

# *Receding and disparity cues aid relaxation of accommodation*

Article

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Abstract: Purpose

Accommodation can mask hyperopia and reduce the accuracy of non-cycloplegic refraction. It is therefore important to minimize accommodation to obtain as accurate a measure of hyperopia as possible. In order to characterize the parameters required to measure the maximally hyperopic error using photorefraction, we used different target types and distances to determine which target was most likely to maximally relax accommodation and thus more accurately detect hyperopia in an individual.

Methods

A PlusoptiX S04 infra-red photorefractor mounted in a remote haploscope presented the targets. All participants were tested with targets at four fixation distances between 0.3m and 2m containing all combinations blur, disparity and proximity/looming cues. 38 infants (6-44 wks) were studied longitudinally, and 104 children (4 -15 yrs (mean 6.4yrs)) and 85 young adults, with a range of refractive errors and binocular vision status, were tested once. Cycloplegic refraction data was available for a sub-set of 59 participants spread across the age range.

Results

The maximally hyperopic refraction (MHR) found at any time in the session was most frequently found when fixating the most distant targets and those containing disparity and proximity/looming cues. Presence or absence of blur was less significant, and targets in which only single cues to depth were present were also less likely to produce MHR. MHR correlated closely with cycloplegic refraction ( $r = 0.93$ , mean difference 0.07D,  $p = n.s.$ , 95%CI  $\pm < 0.25D$ ) after correction by a calibration factor.

Conclusion

Maximum relaxation of accommodation occurred for binocular targets receding into the distance. We suggest that proximal and disparity cues aid relaxation of accommodation to a greater extent than blur, and thus non-cycloplegic autorefraction targets should incorporate these cues. This is especially important in screening contexts with a brief opportunity to test for significant hyperopia. MHR in our laboratory was found to be a reliable estimation of MSE by cycloplegic refraction.



# Receding and disparity cues aid relaxation of accommodation

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1    Abstract

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9    *Methods*

10   A PlusoptiX SO4 infra-red photorefractor mounted in a remote haploscope presented the  
11   targets. All participants were tested with targets at four fixation distances between 0.3m  
12   and 2m containing all combinations blur, disparity and proximity/looming cues. 38 infants  
13   (6-44 wks) were studied longitudinally, and 104 children (4 -15 yrs (mean 6.4)) and 85  
14   adults, with a range of refractive errors and binocular vision status, were tested once.  
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21   which only single cues to depth were present were also less likely to produce MHR. MHR  
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25 Maximum relaxation of accommodation occurred for binocular targets receding into the  
26 distance. We proximal and disparity cues aid relaxation of accommodation to a greater  
27 extent than blur, and thus non-cycloplegic refraction targets should incorporate these cues.  
28 This is especially important in screening contexts with a brief opportunity to test for  
29 significant hyperopia. MHR in our laboratory was found to be a reliable estimation of  
30 cycloplegic refraction.

31

## 32 *Key Words*

33 Accommodation cues hyperopia photorefraction infant

34

1 The motivation for this study was to determine how best to estimate maximally  
2 hyperopic spherical refraction (MHR) using non-cycloplegic photorefractometry. In our  
3 laboratory this is particularly important for our research into the development of  
4 accommodation, since many infants and children are known to be hyperopic, and  
5 this hyperopia may not only change rapidly in infancy<sup>1, 2</sup> but also is likely to  
6 influence accommodation responses. Cycloplegic refraction gives a “gold standard”  
7 measure of refractive error in children, but cycloplegic refraction is not practicable  
8 with frequently repeated sessions and is ethically questionable in typically  
9 developing children, so we were keen to ascertain the most accurate non-cycloplegic  
10 estimate of refraction.

11 Outside the research context, it is not practicable to use cycloplegic refraction in  
12 large-scale screening situations, and so non-cycloplegic autorefractometry is commonly  
13 used for detecting and assessing significant refractive error. It is quick, acceptable to  
14 children and can be administered by less highly trained personnel. There is always,  
15 however, a risk of underestimation of hyperopia (and over estimation of myopia<sup>3, 4</sup>)  
16 if accommodation is active. Recent reports by Dahlman-Noor et al<sup>5, 6</sup> show that the  
17 Plusoptix SO4 photoscreener we discuss here, if used alone, may underestimate  
18 refractive error and may miss significant clinical problems. Kaakinen and Ranta-  
19 Kemppainen<sup>7</sup>, using a two-flash method, also reported false negatives, and under-  
20 referral of hyperopia, as did Ghose et al using a NR-1000F Auto Refractometer<sup>8</sup>.  
21 Hyperopia is, however, arguably the most important refractive error to detect in  
22 young children because of its association with strabismus and amblyopia<sup>9-12</sup>.  
23 Hyperopia is also reported to be associated with poor progress at school<sup>13,14</sup> and



24 poorer motor skills<sup>15</sup>. It is therefore important to develop screening paradigms  
25 which have the best chance of correctly detecting hyperopia, and therefore lead to  
26 more hyperopic children receiving prompt correction.

27 In more general accommodation research it may also be important to open the  
28 accommodation loop to study responses. Most methods used are based on the  
29 assumption that blur is the main cue to accommodation, so minimizing blur cues will  
30 open the loop and help minimize accommodation. Although absence of all visual  
31 stimuli leads to intermediate levels of accommodation, such as in the case of dark  
32 focus<sup>16</sup>, different methods at higher light levels have been found produce responses  
33 nearer to those found under cycloplegia. Experimentally, pinholes or difference of  
34 Gaussian (DoG) targets<sup>17</sup> can be used, while different commercial autorefractors  
35 minimize accommodation by placing the targets at optical infinity, or using non-  
36 accommodative targets such as spot lights or LEDs.

37 In optometric practice, the fogging technique is a common method used to minimize  
38 accommodation during refraction<sup>18, 19</sup>. Queiros et al<sup>20</sup> used autorefraction to  
39 compare open field accommodative responses with non-fogged viewing, +2.00D  
40 fogging lenses, and responses with cycloplegia and found that fogging lenses helped  
41 relaxation of monocular accommodation.

42 In terms of target distance, Suryakumar & Bobier<sup>21</sup> compared different types of  
43 autorefractor at the manufacturer's recommended testing distances and also added  
44 a 3.5m DoG target. They found that farther testing distances and a DoG target aided  
45 detection of maximum hyperopia.

46 Many of the above studies only reported results from one eye and some did not  
47 specify whether the children were occluded at the time of refraction. We <sup>22</sup>, and  
48 others <sup>23</sup> have found, in both infants and older subjects, that disparity cues have a  
49 large influence on accommodative responses, supporting views for a strong role for  
50 vergence accommodation<sup>24-26</sup>. It is therefore possible that disparity also plays a role  
51 in the relaxation, as well as the exercise of accommodation. Proximal / looming cues  
52 may also have a role, especially in early infancy where not only may disparity  
53 detection be immature but blur cues also be unreliable due to poor acuity <sup>27</sup> or the  
54 high prevalence of refractive errors <sup>1</sup>.

55 Although there have been reports comparing different photoscreening methods <sup>28-31</sup>  
56 and others comparing accommodative responses to some of the techniques  
57 commonly used to relax accommodation<sup>18-20</sup>, there have been no reports specifically  
58 addressing a wide spectrum of target types during autorefraction in a within-subjects  
59 design with a range of participants and age-groups.

60 Our laboratory has been investigating accommodation and vergence responses to  
61 different combinations of the three main near cues of disparity, blur and  
62 proximity/looming using an autorefraction technique in a large group of participants  
63 from infancy to adulthood. We have used this dataset to establish the target type  
64 that maximizes hyperopic refraction within a testing session and have compared this  
65 estimate of refraction (mean spherical equivalent (MSE)) to that obtained from a  
66 “gold standard” cycloplegic retinoscopy in a subsample of participants. We have  
67 considered whether increasing target distance beyond 1 meter increases accuracy  
68 and whether statistical differences are large enough to be clinically significant. We

have also examined the data to ascertain whether our findings are applicable across the age span. If we can demonstrate that they are, our findings may also help to improve accuracy of photoscreening and refraction in a wider context.

## Methods

All studies adhered to the tenets of the Declaration of Helsinki and were scrutinized by University of Reading and UK National Health Service Ethics Committees. Adults and parents of children under 6 years gave fully informed consent. Parents of children older than 6 years gave fully informed consent and the children themselves gave informed assent appropriate to their age.

Our laboratory uses a remote haploscopic videorefractor (RHV) to measure vergence and accommodation responses in naturalistic conditions. This apparatus has been described in detail elsewhere<sup>22</sup> but is described briefly here. It combines two optical pathways, one for target presentation and manipulation and one for data capture (Figure 1). The participant sees that target approaching and receding in the mid-line, while infra-red photorefraction occurs in the same plane independent of target position.

.....Figure 1 .....

### *Photorefraction Pathway*

We use a commercially available infra-red photorefractor (PlusoptiX S04, Plusoptix GmbH, Nuremberg, Germany). This is primarily marketed and used for child vision screening in the “C-Mode” but also incorporates a PowerRefII (“R-Mode”) that

90 makes simultaneous recordings of accommodative state and gaze direction, which  
91 we are using to carry out our more detailed studies. In our laboratory the PlusoptiX  
92 S04 captures the image of the participant's eyes via a large 600mm diameter "hot"  
93 mirror which reflects infra-red wavelengths but allows through visible light. As we  
94 are interested in binocular responses, the camera is mounted in the midline between  
95 the eyes. The fixation LEDs on the photorefractor are covered with opaque tape.  
96 When no target is presented, the infra-red sources can be seen subjectively as very  
97 faint red dots, but when any fixation target is on the target monitor, these are  
98 obscured by the brighter target elements and are invisible to the participant.

99 During the calibration phase of our studies we consistently measured a smaller  
100 accommodative response (more hyperopic spherical refraction) to target demand  
101 with the RHV in comparison to dynamic retinoscopy, and this increased away from 0  
102 D, as found by Harb et al using an earlier version of the PowerRefractor<sup>32</sup>. We used a  
103 correction function of  $1.2385x + 0.799$ , where  $x$  = accommodation measured by the  
104 PowerRefII, to adjust estimates of refraction in our lab.

#### 105 *Target Pathway*

106 The targets are presented on a video monitor mounted on a motorized beam and  
107 viewed via two concave mirrors such that the image is placed optically at target  
108 positions between 0.25m and 2m from the participant. Targets are presented at five  
109 different fixation distances in a pseudo-random order (0.3m, 2m, 0.25m, 1m, 2m),  
110 representing 4D-0.5D demand. Data from the 0.25m target was discarded due to the  
111 unacceptable loss of data caused by small pupils in many participants, but the target

position was retained in the presentation sequence because it meant that a distant target was always presented after a near one and vice versa.

The advantages of the mirror system are that target presentation and photorefraction can occur in the same plane without the sensors obscuring the target, or vice versa, and also that disparity cues can be removed by occluding half of the upper mirror remote from the participant (F in Figure 1), so there is no distracting occluder visible to the participant.

### *Targets*

The same range of targets was used for all participants, designed to maximize or minimize access to blur, disparity and proximity cues separately. Blur cues were made available by using a high contrast brightly colored clown target containing a wide range of spatial frequencies. Blur cues were minimized using a similar sized DoG target against a black background, which has been found to open the accommodation loop<sup>17</sup>. Both targets alternated at 1Hz between two different forms in terms of color (DoG target) and detail (clown target) to maintain attention of the youngest participants. Disparity cues were available when both eyes viewed the target, and eliminated by remote occlusion at the level of the upper mirror. The occlusion is invisible to the participant and even approximately 30% of adults were unaware that they had been monocular at times. Looming / proximity cues were made available by presenting the same size target at each fixation distance and allowing the participant to watch the monitor move between target positions (both the clown and the DoG targets subtended  $3.15^\circ$  at 2m and  $18.26^\circ$  at 33cm). Proximity cues were minimized by scaling the targets so that they subtended the

135 same angular subtense at each fixation distance (3.15°), and also by obscuring the  
136 participants' view of the screen with an opaque black cloth screen as it moved  
137 between fixation distances so that the target was only uncovered once the monitor  
138 had stopped moving and its position could not be guessed from changing size cues.

139 We were therefore able to present all combinations of the three main cues to  
140 vergence and accommodation. Although the monitor and camera are mounted  
141 within black painted shuttering, some residual minimal looming and blur cues are  
142 still available from the background luminance of the black screen background against  
143 the screen edge, despite efforts to mask this with graduated filters, so a "zero" cue  
144 condition was also included to assess the impact of residual cues we could not  
145 eliminate. Testing order was standardized across all participants and was designed to  
146 maximize infant data, where a full testing session with all cue combinations  
147 presented might exceed attention span, but where we were particularly interested in  
148 the relative use of the different cues. We, and others, have reported that infant  
149 attention reduces under monocular conditions<sup>23,33</sup> and we anticipated that  
150 removing either of the other two cues could have similar effects, while removing two  
151 of the three cues might be even more disruptive. In order to maximize data in infants  
152 with limited attention, we chose to present the all-cue (blur, disparity & proximity  
153 (*bdp* – binocular, looming, clown)) condition first, followed by a block of the three  
154 conditions in which one-cue was removed (*bd* (binocular, scaled clown),  
155 *bp*(looming, occluded clown) or *dp* (binocular, looming DoG) with testing order  
156 counterbalanced across participants. If attention permitted, we then tested the  
157 three conditions in which one cue only was presented (*b* (occluded, scaled clown), *d*

(binocular, scaled DoG) or *p* (occluded, looming DoG)), also counterbalanced between participants. A penultimate “zero cue” (occluded, scaled DoG) was presented next, followed by a final all-cue (*bdp*) condition. Repeating the all-cue condition at the end enabled us to assess whether waning attention was due to reducing cues or fatigue. All participants reported here were those who completed testing with all eight target conditions. With all except the youngest infants, testing was repeated within the testing session in a counterbalanced order.

### *Participants*

Participants were recruited from the Infant Database and Psychology Undergraduate Research Panel at the University of Reading, as well as local hospital children’s eye clinic patients and their siblings. As we were interested in providing data that could be used to improve testing in unselected populations we have included all the participants tested in our laboratory who were able to complete testing with the full range of targets. We therefore did not select on the basis of visual acuity, refractive error or binocular status. Any participants showing refractions outside the operating range of the PowerRef II (-7.0D to +5.0D) at any time were excluded.

38 infants were able to provide a full dataset and were seen on between one and nine occasions (mean 3.05 visits) between the ages of 6 and 44 weeks as part of a longitudinal study of typical development. None have subsequently developed strabismus. As refractive error is known to change rapidly throughout early infancy we have included data from repeated testing sessions. 104 children between 4 and 15 years were assessed (mean age 6.4yrs SD±1.9yrs). 52 of these were developing typically with visual acuity of better than 0.2 LogMAR in either eye and no

181 strabismus. 52 children had a refractive error within the operating range of the  
182 Plusoptix S04 and/or intermittent strabismus. Six had small angle constant  
183 strabismus with gross stereopsis on the Titmus stereotest and 33 had intermittent  
184 eso- or exotropia with normal binocular vision (60 seconds of arc on the TNO  
185 stereotest ) when the deviation was controlled. For this study all measurements  
186 were carried out without spectacles. We also tested 85 young adults between 19 and  
187 25 years of age. All had had a recent subjective refraction. 59 of the adults did not  
188 wear a correction (refraction MSE within 0.75D of emmetropia) and the others had a  
189 range of refractive errors and were tested either with their own contact lenses  
190 (n=16) or without glasses if worn (n=10).

191 All non-infant children and adults were tested on only one visit but measurements  
192 were repeated within the session to assess for repeatability. As many of our studies  
193 are on infant development, we made strenuous efforts to ensure that our older  
194 participants were completely naïve to vision experiments and the theory of vision.  
195 None of the child or adult participants had been given orthoptic exercises that might  
196 have changed their habitual responses to blur or disparity cues.

197 Of this large group of infants and children, we were able to obtain recent cycloplegic  
198 refraction data on 59 participants. This testing was carried out 40 minutes after using  
199 2 drops of cyclopentolate hydrochloride 1% in each eye, within 3 months of testing  
200 in the laboratory for the children and within one month for the infants (17 of which  
201 were infants at 26 weeks) who might be emmetropizing more rapidly.

## 202 *Analysis*



Data was recorded and analyzed initially using Excel. Statistical analyses were carried out using SPSS 14.

## Results

Data were available from 316 testing sessions with 227 participants. Because of the testing sequence used, all targets were tested at least once, but the *bdp* target was tested at the beginning and end of testing. Examination of repeated data (*bdp* at the start and end of each testing sequence, and repetition of all targets in a counterbalanced order if co-operation allowed) showed no significant differences in accommodation responses between testing early or late in the sequence ( $p > 0.4$  in all comparisons), i.e. there were no fatigue or practice effects.

For each participant, the target which produced the maximally hyperopic refraction during the session was determined. Figure 2 shows the percentage of MHR found for each target condition. There was a significant difference in the distribution of the MHR across targets ( $\chi^2 = 110.0$ , df 7,  $p < 0.00001$ ). MHR was most frequently found when using the *bdp* (binocular, looming clown) and *dp* (binocular, looming DoG) targets. These two target conditions together contributed 49.8% of all maximum hyperopia / minimum myopias.

.....Figure 2 .....

Figure 3 shows the numbers of MHR found if a target did, or did not contain an individual cue. Any target that contained proximal / looming clues (*bdp*, *dp*, *bp* and *p*) was more effective in producing maximum hyperopic error than those that did not ( $\chi^2 = 111.6$ , df 1,  $p < 0.00001$ ). A similar comparison between targets that containing

disparity cues versus those without disparity showed that MHR was found more often when the target contained disparity cues ( $\chi^2 = 54.1$ ,  $df\ 1$ ,  $p < 0.00001$ ) but the effect for proximity was larger than for disparity. The MHR was also more likely to be found in targets that included blur as a cue to depth than those without ( $\chi^2 = 12.83$ ,  $df\ 1$ ,  $p < 0.0003$ )

So despite literature suggesting that minimizing blur cues helps relax accommodation, more MHRs were found with targets containing target detail than those which did not. While all three cues appear significantly associated with helping to relax accommodation, including proximity and disparity in the target appears the most effective in relaxing accommodation.

.....Figure 3 .....

The data were then divided by age group. We grouped the data into 3 groups - infants, children between 4 & 15 years, who have passed the most active phases of the visual critical period but who would be expected to have the most active accommodation, and adults (Figure 4).

.....Figure 4 .....

There were no significant differences in the distribution of the target which produced the MHR between age groups. The largest age difference was in the  $dp$  condition, where infants showed proportionally more MHR than children or adults, but even this difference failed to reach significance ( $\chi^2 = 1.89$ ,  $df\ 2$ ,  $p = 0.38$ ).

.....Figure 5 .....

Figure 5 shows the percentage of MHR found at each target distance with Figure 5a showing the results for all participants and Figure 5b showing the results for only those participants with an MHR greater than +2.00D. When all participants were considered together, the MHR was overwhelmingly found for the most distant target ( $\chi^2=305.2$ , df 3,  $p<0.0001$ ). When examined by age group this pattern remained stable ( $p<0.0001$  in all cases). When the higher refractive errors ( $>+2.00$ DS) were examined separately, MHR's were found almost equally at the 0.5 and 1D targets ( $\chi^2=0.02$ , df 1,  $p=0.88$ ). Although small numbers limited statistical analysis of these hyperopes by age, it was noticeable that of the 19 over 4 yrs of age there appeared to be less association between target distance and MHR ( $n=7,7,6,3$  at 0.5D, 1D, 2D and 3D demand respectively).

We considered whether the significant difference in refraction between fixation at 1m and 2m (as found by Suryakumar & Bobier<sup>21</sup>) was large enough to be clinically meaningful and whether it differed across targets. Mean accommodation at 0.5D demand was significantly less than that at 1D across all target conditions (mean difference 0.23D, 95%CI  $\pm 0.05$ D ( $F=159.7$ , df1,292,  $p<0.0001$ ) but with no significant interaction with target type ( $F(7,2044)=1.3$ ,  $p=0.22$ )(Fig 6). The variance in these data was remarkably similar. There was a small difference in variance between target type ( $F(7,4832)=2.41$ ,  $p=0.019$ ), with the *bdp* target having the smallest variance, but there were no difference between the variances for the 0.5D and 1D target distances ( $F(7,4838)=2.46$ ,  $p=0.116$ ), and, overall, these differences in standard error (between  $\pm 0.125$  and 0.156D) were not large enough to be clinically significant.

269 .....Figure 6 .....

270 We next considered how MHR compared with other actual and extrapolated  
 271 measures of refraction we had available in our dataset. In previous studies, we have  
 272 used the y-intercept of the accommodative response against demand as an estimate  
 273 of refraction at infinity, and therefore maximum refractive error<sup>33</sup>. In the current  
 274 study, both measures were available, so we compared y-intercept across targets and  
 275 with MHR.

276 As with the MHR counts, the maximally hyperopic intercepts for most individuals  
 277 were found with the *bdp* and *dp* targets, but even the most hyperopic of the mean y-  
 278 intercepts ( found in the *bdp* condition) is 0.32D less hyperopic than the mean  
 279 MHR( $t=9.94$ ,  $df\ 315$ ,  $p<0.00001$ ). (Figure 7)

280 .....Figure 7.....

281 Finally, we were able to compare MHR and mean spherical equivalent (MSE) derived  
 282 from cycloplegic retinoscopy on the 59 participants for whom we had recent data  
 283 (Figure 8).

284 Mean cycloplegic retinoscopy was only 0.07D ( $\pm 95\%$ CI of 0.23D) more hyperopic  
 285 than MHR, with a high correlation co-efficient of 0.93 in this very heterogeneous  
 286 group. If MHR is compared with the “gold standard” cycloplegic retinoscopy, using a  
 287 criterion of +2.0 for a marginally clinically significant error, MHR showed a sensitivity  
 288 of 83.3% and a specificity of 91% in detecting refractive error of  $>2.00D$ , comparing  
 289 very favorably with other methods<sup>29, 30, 34</sup>. If the same comparison is made with y-  
 290 intercept of accommodation against demand using the *bdp* target (which we found

the most accurate of the estimates of refraction)(open data points in Figure 8), sensitivity falls to 45% indicating that some hyperopes would not be detected by using this measure, although specificity remained high at 95%

.....Figure 8 .....

### Discussion

The primary motivation for this analysis was to determine how best to estimate refractive error in a group of infants we are studying in our laboratory. In doing so we have also collected data from participants of all ages, using a repeated measures design, the same equipment and lighting conditions and a minimal instruction set. The only experimental manipulation was the target type and position. Our findings, therefore, have wider clinical applications

In general, more cues are better than fewer when assessing maximal hyperopic error. The target most likely to elicit maximum hyperopia or minimum myopia for an individual was not necessarily a blurred target, as might be expected from the common clinical use of fogging lenses to relax accommodation, but one that contained disparity and looming cues as the target was observed receding into the distance. Presence or absence of blur was the least influential of the three near cues we tested, and MHR was just as likely to be found in a target condition that contained detail as in one that did not. Removing blur from the 3-cue condition (*bdp* vs *dp*), or adding blur as a single cue (*b* vs *o* condition) made little difference to the proportions of MHR found between these categories. This intuitively surprising finding differs from the findings of Queiros et al <sup>20</sup>who found that fogging lenses

helped relax accommodation. Suryakumar & Bobier<sup>21</sup> found that refraction using a DoG target was more hyperopic than using a LED fixation target. However in their study the different fixation distances used with these two targets make it difficult to differentiate the effect of the target from that of fixation distance. They also state, in an appendix to the paper, that a pilot study failed to find differences between LEDs and high contrast accommodative targets at the same fixation distance. It is possible that the differences in our data may be explained by our DoG target being too blurred or qualitatively different in comparison to the usual +2.00D fogging lens, and so induce some pseudo-myopia<sup>35</sup> rather than relaxing accommodation, but Chiu et al<sup>18</sup> have suggested that the amount of fogging is of relatively little importance, so this explanation seems unlikely.

Although some studies have looked at the best target and testing distance to help relax accommodation<sup>20, 21</sup>, none have looked systematically at target type and distance in the same participants. Our findings largely support those of others<sup>21</sup> in that distant targets relax accommodation more than nearer ones, but we suggest that additional hyperopia can be revealed in many individuals by using a binocular, receding target.

It is not surprising that the most distant target produced most MHRs, and we found that the difference in refraction between the 2m and 1m targets remained relatively constant across targets. Suryakumar & Bobier<sup>21</sup> also found that the farthest distant targets relax accommodation the most, but also found that responses were less variable at these greater fixation distances. We found non-significant differences in the variance between the two most distant fixation targets in any of the cue

conditions. In participants with refraction  $< +2.0\text{D}$ , MHR occurred less reliably at the 2m target, possibly suggesting more variability or less sensitivity to target distance in these individuals, which would benefit from further study.

Our results are supported by our previous research. We have reported that in normal, emmetropic, naïve adults, disparity is the primary cue for both vergence and accommodation to near targets<sup>22</sup>. Reducing disparity, therefore, may well help relax accommodation as well as it drives it, increasing the number of MHRs found (e.g. the large difference between *bdp* vs *bp* conditions) although alone (the *d* vs *o* condition) disparity seems to have little effect. Fukuda et al<sup>36</sup> found that accommodation velocity was also greater in binocular conditions, so giving additional support to the view that disparity helps accommodation accuracy more than does blur.

The strong effect of proximity / looming was less expected. Like disparity, it seems to have a weak effect as a single cue (*p* vs *o* condition), but in combination with disparity it was the cue which predicted the highest proportion of MHRs. We have reported that proximity is an extremely weak cue in comparison to disparity<sup>22</sup> in driving both vergence and accommodation to near targets in naïve adults (as opposed to those with some knowledge of vision experiments as studied by others<sup>37</sup>). Hung et al<sup>38</sup>, also suggested that proximity played a small part under naturalistic conditions, but here, in combination with disparity in a very naturalistic setting, the “negative looming” of the moving target seems to help in relaxing accommodation in the distance.

If a correction is made for the systematic underestimation of accommodation by the PlusoptiX SO4 in our laboratory, MHR also agreed extremely well with cycloplegic

refraction. When analyzed by age group and refractive error, we found no systematic age differences, so our findings may be useful not only in our laboratory, but also in clinical settings.

In the past we have used y-intercept of accommodation response slopes as a proxy measure of refraction in our laboratory<sup>33, 39, 40</sup>, but because of the variance in some of the infant data, where responses may be more erratic, and the flatter response slopes in impoverished cue conditions, we now believe that MHR found at any time within a session is a more reliable estimate of true refraction in our laboratory, as demonstrated by the close correlation with cycloplegic refraction (with narrow confidence limits of less than  $\pm 0.25D$ ). MHR has a much greater sensitivity in detecting significant hyperopia than when using y-intercept. However, the scope for statistical analysis of our categorical data was somewhat limited and so further corroborative research may be necessary.

A further area for future research is to consider groups that would not be expected to have normal disparity detection mechanisms e.g. the very youngest infants under 12-16 weeks, before stereopsis has fully developed<sup>41</sup>, and strabismic older children with constant suppression. Our numbers were too small here, and we had no participants with total absence of binocularity, but we would predict that disparity cues would be less influential in these individuals and may differ depending on the strength of binocularity or suppression. Such groups also have a high prevalence of refractive error, so they may rely even more heavily on proximal cues.

These data have some wider clinical implications. In terms of refractive errors, while myopia may be more of a problem with older children, hyperopia is arguably the



most pressing condition for younger children. As well as reducing visual acuity, hyperopia is co-morbid with strabismus, amblyopia and failure at school<sup>42, 43</sup> and needs more prompt referral to avoid amblyopia and loss of binocularity. It may, however, remain undetected or underestimated if accommodation is exerted at the time of testing. Picking a target that increases the chances of detecting maximum hyperopia is clearly preferable in young children.

In the absence of cycloplegia, there are many optometric techniques available to reveal maximum hyperopia during a detailed subjective refraction within a comprehensive and skilled examination. We did not assess the sustained responses that are necessary for such testing and so our findings may not necessarily transfer to these situations. Autorefraction screening situations, however, often use unskilled personnel in a “one off” event and using a pass/fail criterion. We have found that changing the target increases the chances of revealing a maximum hyperopia which is very close to that of a cycloplegic refraction. Our findings appear to be consistent across all the participants tested, so may be useful in developing techniques to reduce false positives in the case of myopia and false negatives in the case of hyperopia. No one target always produces MHR, and MHR can be found with any target, so non-cycloplegic autorefraction still risks missing some hyperopic children, but a binocular receding target, whether blurred or clear, increases the probability of maximum accommodative relaxation, so increasing sensitivity & specificity in detecting hyperopia. Adding a looming component to a binocular fixation target may also aid subjective refraction in office situations and may be a fruitful topic for future clinical research.

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- 515



## 516 Figure Legends

### 517 Figure 1

518 Remote haploscopic videorefractor. A. Motorised beam. B. Target monitor. C. Upper  
519 concave mirror. D. Lower concave mirror. E. Hot mirror. F. Image of participant's eye  
520 where occlusion takes place. G. PlusoptiX SO4 PowerRef II. H. Headrest J. Raisable  
521 black cloth screen.

### 522 Figure 2

523 Percentages of MHR found for each target condition

### 524 Figure 3

525 Distribution of MHR according to whether an individual cue was present or absent in  
526 the target. Pale bars = cue present, dark bars = cue absent.  $p =$   
527 proximity/looming ( $bdp, bp, dp, p$  targets vs.  $bd, b, d, o$ ),  $d =$  disparity ( $bdp, bd, dp, d$   
528 targets vs.  $bp, b, p, o$ ),  $b =$  blur ( $bdp, bd, bp, b$  vs.  $dp, d, p, o$ ). All differences between  
529 present and absent cues significant.

### 530 Figure 4.

531 Distribution of MHR across age groups and target. There were no significant  
532 differences between age groups.

### 533 Figure 5

534 Target distances where MHR found (%). a) all participants ( $n = 316$ ) b) hyperopes  
535  $\geq 2.00D$  only ( $n = 55$ )

### 536 Figure 6

537 Accommodation responses at 2m (0.5D) and 1m (1D) fixation distances. NB. Includes  
538 a wide range of refractive errors and ages. Note similar size standard error bars in  
539 every cue condition.

540 Figure7.

541 y-intercepts of mean accommodation (response against target demand) by target  
542 type (dotted line = mean y- intercept across all targets). Minimum (most hyperopic)  
543 y-intercepts also found in the bdp and dp conditions, but always less hyperopic than  
544 mean MHR (dashed line) in the same participants.

545 Figure 8.

546 MHR and y-intercept of accommodation (*bdp* target) against demand compared with  
547 refraction obtained from cycloplegic refraction (mean spherical equivalent). Filled  
548 points and solid fit line = MHR vs cyclo. Open points and dotted fit line = y-intercept  
549 vs cyclo.

550

Figure

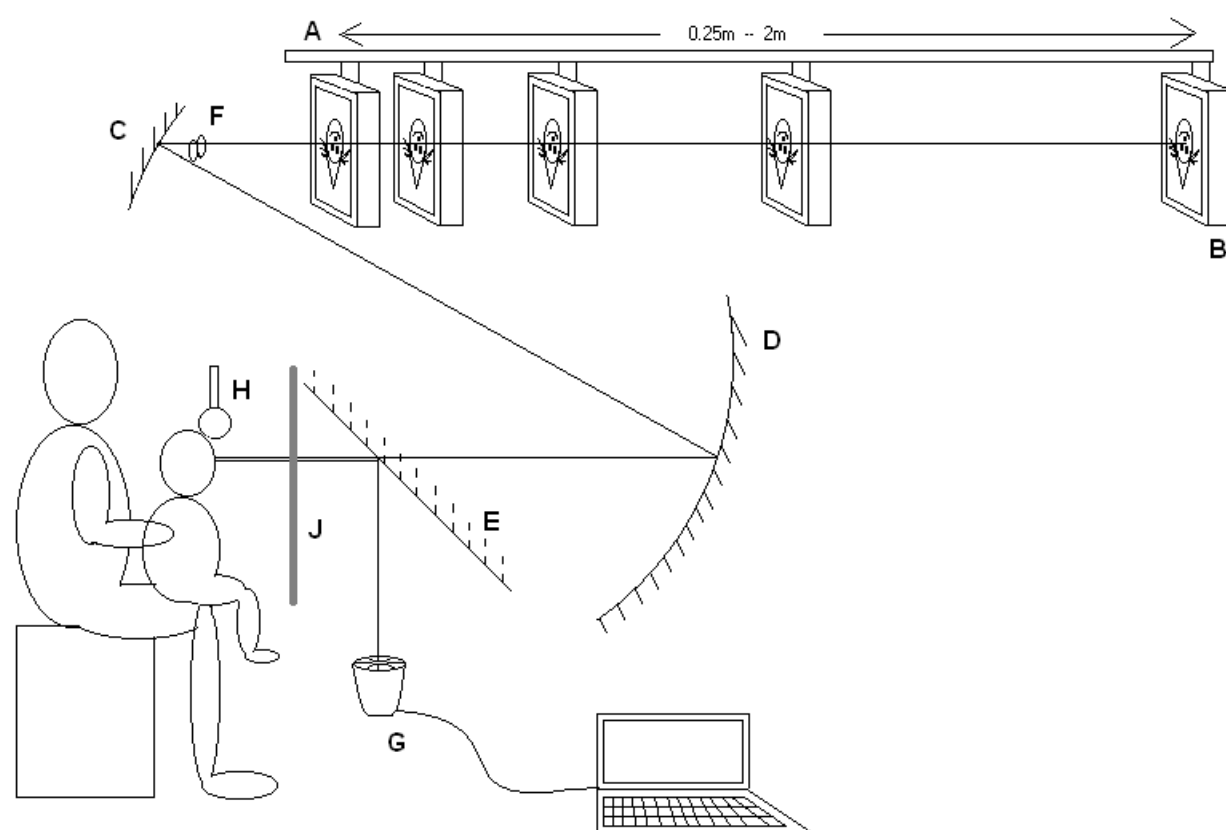


Figure 1

Figure

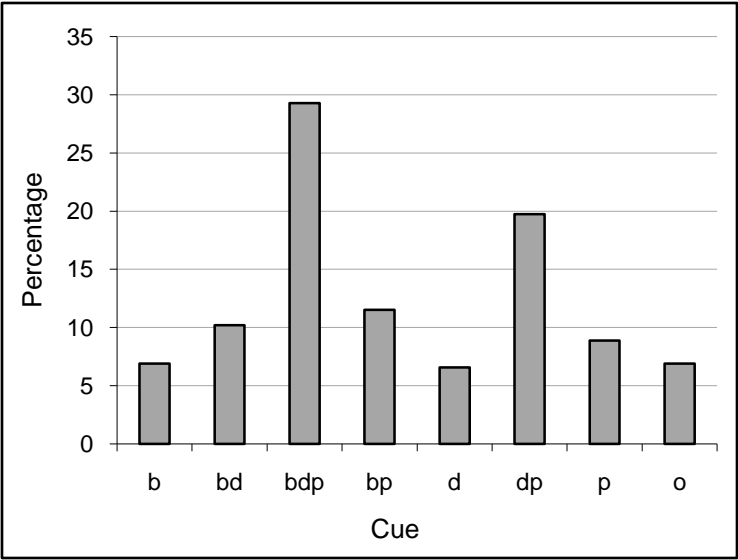


Figure 2

Figure

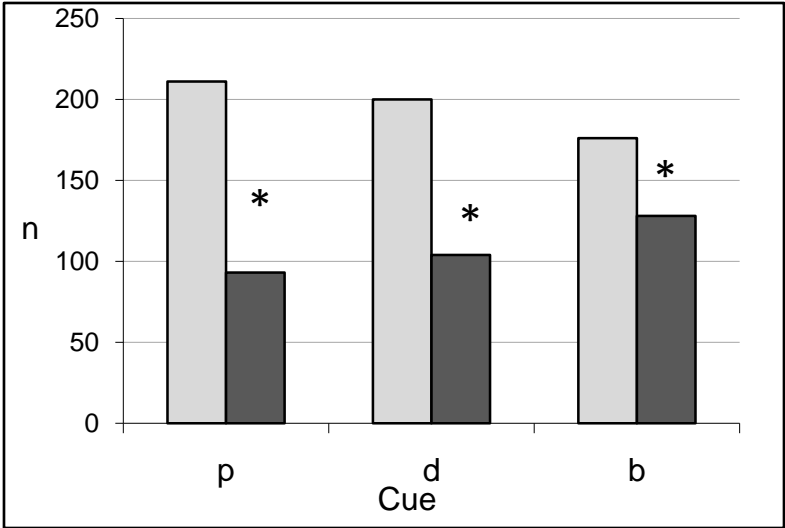


Figure 3

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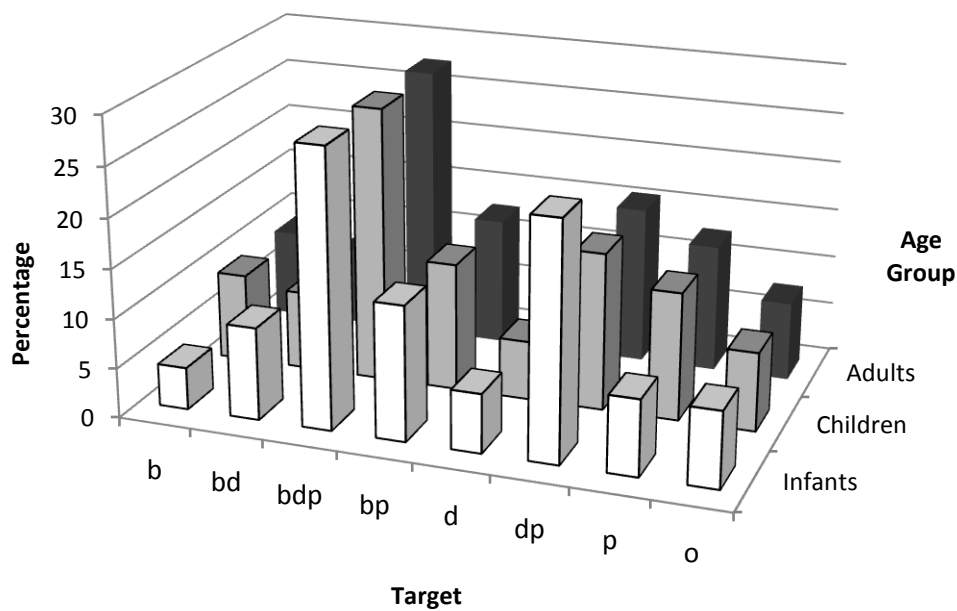


Figure 4

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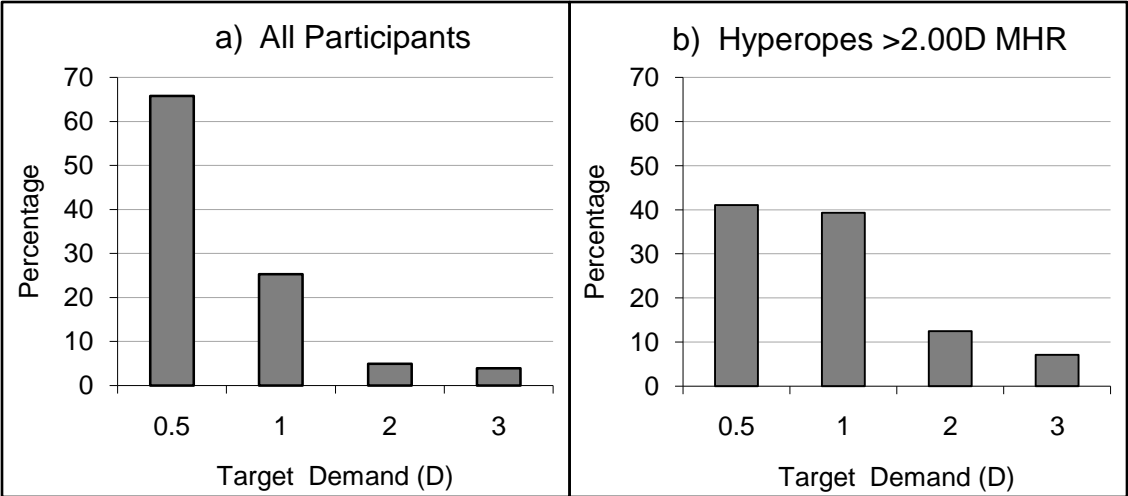


Figure 5

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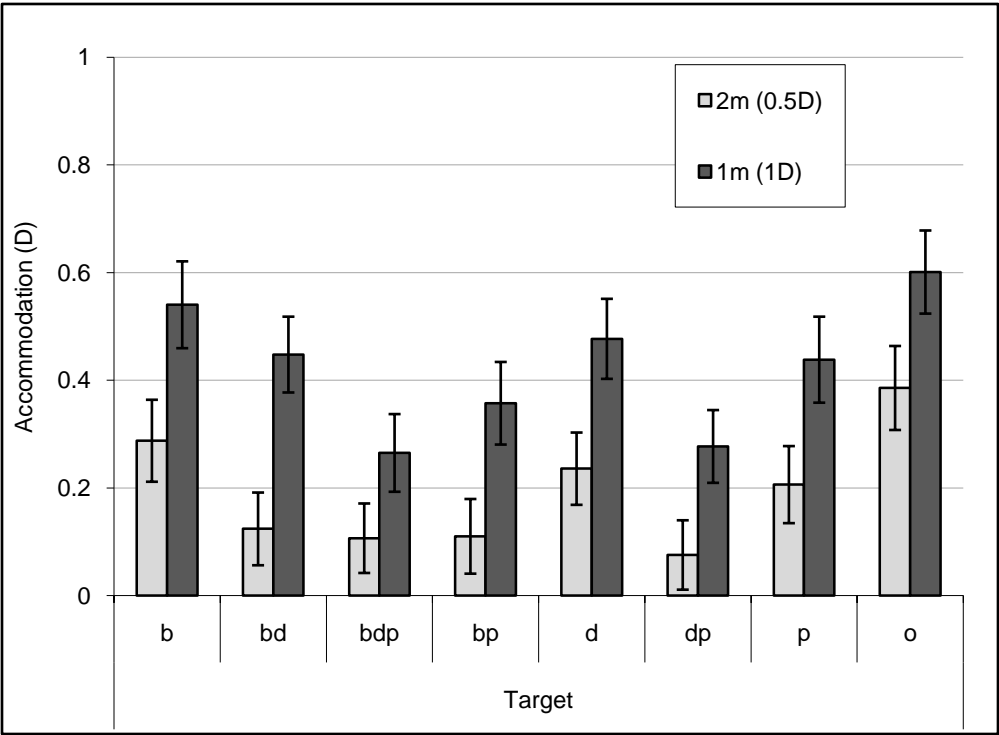


Figure 6



Figure

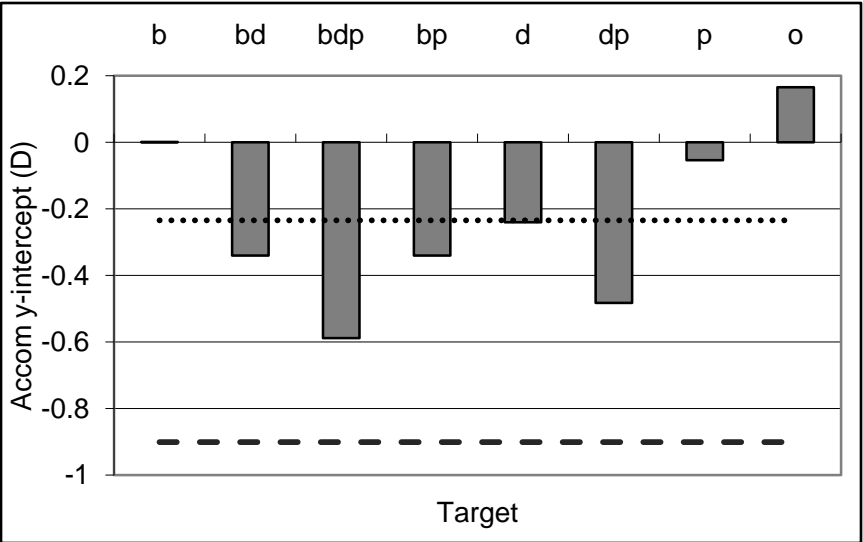


Figure 7

Figure

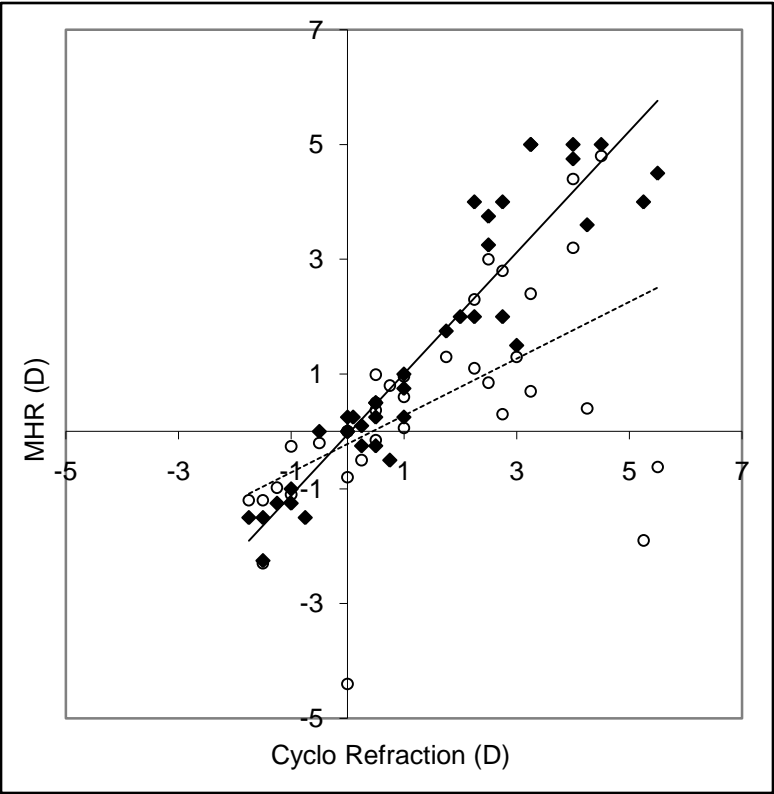


Figure 8