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Patterns of Nonlinearity in the Ratio of Stimulus Accommodative Convergence to Accommodation

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BACKGROUND

This study disputes the assumption that the stimulus accommodative convergence to accommodation (AC/A) ratio is linear.

SUBJECTS AND METHODS

Accommodative convergence induced by minus lenses of varying power (-1.50 to 6.00 D, at intervals of 1.50 D) was measured on the Synoptophore in a group of 96 non-strabismic children aged 6 years 3 months to 11 years 2 months (mean 8.8 ± 1.4 years).

RESULTS

The mean AC/A ratios obtained with a stimulus to accommodation of -1.5 D, -3.0 D, -4.5D, -6.0D were 2.25 ± 1.47 , 2.88 ± 1.15 , 3.28 ± 1.02 , 3.49 ± 0.85 respectively. Five patterns of change in AC/A ratio with stimulus are described.

CONCLUSION

Further studies in all age groups are necessary to investigate the nonlinearity of the AC/A ratio over repeated measurements and the repeatability of the testing method.

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CONVERGENCE IS ONE FACTOR WHICH contributes to eye position. Components of convergence include tonic, proximal, fusional, and accommodative elements. Accommodative convergence is the amount of convergence induced by accommodation. Accommodative demand can be altered by the introduction of lenses at a set distance. Maintaining this set distance avoids any change in proximal effects. On distance viewing, a minus lens may be introduced to stimulate accommodation; on near viewing, a plus lens may be used to relax accommodation. The amount of accommodative convergence which occurs per diopter (D) of accommodation is known as the AC/A ratio.

Clinical measurement of the AC/A ratio assumes that it is linear in nature. However, a number of authors have demonstrated departures from linearity using a variety of different testing methods.¹⁻⁵ In many of these studies, artificial pupils are employed and the subjects are of college age or older.

Clinical measurement also assumes that the change in accommodation is equal to the change in accommodative stimulus. This is not so, but as equipment is seldom available to measure the response to the stimulus, this assumption has to be made. Due to potential differences in these two measurements, Alpern et al described the stimulus AC/A ratio (the magnitude of vergence associated with a unit change in accommodative stimulus) and the response AC/A ratio (the magnitude of vergence associated with a unit change in accommodative response).⁵ Each is related to the other, the response AC/A ratio being slightly higher due to the normal accommodative lag which occurs.

The AC/A ratio is assessed clinically to help in the diagnosis and management of certain types of strabismus.

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The aim of this work was to consider the linearity of the stimulus AC/A ratio when tested under normal clinical conditions in a group of school children.

SUBJECTS AND METHODS

All subjects had bifoveal binocular single vision confirmed by the 4 diopter prism reflex test. No subject had any history of problems with either ocular motility or binocular vision. Children with refractive error were included, but tests were performed with refractive correction.

The Synoptophore gradient method was employed to measure the stimulus AC/A ratio over a range of 6 D of accommodation, in steps of 1.5 D. The angle of deviation was measured with each lens using specially designed slides composed of a vertical row of mixed letters and pictures on one slide and a vertical line on the other. Each subject was asked to move the line so that it bisected the letters/pictures, with this subjective measurement being confirmed objectively. One measurement was taken for each lens used and it is acknowledged that a measurement error of ± 1 prism diopter (D) could occur. The subject was excluded if a clear image could not be achieved through any of the four lenses. Apertures to fix pupil size were not used, as standard clinical testing conditions were desired.

The AC/A ratio was calculated by the following formula:

$$\frac{(\text{measurement } \Delta \text{ with lenses}) - (\text{measurement } \Delta \text{ without lenses})}{\text{power of lens used (D)}}$$

A change in the AC/A ratio by a factor of 1 was judged to be clinically meaningful. The AC/A ratio was considered to be linear if a difference of less than ± 1 change in accommodative convergence occurred for each diopter of accommodation.

RESULTS

A total of 98 non-strabismic children were tested; two were excluded as a clear image could not be maintained through all lenses. Thus, 96 children are reported. Their mean age was 8.8 ± 1.4 years (range: 6 years 3 months to 11 years 2 months).

The mean AC/A ratios obtained with each lens are as

shown in Table 1. However, these ratios for the whole group mask several different patterns. Five groups were identified (Table 2).

Group 1

The first group consisted of seven subjects showing linearity with lower amounts of accommodation but a clinically significant increase in the AC/A ratio with 6 D of accommodation (Fig. 1, Table 2).

Group 2

The second group comprised 34 subjects who demonstrated a clinically significant increase in the AC/A ratio between measurements with 1.5 D and 3 D of accommodation but who were effectively linear with higher levels of accommodative stimulus (Fig. 2, Table 2).

Group 3

Twelve subjects formed Group 3. Clinically similar AC/A ratios were found with levels of accommodation of up to 3 D. At higher levels of accommodation (4.5 and 6 D) similar levels of the AC/A ratio also occurred but a clinically significant increase occurred between 3 and 4.5 D of accommodation (Fig. 3, Table 2).

Group 4

Only three subjects fell into Group 4. They demonstrated a high AC/A ratio with a low level of accommodative stimulus; this then fell and became linear with increased demand on accommodation (Fig. 4, Table 2).

Group 5

The final group included those subjects considered to be linear throughout the range of accommodation tested. Of the 96 subjects, 33 fell into this group (Fig. 5, Table 2).

The remaining seven subjects showed various inconsistent patterns.

Table 1. Mean stimulus AC/A ratios

| Lens | AC/A Ratio |
|--------|-----------------|
| -1.5 D | 2.25 \pm 1.47 |
| -3.0 D | 2.88 \pm 1.15 |
| -4.5 D | 3.28 \pm 1.02 |
| -6.0 D | 3.49 \pm 0.85 |

n=96

Table 2. Mean AC/A ratios at various accommodations.

| Lens | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|--------|------------|------------|------------|------------|------------|
| -1.5 D | 1.43 ±0.81 | 1.45 ±0.99 | 1.94 ±0.66 | 5.78 ±0.77 | 2.77 ±1.14 |
| -3.0 D | 1.67 ±0.75 | 3.05 ±1.09 | 2.33 ±0.53 | 4.11 ±0.84 | 2.81 ±0.92 |
| -4.5 D | 2.03 ±0.63 | 3.30 ±0.95 | 3.70 ±0.55 | 4.22 ±0.59 | 3.09 ±0.96 |
| -6.0 D | 3.29 ±0.87 | 3.42 ±0.84 | 3.64 ±0.66 | 4.50 ±0.60 | 3.31 ±0.84 |
| | n = 7 | n = 34 | n = 12 | n = 3 | n = 33 |

Additional Observations

Examination of the age of the subjects in each group revealed no statistical difference between groups ($p=0.537$) or between the subjects showing linearity or nonlinearity ($p=0.42$).

Comparison of groups with each lens using one-way analysis of variance revealed:

- a statistically significant higher AC/A ratio in Groups 4 and 5 with 1.5 D of accommodation than the other groups ($p<0.05$);
- a statistically significant lower AC/A ratio with 3 D ($p<0.05$) and 4.5 D ($p<0.05$) of accommodation in Group 1, and a higher AC/A ratio with 3 D of accommodation ($p<0.05$) in Group 4;
- at 6 D, there was no statistical difference between the groups.

DISCUSSION

Some comparison may be made to the findings of Martens and Ogle in the patterns of nonlinearity described using concave lenses.² They reported a decrease in accommodative convergence with increasing accommodative demand, perhaps similar to Group 4, and an increase in accommodative convergence with increasing minus lenses, similar to our Group 1. They suggested nonlinearity to be more frequent in patients with more complicated oculomotor problems.

As mentioned above, many of the studies reported were performed on young to middle-aged adults. One feature of the AC/A ratio is its constancy;⁶ however, it has been shown that there is a decrease with age, particularly when presbyopia develops.² It is possible that the large departure

from linearity may be an element in the developmental process. Helmholtz suggested that the "AC/A association" may develop with use.⁷ If the visual system is more immature, as in our young subjects, such development may still be ongoing. Across the small age range tested here, no link was found between age and the pattern of the AC/A ratio.

Miles and Judge have shown that it is possible to alter the AC/A ratio, and that adaptation can occur at one distance without it occurring at another.⁸ Thus, if other constants which induce convergence are not linear then the AC/A ratio will adapt to compensate.

Proximal convergence is also assumed to be linear throughout the range over which it occurs, probably from 3 meters and nearer.⁹ Cornell and Mitchell show that the proximal convergence obtained is less than expected for distances closer than 16 cm.¹⁰ This may account for higher levels of accommodative convergence at higher levels of accommodative demand, as demonstrated in Group 1.

The degree and accuracy of accommodation may also affect results. Over-accommodation tends to occur when the demand on accommodation is low; conversely, under-accommodation occurs when the demand on accommodation is high.¹¹

Over-accommodation at low levels of demand could explain why the AC/A ratio may be relatively high with the first lens introduced (-1.5 D). Only three subjects demonstrated this pattern. However, if the resting state is 1 D of accommodation then introduction of a minus 1.5 D lens will stimulate only a small change in accommodation and thus a low AC/A ratio will be found, as in Group 2. Sloan and colleagues demonstrated little change in accommodative convergence for the first 1 or 2 D of accommodation.¹²

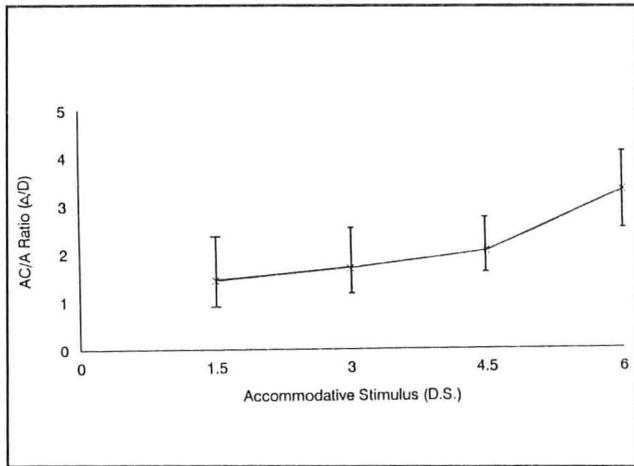


Figure 1. AC/A ratio obtained in Group 1.

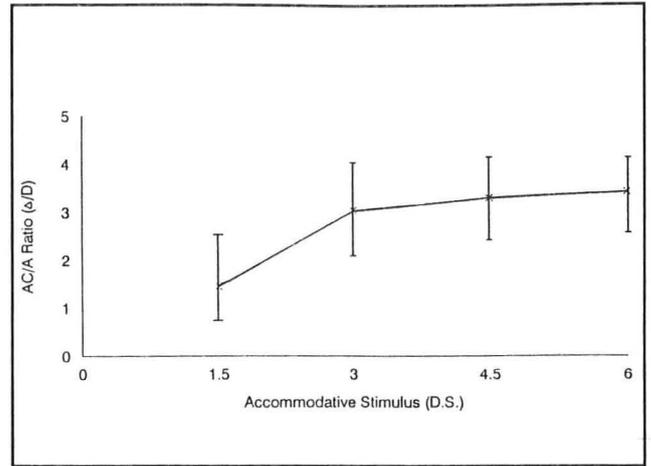


Figure 2. AC/A ratio obtained in Group 2.

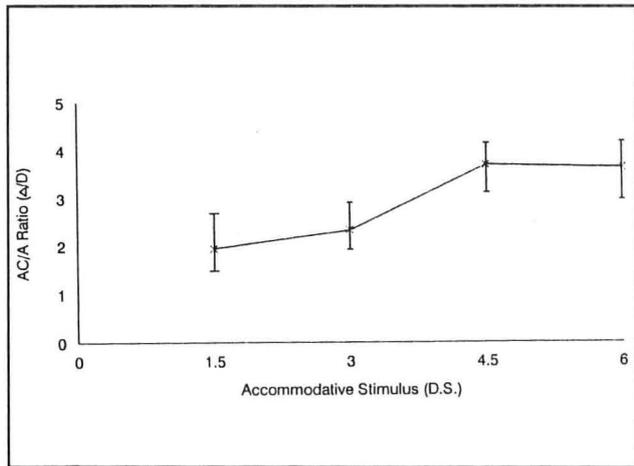


Figure 3. AC/A ratio obtained in Group 3.

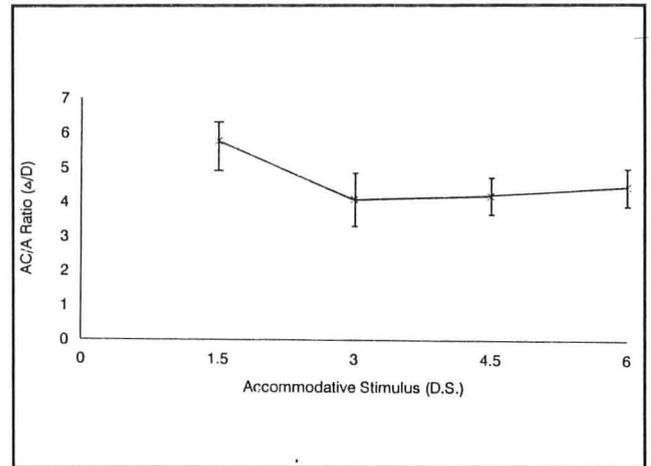


Figure 4. AC/A ratio obtained in Group 4.

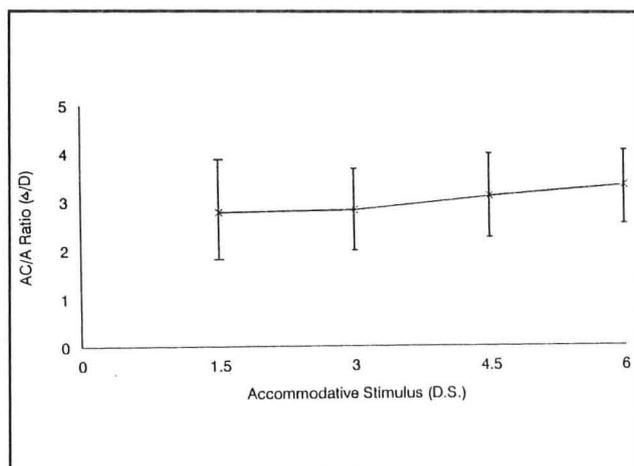


Figure 5. AC/A ratio obtained in Group 5.

The effects of over-accommodation with a small level of demand could be exaggerated if a small degree of myopia is present, and the effect of under-accommodation at high levels may be exaggerated in the presence of small degrees of hypermetropia (necessitating more accommodation than emmetropia). In this group of subjects, small uncorrected refractive errors could have been present.

Although nonlinearity has been demonstrated in our subjects, the relevance to clinical practice is debatable. The AC/A ratio may be investigated for various reasons in the management of strabismus, such as the effect of alteration of refractive error or the choice of surgical correction to be performed. In our normal subjects, a variation of less than 2 per diopter of accommodation occurred. This degree of nonlinearity would be clinically significant in patients with a low or high AC/A ratio, but would probably not affect the management of the patient with an average AC/

A ratio. However, this study has investigated only normal subjects and should the degree of nonlinearity be greater in a strabismic population, this could become an important part of clinical examination.

SUMMARY

We have shown that under normal clinical testing conditions the AC/A ratio shows nonlinearity over a range of 6 D of accommodation in the majority (65.6%) of non-strabismic subjects, with at least five different patterns identified in our study. Clinically, the AC/A ratio is often measured with only a minus 3 D lens. We recommend testing the AC/A ratio over a range of minus 1.5 D to 6.0 D to further investigate the possible non-linearity of the stimulus AC/A ratio.

Acknowledgements

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