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Accommodation and vergence response gains to different near cues characterize specific esotropias

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KEY WORDS AC/A; Accommodation; CA/C; Convergence; Esotropia

ABSTRACT

Aim. To describe how the profile of the use of blur, disparity and proximal cues varies between non-strabismic groups and those with different types of esotropia.

Design. Case control study

Methodology. A remote haploscopic photorefractor measured simultaneous convergence and accommodation to a range of targets containing all combinations of binocular disparity, blur and proximal (looming) cues. 13 constant esotropes, 16 fully accommodative esotropes, and 8 convergence excess esotropes were compared with age and refractive error matched controls, and 27 young adult emmetropic controls. All wore full refractive correction if not emmetropic. Response AC/A and CA/C ratios were also assessed.

Results. Cue use differed between the groups. The constant esotropes with weak binocular vision (BV) showed trends for more stable responses and better vergence and accommodation than those without any BV, although even those with constant suppression still responded to disparity cues. The accommodative esotropes made less use of disparity cues to drive accommodation (*p*=0.04) and more use of blur to drive vergence (*p*=0.008) than controls. As expected, all esotropic groups did not show the strong bias for better responses to disparity cues found in the controls, with convergence excess esotropes favoring blur cues. AC/A and CA/C ratios existed in a broadly reciprocal relationship in the different groups. Accommodative lag was common in esotropia.

Conclusion. Esotropic children use near cues differently from matched non-esotropic children in ways characteristic to their deviations. Relatively higher weighting for blur cues in accommodative esotropia compared to matched controls may explain both etiology and why treatment with spectacles can be so effective.

INTRODUCTION

In 2008 we presented a novel laboratory method of assessing vergence and accommodation responses to the three main cues to near vision (blur, disparity and proximity/size change/looming) (Horwood & Riddell, 2008; Horwood & Riddell, 2009) We hypothesized that the weighting and response profiles of these cues, both alone and in combination, might characterize different clinical diagnoses.

In our laboratory, we consistently find that in typical children and adults blur and disparity are not used equally as cues to drive responses to target distance (Horwood & Riddell, 2008). Both convergence and accommodation to any target containing disparity cues are much better than to those where disparity is excluded, with blur playing a lesser role and proximity playing a minor part. However, infants appear to respond best to proximal cues in their first weeks, then use all cues relatively equally in “middle infancy” (10-26 weeks of age). By 5 years of age children behave similarly to adults, with best responses to targets containing disparity cues. Blur retains similar weighting from infancy to adulthood (Horwood & Riddell, 2009) (and manuscript in preparation).

In the case of childhood concomitant strabismus, disparity detection might be primarily defective, secondary suppression might disrupt it, or refractive error or abnormal AC/A (accommodative convergence to accommodation) relationships disrupt use of blur cues; so atypical patterns of cue weighting would be predicted. Development might be arrested at the level it had reached before onset of the deviation or new weightings emerge. Intact cues (such as blur or proximal /looming) might "make up the difference" to drive an appropriate response to approaching targets, or still only drive the same (reduced) responses that that cue would in drive in typical children, resulting in lag for near. Strabismic individuals might only respond to disparity cues if some binocular vision (BV) is retained via abnormal retinal correspondence (ARC) or peripheral fusion is retained. We might also predict that children with accommodative esotropia and a high AC/A ratio (which by definition implies that response to blur drives extra convergence) might use blur cues to drive both accommodation and vergence more than children without accommodative esotropia.

This preliminary paper explores these predictions using data from small groups of patients with different clinical diagnoses to illustrate differences in response profiles in comparison to matched control groups.

MATERIALS AND METHODS

The study adhered to the Declaration of Helsinki and was allowed to proceed by UK National Health Service and institutional ethics committees. We studied seven groups of participants (see Table 1), four groups of esotropes (constant with weak BV, constant without any BV, fully accommodative esotropia and convergence excess esotropia) and three control groups (typical emmetropic young

		n	***Matched with***	***Age***		***Deviation***	***BV***	***Ref***	

adults, and two non-strabismic groups matched by age and refractive error to the strabismic children so that strabismic and non-strabismic responses could be compared as much as possible while controlling for age and refractive error). Some of the non-accommodative constant esotropes had residual esodeviations following surgery. All participants who had been prescribed spectacles wore a full cycloplegic refractive correction for testing, so accommodation started from the same refractive baseline for distant fixation.

				(yrs)		***(PCT) at 33cm** (unless stated otherwise)*		***Error (MSE)***	
				mean	range			Mean	range
Group 1 (control)	Emmetropic non-strabismic adults	27		20.2	18-24	0-3Δexo	<120” TNO	+0.3D	-0.25D-+0.5D
Group 2 (control)	Non-strabismic children	13	Individually matched to constant esotropes in Group 3&4	5.05	4.0-6.3	0-3Δexo	<120” TNO	+2.09D	0.0D-+6.0D
Group 3	Non-accom ET Weak BV	7	Individually by age & refractive error (within 1.0D MSE) with Group2 children	4.85	4.5-5.0	2-35Δ eso	>400”, +ve Bagolini Gls or Lang stereotest	+1.75D	0.0D-+5.5D
Group 4	Non-accom ET No BV	6	Individually by age & refractive error (within 1.0D MSE) with Group2 children	5.16	4.5-6.3	5-25Δ eso	None, + constant suppression on Bagolini Gls and Worths Lights and synoptophore	+2.41D	0.0D-+6.0D
Group 5 (control)	Non-strabismic hypermetropic	10	Group matched with Group 6 by age and refractive error	5.9	5.0 - 8.5	2Δexo-2Δ eso	<120” TNO	+4.02D	+2.5D-+6.0D
Group 6	Fully accomodative ET	16	Group matched with Group 5 by age and refractive error	5.79	4.3-8.0	1-8Δ with gls, 15-45 Δ without gls	<120” TNO with gls	+3.9D	+2.25D-+6.0D
Group 7	Convergence Excess ET	8		6.4	4.5-7.1	20-45 Δ eso Nr, 0-6 Δ eso Dist	<120” TNO with +3.0 add	+2.18D	0D-+4.75

Table 1 Study groups and clinical characteristics

The laboratory method has been described in detail elsewhere(Horwood & Riddell, 2008), but briefly all participants watched the target being presented via a two-mirror optical system, while a PlusoptiXSO4 PowerRefII photorefractor collected simultaneous eye position and refraction measurements (Fig. 1). Targets moved between five different fixation distances (0.33m, 2m, 0.25m[1], 1m, 0.5m) in a pseudo-random order.

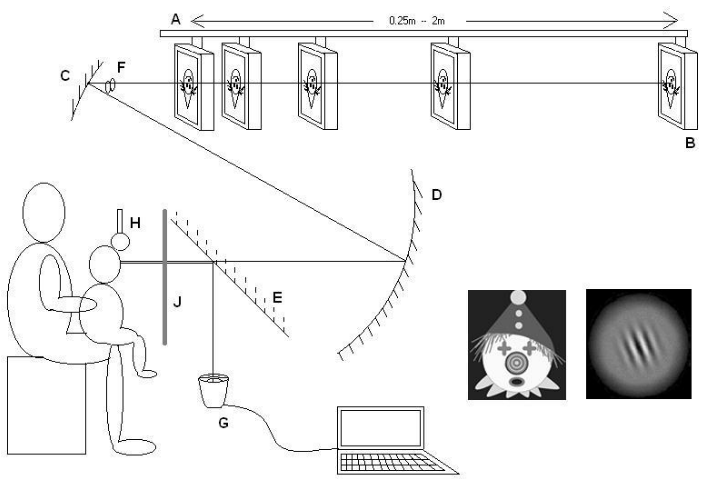

Fig 1

We could manipulate blur (*b*), disparity (*d*) and proximal (looming)(*p*) cues separately, while all other aspects of the data collection and testing paradigm were identical. Blur cues could be presented by using a complex cartoon clown target containing a wide range of spatial frequencies and detail down to 1 pixel (<1min arc), or could be minimized by using a blurred difference of Gaussian (DoG) image to open the accommodation loop as much as possible while retaining fusible features for the binocular conditions. Disparity cues were available when both eyes could view the target, and could be eliminated by occluding half of the upper mirror (C in Fig. 1), so that the target was then only visible to one eye. Proximal and looming cues were available when the target remained the same size on the screen and could be watched as it moved backwards and forwards, or these dynamic and size cues could be minimized by scaling the target so that it

[1] The data from this target position were discarded for technical reasons not associated with the study

subtended the same retinal angle at each distance and hiding the screen from view with a black curtain while it moved between positions. Thus eight target conditions were possible (Table 2) and by using these cue conditions we could assess naturalistic responses (*bdp* condition), two different ways of assessing the influence of each cue (firstly, when it was eliminated from a naturalistic situation (*bd*,*bp* and *dp* conditions) as might occur in suppression or refractive error, and then when it was the only cue presented (*b*,*d*, and *p* conditions), and also the effect of any residual cues we could not totally exclude (*o* condition). Instructions were minimal (just "look at the picture") so that we could assess responses in as naturalistic manner as possible.

Target name	**Cues available**	**Target**
bdp	Blur+disparity+proximity	Binocular looming clown
bd	Blur+disparity	Scaled binocular clown
bp	Blur+proximity	Occluded looming clown
dp	Disparity +proximity	Binocular looming DoG
b	Blur only	Occluded scaled clown
d	Disparity only	Binocular scaled DoG
p	Proximity only	Occluded looming DoG
o	All cues minimized	Occluded scaled DoG

Table 2 Cue conditions

A macro calculated dioptres of accommodation (D) and meter angles of vergence (MA) from short vignettes (one second of data once stabilization had occurred) of raw refraction and eye position data, making individual corrections for measured angle lambda and inter-pupillary distances (IPD). By using MA we were able to compare simultaneous vergence and accommodation responses in relation to target distance more accurately between participants with different IPDs and also plot both responses on the same chart e.g. a 50cm target demands 2D of accommodation and 2MA of vergence from all participants. A response gain of 1.0 indicates a 100% response to target demand and a lower gain shows under-response to the approaching target (lag for near). In all cases, a low response gain (flat response) was due to differences in responses to near targets and not distance ones e.g. under-response for near and good responses for distance, rather than over response at distance and good responses for near. In the participants with constant esotropia, a vergence response gain of 1.0 indicates "convergence with the deviation" i.e. a "normal" amount of near/distance change has occurred in addition to the distance angle, whereas a zero gain indicates that no additional vergence or accommodation occurred for near fixation. Response AC/A ratios were calculated from change in vergence divided by change in accommodation between 2m and 33cm in the blur-only *b* condition, and response CA/C ratios were calculated from the change in accommodation divided by the change in vergence between 2m and 33cm in the disparity-only *d* condition. We did not assess very slow tonic changes as we assessed only short vignettes of data.

Multiple statistical comparisons would have been possible between children, diagnoses, cues, targets and vergence/accommodation responses, but our groups were relatively small in these preliminary studies. Comprehensive analysis with post-hoc testing of the total dataset with corrections for multiple comparisons were likely to suffer from lack of power, but as we had some strong predictions as to what differences we would find between groups, we decided to limit the analysis in this largely descriptive paper to a few carefully planned tests, carried out based on our *a priori* predictions.

RESULTS (see Figure 2)

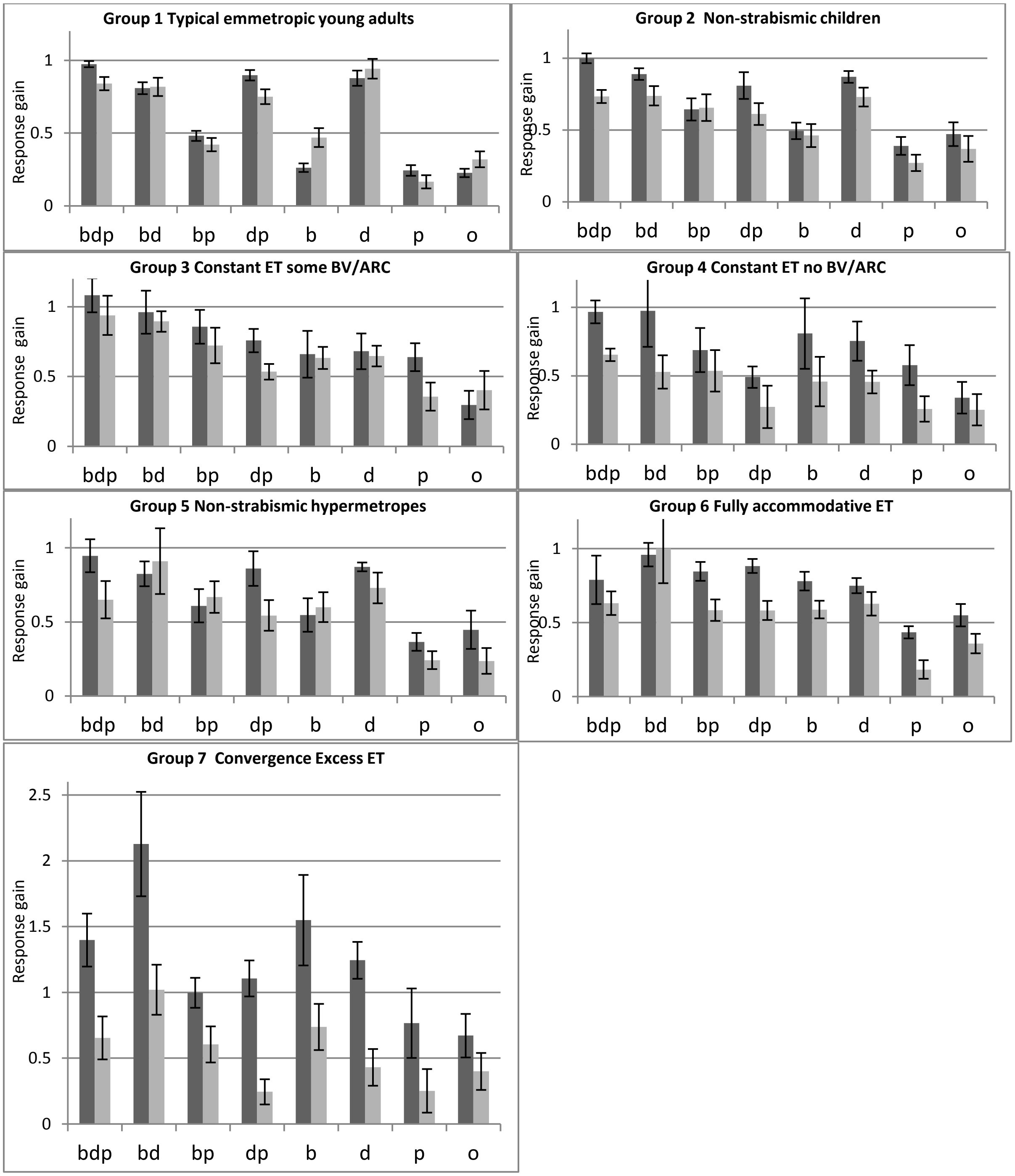
Group 1 Typical emmetropic young adults
Group 2 Non-strabismic children
Group 3 Constant ET some BV/ARC
Group 4 Constant ET no BV/ARC
Group 5 Non-strabismic hypermetropes
Group 6 Fully accommodative ET
Group 7 Convergence Excess ET
Response gain
bdp
bd
bp
dp
b
d
p
o

Figure 2

Group 1 Typical emmetropic young adult controls

This group has shows typical mature emmetropic responses to which the other groups can be compared. To the all-cue *bdp* condition slight accommodation lag for near led to somewhat lower gain than for vergence, as is commonly reported in the literature (Harb, Thorn, & Troilo, 2006; Rouse, Hutter, & Shiftlett, 1984). Both vergence and accommodation response gains were good to any cue that contained disparity information, and dropped sharply when disparity was excluded. To the blur-only (*b*) target vergence response was approximately 60% of the accommodation response, which would be expected with a "normal" AC/A ratio, but both vergence *and* accommodation to blur were considerably worse than those to any cue containing disparity. Much more accommodation was driven by disparity (*d* accommodation gain) than vergence driven by blur (*b* vergence gain).

Group 2 Non-strabismic child controls

Responses in this second, younger, control group were broadly similar to the adults in Group 1, although the cue differences were somewhat less pronounced. These children also had marginally lower accommodation in relation to vergence gains found overall (one-tailed t-test: $t(36)=1.24, p=0.1$). We and others (Candy, Gray, Hohenbary, & Lyon, 2012; Horwood & Riddell, 2011) have also reported that significantly hyperopic children have increased accommodative lag for near, even when corrected, and as six of this group (46%) wore a hyperopic correction, this is likely to account for the slight difference.

Group 3 Constant esotropia with weak BV

Response profiles were more evenly distributed between cues than in the controls, but with poorer responses to targets containing fewer cues, whatever the cue combination (linear trend between 3,2,1 and 0 cues; p=0.005 for vergence and p=0.007 for accommodation), with the all-cue (*bdp*) responses being better than any of the two-cue conditions, the two-cue conditions better than the one cue conditions (except for slightly lower *dp* accommodation gain) and the minimal cue *o* condition driving weakest responses. We did not find the clearly better responses to disparity-containing targets as typical of non-strabismic participants, but neither was there complete absence of response to disparity stimuli, suggesting that disparity cues were still contributing to responses, albeit less strongly .

Group 4. Constant esotropes with no evidence of binocularity

Responses were much more erratic and variable in this small group than in Group 3, but vergence gain to the all-cue *bdp* target was similar to the binocular controls (i.e. convergence to near "with the deviation"). Accommodative lag was very common, despite a similar distribution of hypermetropia in this group and Group 3, and less hypermetropia than the non-strabismic hyperopic control Group 5 below, suggesting that the lag was not due to the hypermetropia alone. As we repeatedly find that most non-strabismic participants use disparity cues to drive accommodation, we had predicted this might be the case, although the trend was not statistically significant mainly due to the large variance in this very small group (t(18)=1.01,p=0.16). It was interesting that despite apparently constant suppression on clinical tests, manipulating disparity cues still affected responses. Adding disparity alone to the minimal-cue *o* condition, significantly increased vergence gain (paired t-test *d* vs *o*: t(6)=2.39,p=0.027) and marginally increased accommodation gain (t(6)=1.78,p=0.06). Eliminating disparity from the naturalistic condition (*bdp* vs *bp*) also marginally degraded vergence (t(6)=1.87,p=0.055) and accommodation (t(6)=1.18,p=0.14).

Group 5. Non-strabismic hyperopes

This group showed the typical bias of non-strabismic individuals towards better responses to cues containing disparity cues, and also showed the accommodative lag for near to the naturalistic *bdp* condition reported previously in hyperopic children (Candy et al., 2012; Horwood & Riddell, 2011; Stewart, Woodhouse, Cregg, & Pakeman, 2007).

Group 6. Fully accommodative esotropes

Despite good stereoacuity when corrected, the overall profile of responses from this group was similar to those from the constant esotropes with weak BV, although there was significantly lower accommodation gain in relation to vergence (Group 3 vs Group 6: t(19=2.21,p=0.02). The strabismic children failed to show the greatest weighting for disparity cues that is evident in age- and refraction- matched non-strabismic controls in Group 5. ANOVA showed significant between-group differences in the *bp* (disparity excluded) and blur-only *b* conditions (F (2,48)=9.65,p=<0.001) and (F (2,46)=4.37,p=0.001). In non-strabismic controls, eliminating disparity causes a large drop in vergence, while manipulating blur makes little difference. The fully accommodative group appeared less dependent on disparity cues than the controls; removing disparity reduced vergence responses significantly less than in the non-strabismics (Group 5 vs Group6: p=0.036), while presenting blur in isolation drove significantly more vergence (p=0.008).

Group7 Convergence excess esotropes

Vergence response gains were excessive in this group as their esodeviations increased for near even with spectacles. Children with this type of esotropia typically have high AC/A ratios, illustrated by the steeper vergence than accommodation gains (as much more vergence occurred for each unit of accommodation). In this group it can be seen that accommodation responses are best to targets including blur cues (*bdp*, *bd*, *bp* and *b*), in contrast to typical children for whom disparity is the primary cue. But the blur response was not the only cause of the excessive convergence. These children also produced steep vergence slopes to non-blur cues, such as disparity-only and proximity-only. In typical children, eliminating blur cues (*bdp* vs *dp*) makes little difference to accommodation gain, but with the children with convergence excess the *dp* accommodation gain was significantly lower than the *bdp* gain (t=1.86,p=0.04).

Blur-driven Vergence vs Disparity Driven Accommodation (AC/A vs CA/C)

Figure 3 illustrates the relationships between blur-driven vergence gain (reflecting the AC/A ratio) and disparity-driven accommodation gain (CA/C ratio) across the groups studied. It can be seen that these gains act in the broadly reciprocal relationship with each other, with one being high if the other is low. Those groups with defective BV, especially if there is a large accommodative element, had higher blur-driven vergence gains and lower disparity driven accommodation gains.

Figure 3 AC/A vs CA/C ratios

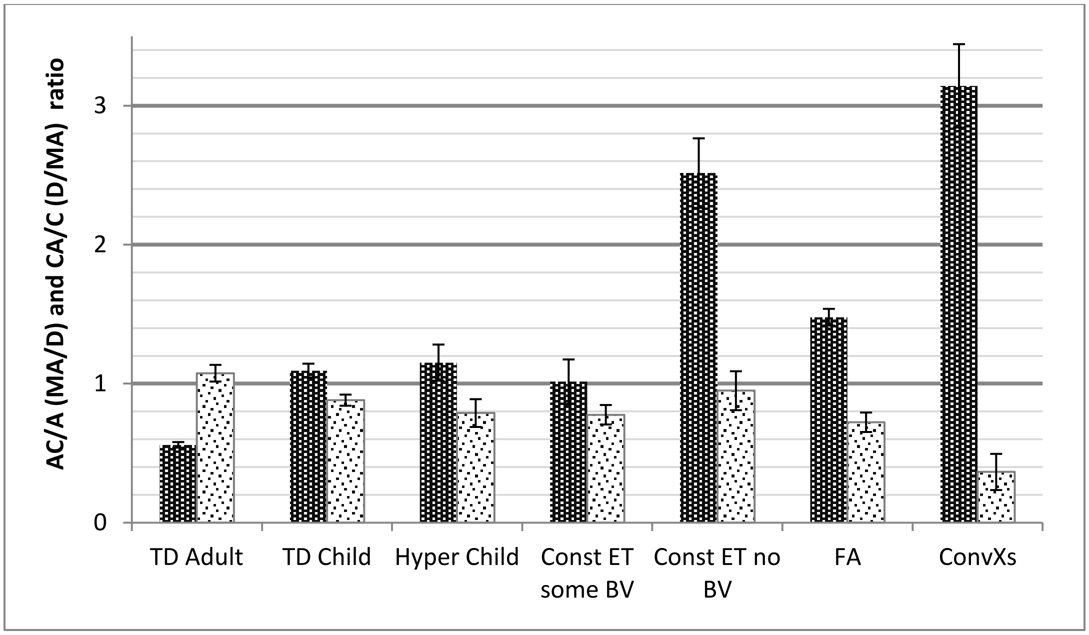

Figure 3

DISCUSSION

The data presented illustrate how near cue response profiles appear to characterize clinical diagnoses. They give insights into how different groups use blur, disparity and proximal cues in characteristic weightings to make a calculation of target distance and drive responses. While the *b*-cue driven vergence responses confirm the high AC/A ratios that have been studied in esotropia many times before (Cassin, Beecham, & Friedberg, 1976; Costenbader, 1957; Havertape, Cruz, & Miyazaki, 1999; Ludwig, Parks, Getson, & Kammerman, 1988; Yan, Wang, & Yang, 1995), our data profiles provide much a much richer understanding of how accommodation and vergence are driven. Our method also allows direct comparisons of AC/A and CA/C ratios (the *d*-cue driven accommodation response) collected under otherwise identical conditions, which is rarely achievable, especially in children.

Even in these small groups, where the naturalistic and uncontrolled nature of the task and the youth of the participants led to variable data, clear trends still emerged and statistical significance was reached in many cases. It can be seen that the profile of cue use is an additional way to describe and explain how different clinical groups use cues to drive their near responses, and so explain etiology and treatment.

Our laboratory enables us to study the influence of a cue in two complementary and corroborative ways; firstly, by seeing how much of the response to a particular target distance can be driven by a cue when presented in isolation; and also to see how much of the total naturalistic response is degraded when it is excluded. The AC/A and CA/C ratios only measure how much vergence is associated with each unit of accommodation (or vice versa). Our data also show which cues best drive these responses; is one cue pre-eminent or can all be utilized; and does presenting or removing a cue affect just vergence, just accommodation or both? For example, a high AC/A ratio (which means that a change in blur of a target changes more vergence than accommodation) may not matter in practice if blur only plays a small part in driving the *total* accommodation response, which in fully binocular participants is more often mainly driven by disparity. Conversely, a high AC/A ratio would matter very much if blur carried more weight.

In the non-strabismic groups (Groups 1, 2 and 6) manipulating disparity (removing it, or presenting it in isolation) made a large difference to responses, while manipulating blur had a lesser effect. The relative strength of disparity cues, which are accurate to within minutes of arc, to drive typical vergence and accommodation, would therefore predict that the CA/C linkage is more important than the AC/A. The somewhat less marked disparity bias in the child controls

(Group 2 vs Group1) may reflect immaturity, as we find that greater weighting to disparity cues develops from infancy to later childhood (Horwood & Riddell, 2009).

In a clinical context this suggests that for non-strabismic people, because blur is a relatively weak cue, refractive error or lens manipulations (such as a new or increased prescription) may make only small differences to the global calculation of target distance and therefore have only small effects on both vergence and accommodation responses. If putting up a lens makes little difference to the angle of deviation, this would also result in the low stimulus AC/A ratios common in typical groups (Gage, 1996; Plenty, 1988); new refractive prescriptions should be tolerated well and make little difference to any heterophoria. However, strong use of disparity cues to drive accommodation might put these individuals at risk of accommodative problems if vergence is disrupted, for example by occlusion or sudden loss of vision in one eye, as the disparity drive to accommodation is lost.

The strabismic groups showed atypical response profiles. Those with constant esotropia but who had retained or developed weak binocularity showed very even cue use profiles, being able to drive near responses by all cues relatively equally, but with better responses as more cues were presented. This pattern could be explained by either a primary defect of binocularity, or secondary suppression, degrading disparity cues so that they are not so clearly superior in accuracy in comparison to blur and proximity.

The group with constant esotropia and a constant suppression response showed very variable responses. They showed more accommodative lag across targets, but fewer differences in vergence, with no clear pattern of cue use behavior. The large accommodation lags seen in this group may reflect the relative weakness of disparity sensitivity and subsequent loss of disparity-driven accommodation. Whether this accommodative lag has any visual or educational consequences may be a topic for further research. The accommodative lag did, however, have the effect of producing the higher response AC/A ratio shown by the steeper *b* vergence slopes.

The large majority of constant esotropes did make an appropriate amount of additional convergence to near targets (convergence "with the deviation"), which would conventionally be interpreted by clinicians as being due to remaining accommodative and proximal influences. Our data supports this to some extent because overall, blur cues appeared as strong as, or stronger than, disparity to drive vergence. It is, however, remarkable that even in these participants with constant suppression and no detectable peripheral fusion, adding disparity cues to the minimal cue *o* condition, or removing disparity from the stimulus (*bdp* vs *bp*) still affects vergence, suggesting that some binocular input must still be occurring.

The two groups of accommodative esotropes also showed more accommodative lag (and high AC/A ratio), with more (or excessive, in the case of the convergence excess group) vergence associated with each unit of accommodation. The fully accommodative esotropes did not show the greater weighting for disparity cues that was found in the very closely matched non-strabismic hypermetrope group, while the convergence excess group showed a profile with greatest weighting for cues containing blur rather than disparity. So for these children, as well as having a high AC/A ratio, the high ratio may *matter* much more, because they use blur as a more strongly weighted cue to drive responses in preference to disparity, even if it means loss of binocularity. In other words, while non-strabismic individuals are "disparity driven", most esotropes are less so, and those with convergence excess appear primarily "blur driven".

This higher relative weighting for blur cues may be another reason (as well as the higher AC/A ratio) why lens manipulations can be so effective a treatment in esotropic, especially accommodative esotropic children. In esotropia, if blur carries higher weighting in relation to disparity, changing blur with lenses will have a greater effect in changing the angle of deviation; and a high AC/A ratio make the effect even greater.

In summary, these small case series illustrate how differences in responses to near cues can differentiate clinical diagnoses and they serve as pilot studies for more research. By understanding how different groups use these cues to drive near responses, we can provide an alternative way of explaining clinical characteristics and responses to common treatments.

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FIGURE LEGEND

Table 1

Group characteristics.

Table 2

Target conditions. The response AC/A ratio can be calculated from the vergence in relation to accommodation driven by the blur-only (*b*) condition. The CA/C ratio can be calculated from the accommodation in relation to vergence driven by the disparity-only (*d*) condition

Figure 1

The remote haploscopic videorefractor. (A) Motorized beam. (B) Target monitor. (C) Upper concave mirror. (D) Lower concave mirror. (E) Infra-red 'hot' mirror. (F) Image of participant's eye where occlusion takes place. (G) Plusoptix SO4 PowerRef II. (H) Headrest. (J) Raisable black cloth screen. Clown and difference of Gaussian targets illustrated lower right; much of the high resolution detail of the clown has been lost in this reduced reproduction.

Figure 2

Response gain profiles of the different study groups showing between–group differences in profiles. Dark bars show vergence response, pale bars show accommodation response. A response gain of 1 indicates the full response to target distance change. Low response gains were always due to indicate under-response for near (lag). High response gains indicate over-response for near (lead). Strabismic groups show less strong bias towards best responses to disparity-containing cues and the convergence excess accommodative esotropes show strongest bias towards cues containing blur.

Figure 3. Blur-driven vergence gains (AC/A) (dark bars) vs disparity-driven accommodation gain (CA/C) (pale bars) in the study groups, showing the broadly reciprocal relationship between the two measures. Strabismic, and particularly accommodative strabismic, groups show more vergence to blur cues than accommodation to disparity cues.