Published in final edited form as:
Ophthalmic Physiol Opt. 2010 March ; 30(2): 152–159. doi:10.1111/j.1475-1313.2009.00706.x.

Differences between naïve and expert observers' vergence and accommodative responses to a range of targets

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Abstract

Purpose—Vergence and accommodation studies often use adult participants with experience of vision science. Reports of infant and clinical responses are generally more variable and of lower gain, with the implication that differences lie in immaturity or sub-optimal clinical characteristics but expert /naïve differences are rarely considered or quantified.

Methods—Sixteen undergraduates, naïve to vision science were individually matched by age, visual acuity, refractive error, heterophoria, stereoacuity and near point of accommodation to 2nd & 3rd year orthoptics and optometry undergraduates ("experts"). Accommodation and vergence responses were assessed to targets moving between 33cm, 50 cm, 1m and 2m using a haploscopic device incorporating a PlusoptiX SO4 autorefractor. Disparity, blur and looming cues were separately available or minimised in all combinations. Instruction set was minimal.

Results—In all cases, vergence and accommodation response slopes (gain) were steeper and closer to 1.0 in the expert group (p=0.001), with the largest expert /naïve differences for both vergence and accommodation being for near targets (p=0.012). For vergence, the differences between expert and naïve response slopes increased with increasingly open-loop targets (linear trend p=0.025). Although we predicted that proximal cues would drive additional response in the experts, the proximity-only cue was the only condition that showed no statistical effect of experience.

Conclusions—Expert observers provide more accurate responses to near target demand than closely matched naïve observers. We suggest that attention, practice, voluntary and proprioceptive effects may enhance responses in experienced participants when compared to a more typical general population. Differences between adult reports and the developmental and clinical literature may partially reflect expert / naïve effects, as well as developmental change. If developmental and clinical studies are to be compared to adult normative data, uninstructed naïve adult data should be used.

Introduction

There are many hundreds of studies reporting adult accommodation and vergence responses to a range of stimuli under open and closed loop conditions. This has resulted in a large and broadly coherent adult literature e.g. review volumes by Franzen et al (2000) and Schor & Ciuffreda (1985). Most studies make efforts to demonstrate consistency, validity and

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repeatability of responses by using visually consistent and often demanding stimuli, multiple repetitions and sometimes extensive training sessions. In addition, and importantly for this study, because much accommodation research takes place in optometry departments, students or staff are frequently used as participants.

Infant and clinical studies of accommodation and vergence responses are much less common and generally produce lower response gains and more variable responses (Bharadwaj and Candy, 2008, Candy and Bharadwaj, 2007, Currie and Manny, 1997, Hainline and Riddell, 1996, Hainline et al., 1992, Tondel et al., 2002, Tondel and Candy, 2007, Turner et al., 2002). It is easy to assume that the differences between infancy and adult studies reflect a developmental change from immature to mature responses and also that differences between patient groups and controls reflect clinical abnormality. However, any differences in responses between experienced and naïve observers have not been considered.

This study was carried out because the psychology students we used as participants during the calibration and adult control data collection phases in our new laboratory gave responses much more similar to those we obtained from infants and children and less like those we expected from the typical adult literature. We hypothesised that our participants could be putting in less “top down” voluntary input into their responses than expert or experienced participants with an interest or knowledge of the subject. It is known that both accommodation and vergence can be driven by proximal cues (Hung et al., 1996, Rosenfield and Ciuffreda, 1990, North et al., 1993), “awareness of nearness” (Mein and Trimble, 1991) and voluntary control (McLin and Schor, 1988, Erkelens et al., 1989, Richter et al., 2005), but these are difficult to quantify and have been poorly studied experimentally in completely naïve observers. Attention has been implicated by others in causing better accommodation and vergence (Andre and Owens, 1999, Francis et al., 2003). Owens et al (2000), alluded to differences between college students and clinical groups in relation to dark focus, and suggested that the difference might lie in “active” vs. “passive” looking. Ciuffreda attempted to address the issue of responses to naturalistic stimuli in a series of studies (Ciuffreda et al., 1990), but still used optometry students as participants, so did not assess naïve participants.

Any expert / naive difference is, however, important to consider when comparing the development of accommodation and vergence because infants and very young children, who are largely uninstructable, may appear excessively immature if compared with experienced adult control groups. In clinical contexts, inaccurate or sub-optimal responses risk being considered atypical if compared with expert controls and this could even lead to unnecessary treatment because of unrealistic definitions of typical ranges.

This study reports vergence and accommodation responses to the three main near cues from two very closely matched groups of young adults differing only in their experience and knowledge of the processes being tested.

Method

Participants

Over 150 students were examined in order to find suitably closely matched pairs for the expert and naïve groups. Sixteen psychology undergraduates between 19 and 23 years of age, naïve to any vision experiments, vision therapy, orthoptic treatment or assessment, were individually matched with 16 2nd or 3rd year orthoptics or 3rd year optometry undergraduates ("experts") across the following parameters:-

- age (±1yr, mean difference 0.55yrs with the experts being the slightly older group (paired t-test; t=−1.77, p=0.095))
- gender
- subjective refraction (± < 0.5D in each axis (range 0 / − 4.5D), (paired t-test comparing MSE; t=−1.5,p=0.15), with the experts being 0.12D less myopic) Contact lenses were worn throughout testing by those who wore a refractive correction, so a contact lens wearer was always matched with another contact lens wearer. All wore their usual soft contact lenses but details of lens type were unavailable. Spectacle wearers were excluded to avoid possible confounding factors introduced into the PlusoptiXSO4 measurements and calculations due to image magnification
- onset of wearing refractive correction (± 1yr estimated from history)
- heterophoria (± 2Δ, range 1 Δ eso / 10 Δ exo at 33cm and 0 Δ /2 Δ exo at 6m, paired t-tests of differences in deviations at near and distance t=−0.14,p=0.889 and t=1.65,p=0.12 respectively).

All participants were completely symptom free, had stereoacuity of at least 60"arc, had near points of convergence and accommodation to less than 7cm from the nose and motor fusion ranges of at least 35Δ base out and 12Δ base in at 33cm. Academic entry requirements to the undergraduate programmes are similar, with a similar academic workload and ethnic mix. All participants were informed that the experiment involved testing ocular responses to approaching targets and were told to simply look at the targets. None were explicitly told that accommodation and vergence responses were being assessed and none of the "experts" were students at the university in which the laboratory is situated, so were not aware of the exact type of work being undertaken in the laboratory. The apparatus is enclosed in shuttering so none were able to guess its optical construction before or during testing. Instruction set was identical and minimal so the only systematic difference between the groups was knowledge of the processes involved in near fixation and the potential to work out what was being tested. We did not match participants *a priori* for prism motor fusion ranges because we felt it was likely that the experts would have larger ranges because of practice/ treatment effects derived from familiarity with practicing investigation and treatment methods, but we considered whether fusion range might be a confounding factor. We therefore planned to compare fusion ranges *post hoc* and if significantly different, use fusion range as a covariate in the analysis.

Equipment

Remote Haploscopic Videorefractor incorporating a PlusoptiX SO4 was used to assess simultaneous vergence and accommodation responses (Figure 1). The method and calibration is described in full detail elsewhere (Horwood and Riddell, 2008) and was designed to be used with uninstructed infants and young children with a wide range of abilities and acuities.

The target pathway presented a range of targets on a monitor moving along a motorised beam between fixation distance of 33cm, 50 cm, 1m and 2m (representing demands of 0.5, 1, 2, and 3 metre angles (MA) and dioptres (D) in a pseudo random order so that a nearer target was always alternated with a farther one. The mirror arrangement of the target pathway in this standard setup is such that if half of the upper mirror is occluded, the participant can only see the target with one eye, while photorefraction can still occur for both eyes. The occluder is not visible to the participant. All verbal participants in our lab are asked after testing if they had been aware of being occluded. Approximately 30% of all child and adult participants report that they were unaware of the occlusion, while a further 30% “knew something different had happened” but could not identify what it had been.

The photorefraction pathway uses a “hot” mirror to capture infra-red photorefraction and eye position data. The participant sees the target approaching along the same optical axis as the photorefraction sensors, which are occluded by the target picture.

There were two fixation targets. The first was a brightly coloured picture of a clown which subtended 3.15° at 2m and 18.26° at 33cm containing a wide range of spatial frequencies and high contrast edges. Separate pilot studies showed that this target produced similar accommodative responses to those using a patch of unfamiliar 8 point nonsense text read out loud (Horwood and Riddell, 2008). Details of the face alternated at 1Hz to maintain attention (nose rings reversed between red and blue, eyes changed from oval to cross) but did not move position within the static face shape. Steady fixation was not specified in order to retain the naturalistic nature of the task. The other target was a reproduction of a difference of Gaussian (DoG) patch against a dark background which allowed binocular fusion without stimulating accommodation. Both targets could be presented in a dynamic looming condition (target size constant and screen movement visible) or scaled for target distance so that there was a similar angular subtense (3.15°) at each fixation distance (proximity-free condition). In the proximity-free condition, all screen movement was hidden by a black cloth that obscured the whole viewing field while the screen was moving between fixation distances, to minimise residual dynamic looming cues of the dim screen edges.

Thus disparity cues could be removed with unilateral occlusion, blur cues could be minimised by using the DoG target, and proximity cues could be minimised by target scaling and obscuring target movement. There were, therefore, 8 target conditions involving 3, 2, 1 or minimal near cues (*bdp* – blur disparity & proximity all available, *bd* – proximity minimised, *bp* – disparity excluded, *dp* – blur minimised, *b* – blur only, *d* – disparity only, *p* – proximity only, *o* – all cues minimised),

Data Processing

From the raw spreadsheet of refraction and eye position data produced by the PlusoptiXSO4 a chart was produced of vergence and accommodation responses over time. Vignettes of 25 data points (1 sec of continuous data) representative of a stable response at each fixation distance were identified according to validated criteria for further analysis (Horwood and Riddell, 2008). From these vignettes the best estimate of IPD and angle kappa could be made from the zero intercepts of the response slopes at the different fixation distances. Using these estimates, vergence could then be calculated in metre angles (MA) and so be directly compared with accommodation responses in dioptres (D). Individual calibrations were made using IPD and angle kappa in order to calculate vergence, but manufacturer's norms were used for refraction and raw eye position. Vergence and accommodation were assessed in terms of response in relation to target demand at each viewing distance, response slope (gain) and r^2, which, in the pseudo-random order of testing, is a good reflection of overall accuracy for target distance. We have described typical naïve adult responses to these cue conditions in detail elsewhere (Horwood and Riddell, 2008).

Data were processed using Excel 2007 and SPSS v16 software. In view of the very close individual matching of the participants, statistical analysis used repeated measures analyses and we report the Greenhouse-Geisser statistics when Mauchly's test of sphericity was significant (mainly due to somewhat increased variance in the accommodation data).

Results

In all matched pairs, both vergence and accommodation response slopes (gain) in the expert group were steeper and closer to the ideal response of 1.0 (Figure 2a and 2b) in every cue condition. In all participants and cue conditions both vergence and accommodation were linear against target demand (r^2 of all response slopes > 0.7 in all participants and targets). A three-way repeated measures ANOVA considered the eight cue conditions (cue), vergence or accommodation responses (response) and whether the participants were "experts" or "naïve" (experience). There was a highly significant main effect of experience ($F(1,15)=18.79, p=0.001$), but no overall significant main effect of response ($F(1,15)=0.057, p=0.814$ i.e. there was no overall difference between vergence and accommodation. Unsurprisingly, in view of our previous reports (Horwood and Riddell, 2008), there was also a highly significant main effect of cue ($F(3.12,46.9)=71.99$, $p<0.0001$). Thus the different cue conditions produced difference response slopes but experts showed steeper response slopes for both vergence and accommodation across all conditions, with greater differences, but also somewhat more variability (in both groups), for accommodation than vergence. The effect size for the difference between the two groups were r=0.77 for vergence and r=0.65 for accommodation, which is large in this relatively small sample.

There was a significant interaction of cue x response ($F(3.11,46.73)=10.32, p<0.0001$), showing, as expected from our previous work (Horwood and Riddell, 2008), that accommodation and vergence slopes were somewhat different in response to different cues, but there were no significant two- or three-way interactions involving experience (($p>0.3$ in all cases), suggesting a similar effect of experience throughout.

Post-hoc paired t-tests comparing expert and naïve responses for vergence responses in the individual cue conditions showed significantly better responses by the experts in all except the *b* and *p* conditions. Accommodation responses were significantly better in the experts in all except the *p* condition (Table 1).

The smallest differences in slopes between the groups were for vergence in the all-cue *bdp* condition (0.1, i.e. 10% of the ideal slope of 1.0) and for both vergence and accommodation in the proximity only *p* condition (0.1 and 0.12 respectively). Differences between slopes in the other conditions were as much as 0.33 and were generally greater in the more impoverished cue conditions.

There were highly significant linear trends for the response slopes of both groups to flatten with a reducing number of cues (3,2,1 or minimal) ($F(1,15)=502.0, p<0.0001$ for vergence and ($F(1,15)=82.27, p<0.0001$ for accommodation). A significant effect of group ($F(1,15)=19.6$, $p=0.0004$) showed that expert slopes were significantly steeper than those of the naïve observers and this difference became greater the fewer cues available ($F(1,15)=23.5, p<0.0001$).

In terms of *percentage* difference between the expert and naïve response slopes, except for vergence to the *bdp* condition, all expert slopes were at least 25% greater than those of the naïve participants, and in the case of accommodation to blur as a single cue, the expert slopes were 85% greater (Figure 4). For the minimum cue *o* condition, vergence was 230% better and accommodation 94% better in the experts. Naïve responses were generally much flatter to more impoverished targets, but the experts showed less flattening and continued accommodating and converging despite weaker stimuli.

We examined responses at 2m and 33cm to determine whether the flatter responses from the naïve participants were due to over-responding for distance or under responding for near (Figure 4). Mean vergence responses across cue conditions at 2m (0.5 MA demand) were 0.58MA for the experts and 0.46MA for the naïve group. Mean accommodation at 2m (0.5D demand) was 0.56D for the experts and 0.68D for the naïves, with no main effect of experience($F(1,15)=0.001, p=0.97$).

Similar analysis of responses at 33cm (3D or MA demand) showed that the experts responded more closely to target demand than the naïve participants in all cases (significant main effect of experience ($F(1,15)=8.27, p=0.012$)). Mean vergence responses across all cue conditions at 33m were 2.31MA for the experts and 1.83MA for the naïve group. Mean accommodation at 33m was 2.42D for the experts and 1.99D for the naïve group.

The post hoc consideration of fusion ranges (base in and base out prism vergence to blur, diplopia and then recovery at both 33cm and 6m) showed no significant differences in size of range or spread of data between the groups ($p>0.25$ in all comparisons), except for a very slightly *larger* base-in range to blur, diplopia and recovery at 6m in the naïve group (mean difference $<2.7\Delta$ in all cases ($t(1,15)= 3.62$ $p=0.003$ to blur, $t=3.32, p=0.006$ to diplopia and $t=2.66, p=0.021$ to recovery).

Discussion

This study was carried out to try to help us separate expert/naïve from developmental differences. The published literature had led us to believe that we would find differences between adults and children, and typical and clinical groups, that were primarily due to developmental progression or pathology, but our naïve adult control data suggested that differences might also lie in experience of visual manipulations, knowledge of vision theory or practice effects. Previous work from our laboratory, using both the PlusoptiXSO4 (Horwood & Riddell 2008) and off-axis photorefraction (Horwood et al 2001) has pointed to these differences, but in this study we were able to explore them in great detail. This study has shown that naïve adults often under-accommodate and under-converge for near in comparison to matched adults with knowledge of the mechanisms being tested, despite identical testing conditions and instructions across a wide range of targets. Even in this relatively small group of participants, our naïve students clearly showed flatter response slopes for both vergence and accommodation responses than the experts, and the differences became greater the more feedback loops were opened. Our naïve adult responses were much more like those of infants and young children being tested in our laboratory.

This is a relatively unexplored topic and there are very few published studies of typical adult behaviour that use participants exclusively and completely naïve to vision science. This is unsurprising because most experimental studies take place in optometry schools, with a readily available participant pool of staff and students, but it may have led to an overestimation of naturalistic adult responses. There have been a few attempts to study naturalistic responses in adults (Ciuffreda et al., 1990, Owens et al., 2000 Andre and Owens, 1999), but most use non-naïve participants We made strenuous efforts to minimize any element of forced effort or attention (or purposive “spacing out”(Francis et al., 2003)) in all our participants, and let the different targets drive the responses, yet we still found a clear difference between expert and naïve responses. In this way our naïve adult responses can be better related to those of uninstructable infants and children.

The variance in the accommodation data was somewhat greater and so, in general, statistical effects were smaller than for vergence, but it is evident that mean differences are of similar magnitude between the vergence and accommodation responses. In every one of our matched pairs of participants, expert responses were better (gain closer to 1.0) than those of the naïve match, with large effect sizes.

Owens et al (2000) suggest that in impoverished conditions and inattention both near and distant responses regress to the individuals’ intermediate dark focus, in which case we might have expected to find differences at both near and distance. The differences we found in response slopes were mainly due to differences in near responses, not distance, None of the differences at 2m were greater than 0.25D or 0.25MA, or approached statistical significance. It is possible that because we did not test at optical infinity, our 2m target was closer to an intermediate resting position that might have been induced by impoverished targets and so masked a difference that might have been significant at infinity, but there were no trends in our data that suggested that would have been the case.

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We suggest there are two possible explanations for our results. Despite our minimal instruction set, the experts may have just been paying more attention to the task because they were interested in visual matters, so that differences are purely due to attention. Alternatively, or in addition to the more global effect of attention, the experts may be able to analyse what is being being tested without being told, or be more practiced in making use of residual cues to work out where the target is. They might therefore have brought “top down” voluntary or “instrumental” control of these specific systems to drive additional responses on top of that driven by the visual cues alone. Proprioception and increased awareness of what eyes feel like when responding may also play a part. Further studies are planned to examine these differences and if, and how, they reduce with practice, which may also be influential in explaining how orthoptic exercises act.

When examined by target type there were significant differences between the expert and naïve group for every cue except for the proximity-cue only *p* condition (and a marginal difference between vergence slopes in the blur-only *b* condition). We had hypothesized that if experts were systematically better at responding, they might bring in “top-down” influences which are generally described as “proximal” and so we expected to find the greatest effect in our proximity only *p* condition which presents looming and relative size cues without disparity or blur cues. Hung suggested that proximal cues may be more influential in more open-loop conditions (Hung et al., 1996). Since our proximity-only condition was the only one that did not produce a statistically significant expert/naïve effect, this suggests that some other “top-down” influence may be occurring that is not stimulated just by target characteristics alone (the image size change or dynamic looming which we manipulated) and may be independent of experience. This might involve a more complex higher calculation of target position which adds to the solely visual cues (such as the “awareness of nearness” that is implicated in instrumental convergence (Mein and Trimble, 1991).

There was a significant trend for a reduction in the number of visual cues to increase the expert / naive difference for vergence. The likely reasons for the smaller accommodation trend are twofold. Firstly there is increased variance in accommodation responses, especially in the naïve participants so the study may be somewhat underpowered. Secondly, the difference between the expert and the naïve accommodation slopes is larger than for vergence slope even at the initial 3-cue level (0.2), and only changes to 0.27 in the minimal cue *o* condition, so the rate of change with reducing cues is less for accommodation. A further study with larger numbers is indicated, but if the trend proves to be robust, it suggests that very controlled, open-loop studies of vergence and accommodation involving practice sessions or training must be viewed with even more caution than less open loop, more cues available, more naturalistic, studies when relating results to real-life situations. It has been suggested that our findings may be instrument-specific, which could only be clarified only by further studies using different methods, but we would argue that there are few experimental paradigms that measure as many facets of the near response in such a systematically stable and naturalistic way so we feel our findings are likely to transfer well to clinical domains. The results we report here have particular significance for the growing field of clinical and infant accommodation and vergence research which has been made possible by the development of more naturalistic and binocular equipment such as the PowerRefractorII.

In developmental science, infants and early childhood responses may appear unfairly immature if an expert adult comparator group is used. Any studies comparing responses between mature and developing groups can only be valid if the control group is similarly naïve to visual testing and experience. It is also possible that there are even more differences between infants and naive adults than this experiment can quantify. It is not likely that our naïve group is completely identical, in terms of effort, to a group of infants. It is likely that any adult taking part in an experiment is "trying to be helpful", paying attention and obeying instructions, while the same cannot always be said for infants and very young children, so even naïve adults may behave differently purely because of better levels of attention.

If clinical patient group responses are compared with data from controls drawn from experienced participants, the patients may appear more "abnormal" than they really are. Normal limits may be much wider than previously thought and we may need to further quantify what makes some individuals symptomatic while others with identical objective responses are symptom-free, before embarking on treatment.

This study suggests that literature which uses expert observers or extended training periods for demanding experimental paradigms in very open loop conditions may not represent typical everyday behavior for most individuals, showing only what *can* be acheived, not what usually *is*. The literature might instead much better reflect optimal physiological responses, and using experienced observers certainly makes more carefully controlled experiments possible, so representing *potential* responses. In contrast, our paradigm tests *performance* in a naturalistic presentation. What constitutes a "true" response is a topic for debate and further study. It would be interesting to carry out a series of experiments on naïve and expert groups under different conditions of instruction set, attention, distraction and effort to identify exactly which aspects of a task influence responses most.

It leaves researchers testing adults in a situation of choice; use naïve participants and minimal instruction set if results are to be compared to immature or clinical groups, or use experts and careful instruction, so that optimal responses can be studied when the visual system is placed under the most taxing conditions. This only becomes a confound if expert results, especially if obtained under different testing conditions, are used to explain clinical findings. If highly controlled laboratory studies on expert observers are used to create clinical norms these issues can become important and might result in misleading normative data.

Acknowledgements

This research was supported by a Department of Health Research Capacity Development Fellowship award PDA 01/05/031 to AMH

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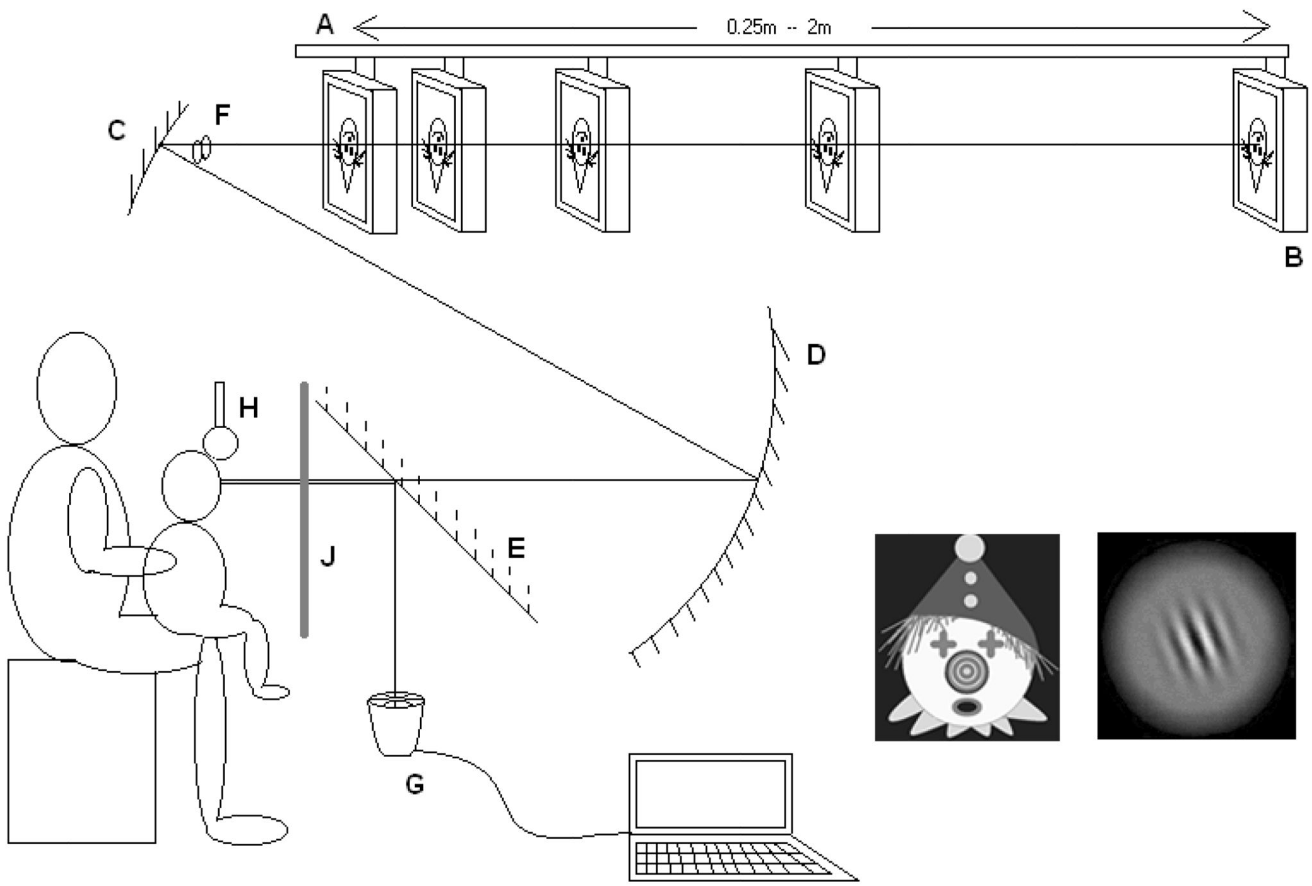

Figure 1.

The Remote haploscopic videorefractor. A. Motorised beam. B. Target monitor. C. Upper concave mirror. D. Lower concave mirror. E. Hot mirror. F. Image of participant's eye where occlusion takes place. G. PlusoptiX SO4 PowerRef II. H. Headrest J. Raisable black cloth screen. Clown and DoG targets illustrated lower right.

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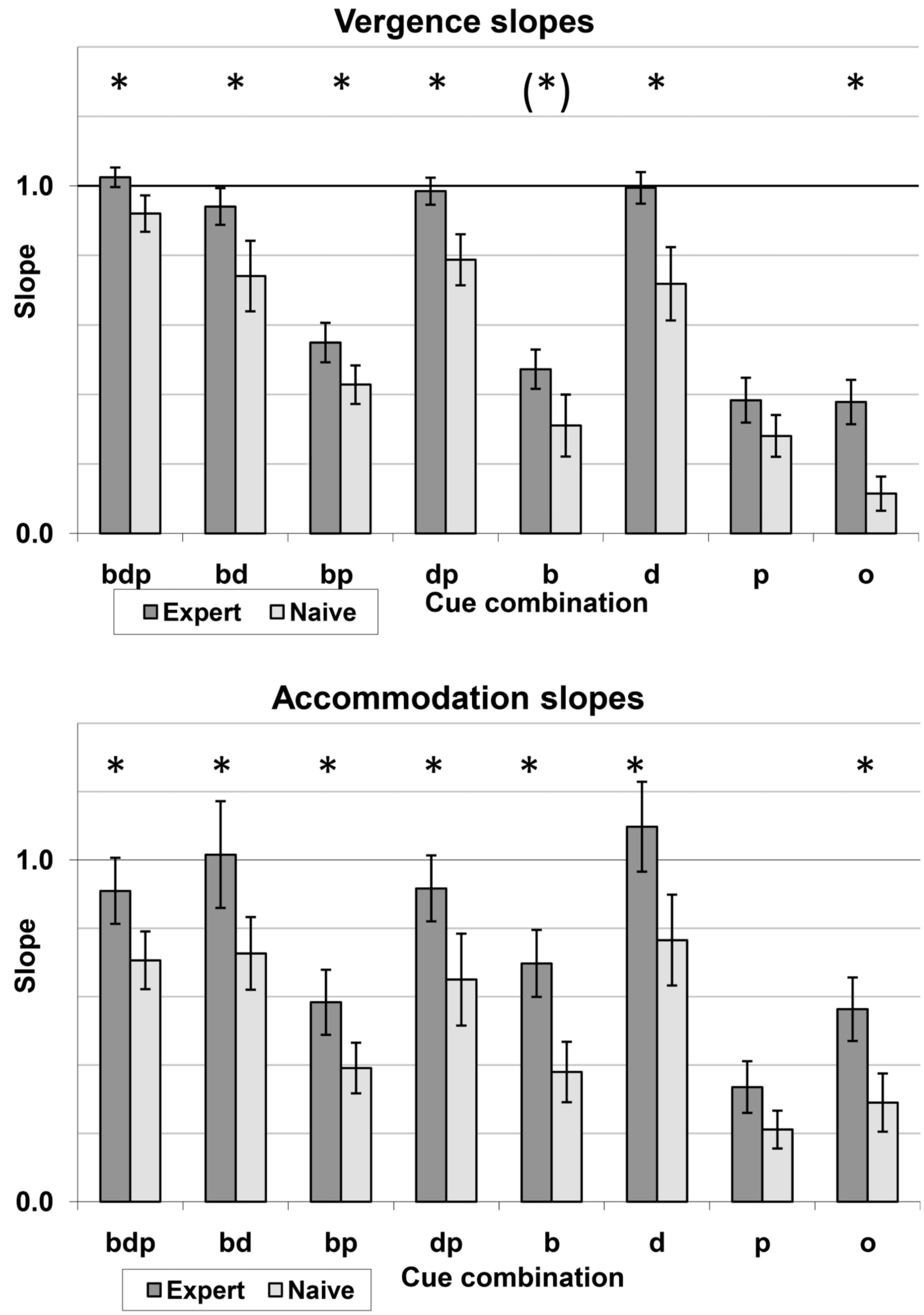

Figure 2a and 2b.

Response slopes to different cue combinations 2a Vergence slopes and 2b Accommodation slopes.

Shaded bars “expert”, pale bars “naïve” responses. Cue conditions: b = clown target (blur available), d = binocular target (disparity available), p = looming dynamic target (proximal cues available), o = all cues minimised.

Asterisks denote statisticallly significant differences between expert and naïve response slopes.

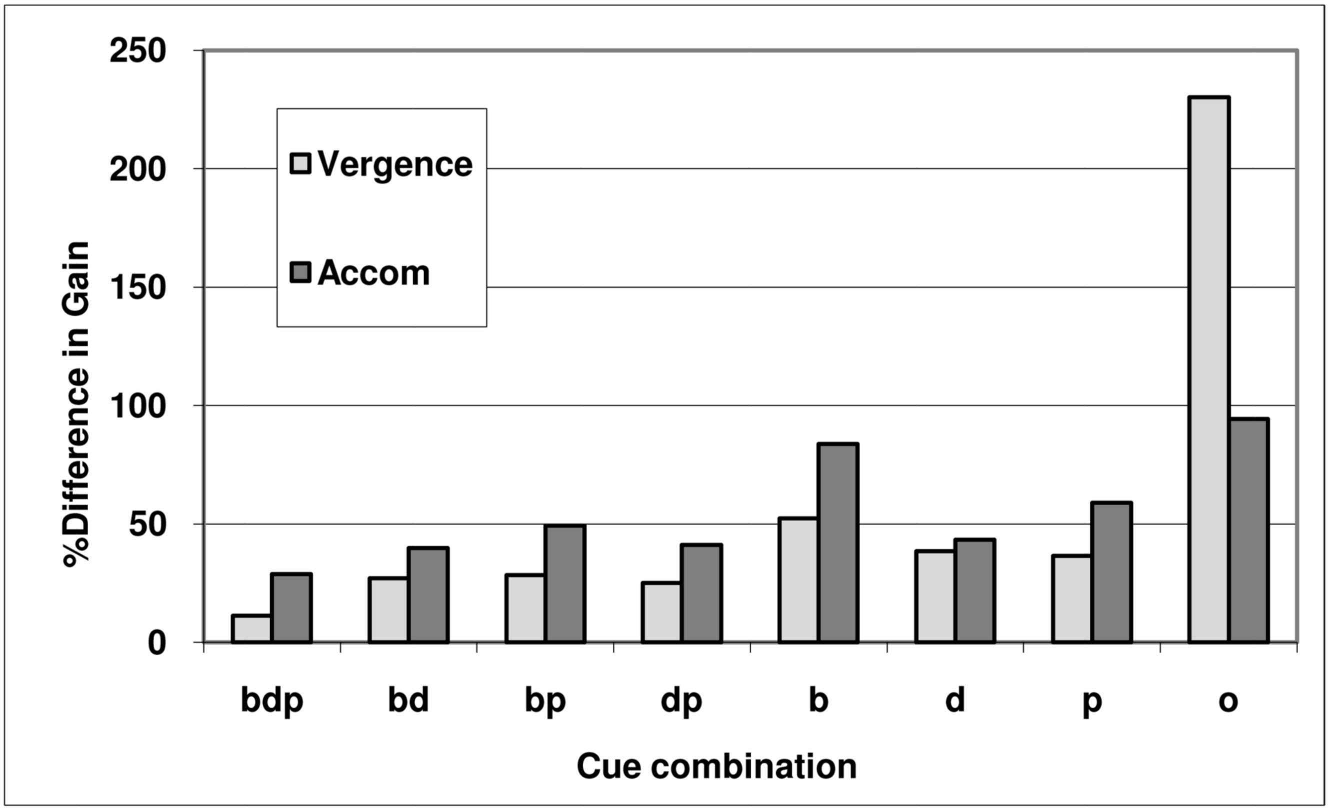

Figure 3.
Differences and percentage increase in gain of expert response on naïve responses. Pale bars = vergence, dark bars = accommodation

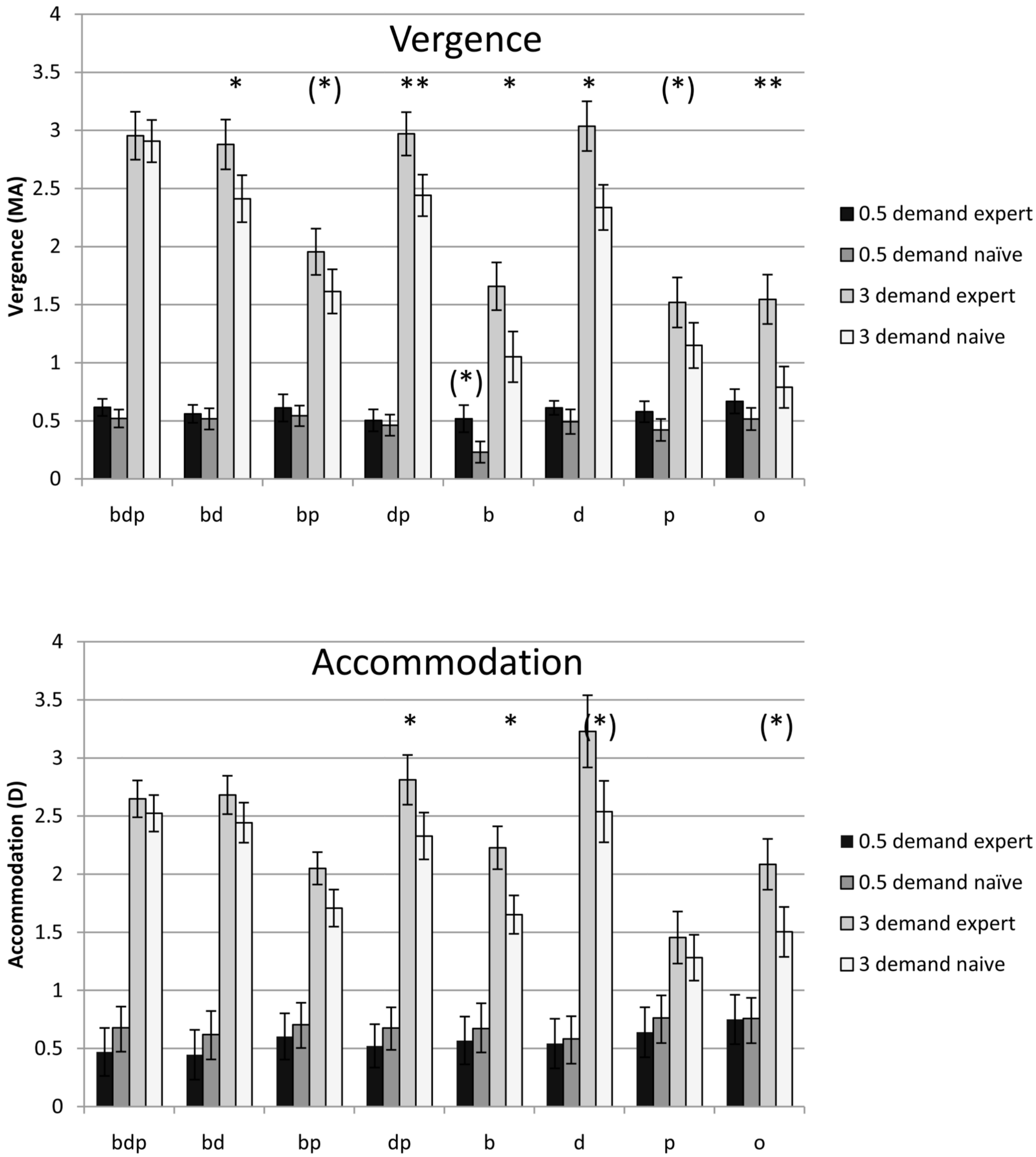

Figure 4a & b.

Vergence responses (in MA) and accommodation responses (in D) at 2m (0.5 demand) and and 33cm (3.0 demand). Asterisks denote significance of individual differences between expert and naïve responses for each cue ((*) = 0.1-0.05, * = 0.05-0.01, ** = <0.009)

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Table 1

Differences in gain (in D for accommodation and MA for vergence) and *p* values of comparisons between expert and naive response slopes at each cue condition. Statistically significant differences in bold text.

GAIN	bdp	bd	bp	dp	b	d	p	o
Vergence Gain Difference (*p* values)	**0.104 (p=0.042)**	**0.200 (p=0.015)**	**0.121 (p=0.018)**	**0.197 (p=0.004)**	0.162 (p=0.089)	**0.276 (p=0.006)**	0.103 (p=0.123)	**0.264 (p=0.003)**
Accom Gain Difference (*p* values)	**0.203 (p=0.022)**	**0.289 (p=0.038)**	**0.192 (p=0.031)**	**0.267 (p=0.023)**	**0.318 (p=0.004)**	**0.332 (p=0.036)**	0.124 (p=0.162)	**0.273 (p=0.017)**