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

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Abstract

Aim—To describe preliminary findings of 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. Even esotropes with constant suppression and no binocular vision (BV) responded to disparity in cues. The constant esotropes with weak BV showed trends for more stable responses and better vergence and accommodation than those without any BV. 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. All esotropic groups failed to 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 an inverse relationship in the different groups. Accommodative lag of $>1.0\text{D}$ at 33cm was common (46%) in the pooled esotropia groups compared with 11% in typical children ($p=0.05$).

Conclusion—Esotropic children use near cues differently from matched non-esotropic children in ways characteristic to their deviations. Relatively higher weighting for blur cues was found in accommodative esotropia compared to matched controls.

Keywords

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

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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, 2009²). We hypothesized that the response profiles to combinations of these different cues might characterize different clinical diagnoses. Wide inter-individual differences were described in early literature (Fincham and Walton, 1957) and continue to feature to this day (Tyler et al., 2012); our paradigm has the potential to explore them in different groups. Although cues driving the near system have been modeled and researched in highly controlled laboratory or theoretical settings (Kruger & Pola, 1985; Kruger & Pola, 1986; Schor, 1989; Schor, 1992; Schor, 1999; Schor & Horner, 1989; Erkelens & Regan, 1986; Erkelens, 2001; Rosenfield & Ciuffreda 1990; Rosenfield & Ciuffreda 1991), clinical studies are less common, and report very small groups or single cases, (Stark et al., 1984) and always use adult participants.

In our laboratory, we are particularly interested in how patient groups behave in real-life situations where single cues rarely occur, and multiple cues often occur in different combinations e.g. if refractive blur degrades detail, but fusion is retained, or if fusion is disrupted but acuity is good. We are also interested in what actually happens when perfect responses are not necessary to perform a task. For example, when looking at a large, easily identifiable, bright picture, do people always bother to clear the image? Is accommodation as accurate as vergence, and are responses better to a clear, monocular target, or a blurred, binocular one? Is it more disruptive to be monocular or blurred?

Many laboratory methods use stimuli designed to elicit maximum or threshold responses and employ tasks that require participants to respond as well as they can. Using such methods blur, disparity and proximal/looming cues can all drive a large percentage of the near response if presented in isolation; if these percentages were added together, they would add up to much more than 100%. The different components of the visual input must therefore be weighted.

In our laboratory we consistently find that in typical children and adults blur, disparity and proximal/looming cues are not used equally 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 proximal /looming cues 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) (Horwood & Riddell, 2009³) (and manuscript in preparation). By 5 years of age typical children behave similarly to adults, with best responses to targets containing disparity cues. Blur retains similar weighting from infancy to adulthood. In the case of blur in particular, even typical adults often do not accommodate well unless the target cannot be identified without doing so (Horwood et al., 2001).

The typical “disparity biased” profile and developmental trajectory would be predicted to be different when cortical binocularity is defective (i.e. suppression or poor stereoacuity) or accommodation and convergence relationships are abnormal (i.e. high or low ratios).

We therefore tested the hypotheses that i) strabismic individuals would not respond to disparity cues if they failed to show any binocular responses to clinical tests, ii) reduced binocular responses would be associated with reduced bias to the use of disparity as the primary cue to drive vergence and accommodation iii) individuals with accommodative esotropia would not only converge excessively in relation to accommodation (high AC/A ratio), but also use disparity cues relatively less than non-strabismic, but similarly hyperopic, children referred for low visual acuity, and iv) if disparity, which is normally a primary drive to accommodation, is degraded in strabismus, blur or proximal cues “take over” to drive more of the accommodative response. Although these hypotheses could be predicted from current literature, this is the first time that objective responses to the main three near cues have been tested under standard conditions in such groups.

This preliminary paper uses data from small groups of esotropic patients to illustrate that differences in response profiles in comparison to matched control groups do indeed occur. They form a basis for more detailed studies in the future.

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 for details and definitions). There were four groups of esotropes; constant esotropia with weak BV such as gross stereopsis or a cross on Bagolini striated glasses; constant esotropia without any BV and constant suppression on Bagolini glasses, Worth’s Lights and synoptophore; fully accommodative esotropia, esotropic without spectacles but controlled with spectacles with at least 120” arc stereoacuity and no central suppression with a 4 base out prism; and convergence excess esotropia (controlled without central suppression at 6m and esotropia on accommodation at 33cm with spectacles, and at all times without spectacles). There were three control groups; typical emmetropic young adults and two non-strabismic child 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. Because of the wide variability of the refractions of the constant esotropes they were matched individually by age (within one year) and refractive error (within 1.0D) to a similar non-strabismic child, while the accommodative esotropes with a narrower range of refractive errors were group matched a non-strabismic group with a similar distribution of age and refractive errors (see Table 1). The children with convergence excess esotropia were not matched with a non-strabismic group but profiles were compared with the other groups. We did not separate infantile and later onset esotropia for this study as we felt it would be more fruitful to divide into BV and no BV categories. Some of the non-accommodative constant esotropes had residual esodeviations following surgery. All patient participants had been refracted under cycloplegia and wore their full cycloplegic refractive correction for testing, so accommodation started from the same refractive baseline for distant fixation. None had astigmatism greater than 1.25D. Manifest angles of deviation never exceeded 45° eso. All matched non-strabismic children were drawn from hospital-recruited hyperopic patient groups originally referred having failed school-entry vision screening. None unilateral or bilateral amblyopia or had anisometropia in any meridian of more than 1.0D. All had corrected visual acuity of at least 0.1 logMAR. Typical, non-hyperopic children

were drawn from our typical child database, in which case they all had visual acuity of at least 0.1 logMAR in either eye, did not wear spectacles, were blurred at 6m using +1.00 lenses and showed no suggestion of hyperopia greater than 0.5D at any time during testing in the lab. We have shown that such refraction estimates from our undilated laboratory method closely estimate cycloplegic refraction (Horwood and Riddell, 2009¹).

The method has been described in detail elsewhere (Horwood & Riddell, 2008), but briefly all participants watched the target being presented on a video monitor 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, 0.25m¹, 1m, 0.5m) in the same pseudo-random order each time. A linear stimulus / response curve to this non-linear testing order helps confirm participant attention. The whole apparatus was encased in matte black shuttering and no peripheral fusion was possible beyond the edges of the mirrors which allow a minimum binocular field of 30°.

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 Gabor image to open the accommodation loop as much as possible while retaining fusible features for the binocular conditions. The Gabor image had a maximum spatial frequency of 1.58 cycles per degree. Unpublished pre-study trials with targets of lower spatial frequency did not further open the accommodation loop but did present a poorer fusional stimulus. 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 but data were still collected by the photorefractor from both eyes via the lower optical pathway. 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 (subtending between 3° and 18° depending on distance), or these dynamic and size cues could be minimized by scaling the target so that it subtended the same retinal angle (3°) 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) and two different ways of assessing the influence of each cue (firstly, when it was eliminated from a naturalistic situation (*bdp* vs *bd*, *bp* and *dp* conditions) as might occur when degraded in suppression or refractive error, and then when it was the only cue presented (*b*, *d*, and *p* conditions). The *o* condition assessed the effect of any residual cues we could not totally exclude. Instructions were minimal (just “look at the picture”) so that we could assess responses in as naturalistic manner as possible.

A specially written Excel macro calculated dioptres of accommodation (D) and meter angles of vergence (MA) using the raw data spreadsheet produced by the photorefractor. We plotted these data on an intermediate chart from which we selected short vignettes of 25

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

stable and representative datapoints (one second of data) at each fixation distance. Inter-tester limits of agreement for two independent assessors' choice of these vignettes were 0.037 ± 0.37 MA for vergence (approximately 0.2°) and 0.0095 ± 0.175 D for accommodation. Corrections were made for measured angle lambda, inter-pupillary distances (IPD) and any spectacle magnification for each participant, all of which can be calculated from raw data collected by the photorefractor (Horwood & Riddell 2008). This is particularly important for assessment of accurate vergence.

Angles of deviation calculated from corneal reflections may not be as precise as methods using fixation movements or subjective responses, but our estimate of *change* between near and distance for each participant is likely to be more accurate than absolute deviation measurement because the Hirschberg ratio (degrees per mm displacement) is more consistent (Riddell, Hainline & Abrahamov, 1994).

Accommodation was assessed as the amount of myopic shift from calculated refraction at infinity (y-intercept of the accommodation response slope in the all cue *bdp* condition). We did not calibrate accommodation individually, but we did make a correction for a small systematic difference between the PowerRefII refraction compared with dynamic retinoscopy found in calibration studies. No participants were significantly anisometropic (<1.0 D). In manifest angles under 15° accommodation was averaged from the right and left eyes. In the few cases where a larger angle was found, accommodation data were only used from the fixating eye to avoid off-axis errors.

By using MA we were able to compare simultaneous vergence and accommodation responses in relation to the demands of the target distance more meaningfully between participants with different IPDs and also plot both responses on the same charts. For example a 50cm target demands 2D of accommodation, 2MA of vergence and thus an AC/A ratio of 1MA:1D from all participants, while an adult with a 70mm IPD would require 14PD of convergence and an AC/A ratio of 7 :1D to respond perfectly at the same distance, while a child with a 50mm IPD would only require 10PD of convergence and a 5 :1D AC/A ratio. A response gain of 1.0 calculated across all four target distances indicates a 100% response to target demand and a lower gain shows under-response to the approaching target. 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 these preliminary studies were carried out to establish proof of concept in relatively small groups as a basis for directing more detailed research. Comprehensive analysis with post-hoc testing of the total dataset

with corrections for multiple comparisons was 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* hypotheses outlined in the introduction.

Where appropriate, Bonferroni corrections were made for multiple comparisons.

RESULTS (see Figure 2)

In all cases, responses to the all cue *bdp* condition suggested appropriate convergence and accommodation (with a small amount of accommodative lag) when changing from distance to nearer fixation. When compared to responses in this condition, lower response gains (flat stimulus-response function) using impoverished targets were generally due to poorer responses to near targets and not over response to distance ones i.e. under-response for near and appropriate responses for distance, rather than over response at distance and good responses for near.

Group 1 Typical emmetropic young adult controls

This group 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. Both vergence and accommodation response gains were good to any stimulus 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 they were to any condition 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, with best responses to any target containing disparity cues, although the cue differences were somewhat less pronounced. Although these children also had slightly lower accommodation in relation to vergence gains overall, the difference did not reach significance (one-tailed t-test: $t(36)=1.24, p=0.1$). Only two children (11%) showed $>1.00D$ accommodative lag at 33cm (group mean lag 0.5D), compared with 15 (46%) of the pooled esotropia groups below (Groups 3,4,6 and 7) ($\chi^2 = 3.8, p=0.05$).

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. The better response to disparity-containing targets found in all non-strabismic participants (Groups 1,2 and 5) was

not found in Group 3, but neither was there complete absence of response to disparity stimuli.

Group 4. Constant esotropes with no evidence of binocularity

Responses were much more erratic and variable in this small group than in Group 3 (see large standard error bars), but vergence gain to the all-cue *bdp* target was similar to the binocular controls (i.e. convergence to near “with the deviation”). Poor accommodation gain was very common (see especially accommodative gains to *bdp*, *bd*, *b*, and *d* target in Figure 2), but this was due as much to over-accommodation for distance as under-accommodation for near. Two of the six children under-accommodated by $>1.0D$ for near while five over-accommodated at 2m by more than $0.2D$. AC/A ratios were significantly higher than in the controls ($t(18)=2.14$, $p=0.046$). 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*) marginally degraded vergence ($t(6)=1.87$, $p=0.055$) but the effect for accommodation did not reach significance ($t(6)=1.18$, $p=0.14$).

Group 5. Non-strabismic hyperopes

This group, individually matched by age and refractive error to Group 6 below, showed the typical bias of non-strabismic individuals towards better responses to cues containing disparity cues, and showed accommodative lag for near to the naturalistic *bdp* condition, with eight (80%) showing more than $0.5D$ lag at 33cm and four (40%) under-accommodating by more $>1.0D$ at 33cm.

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 6 vs Group 3: $t(19)=2.21$, $p=0.02$) in the *bdp* condition where 5 of the 10 esotropic children showed accommodation lag of $>1.D$ at 33cm and only three over-accommodated for distance. The strabismic children failed to show the pattern of better responses to targets containing disparity cues that is evident in age- and refraction- matched non-strabismic controls in Group 5 (and Group 2). A three-way mixed design ANOVA with Bonferroni corrections, with diagnostic group (5 & 6) as a between group factor and response type (vergence or accommodation gain) and cue as a within group factors showed a significant response*group interaction ($F(2,44) = 6.37$, $p=0.004$). Post hoc testing showed significant between-group differences in the *bp* (disparity excluded) and blur-only *b* conditions ($F(2,48)=9.65$, $p<0.001$) and ($F(2,46)=4.37$, $p=0.001$) where the accommodative esotropes showed better vergence responses to these targets than the controls and therefore higher AC/A ratios. In non-strabismic controls, eliminating disparity caused a large drop in vergence, while manipulating blur made little difference. Thus the fully accommodative group appeared less dependent on disparity cues than the controls; removing disparity

reduced vergence responses significantly less than in the non-strabismic children (Group 5 vs Group 6: bdp vs bp $p=0.036$), while presenting blur in isolation drove significantly more vergence (b vs o , $p=0.008$).

Group7 Convergence excess esotropes

Vergence response gains were excessive in this group as their esodeviations increased for near even with spectacles. Six of the eight children showed accommodation lag of $>1.D$ at 33cm in the bdp condition. Figure 2 shows that accommodation responses were best to targets including blur cues (bdp , bd , bp and b), in contrast to non-strabismic groups (1, 2 and 5) for whom disparity is the primary cue (bdp , bd , dp and d). These children also produced steeper vergence slopes to non-blur cues, such as disparity-only and proximity-only. In typical children, eliminating blur cues (bdp vs dp) makes a small, insignificant difference to accommodation gain, but with the children with convergence excess esotropia 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 AC/A ratios and the CA/C ratios across the groups studied, expressed in MA:D instead of the more familiar (but less meaningful between individuals) ΔD^2 . The figure shows that these ratios act in a broadly inverse relationship to 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 and so higher AC/A ratios and lower CA/C ratios.

DISCUSSION

Our data give insights into how different groups use blur, disparity and proximal cues in characteristic ways. While the obvious role of accommodation (and by inference, blur) in influencing the characteristics of many esotropias has been known for many years, the roles of disparity and proximal/looming cues to influence convergence and accommodation in strabismus are more rarely considered, and are technically much more difficult to assess in patients. Studying these cues using a standard paradigm where all are manipulated in turn across clinical diagnoses, and in comparison to matched non-strabismic groups, allows differences to become evident and gives a much richer understanding of how strabismic and non-strabismic children differ in their use of visual input. Our method also allows direct comparisons of the AC/A ratio with the CA/C ratio (the d -cue driven accommodation response) collected under otherwise identical conditions, which is rarely achievable, especially in children.

Our research remit was to establish whether theoretical predictions of differences in cue use profiles across the whole range of binocular vision clinical practice did indeed exist. Now that we have preliminary data supporting these predictions, we will extend and refine our experimental and clinical testing based on these initial findings. Even in these small groups, however, where the naturalistic and uncontrolled nature of the task and the youth of the

²A clinical AC/A ratio of 6 ΔD in a patient with an IPD of 6cm is equivalent to our MA:D ratio of 1:1 (100% of vergence is driven by blur); a normal ratio would be 0.66MA:1D (4 ΔD), showing that 2/3rds of the total vergence requirement is driven by blur.

participants led to variable data, clear trends still emerged and statistical significance was reached in many cases.

In the non-strabismic groups (Groups 1, 2 and 6) we found the slight accommodation lag for near that is commonly reported in the literature (Harb, Thorn, & Troilo, 2006; Rouse, Hutter, & Shiftlett, 1984). We and others (Candy, Gray, Hohenbary, & Lyon, 2012; Horwood & Riddell, 2011; Stewart, Woodhouse, Clegg & Pakeman, 2007) have also reported that significantly hyperopic children have additional accommodative lag for near, even when corrected, and as six of the non-strabismic controls (46%) wore a hyperopic correction in order to be matched to the strabismic children, this is likely to account for the slightly poorer accommodation gain Group 2.

Accommodation lag and shallow accommodation gain were common in the strabismic groups too, especially in the two groups of accommodative esotropes, with more (or excessive, in the case of the convergence excess group) vergence associated with each unit of accommodation producing high AC/A ratios. High AC/A ratios have been reported in esotropia many times before (Cassin, Beecham, & Friedberg, 1976; Costenbader, 1957; Havertape, Cruz, & Miyazaki, 1999; Ludwig, Parks, Getson, & Kammerman, 1988; Yan, Wang, & Yang, 1995; von Noorden and Avilla, 1990). However, 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; does presenting or removing a cue affect just vergence, just accommodation or both? For example, a high AC/A ratio will not influence an angle of deviation much if changing blur only plays a small part in driving the *total* accommodation response, which in fully binocular participants is usually primarily driven by disparity. Conversely, a high AC/A ratio, or change of refractive correction would make a big difference to the angle if blur carries more weight.

The fully accommodative esotropes failed to show the stronger responses to disparity than to blur that was found in the very closely matched non-strabismic hypermetrope group, while the convergence excess group showed a profile of better responses to cues containing blur rather than disparity. So for these children, as well as having a high AC/A ratio, the high ratio may *matter* more, because they respond to blur more than typical children 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.

Conversely, weak responses to change of blur in typical groups may explain both the common finding of low stimulus AC/A ratios (Gage, 1996; Plenty, 1988) and also why new refractive prescriptions make little difference to many small heterophorias. However, it is interesting to speculate whether a 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.

Children 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, with no clear pattern of cue use behavior. 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, although the overall shape of the profile of responses in constantly suppressing esotropes does not suggest that other cues are “taking over” to drive accommodation: they maintain response gains similar to those of non-strabismic children. The group was too small to find statistical significance in the lower accommodation gains seen in this group, although the AC/A ratios were significantly higher as relatively normal vergence was associated with less accommodation.

It is remarkable that even in the participants with constant suppression and no detectable peripheral fusion, adding disparity cues to the minimal cue condition, or removing disparity from the stimulus (*bdp* vs *bp*) (when in both cases everything else about the image, including size, is similar) still affects vergence, suggesting that some binocular input must still be occurring.

In summary, these small case series illustrate how differences in responses to near cues can differentiate clinical diagnoses. It is not clear whether these differences precede or are a consequence of the strabismus. They serve as exploratory studies for more research and we are continuing to study larger numbers in more detail because Type II error is a possibility in these small and varied groups. As well as testing larger numbers in the lab, it is clear that we need to look more carefully at clinical subtleties of accommodative responses, response to dissociation and lenses, binocular vision, retinal correspondence and suppression in order to classify patients more precisely. By understanding how different groups use near cues to drive responses, we believe we can provide an alternative way of explaining clinical characteristics and predict responses to common treatments.

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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 (error bars = standard error of the mean) 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. AC/A vs CA/C ratios

AC/A (dark shading) and CA/C (pale shading) ratios (error bars = standard error of the mean), showing the broadly reciprocal relationship between the two measures. As we use MA/D units (which correct for differences in IPD), the typical adult AC/A ratio shown here of 0.56MA:1D is equivalent to a clinical prism cover test AC/A ratio of 3.4 :1D in a patient with an IPD of 6cm. Strabismic, and particularly accommodative strabismic, groups show high AC/A and low CA/C ratios (more vergence to blur cues than accommodation to disparity cues).

Table 1

Study groups and clinical characteristics

Group characteristics and matching. PCT = alternate prism cover test, MSE= mean spherical equivalent.

		<i>n</i>	<i>Matched with</i>	<i>Age (yrs)</i>		<i>Deviation (PCT) at 33cm (unless stated otherwise)</i>	<i>BV</i>	<i>Ref Error (MSE)</i>		
				mean	range				Mean	range
Group 1 (control)	Emmetropic non-strabismic adults	27		20.2	18-24	0-3 exo	<120" TNO	+0.3D	+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	0-3 exo	<120" TNO	+2.09D	+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	2-35 eso	>400", +ve Bagolini Gls or Lang stereotest	+1.75D	+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	5-25 eso	None, + constant suppression on Bagolini Gls and Worths Lights and synoptophore	+2.41D	+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	2 exo-2 eso	<120" TNO	+4.02D	+4.02D	+2.5D-+6.0D
Group 6	Fully accommodative ET	16	Group matched with Group 5 by age and refractive error	5.79	4.3-8.0	1-8 with gls, 15-45 without gls	<120" TNO with gls	+3.9D	+3.9D	+2.25D-+6.0D
Group 7	Convergence Excess ET	8		6.4	4.5-7.1	20-45 eso Nr, 0-6 eso Dist	<120" TNO with +3.0 add	+2.18D	+2.18D	0D-+4.75

Table 2**Cue conditions**

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

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