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A Novel Experimental Method for Measuring Vergence and Accommodation Responses to the Main Near Visual Cues in Typical and Atypical Groups

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Abstract

Binocular disparity, blur and proximal cues drive convergence and accommodation. Disparity is considered to be the main vergence cue and blur the main accommodation cue.

We have developed a remote haploscopic photorefractor to measure simultaneous vergence and accommodation objectively in a wide range of participants of all ages while fixating targets at between 0.3m and 2m. By separating the three main near cues we can explore their relative weighting in three, two, one and zero cue conditions. Disparity can be manipulated by remote occlusion; blur cues manipulated by using either a Gabor patch or a detailed picture target; looming cues by either scaling or not scaling target size with distance.

In normal orthophoric, emmetropic, symptom-free, naive visually mature participants, disparity was by far the most significant cue to both vergence and accommodation. Accommodation responses dropped dramatically if disparity was not available. Blur only had a clinically significant effect when disparity was absent. Proximity had very little effect. There was considerable inter-participant variation.

We predict that relative weighting of near cue use is likely to vary between clinical groups and present some individual cases as examples. We are using this naturalistic tool to research strabismus, vergence and accommodation development and emmetropisation.

Keywords

Accommodation; AC/A; CA/C; convergence; near cues

INTRODUCTION

The relationship of accommodation to vergence is fundamental to orthoptic practice, particularly in refractive error and deviations where the state of accommodation influences the angle of deviation e.g. accommodative esotropia, intermittent exotropia. The clinical literature generally implies that blur is the major drive to accommodation, and, through the AC/A relationship, to approximately 66% of convergence. Binocular disparity is known to be a major drive to vergence, and the experimental literature suggests that disparity can also be a major drive to accommodation via the CA/C relationship. Proximity (looming, motion parallax, relative size of objects etc.) also has an influential, but less clear, effect. Most experimental studies look at a single response (accommodation or convergence) in relation to a single near cue (blur, disparity or proximity) (for review of this large literature see volume by Ciuffreda & Schor¹). It is not clear, however, which cues are most influential when accommodation and convergence are measured simultaneously and all cues are available. A further problem with the literature is that many experimental studies are highly controlled and involve extended training periods with experienced observers who may be responding differently to uninstructed or young participants.

Experience in our laboratory with naïve adults and infants²⁻⁵ suggested that vergence may be the primary drive to accommodation, and that naïve observers may behave differently to “experts” such as optometry students. These findings led us to develop a flexible experimental method to assess the relative contributions of the main near cues to simultaneous vergence and accommodation that can be used on all age groups from infancy upwards. Here we use as examples the results of an adult study (full details published elsewhere⁶) that will be used as a baseline with which to compare infant development and discrete patient groups. We also give some examples of atypical findings that are forming the basis of future studies.

METHODS & PARTICIPANTS

All studies adhered to the tenets of the Declaration of Helsinki and informed consent was obtained from all participants.

The remote haploscopic videorefractor (RHV) (Figure 1) incorporates a Plusoptix SO4 photorefractor used in R-mode which makes simultaneous infrared recordings of refraction and eye position at 25 Hz. The RHV comprises two optical pathways. The target pathway presents a picture on a monitor moving between 25cm, 33cm, 50cm, 100cm and 200cm in a pseudo-random order, viewed through two concave mirrors so that the target appears to approach directly towards the subject.

The Plusoptix SO4 records responses via a “hot” mirror which is transparent to visible light, while reflecting infra-red for refraction. Occlusion is possible at the level of the upper mirror (F in Figure 1) so that, when occluded, the subject only sees that target with one eye (and is unaware of the occlusion), but responses from both eyes can be recorded.

The target is either a brightly coloured, high contrast, picture of a clown subtending 18.3° at 33cm with high and low spatial frequency details, or a blurred difference of Gaussian (DoG) “Gabor” patch of the same size (Figure 2).

We can remove disparity cues by remotely occluding one eye, minimise blur by using the DoG patch and minimise proximity cues by scaling the target so that it always subtends the same visual angle at each fixation distance and using a black cloth screen to obscure screen movement. We are therefore able to give the participants all possible combinations of three, two, one or minimal near cues. For full details of construction, testing protocol, calibration and validation studies see Horwood & Riddell ⁶.

Raw data is corrected for angle kappa and IPD, and used to calculate accommodation (in dioptres [D]) and vergence (in metre angles [MA]). We use MA so that both accommodation and vergence are on the same scale in relation to target demand and can be directly compared. By assessing the gain of the response slopes we are able to measure the proportion of an ideal response driven by each combination of cues and to assess the relative importance of each cue (Figure 3).

All results from clinical groups must be compared with the results of visually mature behaviour. We have recently published such a study ⁶ of 32 children and psychology undergraduates between 9 & 24 yrs of age and this data forms a baseline against which clinical groups can be compared. All participants were asymptomatic and emmetropic with no more than 4 near exophoria, 6/6 VA either eye, <60” stereopsis, convergence to 6cm and accommodation better 8cm. All were just instructed to “look at the picture”. Analysis used SPSS software to perform ANOVA with planned comparisons.

RESULTS

Figure 4 illustrates the response gains from the normal, visually mature participants for the different target conditions. A slope of 1.0 indicates a perfect response to target demand. It is clear that both vergence and accommodation were relatively accurate as long as disparity was present (*bdp*, *dp(-b)*, *bd(-p)*, *d* columns), and dropped off markedly if disparity was removed (*bp(-d)*, *b*, *p* and *o* columns). If blur was removed from the all-cue condition, there was only a small reduction in responses (*bdp* compared with *dp(-b)*), and responses were poor when blur was the only cue (*b*). Manipulating proximity had a weak effect, with only a small reduction in responses if removed (*bdp* compared with *bd(-p)*). The proximity-only responses (*p*) were marginally worse than the nocue condition (*o*). In the majority of cases, vergence was more accurate than accommodation.

The data we are collecting with this device is considerably more comprehensive than previously available, but still includes conventional indicators of the AC/A (vergence slope in the blur only (*b*) condition) and CA/C (accommodation slope in the disparity only (*d*) condition) ratios.

Table 1 shows results of planned comparisons testing significance of removing one or two clues from the all-cue *bdp* responses. It can be seen that although blur and proximity do have significant influence on responses, these effects are much smaller than the effect of

removing the disparity cue from the full cue condition, and are smaller still when disparity is available.

Individual Differences in Normals

Although Figure 1 illustrates mean and typical responses, there were some individuals with repeatably different patterns of response. 3 (9%) showed dramatic flattening of responses whichever cue was removed, while 4 (13%) showed good responses even with minimal cues. 9 (28%) showed significant lag of accommodation, while a further 9 (28%) showed significant lead, despite complete clinical homogeneity within the group. Many individuals showed poor linkage between vergence and accommodation – often converging well without accommodating appropriately- which suggests that accommodation /vergence linkages may be less firm in many people than the literature suggests.

Clinical examples

Three clinical examples are illustrated in Figure 5.

Figure 5a shows results from a seven year old child with a fully accommodative esotropia (wearing correction). Vergence responses are good with steep slopes showing a tendency to overconverge, but accommodative slopes, even with refractive correction, are very low under all target conditions, suggesting that either accommodation is weak or is being inhibited to facilitate strabismus control. The higher than average vergence response to the blur only (*b*) target suggests the AC/A relationship may be strong.

Figure 5b shows steeper accommodation slopes than vergence slopes in a child with a simulated distance exotropia. Clinically the deviation increased markedly with +3.0 lenses. Target conditions where blur and proximal cues are available show higher slopes than is typical.

Figure 5c shows responses from a 16year old with accommodative spasm. Accommodation is grossly exaggerated in relation to relatively flat vergence responses, especially in conditions where proximal cues are available.

Discussion

It is clear that in the visually mature, normal group, disparity is by far the most important drive to not only vergence, but also to accommodation. This has profound implications for our understanding of both systems. It raises many clinical and research questions which our current four-year study of both normal infants and clinical groups is considering. What happens to accommodation in strabismus, where suppression and amblyopia remove disparity cues? Do squinting children use other cues? Are conditions where accommodation seems implicated in changing the angle of deviation e.g. accommodative esotropia and intermittent exotropia, exceptions to this typical pattern – and does the style of cue use precede or reflect the strabismus? What happens to accommodation in uncorrected (or undercorrected) refractive error and heterophoria?

Preliminary analysis of results show that, in infants, vergence is largely developed by eight weeks of age, while accommodation slopes are less predictable, but steeper than in adults.

Preliminary observations of clinical cases suggest that some accommodative esotropes may chronically under-accommodate in order to maintain alignment even when corrected, as in Figure 5a, but it is not clear whether this is primary or secondary response. Some distance exotropes appear to use proximity or blur as a cue much more than usual, agreeing with clinical observations that proximal fusion and accommodation influence control ⁷. An alternative explanation for the steep accommodation slope in the example in Figure 5c, and the one that our adult data would lead us to favour, is that excessive vergence accommodation is being driven by the convergence effort that is used to control the exotropia, as recently suggested by Firth ⁸.

This equipment is a powerful research tool with which we can study many aspects of binocularity that are of relevance to orthoptics, optometry and vision science. Its flexibility and ease of use for the participants makes it possible to carry out detailed studies that might help us construct new theoretical models of binocular vision.

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Figure 1. Remote Haploscopic Videorefractor. A: target, E: "hot" mirror, F: position of occluder, G: Plusoptix SO4 autorefractor, J: cloth screen. Reproduced by permission of Elsevier Publications.

Figure 2.

Fixation targets to maximise (a) and minimise blur(b) cues. 2a : unscaled coloured detailed clown target. 2b: DoG target scaled for target distance. Details and colours alternate at 1Hz.

Figure 3.

Typical responses from an adult participant. Slope of responses represent gain in relation to target demand. This participant shows almost perfect vergence for demand. Accommodative y-intercept represents manifest refractive error at infinity and vertical offset of accommodation slope represents accommodative lag. Reproduced by permission of Elsevier Publications.

Figure 4.

Mean response gain($\pm$ 95%CI) for different combinations of near cues. A slope of 1.0 denotes perfect response to demand, while slopes of less than 1.0 denote under-responses. Vergence - solid bars; accommodation - hatched bars. Cues available denoted by b=blur, d=disparity, p=proximity e.g. dp(-b)=disparity and proximity cues, but blur minimised (both eyes viewing looming DoG target). o= all cues minimised (occluded, scaled, DoG). Reproduced by permission of Elsevier Publications.

Figure 5.

Clinical examples. 5a. Fully accommodative esotropia (wearing correction). Under accommodation throughout with slight over-convergence. 5b. Distance exotropia. Unusually steep slopes when blur and proximity cues present. Over-accommodation. 5c. Accommodative spasm. Excessive accommodation despite flat vergence slopes.

Table 1

Results of ANOVA with planned comparisons on response slopes comparing effects of removing a cue from the stimulus. Reproduced by permission of Elsevier Publications.

	VERGENCE		ACCOMMODATION	
	F	p	F	p
Removing DISPARITY				
BDP vs BP	246.98	<0.0001	100.19	<0.0001
DP vs P	280.31	<0.0001	103.20	<0.0001
BD vs B	214.36	<0.0001	51.72	<0.0001
Removing BLUR				
BDP vs DP	8.09	0.008	9.37	0.005
BD vs D	1.05	ns	3.89	ns
BP vs P	73.17	0.0001	37.62	<0.0001
Removing PROXIMITY				
BDP vs BD	21.77	0.000	0.14	ns
BP vs B	13.78	0.001	4.18	0.049
DP vs D	0.55	ns	9.49	0.004