Convergence accommodation to convergence (CA/C) ratio: stability with different levels of convergence demand

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Abstract

Aim: **To measure the convergence accommodation to convergence (CA/C) ratio over a range of levels of convergence demand.**
Methods: **Convergence accommodation was measured in 26 subjects with normal binocular single vision. The CA/C ratio was calculated by measuring the accommodative changes induced with base-out prisms of 5^Δ to 20^Δ in 5^Δ steps whilst the participant maintained binocular fixation on a pseudo-Gaussian target at 40 cm. Accommodative change was measured using the open-field view Shin-Nippon SRW-5000 autorefractometer [Grand Seiko Company, Fukuyama, Japan].**
Results: **The mean age of the participants was 20 ± 2.5 years (range 18–29 years). The mean ($\pm$ SD) CA/C ratio for the 5^Δ, 10^Δ, 15^Δ and 20^Δ prisms was 0.13 ($\pm$ 0.07) D/PD, 0.12 ($\pm$ 0.05) D/PD, 0.13 ($\pm$ 0.05) D/PD and 0.13 ($\pm$ 0.05) D/PD, respectively. The overall mean ($\pm$ SD) CA/C ratio was 0.13 ($\pm$ 0.04) D/PD (range 0.04–0.20 D/PD). One-factor repeated measures ANOVA found that the CA/C ratio did not change significantly with an increase in convergence ($F = 0.202$, d.f. = 3, 69, $p = 0.8947$).**
Conclusion: **The CA/C ratio did not change significantly with increasing induced vergence. The data suggest that some degree of non-linearity/variation should be expected in the normal, healthy population of the same age group.**

Key words: Binocular single vision, Convergence accommodation/convergence ratio, Open loop accommodation

Introduction

Vergence is used in everyday visual tasks to maintain clear binocular single vision as an object moves towards the eyes or recedes from them, allowing a stereoscopic view of the image. As the eyes converge a small amount of accommodation is produced, which is termed convergence accommodation. The ratio of convergence-initiated accommodation per prism dioptre of convergence is known as the convergence accommodation to convergence (CA/C) ratio [D/PD].[1]

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Convergence accommodation was first described by Fincham and Walton[2] as reciprocal actions of vergence and accommodation. In order to measure the convergence accommodation, accommodation should be rendered open-loop. The accommodation loop can be opened by using binocular pinholes,[2–6] or by presenting a pseudo-Gaussian/difference of Gaussian (DoG) target.[3,7–11] In theory, all blur-induced accommodation needs to be eliminated. Therefore, the target has to be one that provides a sufficiently strong stimulus for retinal disparity cues for vergence but not blur cues.[8,10]

The CA/C ratio has been found to range from 0.04 D/PD to 0.22 D/PD.[2–12] Table 1 summarises a number of studies that have measured the CA/C ratio using a number of different methods, including an optometer, prisms and difference of Gaussian targets to measure the CA/C ratio accurately.

The aim of this study was to measure the CA/C ratio in a laboratory setting and determine whether it remained similar as the amount of convergence increased.

Methods

Design

A repeated measures design was used. The dependent variable was accommodation and the independent variable the prism strength in prism dioptres (PD).

Participants

Twenty-six students were recruited from the orthoptic student population via an e-mail request. The Unit's ethics committee approved the study. In compliance with the Helsinki Declaration, the main objectives and methods of the project were explained to all participants and an information sheet given. Written consent was obtained.

Inclusion criteria were: participants had normal binocular single vision at 40 cm; stereo-acuity ≥ 60 seconds of arc on TNO, as this is accepted as 'normal' level of stereo-acuity; visual acuity ≥ 0.2 logMAR in each eye, aided or unaided with contact lenses; no greater difference than 0.1 logMAR interocular difference, unaided or aided with contact lenses; and the ability to overcome a 20^Δ base-out prism with either eye. Cover test was performed at 40 cm, but any phoria detected was not measured.

Table 1. Summary table of previous studies that have measured the CA/C ratio

Study	Sample size	Age (years)	Equipment used	Accommodation loop	CA/C ratio
Hasebe *et al.* (2005) [7]	109	6–40	Fresnel prisms, WV-500	Pseudo-Gaussian 'blob'	Stimulus 0.08 ± 0.04 D/PD
Suryakumar (2005)[8]	6	Young adults	Power refractor	DoG target	Stimulus 0.13 ± 0.05 D/PD Response 0.15 ± 0.09 D/PD
Nonaka *et al.* (2004)[9]	78 10 (normal)	12.9 ± 6 25 ± 9.7	Fresnel prisms Open field infrared autorefractor	Pseudo-Gaussian target	Stimulus 0.081 ± 0.042 D/PD 0.091 ± 0.036 D/PD
Suryakumar and Bobier (2004)[10]	37 (children) 8 (adults)	4.0 ± 1.31 23 ± 0.2	Fresnel prism Power refractor	DoG target	Stimulus 0.11 D/PD (children) Stimulus 0.10 D/PD (adults)
Heron *et al.* (2001)[4]	13	16–48	SRI dual Purkinje 3D eye tracker High-contrast Maltese cross	0.5 mm pinholes	Response −0.02–0.18 D/PD
Bobier *et al.* (2000)[3]	8 (infants) 6 (adults)	5.4 ± 1.0 months	Fortune Optical VRB-100 Video refractor	DoG 'blob' Diffuse target + pinhole	Response −0.17 D/PD Response −0.04 D/PD
Eadie *et al.* (2000)[11]	2	25	Infrared eye tracker	Gaussian blurred vertical line (0.5 cycles/degree)	(1) Response 0.3 D/MA (2) Response 0.87 D/MA
Wick and Currie (1991)[6]	6	14–42	SRI dual Purkinje 3D eye tracker Optometer	1.3 mm pinhole	Response 0.019–0.129 D/PD
Kersten and Legge (1983)[12]	5	20–30	Binocular laser optometer	Speckle pattern	Response 0.141–0.16 D/PD (0.27–1.41 D/MA)
Kent (1958)[5]	17	9–48	Co-incidence optometer	0.5 mm pinhole	Stimulus 0.04–0.22 D/PD
Fincham and Walton (1957)[2]	25	11–62	Stigmascopy	1 mm pinhole	1:1 ratio up to 22 years of age

PD, prism dioptre; DoG, difference of Gaussian.

Participants were excluded from the study if they had any known pathological defects of the eyes such as cataract or ocular disease, or wore glasses (to avoid the prismatic effect caused by the lenses).

Apparatus

A pseudo-Gaussian target was created using a 5 mm light-emitting diode (LED), powered by a 9 volt AA battery (similar to the kind used by other authors[6,7,9,13]). The target was placed behind a diffusing screen, which was placed 40 cm in front of the participant. The resulting target had a gradual decline in luminance from the centre towards the edge creating weak contours with no definite edge, which created cues to retinal disparity but not blur, thereby opening the accommodation loop.

Accommodative response change was measured using the open-field view Shin-Nippon SRW-5000 auto-refractometer [Grand Seiko, Fukuyama, Japan]. Convergence responses were induced through the use of loose prisms (placed base-out) before the right eye whilst taking the measurement of refraction from the left eye. The magnitude of the prism provided the stimulus level of convergence: 5^Δ BO, 10^Δ BO, 15^Δ BO and 20^Δ BO.

Procedure

Participants were asked to binocularly fixate on the pseudo-Gaussian target through the Shin-Nippon SRW-5000. The room was completely darkened with the exception of the stimulus light. No time was given to dark-adapt. While loose horizontal prisms of strength 5^Δ BO, 10^Δ BO, 15^Δ BO, 20^Δ BO and no prism (referred to

as 0^Δ BO) were held in a random order before the right eye (asymmetric vergence), the participant was instructed to maintain a single image of the pseudo-Gaussian target and three successive readings of refraction were taken from the left eye. To ensure binocularity was maintained after introduction of a prism, the participant was asked whether the target was double or single. Measurements were only taken when the target was fused. The measurements were taken quickly in order to reduce the effect of vergence adaptation to the prism. A 30 second rest was given between each prism. A complete data set required successful measures for all five conditions of convergence.

Analysis of data

The 'representative value', calculated by the auto-refractometer, was used in the analysis. The best spherical equivalent (BSE) (sphere + ½ cylinder) was calculated for each measurement. The BSE values from the 5^Δ BO, 10^Δ BO, 15^Δ BO and 20^Δ BO prisms were subtracted from the reference (0^Δ) in order to calculate the accommodative response, which in turn was used to calculate the CA/C ratio as follows:

$$\text{CA/C ratio} = \frac{\text{Accommodative response (D)}}{\text{Prism power } (^\Delta)}$$

Data obtained for the CA/C ratio for each prism power were statistically analysed using ANOVA (Statview, USA).

Table 2. Mean change in accommodative response and CA/C ratios for each prism

	5^Δ–0^Δ	10^Δ–0^Δ	15^Δ–0^Δ	20^Δ–0^Δ
Mean change in BSE (D)	0.64	1.22	1.90	2.64
SD	0.35	0.46	0.77	1.05
CA/C ratio (D/PD)	0.13	0.12	0.13	0.13
SD	0.07	0.05	0.05	0.05

BSE, best spherical equivalent; D, dioptre; SD, standard deviation; CA/C, convergence accommodation/convergence ratio.

Results

A complete data set was obtained from 24 of the 26 participants. Two were excluded as they were unable to fuse the target when viewing through the 20^Δ BO prism. All subjects were asymptomatic and had no history of orthoptic treatment. The mean age of the subjects was 20 ± 2.5 years (range 18–29 years); 6 were male and 18 female. The mean refractive error at baseline (0^Δ) of the left eye was -0.95 D ± 2.09 D (range -6.00 D to $+3.00$ D). Twelve subjects showed no deviation at 40 cm, 5 a minimal/slight esophoria and 7 a minimal/slight exophoria. All showed excellent recovery.

The mean accommodative responses and the mean CA/C ratios for all the participants are given in Table 2 and shown in Fig. 1A and B, respectively. Fig. 1A shows that there is a linear relationship between accommodative response (D) and prism strength (PD).

Fig. 2 shows the CA/C ratio plotted against prism strength for eight individual subjects chosen at random to demonstrate the differences obtained in individual data. It is evident from Fig. 2 that when CA/C ratio is plotted against prism strength for individuals, the change in CA/C ratio with increasing prism is not always linear. Three participants (3, 9 and 18) showed a greater amount of non-linearity in their CA/C ratios. Participants 3, 9 and 18 also showed the highest mean CA/C ratios of 0.20 D/PD, 0.19 D/PD and 0.18 D/PD, respectively. These three subjects were all myopic (range -1.25 DS to -2.50 DS). One showed no deviation, one a minimal esophoria and one a minimal exophoria at 40 cm.

Calculation of the CA/C ratio takes into account the strength of prism. A one-factor repeated measures analysis of variance (ANOVA) was used to determine whether the CA/C ratio differed significantly with the amount of convergence induced. There was no significant difference in CA/C ratio ($F = 0.202$, d.f. = 3, 69, $p = 0.8947$). ANOVA analysis was repeated excluding participants 1, 3, 9 and 18, who showed a greater degree
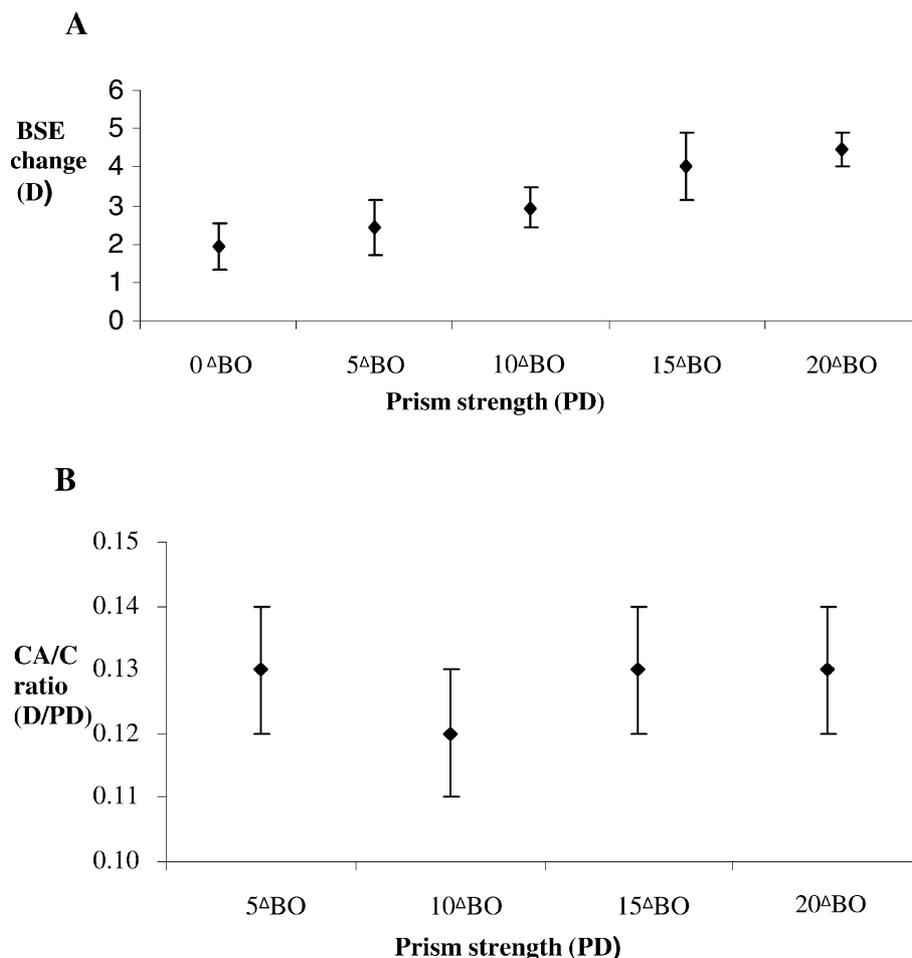

Fig. 1. (A) The mean accommodative responses induced by base-out prisms. (B) The CA/C ratio using the mean CA/A ratio of all subjects.
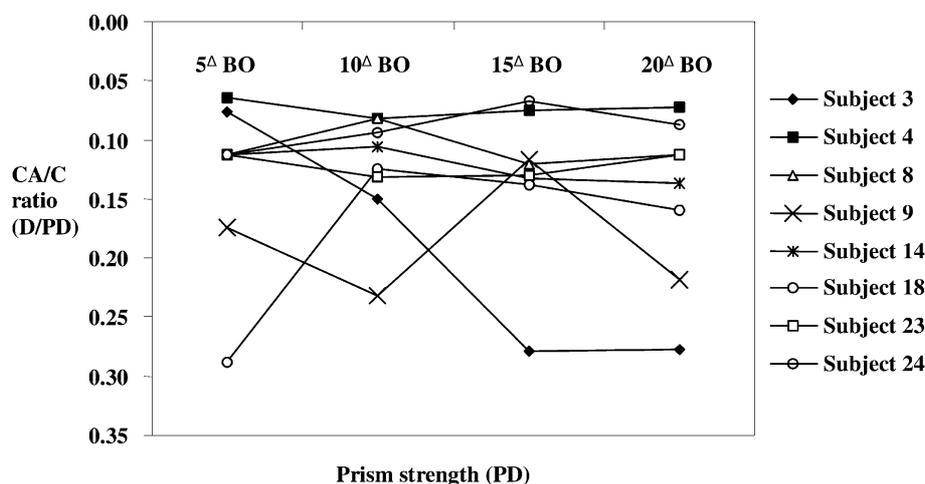
Fig. 2. CA/C ratios for eight individual subjects.

of non-linearity; there was no significant difference in CA/C with increasing induced convergence ($F = 0.146$, d.f. $= 3$, 57, $p = 0.75$).

Discussion

The CA/C ratio is an independent parameter and varies among individuals. Measuring the CA/C with a group of young adult participants with binocular single vision found a range of 0.04 to 0.20 D/PD, with a mean of either 0.12 or 0.13 for induced convergence of 5^Δ, 10^Δ, 15^Δ and 20^Δ. These values compare well with those found by several authors (see Table 1).

Fig. 1A shows that there is a linear relationship between accommodative response (D) and prism strength (PD). Therefore, as found by Nonaka et al.,[9] the accommodative response (referred to as the best spherical equivalent, BSE) increases as base-out prism magnitude is increased. Fig. 1B shows that the mean CA/C ratio remained fairly constant with increased convergence demand.

Consideration of the CA/C ratio for each individual showed the ratio did not increase in a linear fashion with increase in convergence for all individuals. A possible explanation for this could be difficulty for some individuals in maintaining fusion for the higher prism strengths (15^Δ BO and 20^Δ BO). Slight fluctuations in the amount of convergence due to the extra effort to keep the target fused may cause variability in the CA/C ratio for an individual. This extra effort may in part be due to voluntary convergence. There is no evidence in the literature that voluntary convergence does initiate convergence accommodation, but it would be expected that it does.

Similar small non-linearities in the CA/C results have been reported by Wick and Currie[6] and Nonaka et al.[9] Wick and Currie[6] found these non-linearities in both laboratory and clinical settings. In the clinical evaluation of the CA/C ratio, 6 of their 40 subjects showed non-linear measurements. These were statistically but not clinically significant. In the current study, 4 of the 24 subjects appeared to show a slightly greater amount of

non-linearity in their CA/C ratio than others. These results suggest that the non-linearities may be small and should be expected in the normal, healthy population.

Vergence and accommodative adaptation may have caused the slight difference found in the ratios of each subject. Eadie et al.[11] found that the CA/C ratio is capable of adaptation, which shows there is some plasticity in the cross-links. In order to minimise the effects of prism adaptation, measurements were taken as quickly as possible to prevent prolonged viewing through a prism and a rest period was given between prisms.

In the present study, the mean age of subjects was 20 ± 2.5 years (range 18–29 years). Kent[5] found that subjects of similar age could have differing CA/C ratios. He suggested the variation might be due to individual differences in lens thickness and elasticity of the lens capsule. Given the narrow age range of the subjects in this study further research will be required to measure the CA/C ratios in a wider age group of 'normal' subjects.

The role of convergence accommodation has largely been ignored in orthoptic literature and the mechanism for blur during convergence is usually attributed to accommodative convergence. However, it has been suggested that convergence accommodation may be involved in the mechanism for blur during fusion range testing[15] and may play a role in the response to minus lens therapy in distance exotropes.[16]

This study found that convergence-induced accommodation takes place when blur cues are not present. An increase in convergence (induced by prisms) caused the amount of convergence accommodation to increase in a fairly linear fashion, resulting in overall similarity in CA/C measures across the range of convergence induced. However, when individual results are examined, it is apparent that the mean values do mask non-linearities in the CA/C ratio of some of our participants.

Conclusion

The CA/C ratio did not significantly change with

increasing induced vergence. The data suggest that some degree of non-linearity/variation should be expected in the normal, healthy population of the same age group.

The authors have no competing interests.

Investigation of patients was according to the guidelines of the Declaration of Helsinki.

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