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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. 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 PlusoptiXSO4 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 when their deviation was controlled.

Results—Manifest exotropia was more common in the more impoverished cue conditions. When decompensated 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 after 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.

Keywords

Distance exotropia; Accommodation; Decompensation; AC/A; CA/C

INTRODUCTION

Intermittent distance exotropia 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]

Models of vergence and accommodation control treat these systems as closely linked and inter-dependent e.g. Hung [2] and Breinin. [3] Indeed, where clinical AC/A ratios can be high, [4, 5] vergence might be expected to co-vary strongly with accommodation so that control improves as a child accommodates. We have evidence that CA/C linkages are important in typical children, [6] as well as in the exotropes reported here (separate paper in preparation). If this is the case accommodation could fail as 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 the present study, we considered whether accommodation reduces on decompensation; and if it does, whether this was a reliable finding. Such a decrease might have educational implications for children with decompensating deviations, and would also support the theory of a stronger role for CA/C linkages than generally considered. We also studied whether the weighting of disparity, blur and proximal cues to drive accommodation and vergence changes as suppression extinguishes binocular disparity.

METHODS

We used a PlusoptiXSO4 video refractor set in a remote haploscopic device. Full details of construction, calibration and data processing have been published elsewhere. [6] For full details see the Online Supplement and the brief description given below.

The participants watched a target moving in a pseudo random order between fixation distances of 2m, 1m, 50cm, 33cm and 25cm^a (0.5 to 4 dioptres (D) and metre 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 in each cue 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

An opportunistic sample of 19 children with distance exotropia between 4-11 years old was recruited from the Orthoptic Clinic at the Royal Berkshire Hospital. All presented clinically

^aThe data from this target was discarded from the analysis for technical reasons (see online supplement)

with an intermittent exotropia that was manifest or intermittent at 6m and but well-controlled to binocular single vision at 33cm, and all but two had a smaller angle for near than distance on alternate prism cover testing prior to prolonged occlusion. All had normal stereopsis ($<120''$ TNO), convergence to <7 cm from nose and visual acuity of 0.1logMAR (6/7.5) in each eye. None wore spectacles (mean cycloplegic MSE was $+0.02$ D (range $-0.75/+1.00$ D, except for one $+2.5$ D hypermetrope being kept uncorrected in a successful attempt to aid control). None suppressed on 4 base in or out prism testing and none complained of diplopia when manifest. They were not selected on the basis of any specific sub-classification of distance exotropia e.g. true /simulated, controlled by accommodation / fusion, but represented a wide range within published classifications.[1]

Definition of “tropic” behaviour

As is common in such deviations on decompensation, the large manifest deviation was easily detectable when 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 (approximately 14 in 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.

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 a large divergent deviation 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.

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 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.

Accommodation after decompensation

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.

Strength of accommodation / vergence linkage at time of decompensation

Figure 4 shows the relationship between accommodation and vergence change at the 81 decompensation points across all individuals for both near and distance targets. Although accommodation often reduced on 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.

There was obviously less potential for loss of accommodation for distant targets where little accommodation would be expected under normal circumstances. If only the 51 near decompensation events are considered (where more reduction in accommodation could potentially occur) correlation remained extremely poor ($r^2=0.03$, $p=0.25$). 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 >0.50 D and 31.5% of responses demonstrated an increase in accommodation (because the target was approaching) by >0.50 D 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. Unless re-calibration occurs when the deviation becomes manifest, 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 shows response gains when both controlled and manifest. The profile of cue use changed according to our predictions. When controlled, any cue containing disparity drove steeper response slopes than those cues without disparity, but after decompensation these cues drove reduced responses. 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 *o* gains), for both accommodation and vergence, differed statistically, 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 such 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 when decompensated 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 exotropia (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* ($F(1,21)=25.42, p<0.0001$); *dp* ($F(1,20)=25.36, p<0.0001$); *d* ($F(1,24)=31.75, p<0.00001$); but not for any other cue combinations.

AC/A and CA/C linkages after decompensation

We predicted that the AC/A ratio would not change when decompensated 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 $>10^\circ$ change of angle with -3.00D lenses at 6m reducing by an average 0.8 when tropic while two who had $<10^\circ$ 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 decompensation of distance exotropia. We were able to collect data during the decompensation event itself, and also when manifestly exotropic. 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 distance exotropia, accommodation is usually assessed monocularly [7-10] 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, after decompensation, the mean accommodation responses to the naturalistic *bdp* target decreased dramatically in all four children who diverged when viewing this target, resulting in flattened response slopes due to significant under-accommodation for near. A similar reduction in accommodation for near after 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 for a strong CA/C linkage which uses disparity to drive a large proportion of accommodation.

While manifestly exotropic, response slopes (distance-near changes) are reduced for both vergence and accommodation in most cue conditions. To the naturalistic *bdp* target, the steeper vergence slope occurs because, despite manifest divergence, near-distance changes are somewhat greater for vergence than accommodation (which cannot relax beyond zero, unlike vergence). After decompensation, blur and proximal cues appear to drive residual responses. The remaining blur and proximal cues do not appear to re-calibrate their weighting to drive 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, might also

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 distance exotropia. 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. [11] These might enable children with manifest deviations for near to eventually function better for close work than our data suggests. 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, [12] or more extensive. [13] 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.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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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.

Figure 2. Example of decompensation events

“Controlled” episode - dashed circle; “manifest exotropia” 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).

Figure 3. Mean accommodation (filled symbols) & vergence (open symbols) responses to the all-cue (bdp) target
 Controlled (left chart) (n=19) and manifestly 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.

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.

Figure 5. Vergence and accommodation response slopes (gains) of participants across all cues when controlled vs exotropic. The slopes of the all-cue (bdp) target (furthest left) correspond to the response slopes of the data in Figure 3

Upper chart shows responses when “controlled”. In the disparity-free (*bp, b, p, o*) conditions “control” indicates absence of the large exotropia that occurred at other times, although true binocular vision was not possible. Lower chart shows responses when manifestly exotropic (so in this case a good vergence gain means that the manifest divergent angle has reduced on near fixation). 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. Similar hatching denotes pre- and post-decompensation statistical comparisons described in text.

Table 1

Numbers (and % of the 19 exotropes) for who controlled and manifestly exotropic data were available at any target condition. Both “straight” and “manifest” 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

	bdp	bd	bp	dp	b	d	p	o
Children who showed a manifest exotropia episode	4 (21%)	4 (21%)	12 (63%)	4 (21%)	11 (57%)	7 (36%)	10 (53%)	8 (42%)
Children providing both manifest exotropia and controlled data for each cue condition	4 (21%)	4 (21%)	9 (47%)	3 (16%)	8 (42%)	7 (36%)	5 (26%)	3 (16%)