Hypo-accommodation Responses in Hypermetropic Infants and Children

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ABSTRACT

Aims: Accommodation to overcome hypermetropia is implicated in emmetropisation. This study recorded accommodation responses in a wide range of emmetropising infants and older children with clinically significant hypermetropia to assess common characteristics and differences.

Methods: A PlusoptiXSO4 photorefractor in a laboratory setting was used to collect binocular accommodation data from participants viewing a detailed picture target moving between 33cm and 2m. 38 typically developing infants were studied between 6-26 weeks of age and were compared with cross-sectional data from children 5-9 years of age with clinically significant hypermetropia (n=15), corrected fully accommodative strabismus (n=14) and 27 age-matched controls.

Results: Hypermetropes of all ages under-accommodated compared to controls at all distances, whether corrected or not ($p<0.00001$) and lag related to manifest refraction. Emmetropising infants under-accommodated most in the distance, while the hypermetropic patient groups under-accommodated most for near.

Conclusions: Better accommodation for near than distance is demonstrated in those hypermetropic children who go on to emmetropise. This supports the approach of avoiding refractive correction in such children. In contrast, hypermetropic children referred for treatment for reduced distance visual acuity are not likely to habitually accommodate to overcome residual hypermetropia left by an under-correction.

INTRODUCTION

Established best practice in the management of hypermetropia in strabismic children is full correction[1] because moderate hypermetropia carries an increased risk of accommodative strabismus [2-3] and amblyopia. [4-5] Clinical practice in the absence of strabismus, however, varies considerably with clinical “rules of thumb” prevailing, involving various degrees of under-correction, depending on patient age and prescriber’s experience. [6-12]

Under-correction of childhood hypermetropia is common for two main reasons. Firstly, the active accommodation systems of children should be able to overcome small hypermetropic errors. [13-14] Secondly, since accommodation and blur have been implicated in emmetropisation, full correction could hinder this by removing the blur drive to emmetropisation. These assumptions have recently been questioned on the basis of a lack of objective evidence [15] and it is unclear whether just because hyperopic children *can* accommodate, they necessarily *do.* Assessment of accurate accommodation to near targets in this age group may predict outcome [4] or determine treatment, [16-18] but this remains outside mainstream practice.

The problem in infants is even more controversial than in older children because most will emmetropise if left untreated and it is currently not possible to predict whether a particular hypermetropic infant will emmetropise or not.[19] In the past these errors were largely undetected, but programmes such as the US InfantSEE® project will make decisions about follow up and treatment of infantile hypermetropia increasingly necessary as more hypermetropic infants are detected. A strong evidence base for treatment and follow up of this particular group is vital.

Research by Mutti et al [20] explored accommodation and hypermetropia in infants using different retinoscopy techniques. Cycloplegic retinoscopy was used as a measure of full latent hypermetropia, Mohindra retinoscopy (non-cycloplegic, in the dark) was used to estimate of distance defocus, and dynamic retinoscopy was used to estimate near defocus. They concluded that there was no correlation between defocus and change in refractive error and argued against a model of emmetropisation based on response to blur. They suggested that accommodation itself is a "plausible visual signal for emmetropisation" and blur itself is less relevant.

This study compares simultaneous vergence and accommodation responses in developing infants showing different emmetropisation trajectories, with three groups of children with clinically significant hypermetropia and a group of emmetropic children. While many young infants are hypermetropic, most will emmetropise, and we were able to study accommodation characteristics in the presence of emmetropising hypermetropia over time. By studying responses from these infants we hoped to identify differences in vergence or accommodation behaviour that might predict failure of emmetropisation. In comparison, a hospital population comprised those who had not emmetropised and presented at school age with reduced visual acuity. This group was tested to investigate whether hypermetropic children do accommodate to compensate for their refractive error.

METHODS

The study adhered to the tenets of the Declaration of Helsinki and was scrutinised by NHS and University Ethics Committees who gave permission to proceed. Parents of all children gave fully informed consent, and children over 6 gave informed assent appropriate to their understanding.

Equipment

We used a remote haploscopic videorefractor in a laboratory setting. A PlusoptiXSO4 photorefractor in PowerRefII mode, which collects simultaneous eye position and refraction measurements, was set in an apparatus comprising a mirror and monitor track arrangement. Targets are presented at five different fixation distances in a pseudo-random order (33cm, 200cm, 25cm, 100cm, 50cm). This study reports responses to a single, binocular target seen to approach the participant in the mid-line while the photorefractor collects data on the same axis. Light levels are relatively low (10cd/m^2) to allow photorefraction. Details of construction, calibration, raw data processing and validation are published elsewhere. [21]

---Figure 1 --

The target was a large, brightly coloured, high contrast 10x12cm image of a clown on a monitor (outline subtending 3.15° at 2m to 18.26° at 0.33m). The outline of the clown and main features were stable but some internal details alternated at 1Hz to maximise attention. The target elements contained a wide range of spatial frequencies down to 1min arc. Thus detail was available at whatever level of visual acuity was available to the participants and at every distance. The binocular target could be watched as it moved, so containing disparity, blur and looming cues. The older participants were not given any instructions to clear the target, so behaviour on this task reflects naturalistic responses driven by the stimulus itself. All participants were naïve to the experimental setup in particular, and vision experiments in general.

Participants

94 participants were tested (see Table 1). Infants and non-hypermetropic children were recruited from the University of Reading Psychology Department Infant Database. All were full-term, healthy and typically-developing. Infants were tested at 2-week intervals between 6-8 and 24-28 weeks of age and none had strabismus.

	Infants (tested at 2 week intervals)			Hospital recruited Children (tested once)			
	Hypermetropes	Emmetropising hypermetropes	Emmetropic throughout	Corrected hypermetropes (tested with correction)	Uncorrected hypermetropes (tested without correction)	Fully accommodative ET (tested with correction)	Emmetropic controls (no correction worn)
Age	6-26 weeks	6-26 weeks	6-26 weeks	5-9 years	5-9 years	5-9 years	5-9 years
Referral route	UoR Infant database	UoR Infant database	UoR Infant database	School entry screening (low VA)	School entry screening (low VA)	Parental concern (strabismus)	UoR Infant database
n	12	17	9	9	6	14	27
Initial error	>+2.00D	>+2.00D	<+2.00D				
MSE (95%CI)	+3.55(±1.35D)	+2.63(±0.72D)	+0.52D(±0.50D)	+4.11D(±0.92D)	+3.43D(±1.12D)	+3.96(±0.54D)	+0.27D(±0.16D)
Final Error	>+2.00D	>+2.00 & reduced by ≥2.00D	<+2.00D				
MSE (95%CI)	+3.10D(±0.58D)	+0.87D(±0.31D)	-0.06D(±0.53D)				

Table 1

Three patient groups of hypermetropic older children between 5-9 years of age were tested, all drawn from a hospital population at the Royal Berkshire Hospital Eye Clinic: 1) 15 non-strabismic hypermetropes who had presented following failing school-entry visual acuity (VA) testing. Nine were tested with spectacles and 6 without. Those tested without spectacles had either forgotten them when they arrived for testing, or reflections from the lenses had made testing with glasses impossible. There were no differences in visual acuity or experience with spectacles between the groups. 2) 14 children with fully accommodative esotropia tested with spectacles. In all groups, those wearing spectacles wore a full or very slight under-correction (<0.50D less than full cycloplegic error). There were no significant differences between undercorrection of any of the groups and prescription had been made according to their particular ophthalmologists' prescribing practice. 3) 27 similarly aged emmetropic controls reported previously. [21] At the time of testing all had achieved corrected distance and near visual acuity (VA) of at least logMAR 0.1 in each eye and 60" arc stereoacuity or better using the TNO stereotest (with spectacles if worn). By comparing these groups we hoped to identify the range of accommodative behaviour in both corrected and uncorrected hypermetropia under uniform testing conditions.

Infant refraction was estimated by maximum hyperopic refraction (MHR) detected by the PlusoptiXSO4 found at any time during each of our extensive testing sessions, which we have shown compares well to cycloplegic retinoscopy .[22] Cycloplegic retinoscopy data was compared with MHR for 33 of the participants drawn from all groups. Mean cycloplegic refraction for the hypermetropes was 0.24D (95%CI 0.589/-0.107D) more hypermetropic than MHR, but the difference was not significant ($t(32)=-1.406$, $p=0.17$).

Excluded data

Data were excluded as follows: refraction outside the operating range of the PlusoptiXSO4 (-7.00D /+5.00D); all data from the 25cm target due to excessive pupillary constriction; all data from an individual participant if >1 of the remaining data points were missing, or attention prevented steady fixation.

We have included 4 infants who showed occasional data points of up to approximately +7.00 (i.e. out of the linear range of the photorefractor) in weeks 6-8 who emmetropised to provide all data points within the linear range by 10-11 weeks. These isolated large hyperopic readings were excluded from calculations of response slopes which were made on the basis of 3 data points. The data from these infants excluded from calculations involving MHR on any visit when MHR exceeded +5.00D.

Data analysis

The raw PlusoptiXSO4 Excel spreadsheet was processed by a macro designed in our laboratory. Refraction data were converted to dioptres of accommodation (D). Raw eye position data from each eye was converted to metre angles of vergence (MA) using individual angle lambda and inter-pupillary distance (IPD) measurements. By using MA to describe vergence, we could directly compare vergence and accommodation i.e. at 33cm, 3D of accommodation and 3MA of vergence are required. A correction for magnification due to spectacle correction was applied where appropriate.

Responses at the four fixation distances, and response slopes (gain in relation to target demand), were the main test measures. Excel and SPSS v16.0 were used to analyse the data statistically using both repeated measures (target distances and responses tested in the same visit in the same individuals) and between-groups (diagnostic groups) methods (ANOVA with post-hoc *t*-tests, *t*-tests and Pearson's product-moment correlation coefficient *(r)*)

RESULTS

38 infants tested longitudinally were grouped according to whether or not they demonstrated significant manifest hypermetropia in the first three months of life and whether or not this hypermetropia reduced to within normal limits (<+2.00D) by 6 months of age. 5 further children were lost to final follow up at 26 weeks but completed between 1 and 5 visits (mean 2.4) when younger so feature in cross-sectional data. All, except one infant (97%), emmetropised to <±2.00D by 18 months of age.

Distribution of refractive errors in the infant and older hypermetropic groups was similar, (mean infant MHR: +2.06±SD1.95; older children +2.15±SD2.04 ($t=-0.296$, $p= 0.76$), so all had similar levels of near blur.

Vergence responses were appropriate and linear to target demand at all distances and in all groups, (dotted lines in Figure 2) and ANOVA showed no significant differences between groups in terms of response at any one target or response slope ($p>0.3$ in all comparisons). This suggests that vergence accuracy across a wide age range of participants is unaffected by accommodation, refraction or blur state, and confirms that all the participants were attending to the targets at all times. Vergence will therefore not be considered further.

---Figure 2 ---

Our first analysis looked at the error between target demand and response at each target distance (accommodative lag). Across all groups, mixed ANOVA and post-hoc testing showed that hypermetropes showed a greater accommodative lag compared to non-hypermetropes at every fixation distance ($t>7.2$, $p<0.00001$ in every case) and whether corrected or not (solid lines in Figure 2). While accommodative lag for all participants was more variable for nearer targets, lag at each target distance correlated strongly with MHR during the test (2m: r=0.728, 1m: r=0.702, 50cm: r=0.484, 33cm: r=0.403, $p<0.0001$ in all cases). Thus, the greater hypermetropia the larger the accommodative lag at each target distance, with the strongest association for distance targets.

We then analysed the accommodative response slope (or gain). Hypermetropes as a combined group had steeper response slopes than non-hypermetropes (t=3.6, df 244, p=0.003). There were no differences between the response slopes of the three groups of older hyperopic children (whether corrected or not) (F2,26)=0.65, p=0.51), but with highly significant interaction $F(1,350)=13.46, p=0.0003$. Hypermetropic infants had much steeper slopes than child hypermetropes ($t(45.8)=7.45, p<0.00001$)) due to a greater lag of accommodation for distance than near (mean lag at 2m =2.26D, mean lag at 33cm=1.26D), while, in comparison, the older hypermetropes showed shallower slopes since mean lag at near was greater than that for distance (mean lag at 2m =0.90D, mean lag at 33cm =1.73D). There were no significant differences between the uncomplicated corrected hypermetropes' slopes and the corrected fully accommodative esotropes ($t(16)=0.121, p=0.905$).

We then correlated response slope with MHR. The more hypermetropic infants had steeper response slopes, with a modest positive correlation between accommodation slope and MHR ($r=0.392$, $p<0.0001$). For the older children there was also a weak correlation, but in the *opposite* direction ($r=-0.303$, $p=0.007$) with the more hypermetropic children having shallower response slopes. Thus, the relationship between response slope and MHR was different between these groups.

Hypermetropes drawn from a hospital population have, by definition, not emmetropized, while the infant hypermetropes were clearly emmetropising. Since Mutti et al [20] have hypothesised that the exercise of accommodation may support emmetropisation, we therefore examined the infant hypermetropes in more detail to see if there were differences in accommodation responses between those who were hypermetropic and remained so at 26 weeks, those who emmetropized by 26 weeks, and those who remained within normal limits throughout.

One way-ANOVA showed significant differences between these groups ($F(2,272)=6.2, p=0.002$) with the emmetropic infants having the shallowest slopes (slope = 1.1), followed by the infants who emmetropized (slope =1.3), with the persisting hypermetropes having the steepest slopes (slope =1.5) (Figure 3). These group differences become insignificant if MHR is taken in to account ($F(1,251)=1.09, p=0.34$). This suggests that all infants accommodate for near targets, but hypermetropic infants accommodate, in proportion to their refraction, more for near than distance targets.

---Figure 3 ---

The one infant whose hypermetropia did not emmetropise has gradually increased from +4.00D in infancy, to +5.75D in each eye at age 3yrs (tested under cycloplegia). He had lower mean accommodation slope over all testing visits (0.99 compared with a mean of 1.47 for the hypermetropic infants who emmetropised i.e. more lag for near). Although numbers were too small for further analysis, this could suggest that his shallower accommodation response slope might have been predictive of failure to emmetropise.

DISCUSSION

The main finding from this study is that, despite good convergence, a wide spectrum of hypermetropic children habitually under-accommodate in binocular, naturalistic conditions. Some differences in accommodation responses between emmetropising infants and older hypermetropes may also suggest that accommodative behaviour may predict emmetropisation.

We drew participants from two, distinct populations. The infants were a typically developing non-clinical sample and the vast majority emmetropised while the older children had hypermetropia that had not resolved. Despite this, both groups demonstrated a consistent accommodative lag which related to their refraction, with the more hypermetropic participants under-accommodating the most.

The main differences between the typically developing and "pathological" groups lay in the relationship of near to distance responses. The emmetropising infants had steeper response slopes due to better accommodation for near than distance. We have demonstrated that infants use proximal cues more than older participants to drive vergence and accommodation responses, [23]so these proximal influences may be driving additional near accommodation. Alternatively, near targets may be more salient and stimulating for infants because they are available for other experiential learning, such as touch, and so drive more effort to gain clarity. In either case these emmetropising typical infants have clearer images for near than distance and the infants with the greater blur to overcome do more accommodating for near. This extra accommodation could then help to drive emmetropisation as Mutti suggests. [20]

Despite methodological differences with Mutti et al, our results broadly support their findings, and we would argue are more sensitive in comparing near/distance differences, as we used the same method to assess accommodation for near and distance. Ehrlich et al [24] have shown that those with the largest errors often emmetropize more rapidly than those with smaller errors, but we suggest that more attention should be also paid to how the accommodation of hypermetropic individuals responds to near targets.

The older hypermetropic children showed the opposite effect with shallower slopes *negatively* correlated to refraction. We cannot say whether these children had behaved similarly in infancy, but the fact that these children had presented with low VA, or a type of strabismus that manifests when children start doing more detailed close work, suggests that that these individuals had not been accommodating sufficiently before correction to achieve normal visual acuity. In this case, the shallow accommodative response slopes might not have provided these children with the opportunity to learn that clearer images were advantageous, or alternatively, the children had just not used sufficient accommodative effort to achieve them.

As we did not assess accommodation to visually demanding targets that could only be identified by optimal accommodation, we cannot state that the hypermetropic children *could not* accommodate more, just that they often *did* not at the time of testing. Indeed, all the older hypermetropic children could resolve 0.1 logMAR crowded letters at the time of testing (but not referral), implying that they might well be able to resolve small text if necessary; either by operating with an accommodative lag that is at the extreme limit of their depth of focus, or only accommodating when pushed to do so in a testing situation. In comparison, our naturalistic task is likely to demonstrate their habitual accommodative response.

The clinical implications of this study must be considered carefully. In terms of infant emmetropisation, accommodation slope and relative size of near and distance lag might be useful predictors of emmetropisation in hypermetropic infants. Hypermetropia in infants is likely to resolve as long as the change in refractive error over time is towards emmetropia, and accommodation is slightly better for near than for distance. Such accommodation could easily be assessed by photorefraction using the same target at two different fixation distances, a paradigm already used by Atkinson's group. [4] It would be possible to identify the infants who make less accommodative effort for near, with a prediction that this would prove to be a more important risk factor than absolute levels of refraction or lag in accommodation *per se*. While a hypermetropic infant with better accommodation for near than distance target demand may not be a cause for concern, an infant with a shallower accommodative slope might be more likely to develop persisting hypermetropia. We do not have sufficient numbers, or longitudinal data over a long enough period, for quantification of risk, but suggest that this might be a fruitful direction for future research. At what point hypermetropic infants should be corrected is even less clear. A small proportion of such children will need correction eventually, but this study would certainly strongly support the current "wait and see" approach. At present, the tests available to most community services would be inadequate and too unreliable to justify regular testing in very early childhood. Projects such as the InfantSEE® programme in the US may mean that many more hypermetropic infants may be detected, and once diagnosed, these children will need repeated follow up, with associated significant cost and parental anxiety implications, for the benefit of a very few. The vast majority of these infants will emmetropise even if they experience periods of considerable blur in early infancy, and there seems little justification for prescription of spectacles for low or moderate errors in infants or toddlers. If an accurate and simple clinical test could be devised that could identify those at most risk, services might be more accurately targeted.

The clear finding of under-accommodation in the child hypermetropes might be used to suggest that all hypermetropia in children over 3 years (when most emmetropisation will have occurred) should be fully corrected. Although researchers in the past have under-corrected hypermetropia so that residual blur could still drive remaining emmetropisation, [25] their results, and those of others [20, 26] suggest that absolute level of blur does not seem to alter emmetropisation and so this seems remove this justification for under-correction.

We would argue, however, that this cannot be taken to mean that every child with hypermetropia should be fully corrected and given a reading addition. Firstly, our older hypermetropes were from a hospital population and so might be drawn from an extreme sub-group of child hypermetropes in general. The majority of child hypermetropes could remain undetected in the community, symptom free with good vision and accommodation. Our children had presented with poor visual acuity, which only improved with refractive correction, strongly suggesting that these children had *not* been accommodating over their blur and needed correction to achieve good vision. Those with fully accommodative esotropia may have had to choose between clarity and binocular vision if their linkages between vergence and accommodation were inflexible (conventionally termed poor relative fusion) or binocular vision weak, whereas the non-strabismic hypermetropes may have had either more flexible accommodation/vergence linkages or have decided to sacrifice clarity in the interest of single vision. Our results do suggest, however, that children who fail visual acuity screening should always be fully corrected, because they may not make accommodative corrections for residual error themselves. As these children have more accommodative lag for near, they may also still be experiencing somewhat more blur for near than non-hypermetropes.

How much hypermetropia should be treated if detected by screening based on detection of refractive error, especially under cycloplegia, is much less clear. Only a population study seeking out asymptomatic hypermetropes who can accommodate sufficiently to pass vision screening criteria would clarify how important childhood hypermetropia is in the wider community.

Importantly, there is also no evidence to suggest that a degree of blur for casual vision is harmful. As long as clear vision *can* be obtained, such as during VA testing or when engaged in detailed near work, the fact that a child habitually keeps their accommodation more relaxed until it is needed might be insignificant. We suggest that more use of tests such as dynamic retinoscopy to detailed and binocular distance and near targets and post-cycloplegic subjective testing might help exclude excessive lag and differentiate it from ametropic amblyopia in children with hypermetropia. If this is not possible, however, and reduced corrections are ordered and good vision not immediately restored, consideration should be given to quickly increasing correction to the full plus. Further study is also necessary of those children who do not settle into full corrections easily; we would predict that they may not have the under-accommodation that we report here and so may represent a different sub-group of hypermetropes.

There is some evidence that hypermetropia may be associated with poorer developmental or educational progress,[27-29]but even if the association is clear, the causal direction is not. Near blur might hinder reading, but alternatively, lack of interest in close work or weak motor skills could lead to habitual under-use of accommodation, or a third more general factor could cause problems in both. Atkinson et al [30] considered this possibility and found that the majority of hypermetropic children had a mild deficit in a battery of general motor skills tests (despite the fact that these tests could be performed with a mild degree of blur and so were not acuity-dependent). Their finding supports the second or third theories. If under-accommodation is secondary to poor motor or educational attainment or co-morbid with poor accommodation because of a third factor, a refractive correction would make less or no difference to educational progress. Only a longitudinal RCT comparing the developmental progress of children given full- or under-correction of hypermetropia, taking accommodative lag into account, would clarify causal directions, but currently there is not sufficient evidence to justify large-scale correction of mild errors in asymptomatic children, although it does add further support to school entry vision screening to identify children with poor near vision.

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Figure & Table Legends

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.

Table 1 Clinical data for the participants. Typically developing children and all infants recruited from the University of Reading (UoR) Infant Database. Hypermetropic children recruited from Royal Berkshire Hospital.

Figure 2. Vergence (in metre angles (MA – dotted line) and accommodation responses (in diopters (D) – solid line) to targets at 2m,1m,0.5m and 0.3m (0.5,1,2 & 3D and MA demand)i.e. nearer targets towards right of charts. Minus figures on y-axis denote "negative accommodation" (hypermetropic refraction) positive figures denote accommodation (and vergence) responses i.e. myopic refraction. a),c),e): emmetropic infants and children; b),d),f): hypermetropic infants and children : g) corrected fully accommodative esotropias; h) uncorrected hypermetropes. Pale grey line indicates ideal response for target demand. Error bars denote standard error. Note accurate vergence responses in all groups.

Figure 3. Examples of differences in mean slopes between hypermetropic infants who remained hypermetropic at 26 weeks, hypermetropic infants who became emmetropic by 26 weeks and infants who remained emmetropic throughout. Responses illustrated at 10-11 weeks of age, but findings similar at all infant ages.Vergence (dotted line) and accommodation responses (solid line) to targets moving between 2m and 33cm (see legend for Figure 2 for details of graph notation). Pale grey line indicates ideal response for target demand. Error bars denote standard error.

Licence for Publication

"Competing Interest: None to declare."

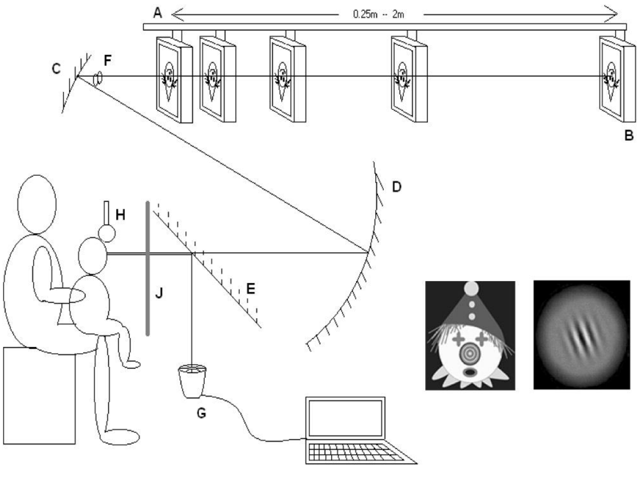
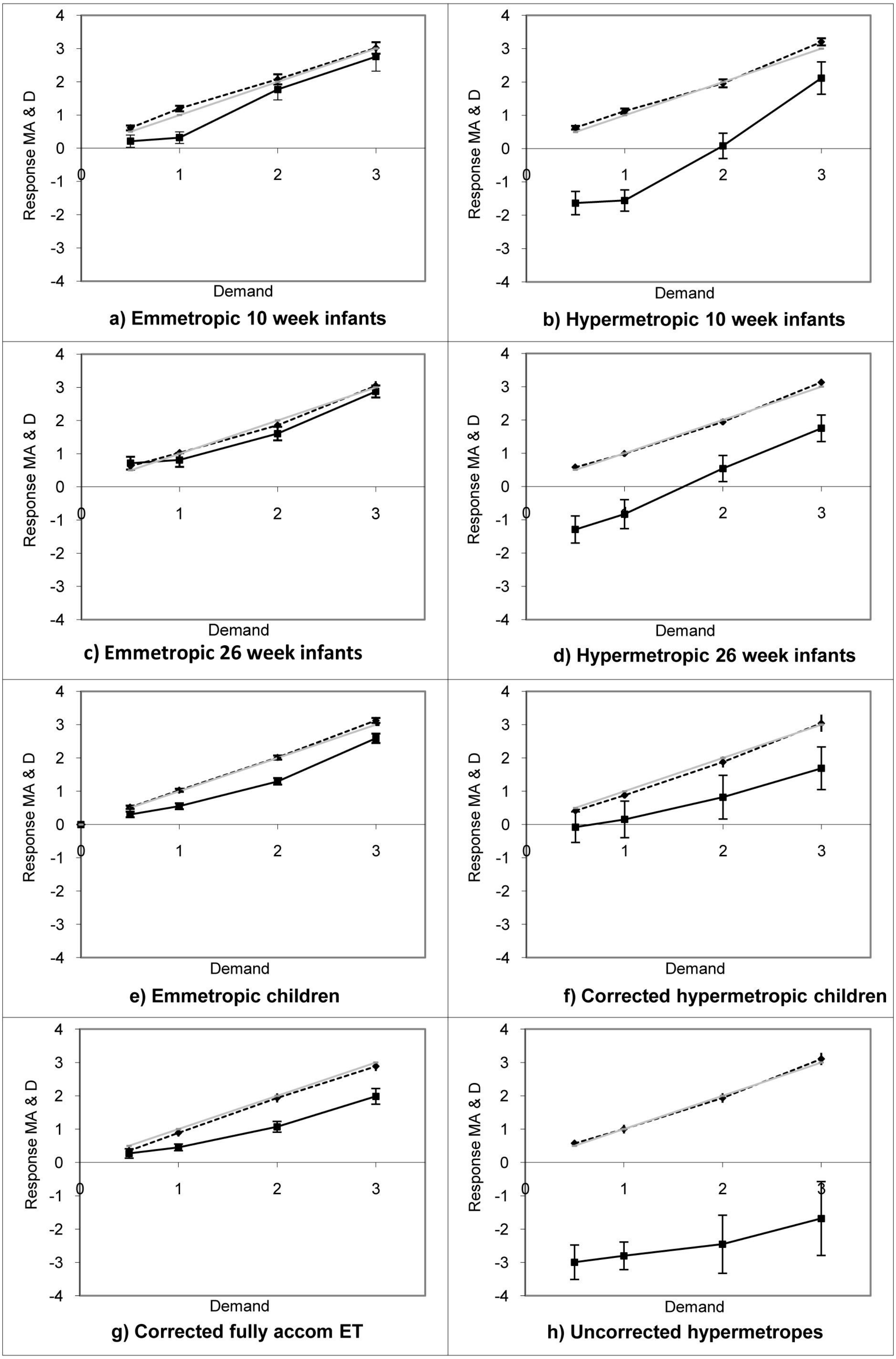
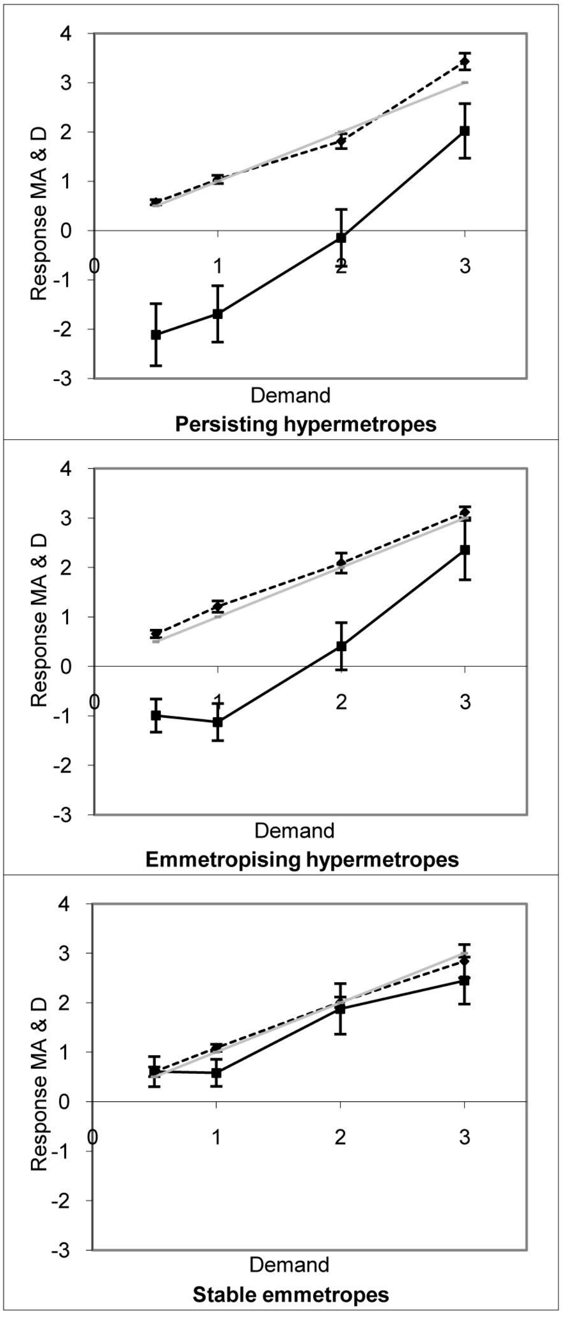


Figure 1


Response MA & D
Demand
a) Emmetropic 10 week infants
b) Hypermetropic 10 week infants
c) Emmetropic 26 week infants
d) Hypermetropic 26 week infants
e) Emmetropic children
f) Corrected hypermetropic children
g) Corrected fully accom ET
h) Uncorrected hypermetropes



Response MA & D
Demand
Persisting hypermetropes
Emmetropising hypermetropes
Stable emmetropes