, even when working distance and amount of near work are unchanged.[9,13]

These contradictory theoretical speculations and clinical reports make it clear that just what changes occur in the convergence systems with the onset of presbyopia is largely unknown. This longitudinal study was performed to investigate this area of conflict and confusion.

METHODOLOGY

In order to rule out as many confounding variables as possible, case records were sought from the same practitioner who has been using essentially the same examination procedures throughout his years in practice. Thus inter-subject and inter-clinician experimental error could both be minimized in a longitudinal study.

Subjects included in this study met the following criteria: (1) exam records in at least three of the five year periods between ages 35 and 60. (One subject did not meet this criteria, but did have three exams, so was included); (2) no overt pathological process affecting the visual system; (3) 20/20 or better acuity throughout the age intervals; and (4) no past history of strabismus and/or amblyopia.

Seven clinical tests were selected and analyzed from the examinations recorded from each patient. The tests were #8 (distance lateral phoria), #10 (distance base-out to break and recovery), #11 (distance base-in to break and recovery), #14B (binocular cross-cylinder at near), #15B (phoria through the near binocular cross-cylinder finding), #16B (base-out to break and recovery at near), and #17B (base-in to break and recovery at near). Ages and distance refraction for each examination were also collected. As the practitioner followed the examination procedure outlined by the Optometric Extension Program, additional information on the details of the routine may be obtained from that source.*

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*Hendrickson, Homer; The Behavioral Optometry Approach to Lens Prescribing; Optometric Extension Program Foundation, Inc.; 1980: Duncan, Oklahoma.

Analysis of individual tests such as the far phoria and cross-cylinder phoria, involved computing means from each examination from each subject who had data for that age period. If multiple examinations for a single subject existed for a five-year period, the average of the test findings within the interval was used for that subject's interval finding. Analysis also included computation of convergence index scores. This statistical composite method allowed assessment of the convergence-divergence system using both phoria and duction measurements compared to population norm.**

The #15B (phoria through the binocular cross-cylinder finding at near) was chosen as the near phoria to use in the analysis for several reasons. First, previous studies had used arbitrary amounts of plus at near which may have either "over- or under-plussed" the subject. Secondly, the near phoria and ductions were, for the most part, taken through the #14B lens (binocular cross-cylinder finding at near) which, with aging of the accommodative system, allowed 20/20 acuity and allowed measurements to be taken under comparable conditions.

**Convergence index (C_i) scores are part of Normative Analysis as developed by Professor Harold Haynes of Pacific University, Forest Grove, Oregon. This system of analysis is based on population norms for individual optometric tests. An individual subject's examination results are scaled according to the number of probable errors from that test's norm. These scaled individual test ratings are then compiled to yield a composite system score. Phorias, ductions, and their interactions are thus rated and utilized to determine the convergence index score. The convergence index score is, therefore, a general measure of the overall ability of the convergence-divergence system. A patient whose findings are all within one probable error of the population norm would obtain a convergence index score of 30.5. A standard deviation of 4.25 has been determined for convergence index scores, with a lower score indicative of a less efficient system.

For statistical purposes, the 5% level of confidence was arbitrarily accepted for rejection of the null hypothesis for any single finding changes. A similar standard was adopted for evaluation of convergence index scores.

RESULTS

Approximately 2,000 case records were reviewed to yield the twenty-one subjects used in the analysis. Patients' records were grouped into predetermined five-year intervals. Group means for each test for each age interval were computed, using all subjects with an exam in that age period. The group and individual means for various tests are included in Appendices I through V. The group means were then plotted against base-out or base-in prism diopters as a measure of either the phoria or duction, as specified, and also for statistical analysis. Conventional statistical computations were performed to yield mean and standard deviations for the individual tests.

Graphs 3 and 4 show the mean change in the far and near phoria over time. The base-out duction recovery at near is shown in Graph 5, while convergence lag (comparing the near base-out duction to the cross-cylinder near phoria) is illustrated in Graph 6. Graph 7 is the plot of the means for each age interval of the convergence index scores.

Inspection of Graphs 3 and 4 reveals that with the onset and progression of presbyopia an increase in exophoria was found, but only at near and only of approximately two prism diopters. The far lateral phoria did not significantly change. The base-out recovery at near, Graph 5, although appearing graphically to decrease with age, did not change with any statistical significance as measured with a chi-squared test ($p = 0.05$). Analysis of the convergence lag again revealed no significant change with age, as shown by Graph 6.

Comparison of the convergence index scores revealed a statistically significant decay, even though the individual components used to calculate this measure did not. (see Graph 7). While the decay shown in the graphs for individual findings were not statistically significant, a cumulative effect was detected by analysis of the convergence index score.

The wide variability found in this data is illustrated by the tables of convergence index score (C_i) and various tests for individual examinations for each subject.

DISCUSSION

Included in the many questions which acted as a springboard for this study was whether or not the phoria did indeed become more exophoric with the onset of presbyopia and, if so, how were patients able to compensate for this change. As reports of asthenopia in the presbyopic population are rare,[9,13] it seemed logical to assume that convergence skills were able to physiologically adapt to the loss of accommodation and other unspecified aging processes of the visual system. This study, however, found that even in the face of the small exophoric shift, base-out breaks and recoveries remained approximately the same. It thus appears that convergence skills did not increase. The difference between the near point cross-cylinder phoria (15B) and the base-out prism recovery (#16R) held approximately constant. Convergent index scores showed an overall decline during the period. In comparison of first and last age interval scores, seven subjects showed a decline, while fourteen subjects remained within one standard deviation. None of the subjects showed an increase.

In looking over the data from the near phoria, although the means of all subjects within the age intervals do show a slight shift to exophoria, large variations are found both between and within subjects. Some subjects showed changes of only two diopters between all of the exam dates, while other subjects experienced as much as a six prism diopter shift. Although the number of subjects prevents drawing any statistically significant conclusions, it is interesting to note that several of the subjects who experienced a large swing to exophoria also experienced a compensatory swing to esophoria at some later date. These contradictory swings and large variations may all be part of the adaptive mechanism of the early presbyope.

The most outstanding characteristics of the data collected on each test were the wide variability, again both between and within subjects. It might be that this variability partly reflects changes associated with the ongoing adaptive process, with each subject having his/her own individual response pattern to the loss of accommodation and the disruption of lifelong accommodative convergence interaction. These differences in individual responses were discussed for the near phoria in the above paragraph, and is also illustrated for convergence index scores in Graph 7 where three different subjects are seen to have three different patterns of change throughout the twenty-year period.

If the component model of convergence is followed, as accommodative convergence is lost with the decay in accommodation, greater exophoria at near is expected and the base-out duction (fusional convergence) would be expected to decrease. This loss might be expected to result in asthenopia or other related complaints. Since asthenopia is not characteristic of the presbyopic population, it would seem that fusional convergence skills should increase or at best remain constant. However, in this study the base-out recovery showed no significant change from age 35 to 55. The question then remains as to how presbyopes cope with the assumed loss of accommodative convergence.

Saladin and Sheedy[9] raise the possibility that presbyopes do not lose accommodative convergence. Instead, presbyopes are able to freely use as much accommodative convergence as needed, since blurring of the target from excessive innervation is impossible due to the inability of the lens to respond. No independent physiological correlates of accommodative convergence are referenced to support this speculation. Therefore, it appears that presbyopes may be adapting by responding to the fixation plane distance alone and are no longer relying on any accommodative element. The assimilation of this adaptive process may be responsible for the wide intra-subject variability rather than the generalized decay of the convergence ability.

Previous studies of convergence amplitude changes with age[6,7] also found a generalized decrease which is in accord with our findings. Tait[7] also raises the possibility that presbyopes utilize accommodative convergence even though little, if any, accommodative ability remains. Other researchers,[2,3,11] in investigating AC/A changes with age, found the drop in accommodative amplitude was paralleled by an increase in accommodative convergence. Our study would support these hypotheses.

Our study did not attempt to determine the change in AC/A ratios over time since many of the contradictory findings reported in this area[2,3,7,11,12,13] seem due to errors and artifacts in experimental design. For instance, near point lenses used in the phoria measurements varied between subjects, and some experimentors assumed that accommodative response equalled accommodative stimulus. To avoid simple verification of previous studies, by our use of cross cylinder near-point lenses, we sought to determine if an exophoria shift occurred even with appropriate near point lenses, and if the convergence-divergence system exhibited a compensatory adaptation.

CONCLUSION

In conclusion, the onset and progression of presbyopia is associated with changes not only of the accommodative system, but also of the convergence system and the interaction between the two. These changes are complex and probably are individualistic, with a dynamic adaptation allowing adequate functioning by the patient.

GRAPHS

The graphs of this study's results (Graphs 3 - 7) show the changes occurring in five-year intervals from age 35 to 60. Dashes above and below the plotted lines indicate standard deviations.

Graph 1

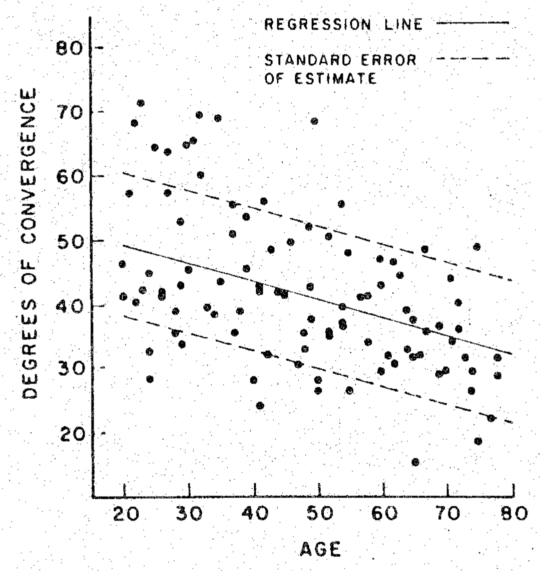
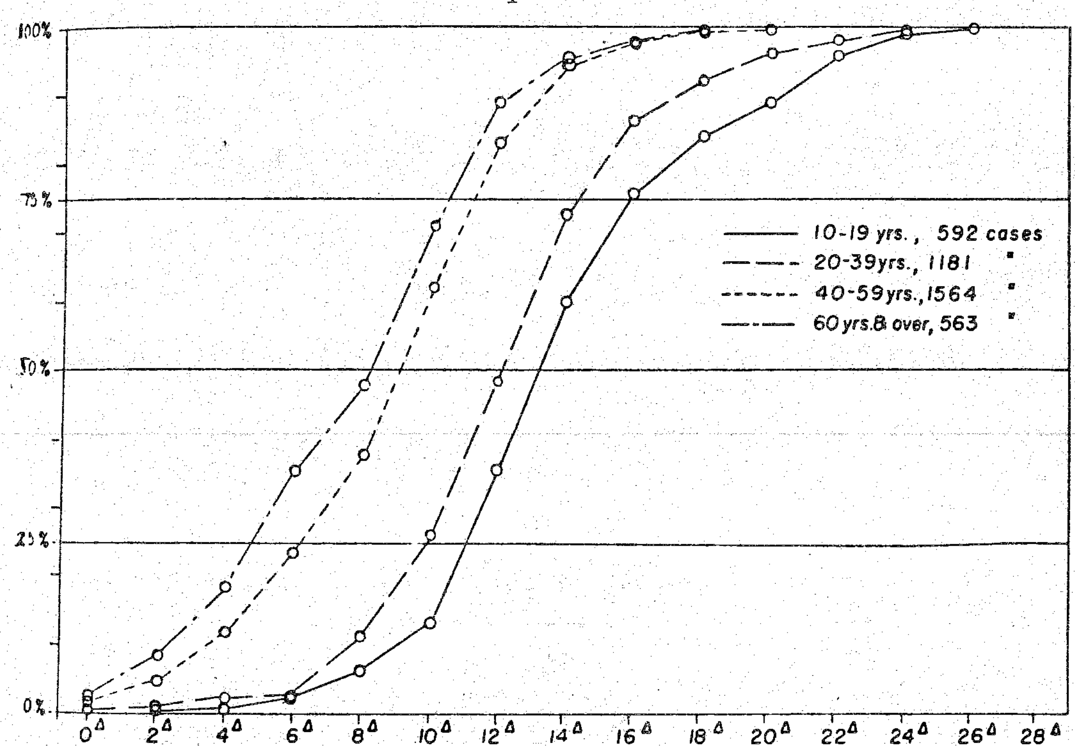


Table 1

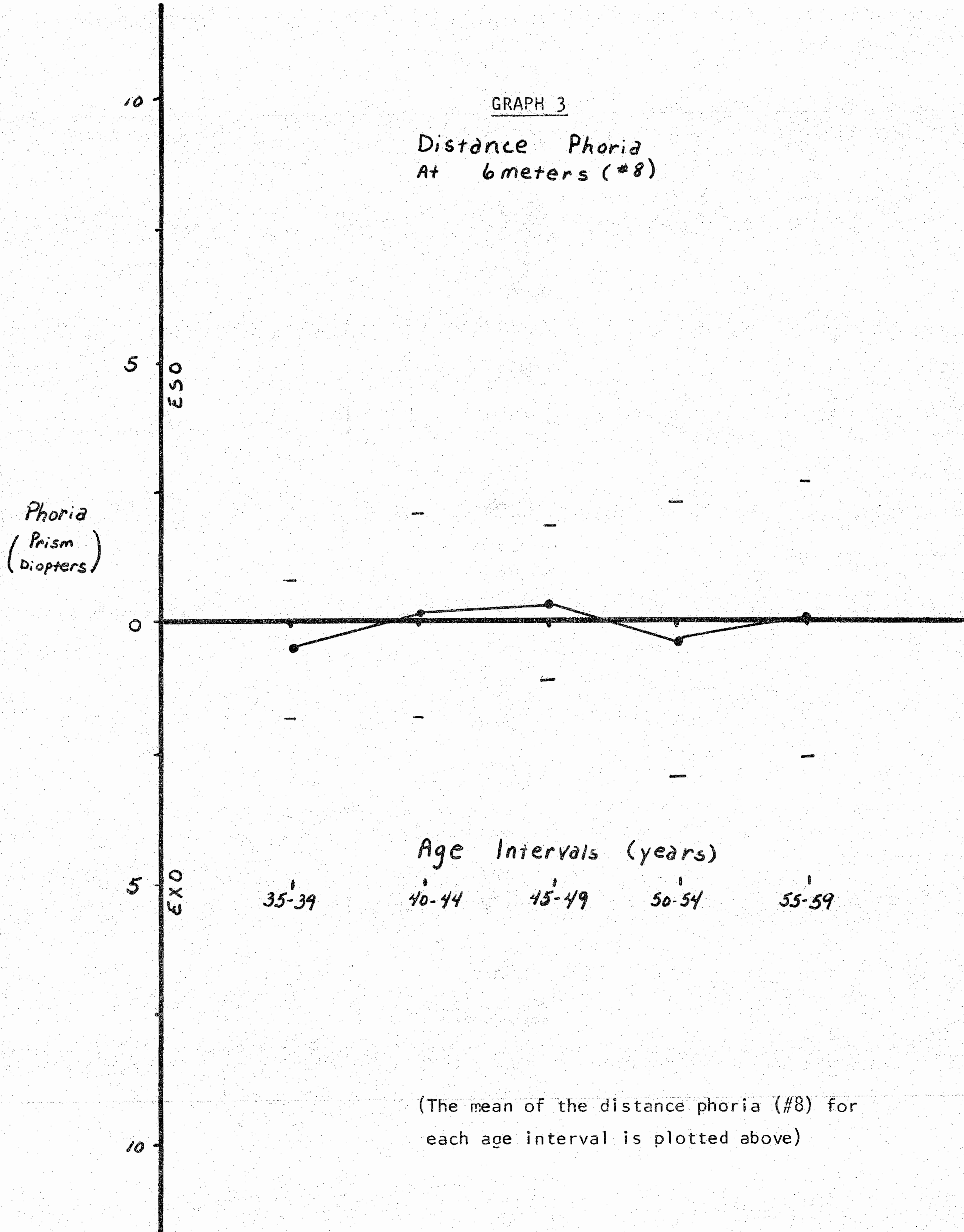
VALUES OF ACCOMMODATIVE CONVERGENCE IN 3,900 OCULARLY COMFORTABLE SUBJECTS IN FOUR AGE GROUPS*

Accommodative Convergence	Ages			
	10-19	20-39	40-59	60 & Over
0^{Δ}	0	5	25	12
1^{Δ}	0	4	13	8
2^{Δ}	1	3	31	20
3^{Δ}	2	4	31	23
4^{Δ}	2	8	65	32
5^{Δ}	1	14	56	21
6^{Δ}	5	23	108	56
7^{Δ}	7	22	87	45
8^{Δ}	15	42	125	39
9^{Δ}	15	33	126	35
10^{Δ}	25	118	241	91
11^{Δ}	30	75	119	30
12^{Δ}	83	162	199	65
13^{Δ}	50	118	109	32
14^{Δ}	86	161	105	23
15^{Δ}	54	102	49	10
16^{Δ}	50	89	36	10
17^{Δ}	35	53	8	2
18^{Δ}	31	40	8	5
19^{Δ}	8	25	8	0
20^{Δ}	19	27	2	2
21^{Δ}	19	14	2	0
22^{Δ}	24	15	6	2
23^{Δ}	7	7	2	0
24^{Δ}	10	9	0	0
25^{Δ}	3	1	0	0
26^{Δ}	6	1	2	0
27^{Δ}	2	0	0	0
28^{Δ}	0	3	1	0
29^{Δ}	0	1	0	0
30^{Δ}	2	2	0	0
Total No. of Cases	592	1,181	1,564	563

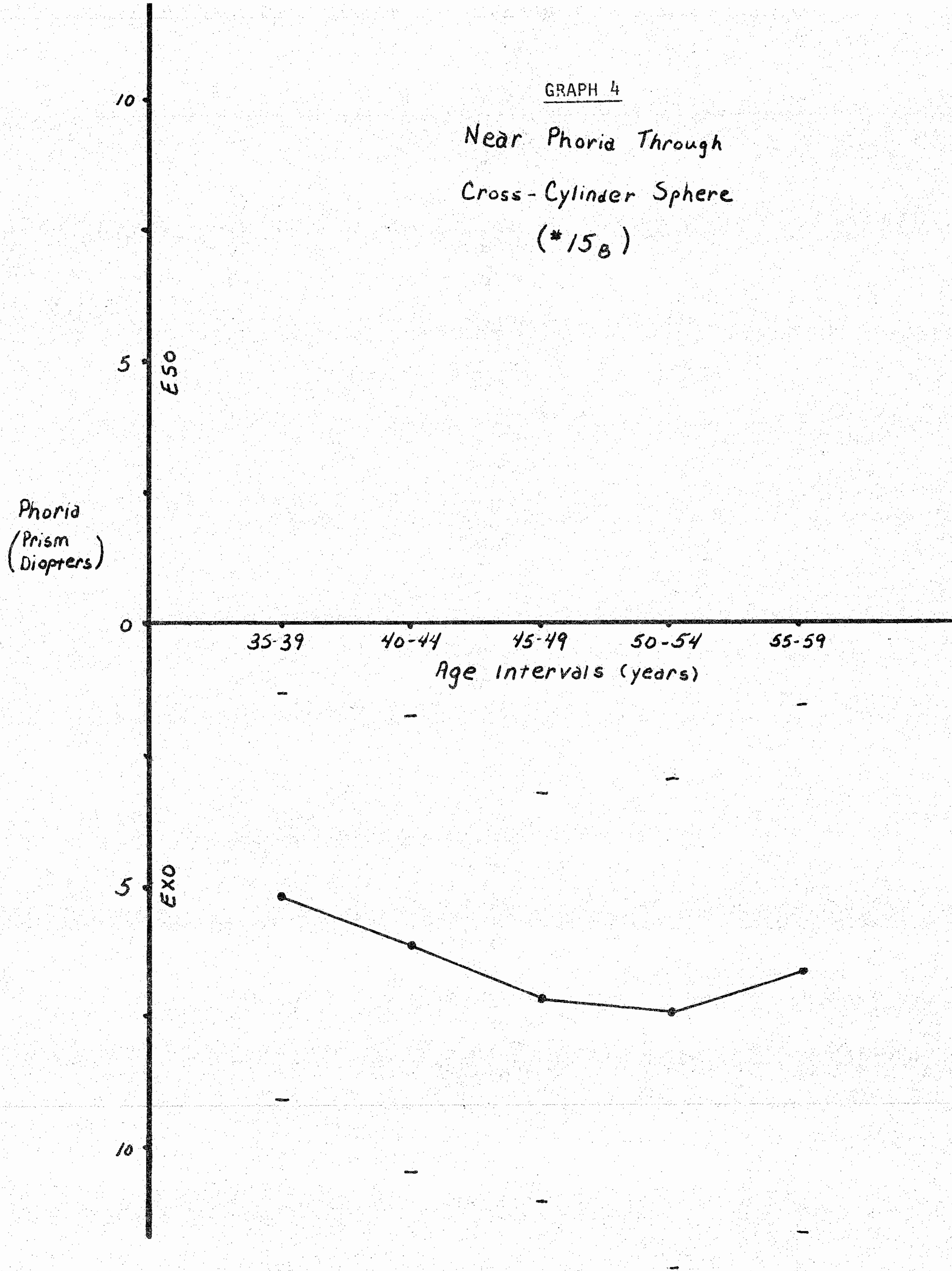
Graph 2



Accumulated distribution of accommodative convergence in 3,900 ocularly comfortable patients within various age groups.

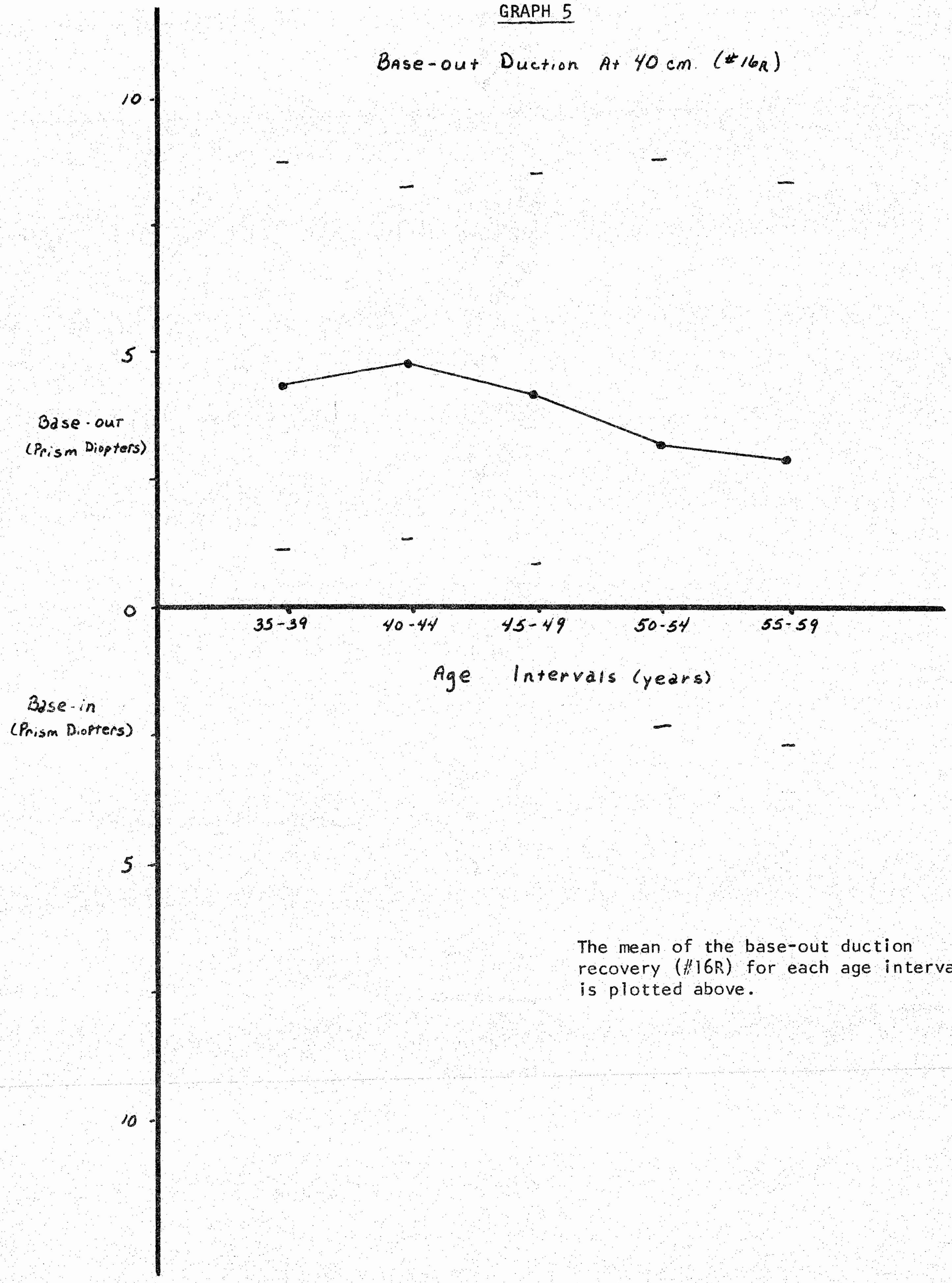


(The mean of the distance phoria (#8) for each age interval is plotted above)

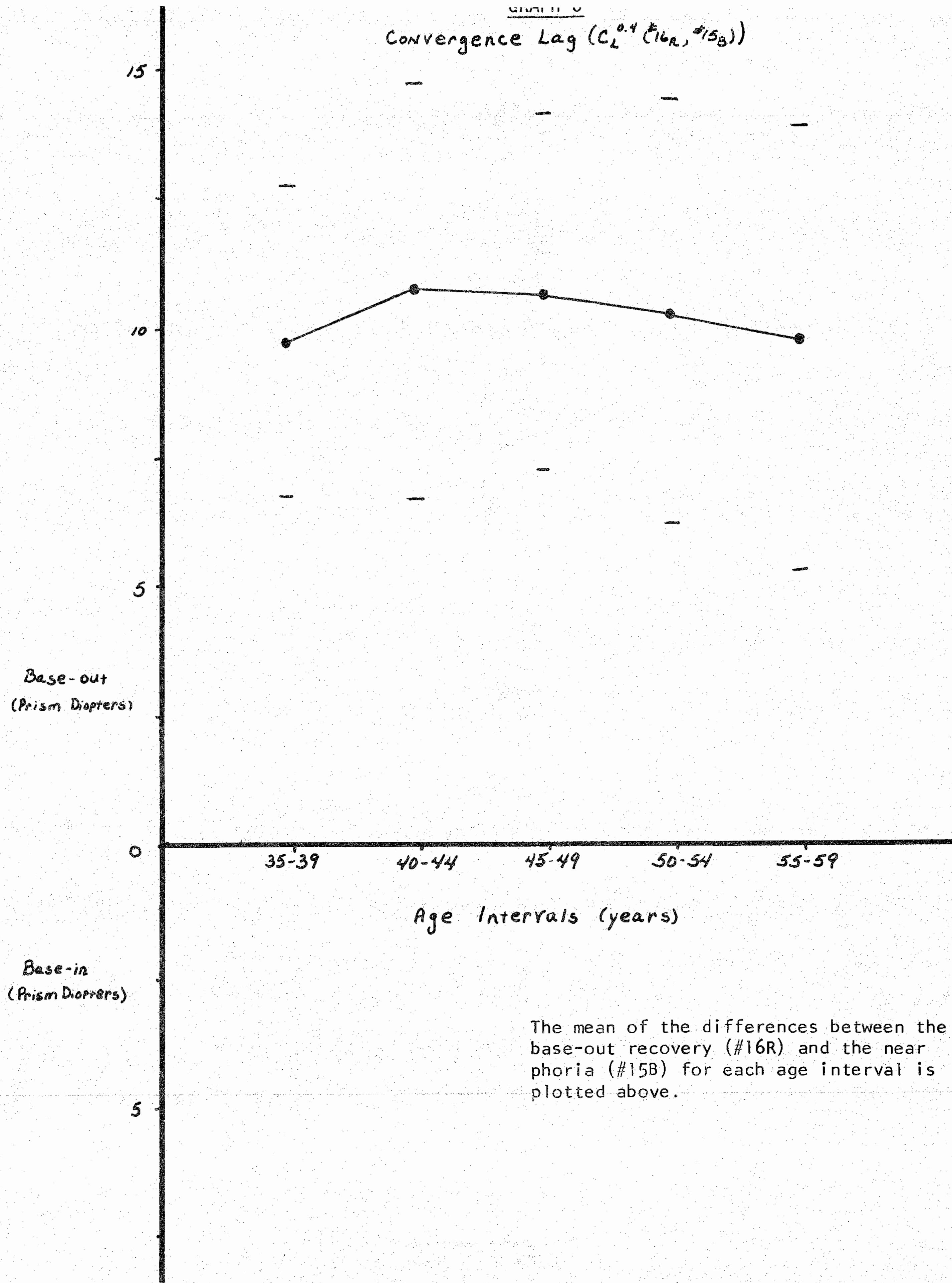


The mean of the near phoria (#15B) for each age interval is plotted above.

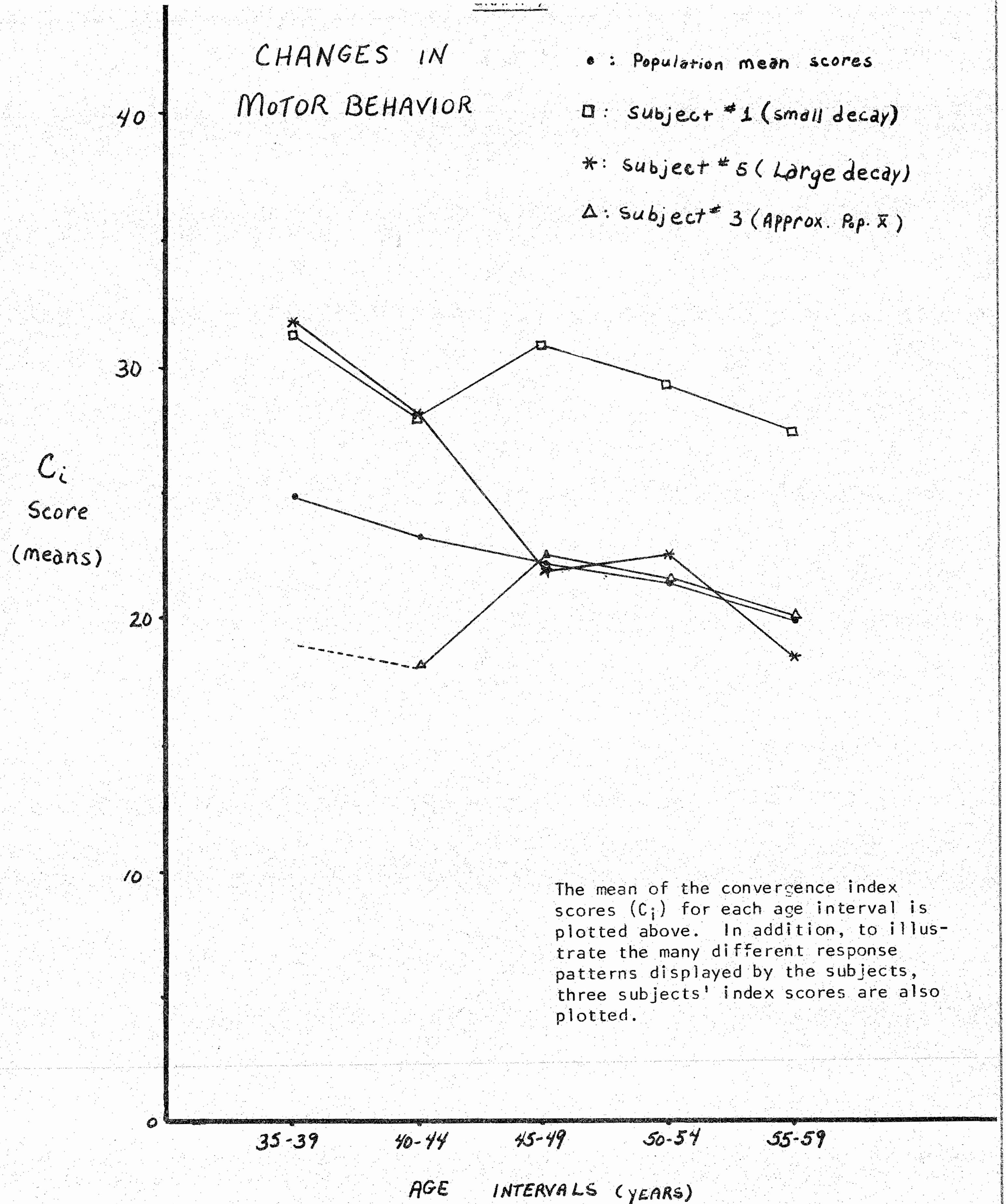
GRAPH 5



The mean of the base-out duction recovery (#16R) for each age interval is plotted above.



The mean of the differences between the base-out recovery (#16R) and the near phoria (#15B) for each age interval is plotted above.



The mean of the convergence index scores (C_i) for each age interval is plotted above. In addition, to illustrate the many different response patterns displayed by the subjects, three subjects' index scores are also plotted.

APPENDICES

APPENDIX I

Table of the Means of the Distance Lateral Phoria (#8)

Subject	35-39	40-44	45-49	50-54	50-59
1	-0.75	-1.0	-0.75	-1.25	-1.0
2	1.0	0	-1.25	-	-
3	-	-1.0	-2.0	-2.0	-2.0
4	-0.33	-1.0	-1.0	-1.0	-2.0
5	-1.0	-2.6	-3.5	-5.0	-4.0
6	-1.5	0	-	-1.0	-1.0
7	1.5	2.0	1.5	0.5	-
8	-1.0	1.0	1.0	1.0	0.5
9	1.0	1.75	1.5	4.0	3.5
10	-3.3	-1.75	-2.0	-2.0	-2.0
11	0	0.5	-	0.75	0
12	-2.5	-	-	-6.0	-
13	0	1.5	-0.5	2.0	0
14	-	-	1.6	1.0	2.0
15	-	1.0	0.25	2.0	2.0
16	1.75	1.0	0	-1.0	-
17	-1.0	-1.0	-0.75	-1.5	-
18	-0.75	-	-0.25	-0.5	-1.0
19	-	5.5	2.0	4.0	7.0
20	-1.25	-2.0	-1.0	-1.0	-1.0
21	-0.5	-0.5	-1.0	-	-0.5
N	17	18	18	19	16
$\overline{X}$	-0.51	0.19	0.35	-0.37	0.03
SD	1.33	1.88	1.45	2.55	2.6

A negative entry indicates an exophoric shift while a positive entry indicates an esophoric shift compared to the previous exam.

APPENDIX II

Table of Means of the Phoria Through the Binocular Cross-Cylinder at Near (#15B)

Subject	35-39	40-44	45-49	50-54	55-59
1	-2.0	-4.0	-8.0	-8.75	-4.5
2	-3.5	-9.0	-10.75	-	-
3	-	-6.5	-7.0	-	-11.0
4	-8.75	-12.0	-10.25	-8.0	-
5	-	-13.75	-17.5	-16.0	-19.0
6	-8.0	-7.0	-	-8.0	-8.0
7	-1.0	-2.0	-4.75	-7.0	-
8	-1.0	-1.0	-1.25	-0.25	-2.5
9	0	0	-3.5	-0.25	0
10	-11.25	-9.5	-9.0	-10.5	-
11	-5.0	-2.0	-	-5.0	-5.0
12	-13.0	-	-	-14.0	-
13	-3.0	-2.0	-5.0	-	-4.0
14	-	-	-7.5	-8.0	-9.0
15	-	-5.0	-6.0	-3.5	-
16	-3.25	-8.0	-6.0	-	-
17	-4.0	-7.0	-7.0	-9.0	-
18	-3.0	-	-2.0	-3.5	-3.25
19	-	0.25	-3.0	-5.5	-2.0
20	-8.25	-12.25	-11.5	-12.0	-7.0
21	-8.5	-10.0	-9.0	-	-11.0
N	16	18	18	16	13
$\overline{X}$	-5.22	-6.15	-7.17	-7.45	-6.63
SD	3.9	4.41	3.92	4.44	5.06

A negative entry indicates an exophoric shift while a positive entry indicates an esophoric shift compared to the previous exam.

APPENDIX III

Table of Means of the Base-Out Recovery at Near (#16R) - Increasing Numbers Indicate a Larger Base-Out Reading

Subject	35-39	40-44	45-49	50-54	55-59
1	9.5	11.5	9.0	8.0	9.0
2	4.5	5.0	6.0	-	-
3	-	7.0	6.0	-	3.0
4	0.5	4.0	-4.0	-6.0	0
5	2.0	3.0	1.5	-7.0	-8.0
6	0	-1.0	-	-7.0	-10.0
7	7.0	9.0	6.5	8.0	-
8	9.0	7.0	7.0	11.0	6.5
9	5.5	3.0	1.0	6.5	10.0
10	5.0	3.5	3.5	1.0	4.0
11	0	4.0	-	6.0	5.0
12	-1.0	4.0	-	3.0	-
13	9.0	3.0	2.5	-	3.0
14	-	-	5.0	5.0	1.0
15	-	9.0	5.0	2.0	6.0
16	4.0	1.0	3.0	-	-
17	4.0	8.0	8.0	5.5	-
18	6.0	-	6.0	6.0	4.5
19	-	9.0	6.0	7.0	9.0
20	3.0	2.0	3.5	1.0	2.0
21	7.5	0	1.0	-	1.5
N	17	19	18	16	16
$\overline{X}$	4.44	4.84	4.25	3.13	2.91
SD	3.35	3.42	3.32	5.54	5.51

APPENDIX IV

Table of Differences Between the Base-Out Recovery and the Near Phoria (#16R and #15B) - Increasing Numbers Indicate a Larger Lag of Convergence.

Subject	35-39	40-44	45-49	50-54	55-59
1	10.5	14.5	16.0	15.0	16.0
2	8.0	14.0	13.0	-	-
3	-	13.0	13.0	-	14.0
4	8.5	16.0	6.0	4.0	6.0
5	12.0	14.0	16.0	9.0	10.0
6	8.0	6.5	-	2.0	-2.0
7	8.0	11.0	10.0	13.0	-
8	10.0	5.5	7.0	10.5	9.0
9	5.5	3.0	4.5	8.0	11.0
10	13.0	11.0	13.0	11.0	16.0
11	5.0	6.0	12.0	10.5	10.0
12	14.5	-	-	17.0	-
13	12.0	6.5	7.5	-	7.0
14	-	13.5	-	13.0	10.0
15	-	14.0	11.0	5.0	8.0
16	7.5	9.0	9.0	-	-
17	9.0	15.0	14.0	14.0	-
18	9.0	-	8.0	9.5	8.0
19	-	9.0	9.0	12.5	11.0
20	11.5	14.25	15.0	13.0	9.0
21	16.0	10.0	10.0	-	12.5
N	17	18	18	16	16
$\overline{X}$	9.88	10.93	10.78	10.44	9.72
SD	2.99	3.95	3.44	4.10	4.27

APPENDIX V

Table of Means of the Convergence Index Scores (C_i)

Subject	35-39	40-44	45-49	50-54	55-59
1	31.33	28.0	30.89	29.33	27.33
2	26.0	26.34	25.54	-	-
3	-	18.33	22.67	21.33	20.0
4	23.78	20.0	16.44	15.33	-
5	32.0	28.37	22.19	22.67	18.67
6	26.0	22.67	-	16.0	14.67
7	25.33	25.33	22.67	25.33	-
8	20.0	26.0	22.67	21.67	18.0
9	24.54	27.34	23.67	22.67	20.67
10	26.33	24.4	24.0	25.34	-
11	21.33	20.0	-	20.67	16.67
12	27.0	-	-	26.0	-
13	27.33	23.33	21.57	-	19.33
14	-	-	23.0	19.33	23.33
15	24.67	22.0	23.34	16.67	-
16	21.11	16.0	15.0	-	-
17	25.0	29.33	26.22	25.33	-
18	20.67	-	19.67	19.0	19.33
19	-	23.0	24.0	21.67	19.33
20	22.93	18.83	19.67	16.0	19.37
21	26.34	21.33	16.67	-	22.34
N	18	18	18	17	13
$\overline{X}$	25.09	23.37	22.22	21.43	19.93
SD	3.28	3.82	3.78	4.05	3.13
Σx	451.69	420.6	399.88	364.34	259.04
Σx^2	11517.11	10076.09	9126.42	8070.38	5279.35

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