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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 photorefracton, 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 SO4 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 autorefracton 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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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 photorefraction. 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^{1, 2} 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 autorefraction 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^{3, 4})
16 if accommodation is active. Recent reports by Dahlman-Noor et al^{5, 6} 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 Kemppainen⁷, 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 Refractometer⁸.
21 Hyperopia is, however, arguably the most important refractive error to detect in
22 young children because of its association with strabismus and amblyopia⁹⁻¹².
23 Hyperopia is also reported to be associated with poor progress at school^{13,14} and

24 poorer motor skills¹⁵. 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 focus¹⁶, 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) targets¹⁷ 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^{18,19}. Queiros et al²⁰ 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 & Bobier²¹ 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 ²², and
48 others ²³ 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 accommodation²⁴⁻²⁶. 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 ²⁷ or the
54 high prevalence of refractive errors ¹.

55 Although there have been reports comparing different photoscreening methods ²⁸⁻³¹
56 and others comparing accommodative responses to some of the techniques
57 commonly used to relax accommodation¹⁸⁻²⁰, 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

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

72 Methods

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

78 Our laboratory uses a remote haploscopic videorefractor (RHV) to measure vergence
79 and accommodation responses in naturalistic conditions. This apparatus has been
80 described in detail elsewhere²² but is described briefly here. It combines two optical
81 pathways, one for target presentation and manipulation and one for data capture
82 (Figure 1). The participant sees that target approaching and receding in the mid-line,
83 while infra-red photorefraction occurs in the same plane independent of target
84 position.

85Figure 1

86 *Photorefraction Pathway*

87 We use a commercially available infra-red photorefractor (PlusoptiX S04, Plusoptix
88 GmbH, Nuremberg, Germany). This is primarily marketed and used for child vision
89 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 PowerRefractor³². We used a
103 correction function of $1.2385x+0.799$, where x = accommodation measured by the
104 PowerRefractor, 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

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

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

119 *Targets*

120 The same range of targets was used for all participants, designed to maximize or
121 minimize access to blur, disparity and proximity cues separately. Blur cues were
122 made available by using a high contrast brightly colored clown target containing a
123 wide range of spatial frequencies. Blur cues were minimized using a similar sized
124 DoG target against a black background, which has been found to open the
125 accommodation loop¹⁷. Both targets alternated at 1Hz between two different forms
126 in terms of color (DoG target) and detail (clown target) to maintain attention of the
127 youngest participants. Disparity cues were available when both eyes viewed the
128 target, and eliminated by remote occlusion at the level of the upper mirror. The
129 occlusion is invisible to the participant and even approximately 30% of adults were
130 unaware that they had been monocular at times. Looming / proximity cues were
131 made available by presenting the same size target at each fixation distance and
132 allowing the participant to watch the monitor move between target positions (both
133 the clown and the DoG targets subtended 3.15° at 2m and 18.26° at 33cm).
134 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^{23,33} 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*

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

165 *Participants*

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

174 38 infants were able to provide a full dataset and were seen on between one and
175 nine occasions (mean 3.05 visits) between the ages of 6 and 44 weeks as part of a
176 longitudinal study of typical development. None have subsequently developed
177 strabismus. As refractive error is known to change rapidly throughout early infancy
178 we have included data from repeated testing sessions. 104 children between 4 and
179 15 years were assessed (mean age 6.4yrs $SD \pm 1.9$ yrs). 52 of these were developing
180 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*

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

205 Results

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

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

220Figure 2

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

225 disparity cues versus those without disparity showed that MHR was found more
226 often when the target contained disparity cues ($\chi^2 = 54.1$, $df\ 1$, $p < 0.00001$) but the
227 effect for proximity was larger than for disparity. The MHR was also more likely to be
228 found in targets that included blur as a cue to depth than those without ($\chi^2 = 12.83$,
229 $df\ 1$, $p < 0.0003$)

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

235Figure 3

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

240Figure 4

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

245Figure 5

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

257 We considered whether the significant difference in refraction between fixation at
258 1m and 2m (as found by Suryakumar & Bobier²¹) was large enough to be clinically
259 meaningful and whether it differed across targets. Mean accommodation at 0.5D
260 demand was significantly less than that at 1D across all target conditions (mean
261 difference 0.23D, 95%CI ± 0.05 D ($F=159.7$, df1,292, $p<0.0001$) but with no significant
262 interaction with target type ($F(7,2044)=1.3,9=0.22$)(Fig 6). The variance in these
263 data was remarkably similar. There was a small difference in variance between
264 target type ($F(7,4832)=2.41,p=0.019$), with the *bdp* target having the smallest
265 variance, but there were no difference between the variances for the 0.5D and 1D
266 target distances ($F(7,4838)=2.46,p=0.116$), and, overall, these differences in
267 standard error (between ± 0.125 and 0.156D) were not large enough to be clinically
268 significant.

269Figure 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 error³³. 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)

280Figure 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^{29, 30, 34}. If the same comparison is made with y-
290 intercept of accommodation against demand using the *bdp* target (which we found

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

294Figure 8

295 Discussion

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

302 In general, more cues are better than fewer when assessing maximal hyperopic
303 error. The target most likely to elicit maximum hyperopia or minimum myopia for an
304 individual was not necessarily a blurred target, as might be expected from the
305 common clinical use of fogging lenses to relax accommodation, but one that
306 contained disparity and looming cues as the target was observed receding into the
307 distance. Presence or absence of blur was the least influential of the three near cues
308 we tested, and MHR was just as likely to be found in a target condition that
309 contained detail as in one that did not. Removing blur from the 3-cue condition (*bdp*
310 vs *dp*), or adding blur as a single cue (*b* vs *o* condition) made little difference to the
311 proportions of MHR found between these categories. This intuitively surprising
312 finding differs from the findings of Queiros et al²⁰ who found that fogging lenses

313 helped relax accommodation. Suryakumar & Bobier²¹ found that refraction using a
314 DoG target was more hyperopic than using a LED fixation target. However in their
315 study the different fixation distances used with these two targets make it difficult to
316 differentiate the effect of the target from that of fixation distance. They also state, in
317 an appendix to the paper, that a pilot study failed to find differences between LEDs
318 and high contrast accommodative targets at the same fixation distance. It is possible
319 that the differences in our data may be explained by our DoG target being too
320 blurred or qualitatively different in comparison to the usual +2.00D fogging lens, and
321 so induce some pseudo-myopia³⁵ rather than relaxing accommodation, but Chiu et
322 al¹⁸ have suggested that the amount of fogging is of relatively little importance, so
323 this explanation seems unlikely.

324 Although some studies have looked at the best target and testing distance to help
325 relax accommodation^{20, 21}, none have looked systematically at target type and
326 distance in the same participants. Our findings largely support those of others²¹ in
327 that distant targets relax accommodation more than nearer ones, but we suggest
328 that additional hyperopia can be revealed in many individuals by using a binocular,
329 receding target.

330 It is not surprising that the most distant target produced most MHRs, and we found
331 that the difference in refraction between the 2m and 1m targets remained relatively
332 constant across targets. Suryakumar & Bobier²¹ also found that the farthest distant
333 targets relax accommodation the most, but also found that responses were less
334 variable at these greater fixation distances. We found non-significant differences in
335 the variance between the two most distant fixation targets in any of the cue

336 conditions. In participants with refraction $< + 2.0D$, MHR occurred less reliably at the
337 2m target, possibly suggesting more variability or less sensitivity to target distance in
338 these individuals, which would benefit from further study.

339 Our results are supported by our previous research. We have reported that in
340 normal, emmetropic, naïve adults, disparity is the primary cue for both vergence and
341 accommodation to near targets²². Reducing disparity, therefore, may well help relax
342 accommodation as well as it drives it, increasing the number of MHRs found (e.g. the
343 large difference between *bdp* vs *bp* conditions) although alone (the *d* vs *o* condition)
344 disparity seems to have little effect. Fukuda et al³⁶ found that accommodation
345 velocity was also greater in binocular conditions, so giving additional support to the
346 view that disparity helps accommodation accuracy more than does blur.

347 The strong effect of proximity / looming was less expected. Like disparity, it seems to
348 have a weak effect as a single cue (*p* vs *o* condition), but in combination with
349 disparity it was the cue which predicted the highest proportion of MHRs. We have
350 reported that proximity is an extremely weak cue in comparison to disparity²² in
351 driving both vergence and accommodation to near targets in naïve adults (as
352 opposed to those with some knowledge of vision experiments as studied by
353 others³⁷). Hung et al³⁸, also suggested that proximity played a small part under
354 naturalistic conditions, but here, in combination with disparity in a very naturalistic
355 setting, the “negative looming” of the moving target seems to help in relaxing
356 accommodation in the distance.

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

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

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

372 A further area for future research is to consider groups that would not be expected
373 to have normal disparity detection mechanisms e.g. the very youngest infants under
374 12-16 weeks, before stereopsis has fully developed⁴¹, and strabismic older children
375 with constant suppression. Our numbers were too small here, and we had no
376 participants with total absence of binocularity, but we would predict that
377 disparity cues would be less influential in these individuals and may differ depending
378 on the strength of binocularity or suppression. Such groups also have a high
379 prevalence of refractive error, so they may rely even more heavily on proximal cues.

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

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

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

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408

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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 Figure 7.

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

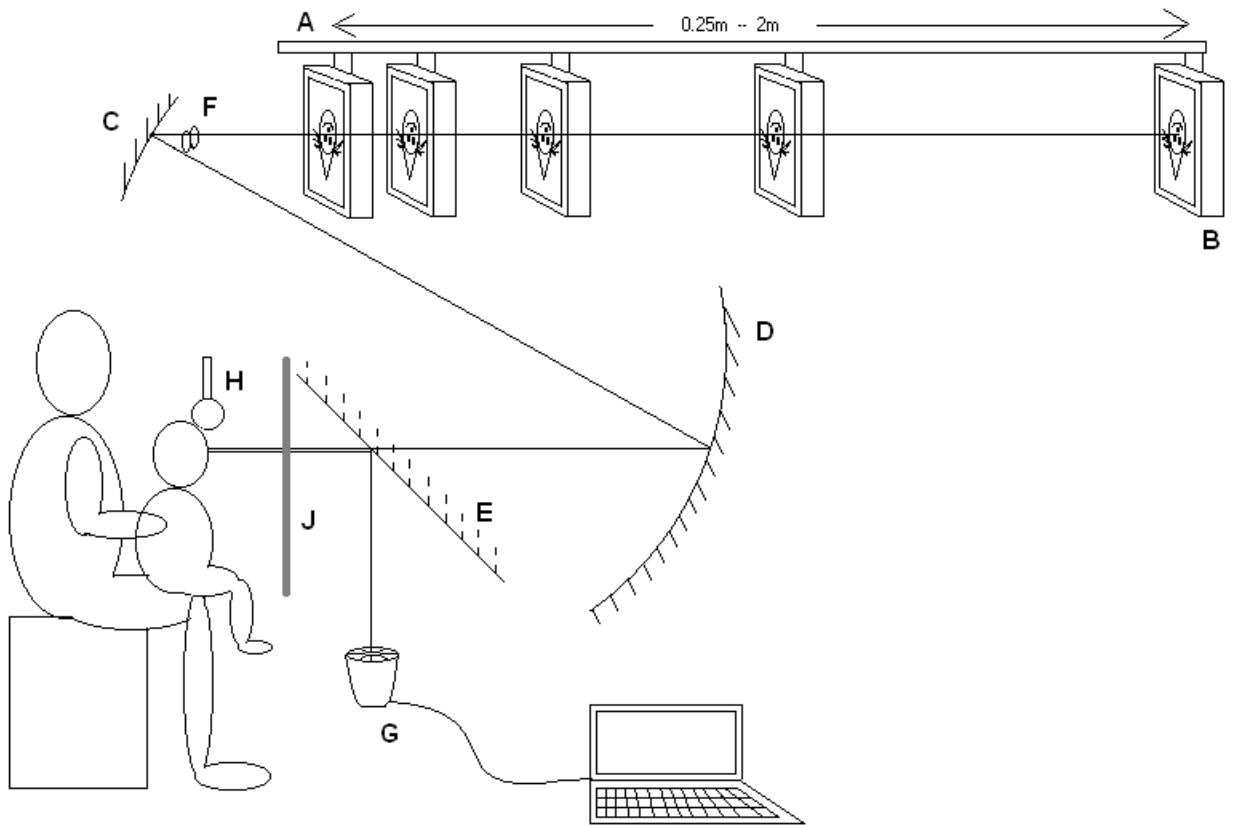


Figure 1

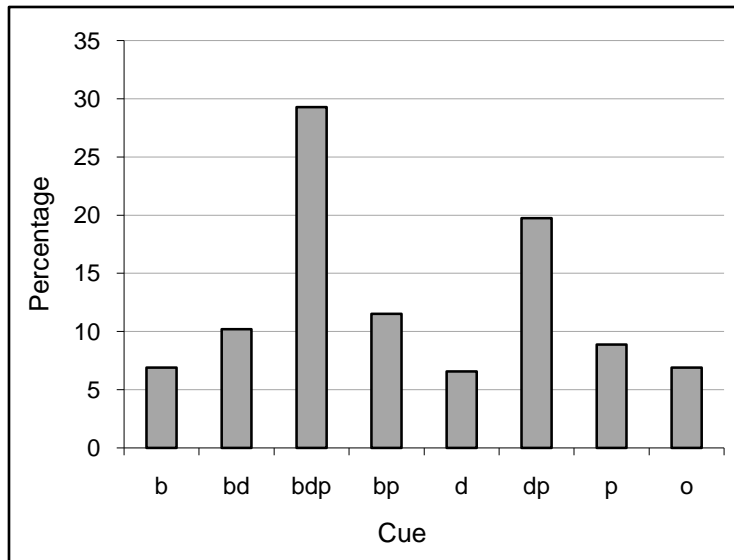


Figure 2

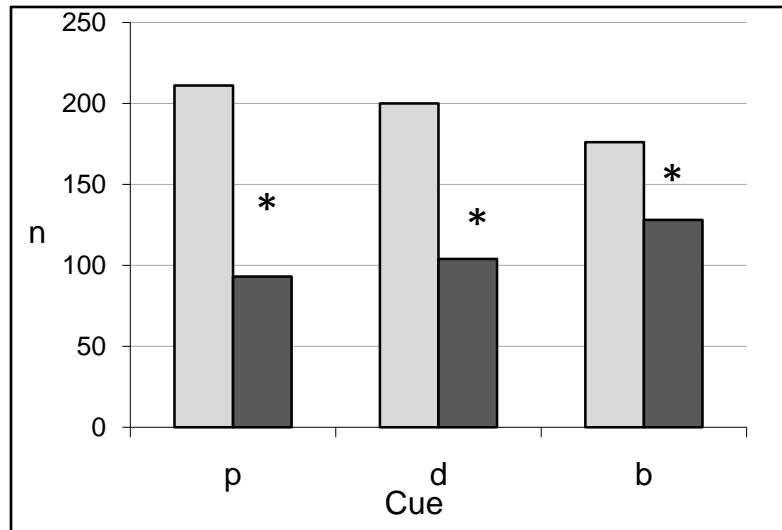


Figure 3

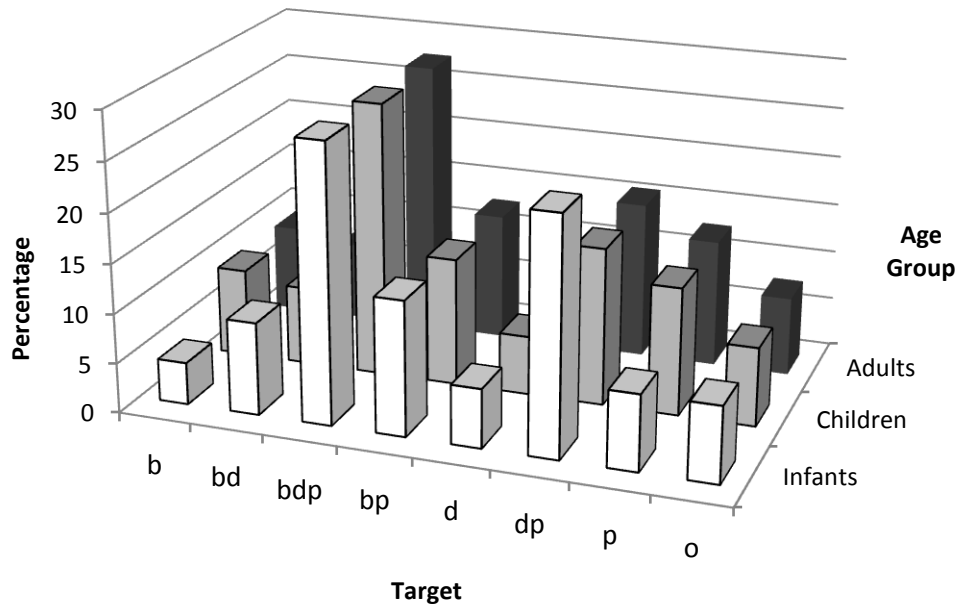


Figure 4

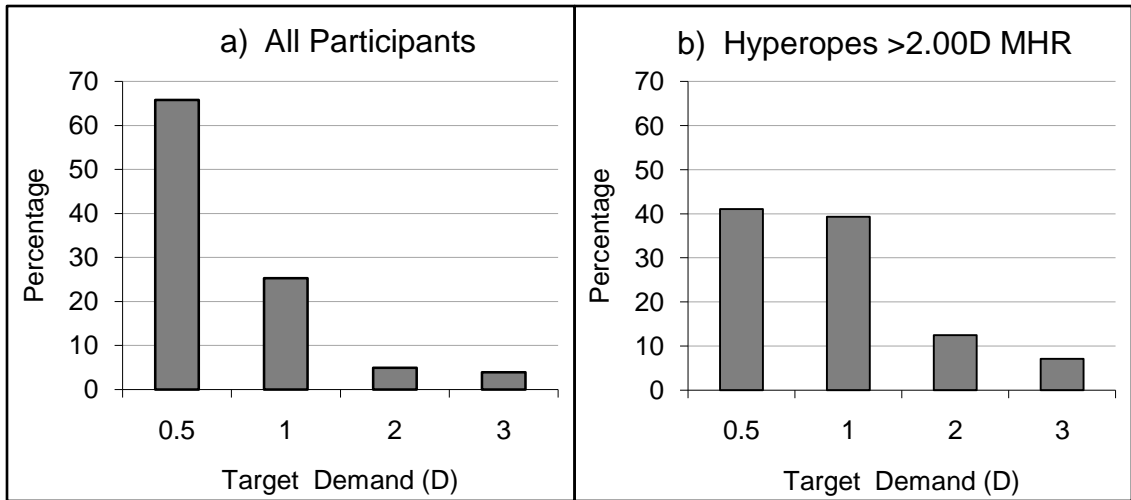


Figure 5

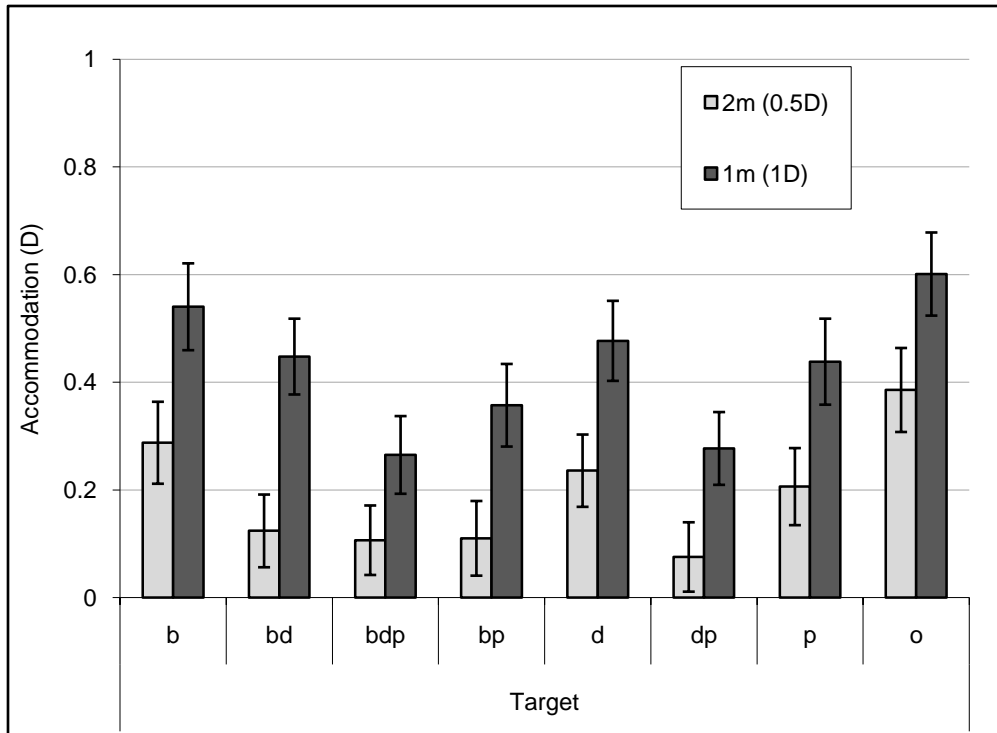


Figure 6

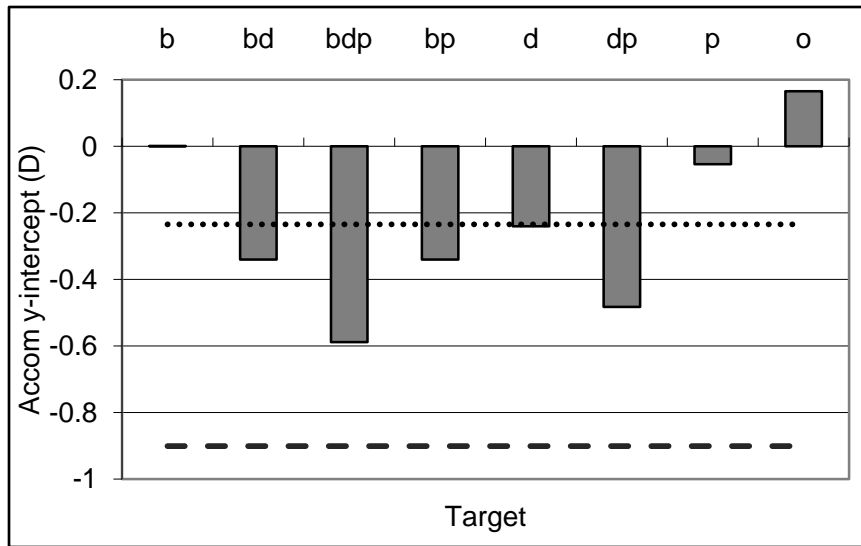


Figure 7

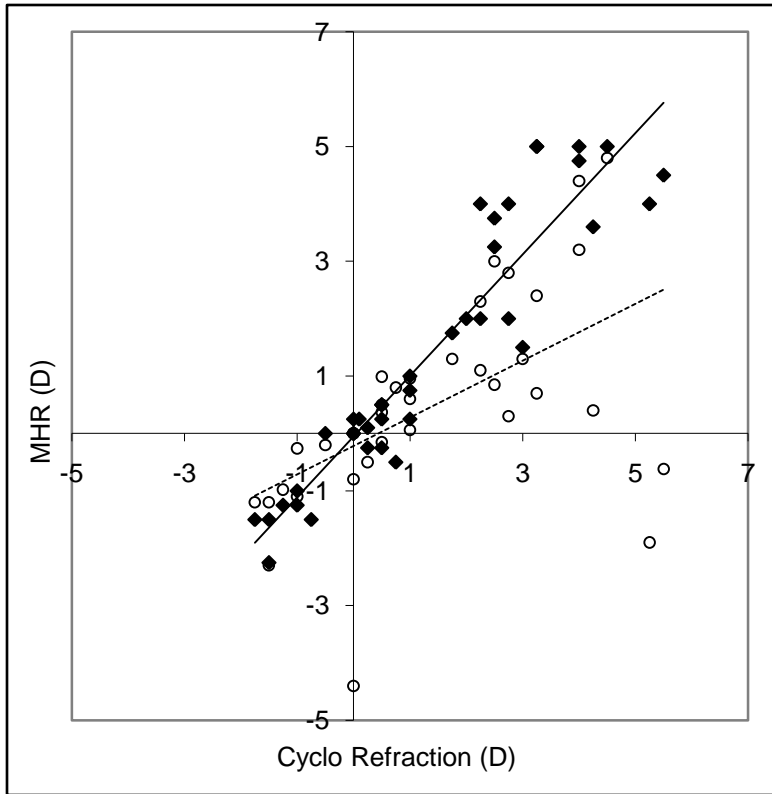


Figure 8