Decreased accommodation during decompensation of distance exotropia

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ABSTRACT

Objective. Disparity cues can be a major drive to accommodation via the CA/C (convergence accommodation to convergence) linkage but, on decompensation of exotropia, disparity cues are extinguished by suppression, so this drive is lost on decompensation. This study investigated accommodation and vergence responses to disparity, blur and proximal cues in a group of distance exotropes aged between 4-11 years both during decompensation and when exotropic.

Methods. 19 participants with distance exotropia were tested using a PlusoptiXS04 photorefractor set in a remote haploscopic device which assessed simultaneous vergence and accommodation to a range of targets incorporating different combinations of blur, disparity and proximal cues at four fixation distances between 2m and 33cm. Responses on decompensation were compared to those from the same children (reported separately) when their deviation was controlled.

Results. Strabismus was more common in the more impoverished cue conditions. Correlation between loss of vergence and drop in accommodation was generally weak ($r^2 = 0.135$), and variable. When decompensation occurred for near, mean accommodation gain for the all-cue (naturalistic) target reduced significantly ($p<0.0001$), with resultant mean under-accommodation of 2.33D at 33cm. The profile of near cues usage changed as expected on decompensation, with blur and proximity driving residual responses, but these remaining cues did not compensate for loss of accommodation caused by the removal of disparity.

Conclusions. Accommodation often reduces on decompensation of distance exotropia as the drive from convergence is extinguished, providing a further reason to try to prevent decompensation for near.
INTRODUCTION

Intermittent distance exotropia (DXT) is characterized by a loss of binocularity, and frequently a larger deviation, for distant targets. Although larger near angles may be found on occlusion or with plus lenses, control is still better for near, implying that near cues are used to signal target distance and drive additional convergence. The two main mechanisms for this control are thought to be fusional convergence driven by binocular disparity and accommodative convergence which results indirectly from blur-driven accommodation (AC/A). [1]

In a companion paper, [2] we demonstrated that when controlling, binocular disparity cues were used by all sub-groups of DXT as the main drive to near responses. We also concluded that raised CA/C ratios in exotropic children led to more accommodation, particularly for near, and we did not find the high AC/A ratios generally implicated.

Models of vergence and accommodation control treat these systems as closely linked and interdependent e.g.Hung [3]and Breinin. [4] Indeed, where clinical AC/A ratios [5, 6] response CA/C ratios, can be high[2], vergence might be expected to co-vary strongly with accommodation so that control improves as a child accommodates (or vice versa) and accommodation fails if the child decompensates for near and disparity cues are suppressed. Few studies have studied accommodation in relation to exotropia control, [7, 8] and those that have consider mainly near exotropias. In our study of DXT, however, we were struck by how a large vergence change was not always accompanied by the accommodation change we expected. We analysed our data further, looking at the strength of the linkage between accommodation and vergence on decompensation. Strong CA/C linkages would predict large decreases in accommodation as vergence fails, with significant implications for schooling and attention for close work. In contrast, weak links would predict, that accommodation is less affected on decompensation. We also predicted that, since suppression removes disparity cues on decompensation, only blur and proximity would remain to signal target distance. As these are generally relatively weaker signals in relation to disparity, this would require re-calibration of their weighting to drive accommodation if accommodation were not to suffer for near. If re-calibration does not occur, however, the exotropic accommodation response gains would be expected to reduce on decompensation. Experimentally, response gains when decompensated should be similar to those when the deviation is controlled, but disparity excluded artificially.

METHODS
We used a PlusoptiX SO4 video refractor set in a remote haploscopic device. Full details of construction, calibration and data processing have been published elsewhere. [9] For full details see the Online Supplement and the brief description given below.

**Figure 1. The remote haploscopic videorefractor.** A. Motorised 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 DoG targets illustrated lower right.

The participants watched target moving in a pseudo random order between fixation distances of 2m, 1m, 50cm, 33cm and 25cm² (0.5 to 4 dioptries (D) and meter angles (MA) demand) stimulus manipulations (detailed picture vs DoG patch, binocular vs occluded, and unscaled and looming vs scaled and non-looming, provided all possible different cue combinations of blur (b), disparity (d) and proximal (p) (looming) cues (bdp, bd, bp, dp, b, d, p, o(minimal)). All participants were tested twice at each condition and vergence responses were calculated in MA and accommodation in D, so that they could be directly compared, and in relation to target demand. Profiles of response slopes across the different cues were charted.

**Participants and definition of “tropic” behaviour**

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*The data from this target was discarded from the analysis for technical reasons (see online supplement)*
The same 19 children with DXT described in detail in the companion paper [2] and Online Supplement provided the data. All had equal visual acuity and <120” arc stereopsis when controlled and constant suppression when manifest.

As is common in such deviations on decompensation, the large manifest deviation occurred suddenly and we were easily able to detect when a deviation had decompensated because the total vergence angle trace reduced dramatically as one eye diverged (Figure 2). Data could therefore be analysed for both “controlled” and “tropic” periods of testing. The Online Supplement provides details of inclusion criteria but in brief, an exodeviation of more than 2.5MA beyond orthophoria (approximately 14Δin this group) had to be present for at least 12 continuous data points (0.5 seconds) to be analysed. These brief episodes, and the relatively short periods of fixation (2-10 seconds) at any distance preclude this data including the effect of slow tonic influences. The accommodation was only analysed from the fixing eye to exclude any off-axis errors. This paper describes the simultaneous vergence and accommodation responses to the different cue conditions at the point of decompensation and when tropic.

Figure 2. Example of decompensation events. “Controlled” episode - dashed circle; “strabismic” episode - dotted circle; solid oval – period of decompensation. Use of meter angles (MA) enables vergence, accommodation (in diopters (D)) and target demand to be plotted on same scale. In this case decompensation occurred during fixation at 33cm(3D & MA demand), 2m(0.5D & MA demand), 25cm(4D & MA demand) and (briefly) 50cm (2D & MA demand), but not at 1m(1D & MA demand). Accommodation was generally poor, with considerable lag, and changed by less than 1D as vergence reduced by approximately 4MA. Child was +1.0D hyperopic OD& OS (reflected by “negative accommodation” at times).

Data were analysed with SPSS v 17 using Pearson’s correlation coefficients and ANOVA. Post-hoc tests used Bonferroni corrections for multiple comparisons. Significant differences between cue
conditions are usual in this paradigm, so only main effects and interactions between groups and targets are reported.

RESULTS

All children decompensated when viewing at least two targets, and for at least two fixation distances within each target condition where divergence occurred. Nine children provided both “controlled” and “tropic” data for the same cue during testing (with control being lost or regained while fixating the target, or being controlled on the first testing session but decompensated for the second) and so their weighting of cues could be directly compared in each condition. Deviations were more likely to be constantly controlled for the more enriched and binocular targets (bdp, bd and dp) and constantly manifest for those with fewer cues (p and o), with both controlled and manifest behaviour being found more commonly for intermediate conditions. As a result, the number of participants in each condition varied. Table 1 shows the number of participants in each cue condition.

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Table 1 Numbers (and % of the whole exotropic group) for who controlled and strabismic data were available at each target condition. Both “straight” and “strabismic” data was sometimes available for the same child for the same target, either within a session or on different testing session (lower row). Column headings: b=blur cues available, d=disparity available, p=proximal (looming) cues available, o=minimal cue condition

Accommodation after decompensation

We were able to observe 81 decompensation events (solid line oval in Figure 2) across a range of target conditions where we were able to collect data both before during and after control changed. Fifty-one episodes of decompensation (61%) occurred for near fixation at 50cm or closer. These nearer positions provide most opportunity for accommodation to show more change from “accommodated” to “relaxed” levels as vergence failed, allowing us to test whether vergence and accommodation were strongly linked.
The main finding was that for the targets that contained disparity (bdp, bd, dp and d), where accommodation responses are generally good in both typical controls and controlled exotropia, the accommodation responses to the nearest targets when tropic were much lower, with mean accommodation at 3.0D demand of only 1.1D (only 45% of the pre-decompensation response of 2.36D). For the four children who diverged for near in the most naturalistic bdp condition, accommodation dropped from 2.6D to 0.77D (Figure 3) while fixating the 3D target.

Figure 3. Mean accommodation (filled symbols) & vergence (open symbols) responses to the all-cue (bdp) target. Controlled (left chart) (n=19) and exotropic (right chart) (n=4). Grey line denotes ideal response to target demand. Right chart shows basic divergent deviation, but appropriate change in vergence for near, while accommodation shows significant lag.

Strength of accommodation / vergence linkage at time of decompensation

Figure 4 shows the relationship between accommodation and vergence change at the point of decompensation or control across all individuals. Although change in accommodation was sometimes associated with decompensation there was a very wide range of responses. The correlation between change in vergence and change in accommodation was weak ($r^2=0.135; p < 0.001$) showing that sudden loss of binocularity did not always result in a corresponding drop in accommodation. If the one hyperopic child who was being treated by under-correction (specifically because the under-correction did aid control) was excluded from the analysis, any correlation between accommodation and vergence change was no longer significant ($r^2=0.02; p = 0.25$). Even within individuals, on one occasion accommodation could drop dramatically during decompensation, and on another, it would remain static when viewing the same near target.
Figure 4. Vergence change vs. accommodation change at time of decompensation. Black triangles = targets at 1m or 2m (distant); grey diamonds = targets at 50cm or 33cm (near). Open circles from single hyperopic child being kept under-corrected to aid control of exotropia. Correlation becomes insignificant if this child is excluded.

If only the 51 near decompensation events are considered (where more reduction in accommodation could potentially occur), 44.4% of the responses showed less than 0.50D change in accommodation at the time of decompensation, 24.1% of responses showed a drop in accommodation of >0.50D and 31.5% of responses demonstrated an increase in accommodation (because the target was approaching) by >0.50D while still diverging. In these accommodating cases, however, this did not reach the typical levels of accommodation to the target measured in the same children when controlled.

“Controlled” vs “tropic” cue-use profiles

We predicted that the profile of responses to the different cues would be altered between controlled and tropic episodes as suppression extinguished disparity cues. Without disparity, the remaining cues to vergence and accommodation (blur and proximity) are still available. If recalibration does not occur when the deviation decompensates, we expected responses to cues involving disparity would decrease to resemble the controlled responses to the cue conditions when disparity has been removed experimentally (bdp vs. bp, bd vs. b, dp vs. p, d vs. o), while responses to the cues which do not involve disparity should remain unchanged. If accommodation and vergence are not strongly linked, we hypothesised that accommodation and vergence might be affected
differentially such that vergence would decrease as disparity is removed either as a result of decompensation or target manipulation, but that accommodation would remain unchanged.

**Figure 5. Response gains of exotropic participants when controlled vs exotropic.** Upper chart shows responses when “controlled”. Lower chart shows responses when strabismic. We predicted, and found, that exotropic responses when strabismic, so suppressing, should be similar to controlled responses when disparity was excluded experimentally (bars in upper and lower charts with matched hatching). When the deviations are decompensated, there is a greater reduction in gains (response slopes flatten) in the conditions where disparity is a major cue (bdp, dp and d). The b responses remain unchanged, and may explain why the bd responses are less affected when disparity becomes unavailable.

Figure 5 shows response gains when both controlled and decompensated. As expected, the profile of cue use did change according to our predictions. None of the differences between the above pairs of conditions (tropic bdp vs pre-decompensation bp gains, tropic bd gains vs. pre-decompensation b gains, tropic dp gains vs pre-decompensation p gains and tropic d gains vs pre-
decompensation of gains), for both accommodation and vergence, approached statistical significance, even for the greatest difference between tropic bdp and controlled bp accommodation. The remaining cues did not appear to “take over” a role in driving a larger proportion of the accommodation response than before decompensation.

Accommodation gain was consistently greater than vergence gain when controlled, but this was not a consistent finding when tropic. A 3-way mixed ANOVA with response type (vergence or accommodation gain) and cue type as within subject factors and group (straight or tropic) as a between subject factor showed the expected differences between the cue conditions (F(3.81,95.2)=4.57, p=0.002), no overall difference between accommodation and vergence (F(1,25)=<0.001, p=0.98) or group (F(1,25)=0.61, p=0.44) but there were significant interactions between cue and group (F(3.8,95.2)=3.13, p=0.02), cue and response (F(3.92,98.16)=4.95, p=0.001), cue, response and group (F(3.92,98.15)=4.16, p=0.004).

Post hoc testing showed that the only significant difference between vergence and accommodation responses on decompensation was in the most naturalistic bdp condition (F(1,21 =7.59, p= 0.012), where the accommodation response gain was more reduced on decompensation than the vergence gain despite the large manifest divergence (Figure 5). The other interactions occurred because of significant reductions in both accommodation and vergence response gains in three out of the four conditions where disparity is normally available when compensated (main effect of group: bdp (F1,21 =25.42, p<0.0001); dp (F1,20 =25.36, p<0.0001); d (F1,24 =31.75, p<0.00001); but not for any other cue combinations.

AC/A and CA/C linkages on decompensation

We have reported that response AC/A ratios in the exotropic children, when controlling, were not significantly different from a control group of non-tropic children, while the CA/C ratios of the exotropic children were higher than in the controls. We predicted that the AC/A ratio would not change on decompensation as the blur cues remain unaltered, but that the CA/C linkage should be extinguished by suppression of disparity cues. The blur driven vergence response gains for this group (reflecting AC/A linkage) were 0.56 compared with 0.65 when tropic (t (23) =0.34, p=0.73, (ns)), while, as predicted, the disparity-driven accommodation gain reduced from 0.7 to 0.03 (t (23) =7.21, p=0.00002).

The finding that some children appeared to have a stronger linkage between vergence and accommodation than others led us to suspect that those with greater angular response to clinical lens manipulations (i.e. showing that accommodation is linked to vergence) might have a greater
drop of accommodation on decompensation than those who did not (controlled vs tropic bdp accommodation gains). Numbers were too small for statistical testing, but there did appear to be such a trend, with the accommodation gains of two children who had >10Δ change of angle with -3.00D lenses at 6m reducing by an average 0.8 when tropic while two who had <10Δ change in angle with lenses only reduced by 0.47.

DISCUSSION

A literature search confirmed that this is the first paper to report vergence and accommodation behaviour during the actual course of decompensation in DXT. We were also able to gather data from the same group of children while both tropic and controlled, which although not unique, [7, 8] is rare. Although studies have looked at accommodation in DXT, accommodation is usually assessed monocularly [7, 8, 10, 11] and so its relationship to alignment is difficult to assess. The PlusoptiXSO4 has a major advantage in that accommodation and vergence data can be obtained simultaneously.

Our major finding is that, on decompensation, the mean accommodation responses to the naturalistic bdp target decreased dramatically in all four children who diverged when viewing this target, resulting in significant under-accommodation for near. A similar reduction in accommodation on decompensation was found in many more children when viewing all the other targets that contained disparity in the cue combination. These are the targets that normally drive the best accommodation responses in the same children when controlling their deviations, and also in typical children. This is further evidence that disparity drives a large proportion of accommodation through the convergence accommodation link.

The remaining blur and proximal cues do not appear to compensate by driving more accommodation than they do when disparity is also available, but continue to drive the same (reduced) amount of the response as before dissociation. This means that many children who decompensate for near may be losing accommodation for close work, with obvious implications for schooling and attention. It would add support to the commonly held view that decompensation for near is an indication for prompt surgery; this might not only serve to preserve stereopsis, but also to help accommodation.

The variability in the amount of accommodation that is extinguished during decompensation suggests that linkages between vergence and accommodation are also variable. Relatively few children decompensated for the bdp target in the laboratory, so further statistical analysis was not possible, but of the few children who did decompensate for this target, those with a clinically greater
response to minus lenses (high distance stimulus AC/A ratio) showed a greater reduction in accommodation on decompensation than those with a lower distance stimulus AC/A ratio. It is possible that a high stimulus AC/A ratio or good response to minus lens therapy, which indicates that manipulating blur affects the angle (or changing vergence affects accommodation as our previous paper suggests [2]) might predict those most at risk of loss of accommodation on decompensation. Those who do not respond to minus lenses may have weaker or no linkage of vergence to accommodation and so risk less blur on decompensation.

The few other studies which have directly addressed accommodation comparisons between control and decompensation did not specifically target patients with DXT. Rutstein & Daum [7] found that accommodation was severely affected when a group of adolescents, with mainly near exotropia, lost control of their deviation, but “relative orthophoria existed when the accommodative response was adequate”. They attributed this to a defect of accommodation, rather than under-accommodation resulting from loss of convergence. Stark et al [8] reported one case with near exotropia combined with accommodative “disfacility” and suggested the two systems interacted in a “pathogenic symbiotic manner”. We suggest that the most likely explanation is that the dissociation causes loss of accommodation normally driven by disparity cues.

The main limitation of this study is that our brief testing session and use of small vignettes of data do not take into account slower tonic influences that could modify static responses [12] that might influence prolonged fixation on close work. We did not attempt to assess these here as we were interested in everyday behaviour, where control of exotropia does “come and go” with fixation distance, attention, light levels or visual task; a situation that may be occurring for many children many times throughout the day, with obvious implications for adequate image clarity and attention for close work.

As our target was never more than 18° across, we cannot definitively state whether the suppression was scotomatous, [13] or more extensive [14]. It is possible that if the suppression was scotomatous, more peripheral disparity cues could have driven better responses in non-experimental, wider-field conditions.

Finally, numbers were relatively small. Fewer children decompensated to targets containing disparity cues (bdp, bd and dp) and few could control to the minimal cue (o) condition, so numbers where comparisons between tropic and controlling in these conditions were smaller. Larger numbers and comparison of more prolonged responses would help clarify questions raised by this research, but
these data suggest that it cannot be assumed that children with intermittent exotropia accommodate as well or steadily as do non-tropic children.
REFERENCES